THE UNIVERSITY OF ALBERTA

THE IMPACT OF GRAZING ON LITTER AND HYDROLOGY IN MIXED PRAIRIE AND FESCUE GRASSLAND ECOSYSTEMS OF ALBERTA

BY

MARY ANNE NAETH

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE

OF DOCTOR OF PHILOSOPHY

IN

RANGE SCIENCE

DEPARTMENT OF PLANT SCIENCE

EDMONTON, ALBERTA

FALL 1988

ISBN 0-315-45456-3

THE UNIVERSITY OF ALBERTA

RELEASE FORM

NAME OF AUTHOR: MARY ANNE NAETH

TITLE OF THESIS: THE IMPACT OF GRAZING ON LITTER AND HYDROLOGY IN MIXED PRAIRIE AND FESCUE GRASSLAND ECOSYSTEMS OF ALBERTA

DEGREE: DOCTOR OF PHILOSOPHY

YEAR DEGREE GRANTED: 1988

Mary Anne Naeth

11328 18 Avenue

Edmonton, Alberta

T6J 4T9

Dated October 13 1988

This day before dawn I ascended a hill and look'd at the crowded heaven,
And I said to my spirit, When we become the enfolders of those orbs,
and the pleasure and knowledge of everything in them,
shall we be fill'd and satisfied then?
And my spirit said, No, we but level that lift to pass and continue beyond.

Walt Whitman

All the rivers run into the sea, yet the sea is not full;
Unto the place whence the rivers come thither they return again.

Ecclesiastes 1:7

THE UNIVERSITY OF ALBERTA

FACULTY OF GRADUATE STUDIES AND RESEARCH

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled THE IMPACT OF GRAZING ON LITTER AND HYDROLOGY IN MIXED PRAIRIE AND FESCUE GRASSLAND ECOSYSTEMS OF ALBERTA submitted by MARY ANNE NAETH in partial fulfillment of the requirements for the degree of DOCTOR OF PHILOSOPHY in RANGE SCIENCE.

Arthur W. Bailey
Supervisor

Peter D Walton

Richard L Rothwell

Donald J Pluth

R. W. Fessenden

Wilbert H. Blackburn
External Examiner

Dated October 13 1988

This dissertation is dedicated to

my mother

Mary Anne Clayton Naeth

ABSTRACT

Studies were conducted to assess the impact of long-term grazing regimes on litter and hydrology at three rangeland locations in southern and central Alberta, Canada. Mixed prairie on a Solonetzic soil, was early (May through July) and late (August through October) season grazed at 0.9 AUM ha^{-1}. At Kinsella, in aspen parkland fescue grassland on Chernozemic soils, grazing was in June and autumn (September 15 to October 15) at light and heavy intensities of 1.5 and 4.4 AUM ha^{-1}, respectively. At Stavely, in foothills fescue grassland on Chernozemic soils, light, moderate, heavy, and very heavy grazing treatments were stocked at 4.8, 2.4, 1.6, and 1.3 AUM ha^{-1}, respectively. Ungrazed controls were evaluated at each site.

Combined heavy intensity/early season grazing regimes had greater impact on litter and hydrology than did light intensity/late season grazing regimes. Under heavy intensity/early season grazing there were reductions in height of standing litter, live vegetative cover, and organic matter mass; there were increases in bare ground, resistance to penetration to a depth of 2.5 cm, and bulk density. These combined factors led to lower infiltration rates and lower amounts of soil water at times of recharge. Soil water to an 80 cm depth was generally increased during the growing season under heavy intensity/early season grazing regimes due to reduced water uptake by more shallow rooted, dominant plants. Grazing in June at Kinsella, at heavy and very heavy intensities at Stavely, and early in the season at Brooks had the greatest negative hydrologic impact.

Although hydrologic condition was reduced with heavy intensity/early season grazing, the overall effect from a physical perspective was small. Changes in infiltration rates and soil water were often only a few cm h^{-1} or mm which would have little overall impact in ecosystems with high precipitation values. Compacting effects of grazing were evident but not to the extent that major problems with plant growth would occur. However, the negative effects of heavy intensity/early season grazing must be taken into account when planning management strategies to optimize rangeland productivity. This is of particular importance in arid rangelands.

ACKNOWLEDGEMENTS

I am truly grateful for the excellent financial support and many long hours of work by countless people who helped in so many different ways.

NOVA Corporation of Alberta is acknowledged for their generous financial support throughout my Ph.D. program. Without this, the study could never have been undertaken. Dr. A.W. Fedkenheuer, who was my liaison with NOVA and served on my supervisory committee, is acknowledged for his efforts. It was particularly gratifying to work with someone so interested in the project and who was always there with a cheery word of greeting or encouragement.

I thank my supervisor, Dr. A.W. Bailey, for his advice and encouragement throughout the study. I thank the other members of my supervisory committee from the University of Alberta, Dr. D.J. Pluth, Dr. R.L. Rothwell, and Dr. P.D. Walton for their advice and guidance. I am particularly grateful for their efforts during Dr. Bailey's study leave and the stimulating discussions throughout the project. I thank my external examiner, Dr. W.H. Blackburn. Dr. R. Hudson, Dr. J. King, and Dr. V. Lieffers are acknowledged for serving on my candidacy examining committee. Dr. R.T. Hardin is acknowledged for advice and guidance on the experimental design of the project and statistical analyses of the data.

I acknowledge the Lethbridge Research Station of Agriculture Canada for access to the Stavely Range Research Substation and for lodging accommodations during my study. Staff of the station are also acknowledged for their help. Dr. Walter Willms, for the meteorological data and the interesting discussions whenever we met. Dale Campbell, for the days of effort to get the access tubes installed and the soil sampled. Hank Coulter, for sharing the ranch house.

Special thanks to Dr. John Dormaar of the Lethbridge Research Station, for helping with soil sampling, securing references, for being there to discuss the things that went well and the things that did not go well, and for the enlightning noon lunch tales of the range and the native Indian tribes. Thank you especially for being such a terrific mentor and showing me the excitement of research need not diminish throughout a long career.

Bill Shanks, of the Eastern Irrigation District, is acknowledged for help at the Brooks site. Whether with good information on keeping cattle away from the meteorological station, what the weather was like before a field trip, or just to chat about the beauty of the range, Bill was always there. I am grateful to the Eastern Irrigation District for access to the Brooks community pasture.

Staff and fellow graduate students of the University of Alberta are acknowledged for assistance in various aspects of the project. Jeff Thurston, for help with the meteorological stations and data compilation. Dr. Peter Crown for help with the initial site selection at Kinsella. Austin Sichinga, for helping soil sample and install access tubes. Bob Howitt, for information and field assistance in detailing soils of the study sites. Barry Irving, for help with SPSSx. John Konwicki, Jaswant Khatkar, Malcolm Black, Charlie Maule, and Les Wetter for their helpful suggestions during the soil analyses. Colin Woytowich, for helping install access tubes at Kinsella. Mike Willoughby for managing the cattle at Kinsella and helping with some of the soil water readings. Verna Clarke and the Plant Science office staff are thanked for their numerous helpful efforts during my tenure as a graduate student in the department.

Staff of the Conservation and Development Branch and the Irrigation Branch of Alberta Agriculture, especially Dr. Colin Mckenzie and Rodney Jones, are acknowledged for their help in getting coring trucks to soil sample and install access tubes.

I acknowledge the Princess Compressor Station personnel of NOVA Corporation of Alberta who provided tools, electrical outlets, and water for the infiltration tests at Brooks.

I am grateful to the summer staff that assisted me on the project. They were a truly wonderful group of people, who worked long hours and long weeks in order to accomplish the numerous field tests and data collections. Thank you Vanessa Naeth, Gerry Hoppe, Murray Klutz, Jenni McGill, Jenny Scott, and Donna White for all that you have done. A very special acknowledgement to my technical assistant Kelly Ostermann, for all the hours in the field, in the lab, in front of the computer, and on the road. Kelly was an unending source of capable assistance. I thank her for this, as well as the friendship and moral support.

I thank my family and friends for their patience and encouragement throughout the years in

which I pursued this degree.

My special thanks go to Dr. D.S. Chanasyk. David was always a source of inspiration, ready to discuss the project when I needed to talk, to offer comfort in the long, dark hours when the words would not come right, to be there with his strength and understanding after a long field trip or an endless night in the lab or at the computer terminal. At times when others might have given up on me, David was there. Thank you for all that you are.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

I. INTRODUCTION

Rangelands are often water limited ecosystems with more than 80% occurring in arid and semiarid zones of the world (Branson et al. 1981). Rangelands are characterized by extremes in hydrologic cycle components such as low and erratic rainfall, high evapotranspiration potential, and low water yield. Soil water is one of the most important factors affecting range productivity (Houston 1965) and water losses due to runoff can reduce productivity, especially in heavily grazed, poor condition rangelands. Infiltration is the hydrologic process that determines the partitioning of precipitation between soil water and surface runoff (Gray 1970). Low infiltration rates can cause irreversible loss of water and soil through runoff and erosion. Erosion removes topsoil, which increases the probability of subsequent runoff and erosion and degradation of soil structure leading to surface sealing and crusting (Gifford and Whitehead 1982; Blackburn et al. 1986). Reductions in available water capacity, infiltration capacity, and soil water, combined with nutrient losses and reduced seedling emergence can lead to lower plant productivity.

Since the soil surface is a major controlling factor in the rate of water movement into the soil profile (Gray 1970), management practices which alter this surface can be used to enhance infiltration (Branson et al. 1981). In order to obtain optimum sustained biomass yields from water limited range ecosystems, range management strategies must involve soil water conservation and aim to reduce soil and nutrient losses through runoff. The most practical and economical means of realizing these objectives may be through manipulation of the grazing animal.

Hydrologic Impacts Of Grazing

Grazing has hydrologic impacts which result primarily from interactions of climate, vegetation, soil, and intensity and duration of grazing (Blackburn 1984). These impacts vary temporally and spatially. The scientific literature contains hydrologic studies on many range types in the United States which are summarized in reviews by Blackburn (1984) and Branson (1984). Alberta rangelands lie in the Northern Great Plains; several studies have been conducted in the American portion of these plains. Blackburn (1984) concludes results from Northern Great Plains research are site specific, differences between lightly and moderately grazed rangeland are usually small, heavy grazing almost always reduces infiltration rates, bulk densities increase with grazing intensity, and results are often confounded by range improvement activities, past grazing, and/or climatic fluctuations. Grazing affects the hydrology of an area by altering plant species composition, plant density, and ground cover; livestock trample vegetation and may compact soil. Grazing may lead to reductions in vegetative cover which can expose soil surfaces to raindrop impact, decrease soil organic matter and soil aggregation, and increase surface evaporation and surface crusting. Combined with compaction, these factors can decrease soil surface micro-roughness and porosity, decrease infiltration rates, increase erosion, and reduce soil water. Hydrologic changes in rangelands are most often associated with heavy grazing intensities, although these changes do not occur linearly with increases in grazing intensity. The hydrologic effects of grazing tend to be manifested at some critical level which differs with range ecosystem.

Infiltration rates are generally negatively correlated with stocking rates, with lower soil water in the grazed sites often attributed to increased runoff. Infiltration rates are reduced with increased grazing intensity and reduced range condition (Rauzi 1960; Reed and Peterson 1961; Branson et al. 1962; Johnston 1962; Rauzi 1963; Dee et al. 1966; Rauzi et al. 1968; Rauzi and Smith 1973; Gifford and Hawkins 1978; Hanson et al. 1978; Blackburn 1984).

Grazing animals may compact the soil (Knoll and Hopkins 1959; Lull 1959; Zeller 1963; McCarty and Mazurak 1976; Martens 1979; Thurow et al. 1986) although in some grazing studies there were no indications of compaction (Laycock and Conrad 1967; Skovlin et al. 1976; Gifford and Hawkins 1978; McGinty et al. 1979; Abdel-Magid et al. 1987). Susceptibility of soil to compaction is affected by vegetative cover (Wood and Blackburn 1984), particularly by plant roots (Gifford et al. 1977). Compaction is frequently greater and deeper on light textured soils than on heavy textured soils (Orr 1960; Smoliak et al. 1972; Van Haveren 1983). The degree of compaction is affected by soil water content at the time of compaction (Alderfer and Robinson 1947; Gifford et al. 1977). Orr (1960) found maximum compaction occurs between wilting point and field capacity. Soil compaction increases as stocking rate increases (Lodge 1954; Reed and Peterson 1961; Rhoades et al. 1964; Whitman et al. 1964; Rauzi and Hanson 1966; Willatt and Pullar 1983; Warren et al. 1986; Abdel-Magid et al. 1987). In most studies the effect of grazing on compaction as measured by soil bulk density was manifested in the top 6 cm.

The effect of grazing on soil water is most pronounced on coarse textured soils (Houston 1965) varying with plant species (Llacos 1962; Buckhouse and Coltharp 1976) and time of year (Kucera 1958; Conard and Youngman 1965; de Jong and MacDonald 1975). In some rangelands, soil water in the Ah horizon decreases with increased grazing intensity (Johnston 1961; Johnston et al. 1971; Smoliak et al. 1972) while in others there was no effect of grazing (Lodge 1954). Reductions in soil water with grazing are attributed to altered rates of infiltration, combinations of soil compaction and sealing through livestock trampling, reduced root channels through the soil, and less litter cover (Hagan and Peterson 1953; Hopkins 1954). Some researchers hypothesize that removal of herbage by grazing results in more soil water because of reduced evapotranspiration (Baker and Hunt 1961; Van Riper and Owen 1964). The soil water regime under grazed grasslands appears to be a function of the modifying effects of grazing on both vegetation and soil characteristics combined with the natural ecological characteristics and climate of a grassland itself.

Hydrologic Impacts Of Litter And Soil Organic Matter

There is no definitive description or terminology for dead vegetative material in range ecosystems. Grassland ecologists have used the terms mulch, litter, debris, duff, and protective cover (Tomanek 1969). Dyksterhuis and Schmutz (1947) subdivided litter into (a) green herbage, consisting of green and live plant material and dead tips of growing grasses; (b) cured herbage, consisting of standing, dried plant material little affected by weathering; (c) fresh mulch, consisting of the upper primary layer of bulky, coarse, fresh, bright, undecayed plant residuum lying on the soil surface; (d) and humic mulch, consisting of largely decayed, disintegrated, and fragmented organic residuum of fresh mulch. Hedrick (1948) divided litter into forage residue and humic mulch. Odum (1960) used the term litter for all dead plant material above the soil surface. Other terms associated with litter include standing litter, ground litter, standing dead (Golley 1965), above and below ground biomass, dead-shoot biomass, recent-dead, and old-dead (Coupland 1979). Soil organic matter is defined as the organic fraction of the soil; which includes plant and animal residues at various stages of decomposition, cells and tissues of soil organisms, and substances synthesized by the soil population (Canada Department of Agriculture 1979).

Litter has beneficial effects on grassland ecosystems: increasing soil aggregation, aggregate stability, and infiltration capacity; decreasing raindrop impact, runoff, and evaporation; stabilizing soil water and soil temperature; and holding seeds in favorable environments for germination (Tomanek 1969). Litter provides a habitat for organisms and retains nutrients (Risser 1984). The unfavorable effects of litter include: interception loss of precipitation; reduction of plant species diversity; and toxic effects of litter from one plant on germination of another (Tomanek 1969).

Herbage production is affected by amount of litter and varies with climate and vegetation (Tomanek 1969). Removal of litter can reduce production, especially in xeric ecosystems (Larson and Whitman 1942; Weaver and Rowland 1952; Willms et al. 1980, 1986). In more humid areas, too much litter can reduce production, as evidenced by increased production with removal of litter (Dyksterhuis and Schmutz 1947; Weaver and Bruner 1948; Hopkins 1956; Penfound 1964; Sinton 1980; Willms et al. 1986). Ehrenreich and Aikman (1963) conclude that when the quantity of mulch exceeds annual vegetative production, yield may be reduced.

Litter production varies with grassland ecosystem and soil type (Passey and Hugie 1963; Zeller 1963; Tomanek 1969), increasing as soil particle size increases, except being higher on silty soils than sandy soils (Rauzi et al. 1968). Effects of topography tend to be overshadowed by soil effects (Beetle 1952). Litter mass varies with season as affected by decomposition rate and inputs from annual growth (Dyksterhuis and Schmutz 1947; Ovington et al. 1963; Wiegert and Evans 1964). Fire, or absence thereof, also affects litter accumulation (Ehrenreich and Aikman 1963; Wright and Bailey 1982). Annual litter mass production reported for ungrazed Great Plains grasslands ranges from 0.033 kg m^{-2} on a South Dakota mixed prairie (Rauzi and Kuhlman 1961) to 2.532 kg m^{-2} on a Kansas mixed prairie (Hopkins 1954). The mean production value from 33 different studies was 0.575 kg m^{-2} (standard deviation = S.D. = 0.540).

Litter mass is reduced by heavy grazing as grazing animals trample vegetation and remove green herbage and standing dead litter (Dyksterhuis and Schmutz 1947; Hopkins 1954; Coupland et al. 1960; Johnston 1961, 1962; Rhoades et al. 1964; Peake and Johnston 1965; Smoliak 1965; Rauzi and Hanson 1966; Tomanek 1969; Johnston et al. 1971; Potvin and Harrison 1984). Litter composition is affected by grazing with a higher proportion of humic to fresh mulch (Zeller 1963) and increased coarse litter (Weaver 1950) in grazed prairie.

Grazing may reduce soil organic matter by reducing the amount of above ground plant material (Kucera 1958; Zeller 1963; Beebe and Hoffman 1968; Smoliak et al. 1972; Dormaar et al. 1977), although in other studies it is reported that grazing increases soil organic matter (Dormaar et al. 1984) or has no effect (Lodge 1954; Johnston et al. 1971; Dormaar et al. 1977). Grazing can affect organic matter from roots, since grazing may reduce root productivity (Coupland et al. 1960; Smoliak 1965; Lorenz and Rogler 1967; Bartos and Sims 1974), although there is also evidence that grazing increases root productivity (Johnston 1961; Pearson 1965; Whitman 1971; Smoliak et al. 1972). Depth of sampling is important in comparing data from different studies. As dominant plant species are altered by grazing, rooting depth is also altered. Thus the amount of root organic matter at different depths will be affected by grazing regime.

Researchers often find the quantity of living plant material and associated litter are more significantly correlated with infiltration than any other measured variable (Steiger 1930; Duley and Kelly 1939; Duley and Domingo 1949; Osborn 1952; Hopkins 1954; Ehrenreich and Aikman 1963; Rauzi 1963; Rauzi and Hanson 1966; Meeuwig 1970). Litter increases infiltration rates by improving soil structure, decreasing the impact of falling raindrops, and reducing runoff and erosion (Tomanek 1969). A relatively impermeable surface can develop on bare soil after exposure to rainfall through slaking and puddling and litter modifies or prevents this process.

Litter can reduce evaporation losses from soil through reduction of wind velocity, stabilization and lowering of soil temperature, and increasing of the diffusion gradient from soil to air

(Stephenson and Schuster 1945; Weaver and Rowland 1952; Hopkins 1954; Barkley et al. 1965; Tomanek 1969) which can increase soil water. Litter can also reduce the amount of water reaching the soil surface through interception of precipitation and subsequent evaporation of the absorbed water. Interception varies with plant species, ranging from 17 to 84% of 25 to 3 mm precipitation events (Clark 1940; Haynes 1940; Kittredge 1948; Weaver and Rowland 1952; Couturier and Ripley 1973). 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 (Helvey and Patric 1965), the water holding capacity of the litter, and the evaporation potential before and after precipitation events (Corbett and Crouse 1968). Water holding capacity of litter varies with vegetation type and ranges from 0.5 to 8.4 mm (Flory 1936; Kittredge 1939; Clark 1940; Weaver and Rowland 1952; Kittredge 1955; Burgy and Pomeroy 1958; Garcia and Pase 1967; Corbett and Crouse 1968; Clary and Ffolliott 1969; Helvey 1971; Thurow et al. 1987).

Branson (1984) states there may be a critical point in relatively moist climates at which litter accumulation has a depressing effect on herbaceous plant yields. These decreases generally occur when annual litter yields exceed 5000 kg ha^{-1}. However, there is considerable uncertainty about amounts of vegetative cover needed to prevent excessive overland flow and erosion under the diverse topography and soil characteristics of most rangelands (Meeuwig 1970). For hydrologic benefit on most arid and semiarid rangelands where litter rarely exceeds 2700 kg ha^{-1}, management for litter accumulation may be as important as management for increased live plant cover, whereas in moister climates, grazing or burning to remove a portion of the accumulated litter may stimulate forage production (Hendricks 1942; Branson 1984; Bailey 1988).

Study Objectives

The ability to quantitatively predict the impacts of grazing on the hydrologic regime is essential for efficient management of rangeland resources. Successful rangeland renovation and reclamation efforts associated with natural resource explorations also require a knowledge of these impacts. In order to predict the hydrologic impacts of grazing on Alberta rangelands, a knowledge of soil, vegetation, climatic, and management interactions within the hydrologic regime are required. Although much work has been done on rangelands in the United States, these data cannot easily be extrapolated to Alberta where there are different climatic regimes, soils, and vegetation. Studies of Alberta rangeland hydrologic systems are few; data for such systems would fill a major void in the current knowledge of water and soil management for Canadian rangelands.

This study was undertaken in an effort to assess the hydrologic impacts of several common grazing regimes utilized in southern and central Alberta. It was hypothesized that the hydrologic impacts of grazing would be most pronounced at the soil surface and would include effects on litter, vegetation, soil compaction, infiltration rate, and soil water regime. These effects were studied for three Alberta grassland ecosystems: the mixed prairie, the foothills fescue grassland, and the fescue grassland in the aspen parkland.

BIBLIOGRAPHY

Abdel-Magid, A.H., Schuman, G.E., and Hart, R.E. 1987. Soil bulk density and water infiltration as affected by grazing systems. J. Range Manage. 40:307-309.

Alderfer, R.B. and Robinson, R.R. 1947. Runoff from pastures in relation to grazing intensity and soil compaction. J. Amer. Soc. Agron. 39:948-958.

Bailey, A.W. 1988. Understanding fire ecology in range management. In: Tueller, P.T. (ed.). Vegetation science applications for rangeland analysis and management. Kluwer Academic Publ. Chapter 21:1-31.

Baker, J.N. and Hunt, O.J. 1961. Effects of clipping treatments and clonal differences on water requirements of grasses. J. Range Manage. 14:216-219.

Barkely, D.G., Blaser, R.E., and Schmidt, R.E. 1965. Effects of mulches on microclimate and turf establishment. Agron. J. 57:189-192.

Bartos, D.L. and Sims, P.L. 1974. Root dynamics of a shortgrass ecosystem. J. Range Manage. 27:33-36.

Beebe, J.D. and Hoffman, F.R. 1968. Effects of grazing on vegetation and soils in southwestern South Dakota. The Am. Midl. Naturalist 80: 96-109.

Beetle, A.A. 1952. A relict area on the Wyoming shortgrass plains. J. Range Manage. 5:141-143.

Blackburn, W.H. 1984. Impacts of grazing intensity and specialized grazing systems on watershed characteristics and responses. In: Developing strategies for rangeland management. NRC/NAS. Westview Press/Boulder and London. Pp. 927-983.

Blackburn, W.H., Thurow, T.L., and Taylor, C.A. 1986. Soil erosion on rangeland. In: Use of cover, soils, and weather data in rangeland monitoring. Symp. Proc. Feb. 12, 1986. Kissimmee, Florida. Soc. Range Manage. Denver, Colo. Pp. 31-39.

Branson, F.A. 1984. Evaluation of "Impacts of grazing intensity and specialized grazing systems on watershed characteristics and responses". In: Developing strategies for rangeland management. NRC/NAS. Westview Press/Boulder and London. Pp. 985-1000.

Branson, F.A., Miller, H.F., and McQueen, I.S. 1962. Effects of contour furrowing, grazing intensities and soil on infiltration rates, soil moisture and vegetation near Fort Peck, Montana. J. Range Manage. 15:151-158.

Branson, F.A., Gifford, G.F., Renard, K.G., and Hadley, R.F. 1981. Rangeland Hydrology. Range Science Series No. 1. Society for Range Management. Kendall/Hunt Publ. Toronto, Ont. 340 pp.

Buckhouse, J.C. and Coltharp, G.B. 1976. Soil moisture responses to several levels of foliage removal on two Utah ranges. J. Range Manage. 29:313-315.

Burgy, R.H. and Pomeroy, C.R. 1958. Interception losses in grassy vegetation. Trans. Amer. Geophys. Union. 39:1095-1100.

Canada Department of Agriculture. 1979. Glossary of terms in soil science. Can. Dept. Agr. Publ. 1459. 44 pp.

Clark, O.R. 1940. Interception of rainfall by prairie grasses, weeds, and certain crop plants. Ecol. Monog. 10:243-277.

Clary, W.P. and Ffolliott, P.F. 1969. Water holding capacity of ponderosa pine forest floor layers. J. Soil Water Conserv. 24:22-23.

Conard, E.C. and Youngman, V.E. 1965. Soil moisture conditions under pastures of cool-season and warm-season grasses. J. Range Manage. 18:74-78.

Corbett, E.S. and Crouse, R.P. 1968. Rainfall interception by annual grass and chapparal. USDA Forest Serv. Res. Pap. PSW-48. 12 pp.

Coupland, R.T. 1979. Grassland ecosystems of the world: analysis of grasslands and their uses. Cambridge Univ. Press. Cambridge, England. IBP 18. 401 pp.

Coupland, R.T., Skoglund, N.A., and Heard, A.J. 1960. Effects of grazing in the Canadian mixed prairie. Proc. Eighth Intl. Grassland Congr. Pp. 212-215.

Couturier, D.E. and Ripley, E.A. 1973. Rainfall interception in mixed grass prairie. Can. J. Plant Sci. 53:659-663.

Dee, R.F., Box, T.W., and Robertson, E. Jr. 1966. Influence of grass vegetation on water intake of Pullman silty clay loam. J. Range Manage. 19:77-79.

De Jong, E. and MacDonald, K.B. 1975. The soil moisture regime under native grassland. Geoderma 14:207-221.

Dormaar, J.F., Johnston, A., and Smoliak, S. 1977. Seasonal variations in chemical characteristics of soil organic matter of grazed and ungrazed mixed prairie and fescue grassland. J. Range Manage. 30:195-198.

Dormaar, J.F., Johnston, A., and Smoliak, S. 1984. Seasonal changes in carbon content, dehydrogenase, phosphatase, and urease activities in mixed prairie and fescue grassland Ah horizons. J. Range Manage. 37:31-35

Duley, F.L. and Kelly, L.L. 1939. Effects of soil type, slope, and surface conditions on intake of water. Univ. Nebraska Agr. Exp. Sta. Res. Bull. 112. 16 pp.

Duley, F.L. and Domingo, C.E. 1949. Effect of grass on intake of water. Univ. Nebraska Agr. Exp. Sta. Res. Bull. 159 pp.

Dyksterhuis, E.J. and Schmutz, L.M. 1947. Natural mulches or 'litter' of grassland with kinds and amounts on a southern prairie. Ecology 28: 163-179.

Ehrenreich, J.E. and Aikman, J.M. 1963. An ecological study of the effect of certain management practices on native prairie in Iowa. Ecol. Monog. 33:113-130.

Flory, E.L. 1936. Comparison of the environment and some physiological responses of prairie vegetation and cultured maze. Ecology 17:67-103.

Garcia, R.M. and Pase, C.P. 1967. Moisture-retention capacity of litter under two Arizona chapparal communities. USDA Forest Serv. Res. Note RM-85. 2 pp.

Gifford, G.F. and Hawkins, R.H. 1978. Hydrologic impact of grazing on infiltration: a critical review. Water Resour. Res. 14:305-313.

Gifford, G.F. and Whitehead, J.M. 1982. Soil erosion effects on productivity in rangeland environments; where is the data? J. Range Manage. 35:801-802.

Gifford, G.F., Faust, R.H., and Coltharp, G.B. 1977. Measuring soil compaction on rangeland. J. Range Manage. 30:459-460.

Golley, F.B. 1965. Structure and function of an old-field brome-sedge community. Ecol. Monog. 35:113-137.

Gray, D.M. (ed.). 1970. Principles of hydrology. Secretariat Can. National Comm. International Hydrologic Decade. Ottawa, Canada.

Hagan, R.M. and Peterson, M.L. 1953. Soil moisture extraction by irrigated pasture mixtures as influenced by clipping frequency. Agron. J. 45:288-292.

Hanson, C.L., Kuhlman, A.R., and Lewis, J.K. 1978. Effect of grazing intensity and range condition on hydrology of western South Dakota ranges. S. Dakota State Univ. Agr. Exp. Sta. Bull. 657. 54 pp.

Haynes, J.L. 1940. Ground rainfall under vegetation canopy of crops. J. Amer. Soc. Agron. 32:176-184.

Hedrick, D.W. 1948. The mulch layer of California annual ranges. J. Range Manage. 1:22-25.

Helvey, J.D. 1971. A summary of rainfall interception by certain conifers of North America. In: Proc. Third International Seminar for Hydrol. Prof., Biological effects in the hydrologic cycle. Purdue Univ., West Lafayette, Ind. July 18-30. Pp. 103-113.

Helvey, J.D. and Patric, J.H. 1965. Canopy and litter interception of rainfall by hardwoods of eastern United States. Water Resour.Res. 1:193-206.

Hendricks, B.A. 1942. Effect of grass litter on infiltration of rainfall on granitic soils in a semi-desert shrub grass area. USDA For. Serv. SW Forest and Range Exp. Sta. Res. Note 96.

Hopkins, H. 1954. Effects of mulch upon certain factors of the grassland environment. J. Range Manage. 7:255-258.

Hopkins, H. 1956. Effects of mulch on yield and cover in mixed prairie. Kansas Acad. Sci. Trans. 59:71-75.

Houston, W.R. 1965. Soil moisture response to range improvement in the Northern Great Plains. J. Range Manage. 18:79-82.

Johnston, A. 1961. Comparison of lightly grazed and ungrazed range in fescue grassland of southwestern Alberta. Can. J. Plant Sci. 41:615-622.

Johnston, A. 1962. Effects of grazing intensity and cover on the water-intake rate of fescue grassland. J. Range Manage. 15:79-87.

Johnston, A., Dormaar, J.F., and Smoliak, S. 1971. Long-term grazing effects on fescue grassland soils. J. Range Manage. 24:185-188.

Kittredge, J. 1939. the forest floor of the chapparral in San Gabriel Mountains, California. J. Agr. Res. 58:521-535.

Kittredge, J. 1948. Forest influences. McGraw-Hill Book Co., New York, NY. 394 pp.

Kittredge, J. 1955. Litter and forest floor of the chapparral in parts of the San Dimas Experimental Forest. Hilgardia 23:563-596.

Knoll, G. and Hopkins, H.H. 1959. The effects of grazing and trampling upon certain soil properties. Trans. Kansas Acad. Sci. 62:221-231.

Kucera, C.L. 1958. Some changes in the soil environment of a grazed prairie community in central Missouri. Ecology 39:538-541.

Larson, F. and Whitman, W. 1942. A comparison of used and unused grassland mesas in the badlands of South Dakota. Ecology 23:438-445.

Laycock, W.A. and Conrad, P.W. 1967. Effect of grazing on soil compaction as measured by bulk density on a high elevation cattle range. J. Range Manage. 20:136-140.

Llacos, L.G. 1962. Water yield as influenced by degree of grazing in the California winter grasslands. J. Range Manage. 15:34-42.

Lodge, R.W. 1954. Effects of grazing on the soils and forage of mixed prairie in southwestern Saskatchewan. J. Range Manage. 7:166-170.

Lorenz, R.J. and Rogler, G.A. 1967. Grazing and fertilization affect root development of range grasses. J. Range Manage. 20:129-132.

Lull, H.W. 1959. Soil compaction on forest and range lands. USDA Misc. Pub. 768.

Martens, H.E. 1979. Content and distribution of organic matter in natural and managed ecosystems in the mixed prairie grassland region in Saskatchewan. Unpubl. M.Sc. Thesis. Dept. Plant Ecology, Univ. of Sask. Saskatoon, Sask. 135 pp.

McCarty, M.K. and Mazurak, A.P. 1976. Soil compaction in Eastern Nebraska after 25 years of cattle grazing management and weed control. J. Range Manage. 29:384-386.

McGinty, W.A., Smeins, F.E., and Merrill, L.B. 1979. Influence of soil, vegetation, and grazing management on infiltration rate and seed production of Edwards Plateau rangeland. J. Range Manage. 32:33-37.

Meeuwig, R.O. 1970. Infiltration and soil erosion as influenced by vegetation and soil in northern Utah. J. Range Manage. 23:183-188.

Odum, E.P. 1960. Organic production and turnover in old field succession. Ecology 41:34-49.

Orr, H.K. 1960. Soil porosity and bulk density on grazed and protected Kentucky Bluegrass range in the Black Hills. J. Range Manage. 13:180-186.

Osborn, B. 1952. Range soil conditions influence water intake. J. Soil Water Conserv. 7:128-132.

Ovington, J.D., Heitkamp, D., and Lawrence, D.B. 1963. Plant biomass and productivity of prairie savanna, oakwood, and maize field ecosystems in central Minnesota. Ecology 44:52-63.

Passey, H.B. and Hugie, V.K. 1963. Some plant soil relationships on an ungrazed range area of south-eastern Idaho. J. Range Manage. 16:113-118.

Peake, R.W. and Johnston, A. 1965. Grazing effects on fescue grassland in western Canada. In: Proc. Int. Grassl. Congr. Sao Paulo, Brazil. Pp. 1627-1630.

Pearson, L.C. 1965. Primary production in grazed and ungrazed desert communities of eastern Idaho. Ecology 46:278-285.

Penfound, W.T. 1964. Effects of denudation on the productivity of grassland. Ecology 45:835-845.

Potvin, M.A. and Harrison, A.T. 1984. Vegetation and litter changes of a Nebraska sandhills prairie protected from grazing. J. Range Manage. 37:55-58.

Rauzi, F. 1960. Water intake studies on range soils at three locations in the Northern Great Plains. J. Range Manage. 13:179-184.

Rauzi, F. 1963. Water intake and plant composition as affected by differential grazing on rangeland. J. Soil Water Conserv. 18:114-116.

Rauzi, F. and Kuhlman, A.H. 1961. Water intake as affected by soil and vegetation in certain western South Dakota rangelands. J. Range Manage. 14:267-271.

Rauzi, F. and Hanson, C.L. 1966. Water intake and runoff as affected by intensity of grazing. J. Range Manage. 19:351-356.

Rauzi, F. and Smith, F.M. 1973. Infiltration rates: three soils with three grazing levels in northeastern Colorado. J. Range Manage. 26:126-129.

Rauzi, F., Fly, C.L., and Dyksterhuis, E.J. 1968. Water intake on mid-continental rangelands as influenced by soil and plant cover. USDA Tech. Bull. 1390. 58 pp.

Reed, M.J. and Peterson, R.A. 1961. Vegetation, soil, and cattle responses to grazing on Northern Great Plains range. USDA For. Serv. Tech. Bull. No. 1252. 79 pp.

Rhoades, E.D., Locke, L.F., Taylor, H.M., and McIlvain, E.H. 1964. Water intake on a sandy range as affected by 20 years of differential cattle stocking rates. J. Range Manage. 17:185-190.

Risser, P.G. 1984. Methods for inventory and monitoring of vegetation, litter, and soil surface condition. In: Developing strategies for range management. NRC/NAS. Western Press/Boulder and London. Pp. 647-690.

Sinton, H.M.M. 1980. Effect of burning and mowing on *Festuca hallii* (Vasey) Piper, *Festuca scabrella* Torr. Unpubl. M.Sc. Thesis. Dept. Plant Sci., Univ. of Alberta. Edmonton, Alta. 140 pp.

Skovlin, J.M., Harris, R.W., Strickler, G.S., and Garrison, G.A. 1976. Effects of cattle grazing methods on ponderosa pine-bunchgrass range in the Pacific Northwest. USDA Tech. Bull. No. 1531. 40 pp.

Smoliak, S. 1965. A comparison of ungrazed and lightly grazed *Stipa-Bouteloua* prairie in southeastern Alberta. Can. J. Plant Sci. 45:270-275.

Smoliak, S., Dormaar, J.F., and Johnston, A. 1972. Long-term grazing effects on *Stipa-Bouteloua* prairie soils. J. Range Manage. 25:246-250.

Steiger, T.L. 1930. Structure of prairie vegetation. Ecology 11:170-217.

Stephenson, R.E. and Schuster, C.E. 1945. Effects of mulches on soil properties. Soil Sci. 59:219-230.

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

Thurow, T.L., Blackburn, W.H., Warren, S.D., and Taylor Jr., C.A. 1987. Rainfall interception by midgrass, shortgrass, and live oak mottes. J. Range Manage. 40:455-460.

Tomanek, G.W. 1969. Dynamics of mulch layer in grassland ecosystems. In: Dix, R.L. and Beidleman, R.G. (eds.). The grassland ecosystem, a preliminary synthesis. IBP Range Science Dept., Science Series No 2:225-240.

Van Haveren, B.P. 1983. Soil bulk density as influenced by grazing intensity and soil type on a shortgrass prairie site. J. Range Manage. 36:586-588.

Van Riper, G.E. and Owen, F.G. 1964. Effect of cutting height on alfalfa and two grasses as related to production, persistence, and available soil moisture. Agron. J. 56:291-295.

Warren, S.D., Nevill, M.B., Blackburn, W.H., and Garza, N.E. 1986. Soil response to trampling under intensive rotation grazing. Soil Sci. Soc. Am. J. 50:1336-1341.

Weaver, J.E. 1950. Stabilization of midwestern grassland. Ecol. Monog. 20:251-270.

Weaver, J.E. and Bruner. 1948. Prairies and pastures of the dissected loess plains of central Nebraska. Ecol. Monog. 18:507-549.

Weaver, J.E. and Rowland. 1952. Effects of excessive mulch on development, yield, and structure of native grassland. Bot. Gaz. 114:1-19.

Whitman, W.C. 1971. Primary productivity and abiotic studies at the Dickinson site, 1970 season. USA IBP Grassland Biome Tech. Rep. No. 116. Colorado State Univ. Fort Collins, Colo. 100 pp.

Whitman, W.C., Zeller, D., and Bjugstad, A.J. 1964. Influence of grazing factors affecting water intake rates of range soils. Abstract from Proc. N. Dakota Acad. Sci. 18:71.

Wiegert, R.G. and Evans, F.C. 1964. Primary production and the disappearance of dead vegetation on an old field in southeastern Michigan. Ecology 45:49-63.

Willatt, S.T. and Pullar, D.M. 1983. Changes in soil physical properties under grazed pastures. Austral. J. Soil Res. 22:343-348.

Willms, W.D., Bailey, A.W., and McLean, A. 1980. Effects of clipping or burning on some morphological characteristics of Agropyron spicatum. Can. J. Bot. 58:2309-2312.

Willms, W.D., Smoliak, S., and Bailey, A.W. 1986. Herbage production following litter removal on Alberta native grasslands. J. Range Manage. 39:536-540.

Wood, M.K. and Blackburn, W.H. 1984. Vegetation and soil responses to cattle grazing systems in the Texas Rolling Plains. J. Range Manage. 37:303-308.

Wright, H.A. and Bailey, A.W. 1982. Fire Ecology. John Wiley and Sons Inc. Toronto, Ont. 501 pp.

Zeller, D.H. 1963. Certain mulch and soil characteristics in major range sites in western North Dakota as related to range condition. Unpubl. M.Sc. Thesis. North Dakota State Univ. Fargo, ND. 84 pp.

II. THE IMPACT OF GRAZING REGIME ON LITTER AND SOIL ORGANIC MATTER IN MIXED PRAIRIE AND FESCUE GRASSLAND ECOSYSTEMS OF ALBERTA

INTRODUCTION

Litter and soil organic matter increase soil aggregation, aggregate stability, and infiltration rate, and decrease raindrop impact, runoff, erosion, and soil surface evaporation (Tomanek 1969). They provide habitats for organisms and retain nutrients (Risser 1984). Litter and soil organic matter production/accumulation vary with ecosystem and are affected by vegetation, soil, season, climate, and grazing regime (Dyksterhuis and Schmutz 1947; Tomanek 1969; Coupland 1979).

In the Canadian Northern Great Plains, accumulated litter ranges from 0.28 to 1.24 kg m^{-2} in fescue grasslands (Johnston 1961; Willms et al. 1986) and from 0.06 to 0.09 kg m^{-2} in mixed prairie (Smoliak 1965; Willms et al. 1986). Grazing reduces litter mass, with lowest values under very heavy grazing (Coupland et al. 1960; Johnston 1961, 1962; Peake and Johnston 1965; Smoliak 1965; Johnston et al. 1971). Some researchers found grazing does not affect soil organic matter (Lodge 1954; Johnston et al. 1971; Dormaar et al. 1977). Others found heavy grazing reduces total carbon in Ah horizons in some grasslands (Smoliak et al. 1972; Dormaar et al. 1977) and increases it in other grasslands (Dormaar et al. 1984). Below ground dry matter can decrease under grazing (Coupland et al. 1960; Smoliak 1965) or increase (Johnston 1961; Smoliak et al. 1972), with the most significant changes occurring in the top 15 cm.

Branson (1984) stated there may be a critical point in relatively moist climates at which litter accumulation has a depressing effect on herbaceous plant yields. This generally occurs when litter accumulations exceed 5000 kg ha^{-1}. In the Canadian prairie grasslands studied, litter accumulation is not high enough to significantly reduce herbage productivity (Willms et al. 1980, 1986), although Sinton (1980) found under certain treatments litter removal resulted in an increase in herbage yield two years later. These studies and others in the American Northern Great Plains indicate litter accumulation, which does not generally exceed 2700 kg ha^{-1}, does not adversely affect range condition or productivity. From a hydrologic perspective, there is considerable uncertainty about amounts of vegetative cover needed to prevent excessive runoff and erosion under the diverse topography and soil conditions of grasslands (Meeuwig 1970). For hydrologic benefit on most rangelands, management for litter accumulation may be as important as management for increasing live plant cover (Branson 1984).

Since litter and soil organic matter have beneficial effects in grasslands, it is important to determine how they are affected by grazing. The major objective of this study was to determine how litter and soil organic matter were affected by season and intensity of grazing in Alberta mixed prairie and fescue grassland ecosystems. It was hypothesized that season and intensity of grazing would affect amounts of soil organic matter and litter. It was also hypothesized that proportions of litter of different particle sizes would vary with season and intensity of grazing due to trampling and breakdown during grazing. Different particle sized litter would decompose at different rates, affecting soil organic matter mass. Therefore a second objective was to categorize litter and soil organic matter according to particle size and to quantify categories within treatments.

MATERIALS AND METHODS

Study Sites

Three study sites representing major grassland ecosystems of southern and central Alberta rangeland were selected. Each study site had long-term grazing treatments, ungrazed controls, grass dominated vegetation that had never been cultivated, and slopes of less than 2%. (See Appendix I for detailed descriptions). Moss (1983) was used as the botanical authority.

Brooks

The Brooks site was located in mixed prairie approximately 225 km east of Calgary (51 ^{O}N latitude and 112 ^{O}W longitude). The area has a continental prairie climate and a semiarid moisture regime (Bowser 1967). Mean annual precipitation is 355 mm with an average annual moisture deficit of 227 mm. Mean annual temperature is 4 ^{O}C, with a July mean of 19 ^{O}C and a January mean of -14 ^{O}C. Elevation averages 745 m above sea level with slopes of less than 2%. Soils are

Brown Solodized Solonetz and Brown Solod developed on till (Kjearsgaard et al. 1982). Vegetation is of the *Bouteloua-Stipa-Agropyron* (blue grama-spear grass-wheatgrass) faciation dominated by *Bouteloua gracilis, Stipa comata, Agropyron smithii*, and *A. dasystachyum*. (Coupland 1961). *Artemisia frigida* and *Selaginella densa* are common forbs. A short grass disclimax dominated by *Bouteloua gracilis* is common as a result of heavy long-term grazing.

Kinsella

The Kinsella site was located in aspen parkland approximately 150 km southeast of Edmonton (53 °N latitude and 111 °W longitude). The climate is dry subhumid (Wonders 1969). Mean annual precipitation is 380 mm; mean annual evapotranspiration is 381 mm. Mean annual temperature is 2 °C, with a July mean of 17 °C and a January mean of -17 °C. Elevation averages 685 m above sea level with gently rolling to hilly topography (Howitt 1988). Grassland soils are dominated by Orthic Black Chernozems developed on till. Vegetation consists of grass and shrub communities with aspen groves occurring at irregular intervals (Moss 1955). *Festuca hallii* (Vasey) Piper (Pavlick and Looman 1984) dominates open undisturbed grasslands and *Stipa curtiseta* co-dominates on grazed areas (Wheeler 1976). Forbs are a common component of the vegetation.

Stavely

The Stavely site was located in foothills fescue grassland approximately 100 km south-southwest of Calgary (50 °N latitude and 114 °W longitude). The climate is subhumid without marked deficiency of precipitation. Mean annual precipitation is 550 mm. Mean annual temperature is 5 °C, with a July mean of 18 °C and a January mean of -10 °C. Elevation averages 1350 m above sea level and topography is gently rolling to hilly. Soils are Orthic Black Chernozems developed on till (Johnston et al. 1971). Vegetation is of the fescue grassland association (Looman 1969) with *Festuca campestris* Rydb. dominating in undisturbed and lightly grazed areas. *Danthonia parryi* and *Festuca idahoensis* are codominants in grazed areas. With heavy grazing, *Festuca campestris* is replaced by annual invaders and *Poa* species.

Grazing Treatments

At Brooks, three grazing treatments were studied within a community pasture that had been established in 1964 (B. Shanks, personal communication, September 1981). The treatments included: (1) early season grazing from May 1 through July; (2) late season grazing from August through October; and (3) a control on an adjacent highway right-of-way that had not been grazed for 25 years. The 0.9 AUM ha^{-1} stocking rate was considered heavy for the area.

At Kinsella, five grazing treatments established in 1973 on the University of Alberta ranch were studied (Bailey et al. 1987). The treatments included: (1) light June grazing from June 1 to 30 at 1.5 AUM ha^{-1} with approximately 35% herbage utilized; (2) heavy June grazing from June 1 to 30 at 4.4 AUM ha^{-1} with approximately 75% herbage utilized; (3) heavy autumn grazing from September 15 to October 15 at 4.4 AUM ha^{-1} with approximately 75% herbage utilized; (4) light autumn grazing from September 15 to October 15 at 1.5 AUM ha^{-1} with approximately 35% herbage utilized; and (5) a control that had not been grazed since 1942. Each grazing treatment included 5.5 ha of grassland and a variable area of shrub and forest. Two 10 by 20 m permanent exclosures, randomly located in each treatment, were also studied.

At Stavely, five grazing treatments established in 1949 on an Agriculture Canada Range Research Substation were studied (Johnston 1961). Treatments were grazed May to October and included: (1) very heavy grazing with 16.2 ha stocked at 4.8 AUM ha^{-1}; (2) heavy grazing with 32.4 ha stocked at 2.4 AUM ha^{-1}; (3) moderate grazing with 48.6 ha stocked at 1.6 AUM ha^{-1}; (4) light grazing with 64.8 ha stocked at 1.2 AUM ha^{-1}; and (5) a control comprised of permanent exclosures of 0.66, 0.41, 0.76, and 0.23 ha in the light, moderate, heavy, and very heavy treatments, respectively.

Experimental Design

The experimental design within each site was a hierarchical (subsampling) arrangement. Within each treatment, three 0.1 ha areas were randomly established. Within each of these areas, points were randomly selected from which samples were collected or measurements were made.

Litter And Soil Organic Matter Sampling And Analyses

For this study, litter refers to all dead organic matter not incorporated with mineral soil and occurring above soil mineral horizons. Soil organic matter refers to the organic fraction of soil, including plant and animal residues at various stages of decomposition, cells and tissues of soil organisms, and substances synthesized by the soil population as defined by the Canada Department of Agriculture (1979).

Sampling was conducted in late August of 1985 and 1986. At each site, in each treatment, in each 0.1 ha area, 10 randomly located 0.1 m^2 quadrats (30 per treatment), with inner dimensions of 20 by 50 cm, were used to collect the samples. In each quadrat, all live vegetation, including dried tips of live plants, was removed with scissors at ground level. Standing litter was removed in the same way. The remaining litter was removed from the soil surface with hand rakes. Soil organic matter was lifted as a slab, after an edging shovel was used to cut down to a mineral soil horizon where a color and texture change indicated the bottom of the Ah horizon. Remaining litter and soil were removed from the sample hole with a brush. Sampling depths varied with site and treatment but averaged approximately 5 to 8 cm at Brooks (no difference in depth among treatments) and 10 to 15 cm at Kinsella (no difference in depth among treatments) and Stavely (the very heavy treatment was shallower than the other treatments).

Live vegetative material was oven dried at 65 °C for 24 hours, then weighed. Litter and organic matter samples were air dried for two weeks then sorted into categories on the basis of size using a bank of sieves mounted on an automatic sieve shaker (Tyler RO-TAP Model B) as modified from Coupland (1973). Five minutes of shaking was required to sort the samples without breaking down plant material. Sieves had openings of 2.0, 0.85, and 0.212 mm (Tyler equivalents of 9, 20, and 65 mesh).

The litter and organic matter categories were: (1) standing litter recognized and collected in the field as standing litter; (2) coarse litter remaining in the top sieve (2 mm) and recognizable as undecomposed plant parts; (3) medium litter that was partly decomposed and collected in the second sieve (0.85 mm); (4) fine organic matter that was relatively decomposed and collected in the third sieve (0.212 mm); (5) very fine organic matter that was decomposed and collected in the bottom pan; and (6) roots large enough to be easily handled which were removed from the samples before sieving. Categories 4 and 5 contained most of the living and dead small roots and root hairs. Above ground organic matter was composed of standing, coarse, and medium litter, and live vegetation. Below ground organic matter was composed of roots, fine, and very fine organic matter. Total organic matter included all the above categories.

To determine the amount of organic matter in each category and to separate it from mineral matter included in the total weight, organic carbon content was determined by oxidation with a Leco Carbon Determinator C12 Model 781-600. In each category, five subsamples from each 0.1 ha area were analyzed (15 per treatment). Soil samples were ground on a Siebtechnik laboratory disc mill, Model TS100A, to pass through a 0.15 mm sieve. Soil carbonates in 10 samples from each study site were determined by acid neutralization to pH 8.2 using a Radiometer Titrator Type TTT 11b (Black 1965). Organic carbon was calculated by subtracting percent inorganic carbon from percent total carbon. Percent organic carbon was multiplied by 1.724 (organic matter is approximately 58% organic carbon) to determine percent organic matter in each category. This value was then multiplied by total mass of each category to give mass in the 0.1 m^2 sample. Masses were then converted to specific mass (kg m^{-2}).

In each 0.1 ha area, ground cover was determined using 10 randomly located 10 point frames (Cook and Stubbendieck 1986) to determine percent bare ground, live vegetation, and dead vegetation (300 points per treatment). Heights (cm) of standing litter, fallen litter, and standing litter height of each major species or group were measured at thirty randomly selected points in each 0.1 ha area (90 per treatment).

Statistical Analyses

Statistical analyses were conducted using variation among the 0.1 ha areas as an appropriate measure of error for testing treatment significance. Data were tested for homogeneity of variance using Cochran and Bartlett-Box tests. The W test was used to test data for normality of distribution

(Shapiro and Wilk 1965). An SPSSx analysis of variance program was used to test for treatment effects. Data with significant F values were further analyzed to separate the means using the Student-Newman-Keul (SNK) test at the 5% level of significance (Steel and Torrie 1980).

Preliminary statistical analyses within each year by treatment combination indicated that variation among the 0.1 ha areas was not significantly different from sampling point variation and therefore in all future analyses, area and sampling point variation were pooled. If additional preliminary statistical analyses within each treatment using the pooled error term indicated significant differences between study years, data were analyzed on a within year basis. Otherwise data from both years were pooled. Sources of variation in the final statistical analysis were treatments and error within treatments.

RESULTS

At the three sites, where ground cover, litter height, and percent organic carbon did not differ statistically between 1985 and 1986, a mean for the two years is presented.

Growing Season Precipitation

Precipitation at Brooks in May (54 mm) and July (63 mm) 1986 was higher than that in 1985 (13 and 39 mm, respectively) or the 1951-80 average (38 and 32 mm, respectively) (Atmospheric Environment Services 1985-1987). At Kinsella, March (23 mm) and July (116 mm) precipitation in 1986 was higher than that in 1985 (3 and 22 mm, respectively) or the 1951-80 average (16 and 76 mm, respectively). Stavely had higher May (65 mm), June (53 mm), and July (43 mm) precipitation in 1986 than in 1985 (30, 11, and 25 mm, respectively) or the 1951-80 average in May (46 mm). The long-term average was higher in June (82 mm) than in 1986 and similar in July (46 mm).

Brooks

Live vegetation and litter components of ground cover were not affected by grazing at the level of sampling used (Table 2.1). Bare ground was 4.7 times higher under early season grazing than in the control. Fallen litter was approximately 6 times higher in the control than in the grazed treatments and standing litter was 1.4 times higher (Table 2.2). Midgrass heights were greater in the control than in the grazed treatments but the lower stature *Bouteloua gracilis* was not affected by grazing.

Percent organic carbon was reduced the most in roots and standing litter under early season grazing (Table 2.3). In contrast there was a greater percent of organic carbon in coarse and medium litter under early season grazing as well as a higher percent carbon in medium litter under late season grazing compared to the control. There were no treatment effects on fine and very fine organic matter. Organic carbon percentages were highest in coarse litter; approximately 7.5 times higher than in very fine organic matter which had the lowest percent organic carbon (statistical significance not depicted).

Above ground organic matter mass was not affected by treatment; below ground and total masses were highest under late season grazing (Figure 2.1). Total organic matter was allocated to approximately 75% below ground and 25% above ground components. Specific masses of roots, standing, fine, and very fine organic matter varied significantly with study year (Figure 2.2, significance between years not depicted). The greatest mass of organic matter was in the fine and very fine categories and the lowest mass was of live vegetation. Above ground litter was comprised mainly of standing and medium litter. Grazing treatment had no significant effect on coarse, very fine, or root organic matter masses in 1985 or on coarse and very fine masses in 1986. Among the other categories, treatment effects varied with year. Consistent trends with organic matter masses included: lowest medium litter in the control; highest fine under late season grazing; and highest live vegetation mass in the control and lowest under late season grazing.

Kinsella

Live vegetation and litter components of ground cover were not affected by grazing (Table 2.4). Bare ground was highest under heavy June grazing. Standing litter was 1.5 to 2 times higher and fallen litter was 4 to 11 times higher in the control than in the grazed treatments, with standing litter being higher in the light autumn treatment than in the other grazed treatments (Table 2.5). *Bouteloua gracilis* and *Koeleria macrantha* were not found in the control and were not affected by grazing treatment. The other major grasses tended to be tallest in the control. *Festuca hallii* standing litter was tallest in the control, intermediate under light grazing, and shortest under heavy grazing.

Organic carbon in roots and coarse litter was not affected by grazing (Table 2.6). In standing litter it was highest in control and heavy June treatments and lowest in the heavy autumn treatment. Organic carbon in medium, fine, and very fine categories was lowest in the control being 1.4 to 1.9 times higher in the grazed treatments. Total organic matter was comprised of approximately two-thirds below ground and one-third above ground componants (Figure 2.3). Above ground organic matter mass was not affected by grazing. Below ground and total organic matter masses were highest in the light autumn treatment. Specific mass of very fine organic matter varied significantly between years (Figure 2.4, between year significance not depicted). Mass of large roots was not affected by treatment. Among other categories, treatment effect varied with year. Consistent trends with organic matter masses were: highest standing litter in the control; highest fine organic matter under light autumn grazing; and lowest very fine organic matter in the control.

Stavely

Bare ground increased under moderate, heavy, and very heavy grazing intensities (Table 2.7). Live vegetative cover was highest under light and moderate grazing, intermediate under heavy and very heavy grazing, and lowest in the control. Litter cover was highest in the control but did not vary among the grazed treatments. Standing and fallen litter height decreased with increased grazing intensity (Table 2.8). Standing litter was 1 to 1.6 times higher in the control than in the grazed treatments and fallen litter was 1.6 to 6.7 times higher. Heights of major grasses comprising standing litter were lowest in heavy and/or very heavy treatments. Forbs were highest in control and very heavy treatments although species differed in the two treatments. *Festuca campestris* and *Danthonia parryi* were not found in the very heavy treatment.

In all litter and organic matter categories, percent organic carbon was not affected by grazing treatment (Table 2.9). Total organic matter was comprised of approximately two-thirds below ground and one-third above ground components (Figure 2.5). Above ground, below ground, and total organic matter masses were lower in the grazed treatments than in the control. Above ground organic matter was lower in the very heavy treatment than in the other grazed treatments. Masses in root, coarse, and fine categories did not differ with treatment (Figure 2.6). Consistent treatment effects on organic matter masses included: highest standing litter in the control; higher very fine organic matter in control, heavy, and very heavy treatments than in light and moderate treatments; and higher live vegetation in the control.

DISCUSSION

Grazing Effects

Although most grazing treatments studied did not lead to a decline in litter cover at Brooks or Kinsella, the large amount of *Festuca campestris* litter that built up under no grazing at Stavely was reduced by treading under continuous grazing treatments which likely facilitated more rapid breakdown of the litter. All grazing regimes studied reduced standing litter height and fallen litter depth. Standing litter height was 1 to 6 times greater in the controls than in the grazed treatments since vegetation and litter were not removed by grazing; depth of fallen litter was 1 to 11 times greater since breakage and compaction by treading did not occur.

Combinations of heavy intensity and early season grazing had the most negative effect on litter and organic matter. Early in the growing season plant growth is rapid, carbohydrate reserves are low, and plant species are more susceptible to grazing damage. Heavy intensities of grazing remove more vegetative material and less regrowth is forthcoming. Two early season treatments: the early season at Brooks and the heavy June at Kinsella support this with increased bare ground. Stavely treatments were also started early in the growing season, but it was only under heavy and very heavy intensities that bare ground increased. The late season treatment at Brooks was also a heavy intensity treatment, but grazing late in the growing season reduced the impact of heavy grazing. Late in the growing season many plant species are dormant and will be less affected by grazing. The negative effects of heavy early season grazing were also supported by higher masses of total organic matter in the late season treatment at Brooks, the light autumn treatment at Kinsella, and the control at Stavely. Higher standing litter in the light autumn treatment at Kinsella compared to the other grazed treatments indicated that late season grazing of a low intensity had the least effect on litter production.

Litter cover at Brooks was high for heavy long-term grazing treatments because *Selaginella densa* comprised an average 58% of the basal area (Naeth 1985). At the time of sampling, *Selaginella densa* appeared to be mostly dead and was classed as litter. The similarity of above ground litter mass between the control and grazed treatments was also related to large amounts of *Selaginella densa* in the grazed treatments that sorted into coarse and medium litter categories. Lower litter height under very heavy grazing compared to heavy grazing at Stavely was also due to a shift in species composition as a result of long-term grazing. Taller plant species are reduced or eliminated under very heavy grazing and replaced by lower growing, shallow-rooted grasses and forbs. Many of these species would be rooting in the upper 20 cm of the soil profile (Coupland 1979). Smoliak (1965) also found grazing reduced the height of plant species. At Stavely, shallow rooted species in heavier grazed treatments (Johnston 1962) may account for higher values in litter categories that included small roots.

Grazing treatment can affect decomposition rate, which will affect organic matter mass in specific categories. Trampling could create better litter-soil contact, facilitating more rapid decomposition by soil microorganisms (McCalla 1943; Dyksterhuis and Schmutz 1947) in the grazed treatments than in the controls. At Brooks, forbs and shrubs were more prominent in the early season treatment and grasses more prominent in the late season treatment (Naeth 1985). Lignin content of grasses is less than that of shrubs and therefore more rapid decomposition may occur (Norman 1933), increasing fine organic matter under late season grazing. Higher below ground and total organic matter masses in the light autumn treatment than in the control at Kinsella were also likely due to trampling, facilitating more rapid breakdown and resulting in larger amounts of organic matter in some finer categories. Total productivity in the Kinsella control is similar to or less than that in the light autumn treatment (Bailey et al. 1987). Grass productivity is higher if grazed due to the stimulating effect of light grazing, which can contribute to greater total litter than would be in the control. At Stavely, higher very fine organic matter masses in very heavy and heavy treatments than in light and moderate treatments may have been due to higher soil temperatures under heavy and very heavy grazing (Johnston 1962) which would create conditions favorable for rapid physical reduction in litter particle size. Heavier utilization may also have broken down litter and facilitated its more rapid biochemical decomposition.

Reduced standing litter with grazing on Alberta rangelands was in agreement with most North American grassland studies (Coupland 1979). However, comparing values to those in the literature is difficult due to differences in sampling technique and geographical location. In mixed prairie studies it is often not known whether *Selaginella densa* was included in litter at sampling time. Above ground litter masses in this study were higher than those for Alberta mixed prairie (Smoliak 1965; Smoliak et al. 1985; Willms et al. 1986) as were below ground masses (Smoliak et al. 1972). Standing and coarse litter were similar to those obtained by Coupland (1973) for Saskatchewan mixed prairie but his coarse, fine, and very fine values are not comparable to those from other categories in this study due to differences in sieve size and depth of sampling. In *Festuca hallii* grasslands, values in this study for above ground litter were higher than others from Alberta (Smoliak et al. 1985; Willms et al. 1986; Bailey et al. 1987) due to differences in sampling.

Organic Carbon

Higher percent organic carbon in roots, standing litter, and coarse litter categories compared to medium fine, and very fine categories reflected the larger proportion of mineral soil to plant material in the latter categories. Organic carbon in different particle sized litter may be affected by CO_2 losses during decomposition. For *Festuca* and *Stipa* species, 28 to 33% of the original carbon in roots and residue may be lost within 47 weeks of incubation (Herman 1974). Plant species differ in their chemical composition (Stoddart et al. 1975) and significant differences in dominant species within treatments as a result of grazing regime may affect total carbon in the organic matter. Data from this study supported those of Dormaar et al. (1977) who report total carbon does not change with grazing intensity. Dormaar et al. (1984) also found higher amounts of total carbon in the heavy grazed treatment compared to the ungrazed site at Manyberries, Alberta. The large amounts of *Selaginella densa* may have contributed to these higher values.

Roots

Partial or complete defoliation can result in reduced plant root mass (Crider 1955). Although root mass consisting of only relatively large roots, was not affected by grazing, treatment differences were found in fine and/or very fine organic matter masses of which smaller roots were a constituent. There were also more roots below the sampling depth, particularly in the control and lightly grazed treatments where deep rooted species dominate.

At Brooks, higher below ground organic matter in the late season treatment was mainly due to higher fine organic matter mass. The fine organic matter reflected the larger root mass in the upper soil profile due to heavy overgrazing which led to dominance of more shallow rooted species. It is difficult to compare root masses from this study to those from other studies which often use flotation methods to separate roots. However, if root biomass and part of the fine organic matter which contains smaller roots were compared to root masses from other studies, values were often similar. If this type of assessment is used, values presented by Coupland (1970) for Saskatchewan mixed prairie were similar to root values for the Brooks site and total root organic matter reported by Johnston (1961) was similar to root organic matter from Stavely.

Annual Variability

Differences in litter and organic matter production and accumulation between years were largely a result of the amount and timing of precipitation. Greater live vegetation masses in 1986 than in 1985 could have resulted from higher spring/summer precipitation in 1986. May-July precipitation occurs during maximum water extraction by native grassland species (de Jong and MacDonald 1975) and is closely associated with forage yield in Alberta mixed prairie (Smoliak 1956). Less live vegetation in 1985 may have led to less standing and coarse litter in 1986.

Higher mass of fine organic matter and lower mass of root and very fine organic matter in 1985 compared to 1986 may be due to differences in separation techniques by different technicians. Small roots were more thoroughly sorted in 1986 and went into the root category; sorting may have broken some remaining root material which fell into the very fine organic matter category.

CONCLUSIONS

Combined early season/heavy intensity grazing had the greatest negative effect on litter and soil organic matter; late season/light intensity grazing had the least effect. Bare ground was greatest under early season/heavy intensity or long-term very heavy continuous grazing. Most grazing treatments studied did not lead to a decline in litter ground cover. Litter height was greatest in controls or light treatments and lowest in heavy treatments. Although standing litter height was generally not reduced with light grazing at Stavely, it was reduced with light June grazing at Kinsella due to the superimposed effect of season. Litter mass was highest under light intensity/late season grazing and lowest under very heavy continuous grazing.

Grazing affected proportions of various litter and soil organic matter particle sizes, with early season/heavy intensity combinations having the most negative effect. Live organic matter mass was greatest in controls and light intensity/late season treatments and lowest in early season/heavy intensity treatments. Higher organic matter in grazed treatments than in controls in some medium and small particle sized categories was probably due to more rapid decomposition when vegetation was trampled and broken down into smaller particle sizes. Higher organic matter in the larger particle sized litter categories, particularly the standing litter, in the grazed treatments compared to the controls was due to the effect of treading and removal by grazing.

Table 2.1. Percent ground cover (bare ground, live vegetation, litter) at Brooks.

Ground Cover	Treatment		
	Early	Late	Control
Bare Ground	7.0a	4.0ab	1.5b
Live Vegetation	12.0a	15.5a	17.5a
Litter	81.0a	80.5a	81.0a

Within category means with the same letters are not significantly different (P<0.05).

Table 2.2. Height (cm) of fallen and standing litter and standing litter by species at Brooks.

Litter Type or Species	Treatment		
	Early	Late	Control
Fallen Litter	0.5b	0.5b	3.2a
Standing Litter	15.7b	16.1b	21.3a
Bouteloua gracilis	10.6a	10.3a	12.6a
Koeleria macrantha	18.0b	19.4b	24.9a
Stipa comata	18.6b	20.8b	26.3a

Within category means with the same letters are not significantly different (P<0.05).

Table 2.3. Percent organic carbon in litter and soil organic matter categories at Brooks.

Litter/Organic Matter Category	Treatment		
	Early	Late	Control
Roots	22.0b	28.0a	25.0ab
Standing Litter	23.2b	29.1a	25.5ab
Coarse Litter	31.4a	30.0ab	27.0b
Medium Litter	14.4a	11.3b	6.2c
Fine Organic Matter	6.0a	6.0a	4.6a
Very Fine Organic Matter	3.9a	4.3a	3.6a

Within category means with the same letters are not significantly different (P<0.05).

Table 2.4. Percent ground cover (bare ground, live vegetation, litter) at Kinsella.

Ground Cover	Treatment				
	Light June	Heavy June	Heavy Autumn	Light Autumn	Control
Bare Ground	0.0b	2.0a	0.5b	0.0b	0.0b
Live Vegetation	35.5a	31.5a	36.0a	38.5a	39.5a
Litter	64.5a	66.5a	63.5a	61.5a	60.5a

Within category means with the same letters are not significantly different (P<0.05).

Table 2.5. Height (cm) of fallen and standing litter and of standing litter by species at Kinsella.

Litter Type or Species	Treatment				
	Light June	Heavy June	Heavy Autumn	Light Autumn	Control
Fallen Litter	2.8b	1.3b	1.9b	3.8b	14.6a
Standing Litter	30.7c	29.6c	25.9c	37.3b	53.9a
Festuca hallii	43.9b	36.7c	27.5d	47.0b	63.7a
Stipa curtiseta	37.7c	33.5c	25.6c	45.5b	60.5a
Agropyron species	38.1c	38.7c	42.3c	52.4b	67.1a
Poa species	32.4b	28.3b	25.2b	42.6ab	48.5a
Koeleria macrantha	21.1a	26.0a	22.4a	27.3a	00.0b
Bouteloua gracilis	21.8a	26.2a	24.7a	24.8a	00.0b
Forbs	19.7b	17.6b	12.6b	21.6ab	29.9a

Within category means with the same letters are not significantly different ($P<0.05$).

Table 2.6. Percent organic carbon in litter and soil organic matter categories at Kinsella.

Litter/Organic Matter Category	Treatment				
	Light June	Heavy June	Heavy Autumn	Light Autumn	Control
Roots	33.2a	34.8a	30.3a	31.3a	27.6a
Standing Litter	31.8b	34.6a	29.7c	31.7b	35.1a
Coarse Litter	26.3a	28.8a	25.9a	29.3a	27.2a
Medium Litter	8.8a	8.8a	10.3a	10.6a	5.5b
Fine Organic Matter	8.7a	8.1a	9.3a	9.5a	5.7b
Very Fine Organic Matter	8.4a	8.8a	9.2a	8.4a	5.9b

Within category means with the same letters are not significantly different (P<0.05).

Table 2.7. Percent ground cover (bare ground, live vegetation, litter) at Stavely.

Ground Cover	Treatment				
	Very Heavy	Heavy	Moderate	Light	Control
Bare Ground	14.5a	10.5b	1.0c	0.5c	0.0c
Live Vegetation	21.0b	22.0b	30.5a	30.0a	12.3c
Litter	64.5b	67.5b	68.5b	69.5b	87.7a

Within category means with the same letters are not significantly different (P<0.05).

Table 2.8. Height (cm) of fallen and standing litter and standing litter by species at Stavely.

Litter Type or Species	Treatment				
	Very Heavy	Heavy	Moderate	Light	Control
Fallen Litter	0.2d	2.2d	4.9c	8.5b	13.4a
Standing Litter	36.4d	48.9c	55.0b	57.3ab	59.6a
Festuca campestris	00.0d	72.5c	78.0b	85.9a	83.6a
Danthonia parryi	00.0d	40.4c	50.5b	52.3ab	61.0
Agropyron species	40.3b	57.8a	60.8a	67.5a	66.1a
Poa species	29.1c	44.6b	52.6a	67.5a	47.0b
Forbs	39.7a	29.2b	33.0b	32.6b	40.3a

Within category means with the same letters are not significantly different (P<0.05).

Table 2.9. Percent organic carbon in the litter and soil organic matter categories at Stavely.

Litter/Organic Matter Category	Treatment				
	Very Heavy	Heavy	Moderate	Light	Control
Roots	40.8a	38.2a	36.4a	37.8a	35.2a
Standing Litter	40.3a	41.1a	39.8a	40.9a	40.8a
Coarse Litter	33.9a	33.3a	33.2a	34.2a	31.9a
Medium Litter	15.4a	14.3a	13.2a	11.5a	11.3a
Fine Organic Matter	16.3a	13.1a	13.3a	10.7a	12.8a
Very Fine Organic Matter	12.8a	11.2a	11.3a	11.3a	11.5a

Within category means with the same letters are not significantly different (P<0.05).

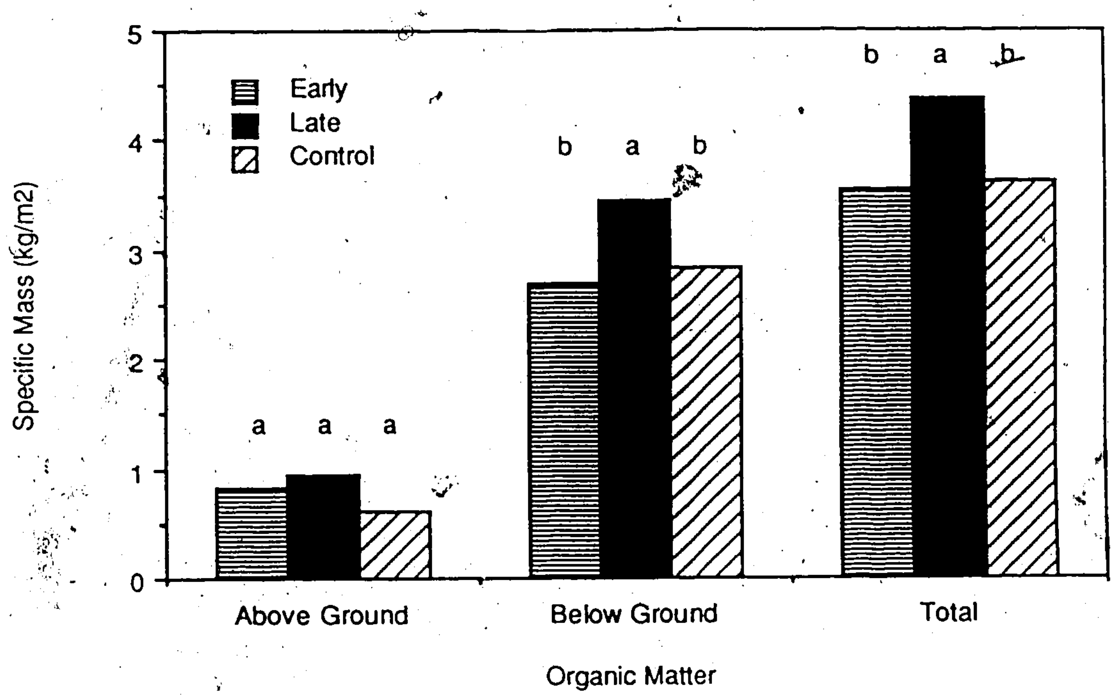


Figure 2.1. Above ground, below ground, and total organic matter at Brooks. Within category means with the same letters are not significantly different ($P<0.05$).

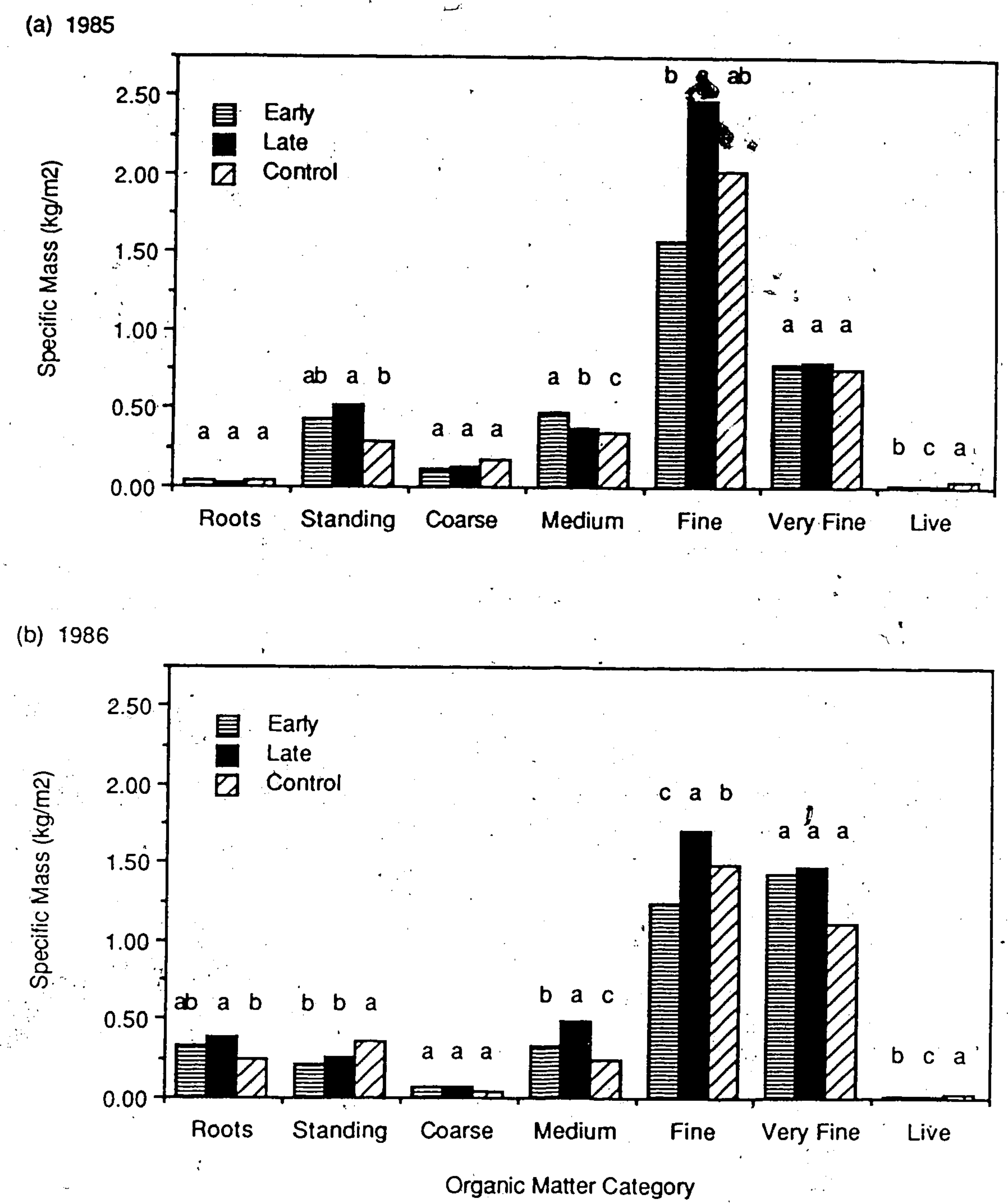


Figure 2.2. Specific mass of organic matter categories at Brooks in (a) 1985 and (b) 1986. Within year and category means with the same letters are not significantly different (P<0.05).

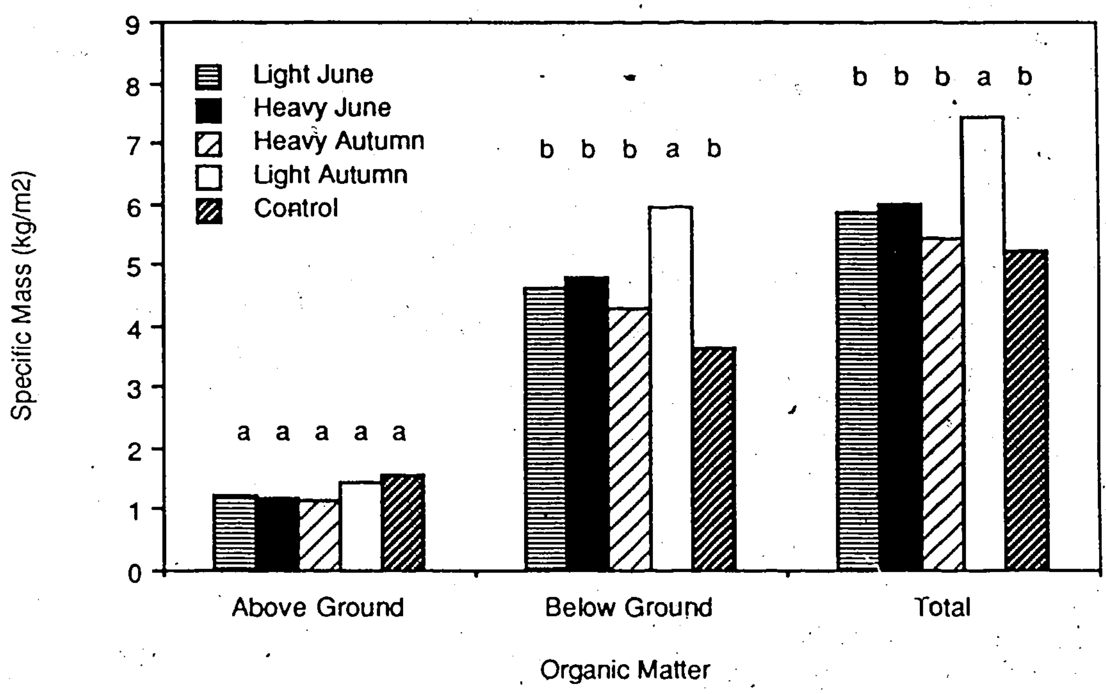


Figure 2.3. Above ground, below ground, and total organic matter at Kinsella. Within category means with the same letters are not significantly different (P<0.05).

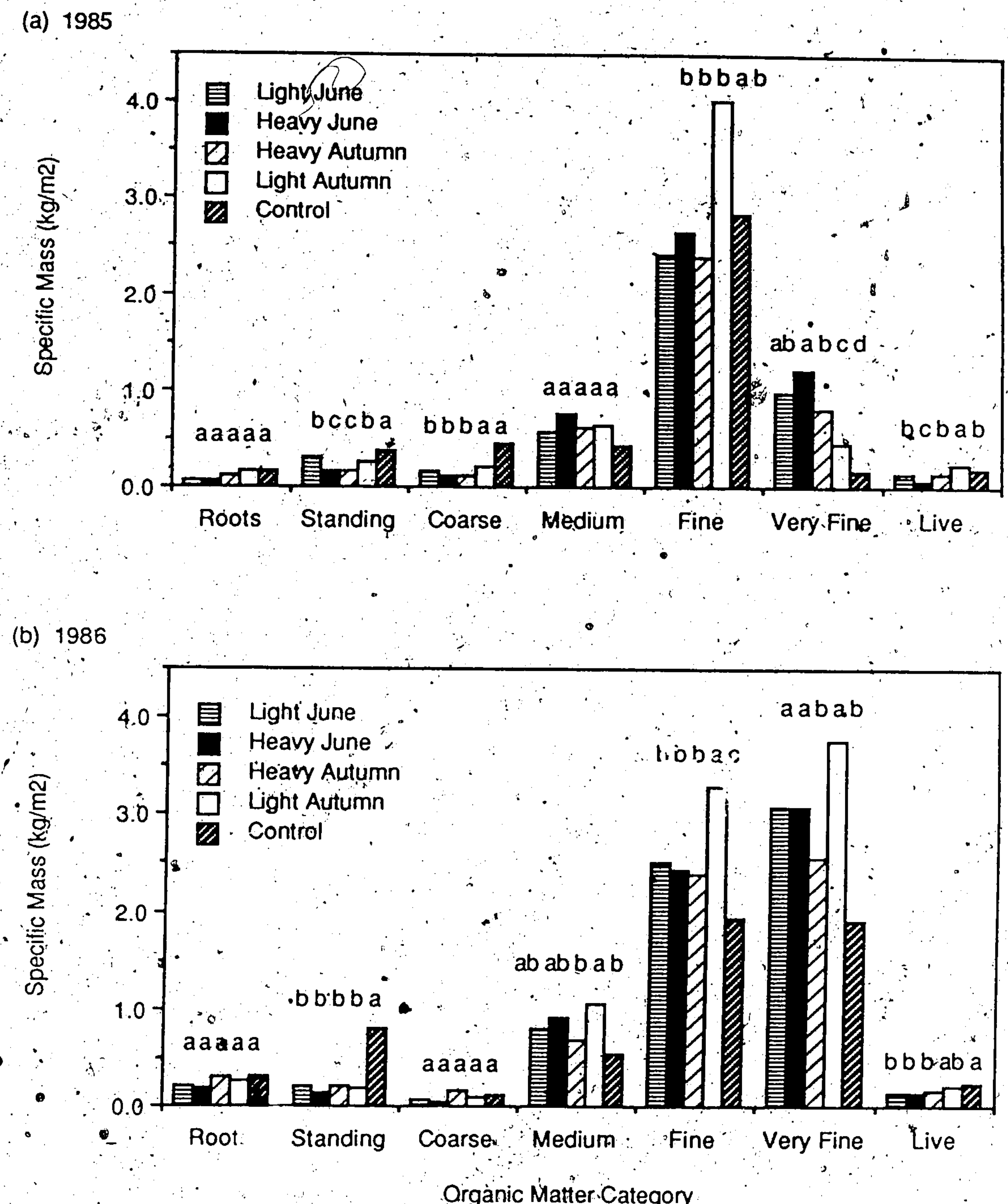


Figure 2.4. Specific mass of organic matter categories at Kinsella in (a) 1985 and (b) 1986. Within year and category means with the same letters are not significantly different ($P<0.05$).

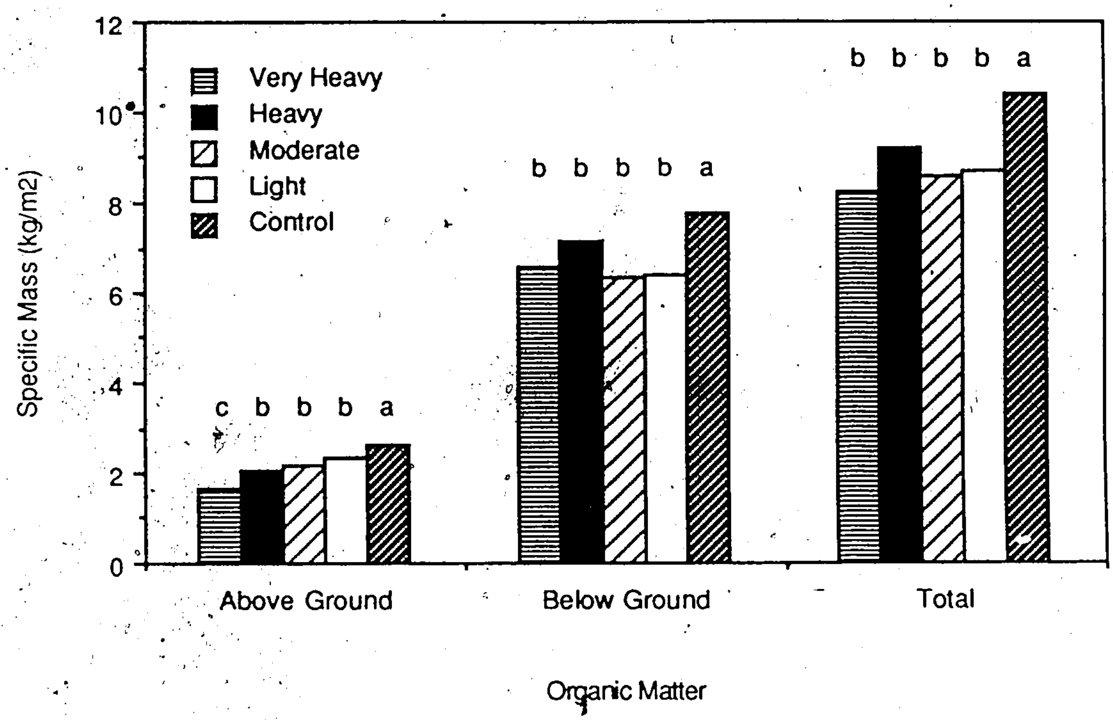


Figure 2.5. Above ground, below ground, and total organic matter at Stavely. Within category means with the same letters are not significantly different (P<0.05).

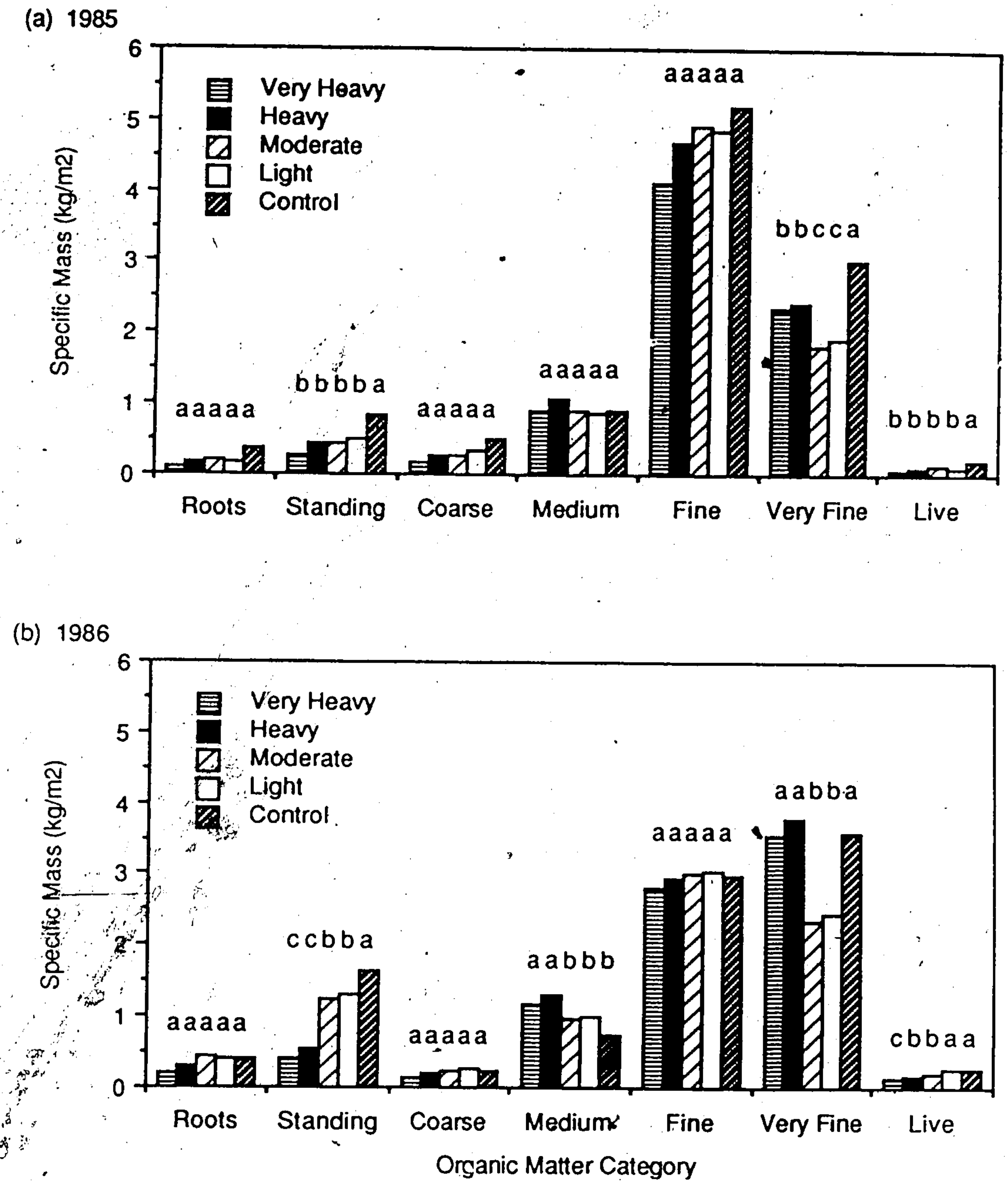


Figure 2.6. Specific mass of organic matter categories at Stavely in (a) 1985 and (b) 1986. Within year and category means with the same letters are not significantly different (P<0.05).

BIBLIOGRAPHY

Atmospheric Environment Services. 1985-1987. Monthly record: meteorological observations in western Canada. Vols. 70, 71, 72. Environment Canada.

Bailey, A.W., Willoughby, M.G., and Irving, B.D. 1987. Effect of grazing on forage and beef production from rough fescue rangeland in central Alberta. Farming for the Future Final Report. Project No. 84-0335. 41 pp.

Black, C.A. 1965. Methods of soil analysis. Part 1: Physical and mineralogical properties, including statistics of measurement and sampling. Agronomy series No. 9. Amer. Soc. Agron. 770 pp.

Branson, F.A. 1984. Evaluation of "Impacts of grazing intensity and specialized grazing systems on watershed characteristics and responses". In: Developing strategies for rangeland management. NRC/NAS. Westview Press/Boulder and London. Pp. 985-1000.

Bowser, W.E. 1967. Agroclimatic areas of Alberta. Institute of Pedology, Univ. of Alberta. Edmonton, Alta.

Canada Department of Agriculture. 1979. Glossary of terms in soil science. Can. Dept. Agr. Publ. 1459. 44 pp.

Cook, C.W. and Stubbendieck, J. 1986. Range research: basic problems and techniques. Society for Range Management. Denver, Colo. 317 pp.

Coupland, R.T. 1961. A reconsideration of grassland classification in the Northern Great Plains of North America. J. Ecol. 49:136-167.

Coupland, R.T. 1970. Matador Project. International Biological Program, third annual report. Univ. of Saskatchewan. Saskatoon, Sask.

Coupland, R.T. 1973. I. Dynamics of aboveground standing crop. Tech. Report No. 27. Canadian Comm. for the International Biological Programme. Saskatoon, Sask. 159 pp.

Coupland, R.T. 1979. Grassland ecosystems of the world: analysis of grasslands and their uses. Cambridge Univ. Press. Cambridge, Engl. IBP 18. 401 pp.

Coupland, R.T., Skoglund, N.A., and Heard, A.J. 1960. Effects of grazing in the Canadian mixed prairie. Proc. Eighth Intl. Grassland Congr. Pp. 212-215.

Crider, F.J. 1955. Root growth stoppage resulting from defoliation of grass. Tech. Bull. USDA No. 1102:2-23.

De Jong, E. and MacDonald, K.B. 1975. The soil moisture regime under native grassland. Geoderma 14:207-221.

Dormaar, J.F., Johnston, A., and Smoliak, S. 1977. Seasonal variations in chemical characteristics of soil organic matter of grazed and ungrazed mixed prairie and fescue grassland. J. Range Manage. 30:195-198.

Dormaar, J.F., Johnston, A., and Smoliak, S. 1984. Seasonal changes in carbon content, dehydrogenase, phosphatase, and urease activities in mixed prairie and fescue grassland Ah horizons. J. Range Manage. 37:31-35

Dyksterhuis, E.J. and Schmutz, L.M. 1947. Natural mulches or 'litter' of grassland with kinds and amounts on a southern prairie. Ecology 28: 163-179.

Herman, W.A. 1974. Chemical composition of roots and decomposing root residues from three grass species. Unpubl. M.Sc. Thesis. Dept. Soil Science. Univ. of Alberta. Edmonton, Alta. 100 pp.

Howitt, R.W. 1988. Soil survey of the county of Beaver. Alberta Soil Survey Report No. 47. Alberta Research Council Open File Report 1987-4. (In press).

Johnston, A. 1961. Comparison of lightly grazed and ungrazed range in fescue grassland of southwestern Alberta. Can. J. Plant Sci. 41:615-622.

Johnston, A. 1962. Effects of grazing intensity and cover on the water-intake rate of fescue grassland. J. Range Manage. 15:79-87.

Johnston, A., Dormaar, J.F., and Smoliak, S. 1971. Long-term grazing effects on fescue grassland soils. J. Range Manage. 24:185-188.

Kjearsgaard, A.A., Peters, T.W., and Pettapiece, W.W. 1982. Soil survey of the County of Newell No. 4, Alberta. Alberta Institute of Pedology Report S-82-41. 197 pp.

Lodge, R.W. 1954. Effects of grazing on the soils and forage of mixed prairie in southwestern Saskatchewan. J. Range Manage. 7:166-170.

Looman, J. 1969. The fescue grasslands of western Canada. Vegetatio Acta Geobotanica 19:127-145.

McCalla, T.M. 1943. Microbiological studies of the effect of straw used as a mulch. Trans. Kansas Acad. Sci. 43:52-56.

Meeuwig, R.O. 1970. Infiltration and soil erosion as influenced by vegetation and soil in northern Utah. J. Range Manage. 23:183-188.

Moss, E.H. 1955. The vegetation of Alberta. Bot. Rev. 21:493-567.

Moss, E.H. 1983. Flora of Alberta. 2nd ed. Revised by J.G. Packard. Univ. of Toronto Press. Toronto, Ont. 687 pp.

Naeth, M.A. 1985. Ecosystem reconstruction and stabilization following pipeline construction through solonetzic native rangeland in southern Alberta. Unpubl. M.Sc. Thesis. Depts. Soil Science and Plant Science. Univ. of Alberta. Edmonton, Alta. 213 pp.

Norman, A.G. 1933. The natural decomposition of plant materials. Sci. Prog. 27:470-485.

Pavlick, L.E. and Looman, J. 1984. Taxonomy and nomenclature of rough fescues, *Festuca altaica, Festuca campestris* (*F.Scabrella* var. major), and *Festuca hallii*, in Canada and the adjacent part of the United States. Can. J. Bot. 62:1739-1749.

Peake, R.W. and Johnston, A. 1965. Grazing effects on fescue grassland in western Canada. In: Proc. Int. Grassl. Congr. Sao Paulo, Brazil. Pp. 1627-1630.

Risser, P.G. 1984. Methods for inventory and monitoring of vegetation, litter, and soil surface condition. In: Developing strategies for range management. NRC/NAS. Western Press/Boulder and London. Pp. 647-690.

Shapiro, S.S. and Wilk, M.B. 1965. An analysis of variance test for normality (complete samples). Biometrika 52:591-611.

Sinton, H.M.M. 1980. Effect of burning and mowing on *Festuca hallii* (Vasey) Piper, *Festuca scabrella* Torr. Unpubl. M.Sc. Thesis. Dept. Plant Sci., Univ. of Alberta. Edmonton, Alta. 140 pp.

Smoliak, S. 1956. Influence of climatic conditions on forage production of shortgrass rangeland. J. Range Manage. 9:89-91.

Smoliak, S. 1965. A comparison of ungrazed and lightly grazed *Stipa-Bouteloua* prairie in southeastern Alberta. Can. J. Plant Sci. 45:270-275.

Smoliak, S., Dormaar, J.F., and Johnston, A. 1972. Long-term grazing effects on *Stipa-Bouteloua* prairie soils. J. Range Manage. 25:246-250.

Smoliak, S., Adams, B.W., Schuler, B.G., Wroe, R.A., Klumph, S.G., and Willms, W.D. 1985. Forage production on selected native prairie sites in southern Alberta. Research Branch, Agriculture Canada. Lethbridge Res. Sta. Cont. No. 5.

Steel, R.G.D. and Torrie, J.H. 1980. Principles and procedures of statistics: a biometrical approach. 2nd ed. McGraw-Hill, New York. 633 pp.

Stoddart, L.A., Smith, A.D., and Box, T.W. 1975. Range Management. 3rd ed. McGraw-Hill Book Co. New York. 532 pp.

Tomanek, G.W. 1969. Dynamics of mulch layer in grassland ecosystems. In: Dix, R.L. and Beidleman, R.G. (eds.). The grassland ecosystem, a preliminary synthesis. Range Science Dept., Sci. Series No. 2:225-240.

Wheeler, G.W. 1976. Some grassland and shrubland communities in the parklands of central Alberta. Unpubl. M.Sc. Thesis. Dept. Plant Science. Univ. of Alberta. Edmonton, Alta. 95 pp.

Willms, W.D., Bailey, A.W., and McLean, A. 1980. Effects of clipping or burning on some morphological characteristics of *Agropyron spicatum*. Can. J. Bot. 58:2309-2312.

Willms, W.D., Smoliak, S., and Bailey, A.W. 1986. Herbage production following litter removal on Alberta native grasslands. J. Range Manage. 39:536-540.

Wonders, W.C. 1969. Atlas of Alberta. Univ. of Alberta Press in association with Univ. of Toronto Press. Edmonton, Alta. 158 pp.

III. WATER HOLDING CAPACITY OF LITTER AND SOIL ORGANIC MATTER IN MIXED PRAIRIE AND FESCUE GRASSLAND ECOSYSTEMS OF ALBERTA

INTRODUCTION

Litter can reduce the amount of water reaching the soil surface through interception of precipitation and subsequent evaporation of absorbed water. Interception losses from small storms are generally high while those from larger storms are under 10% (Corbett and Crouse 1968; Couturier and Ripley 1973). The amount of water evaporated is governed primarily by the mass of accumulated litter (Helvey and Patric 1965), water holding capacity of litter, and the evaporation potential before and after the precipitation event (Corbett and Crouse 1968). Water holding capacity of litter varies with vegetation type, with that of grass litter ranging from 0.5 to 8.4 mm (Flory 1936; Weaver and Rowland 1952; Burgy and Pomeroy 1958; Corbett and Crouse 1968).

Grazing regimes facilitating accumulation of litter and soil organic matter could cause reductions in mineral soil water due to retention of precipitation and potential evaporative loss. It was hypothesized that the water holding capacity of litter would be affected by its particle size distribution. Thus grazing regimes facilitating accumulation of litter or soil organic matter in categories which had high water holding capacities would reduce soil water the most. It was further hypothesized that overall water holding capacity would differ with ecosystem as affected by plant species composition. The objective of this study was to determine the effects of season and intensity of grazing on water holding capacity of litter and soil organic matter in mixed prairie and fescue grassland ecosystems of Alberta.

MATERIALS AND METHODS

Study Sites

Three study sites representing major grassland ecosystems of southern and central Alberta rangeland were selected. Each study site had long-term grazing treatments, ungrazed controls, grass dominated vegetation that had never been cultivated, and slopes of less than 2%. (See Appendix I for detailed descriptions). Moss (1983) was used as the botanical authority.

Brooks

The Brooks site was located in mixed prairie approximately 225 km east of Calgary (51 °N latitude and 112 °W longitude). The area has a continental prairie climate and a semiarid moisture regime (Bowser 1967). Mean annual precipitation is 355 mm with an average annual moisture deficit of 227 mm. Mean annual temperature is 4 °C, with a July mean of 19 °C and a January mean of -14 °C. Elevation averages 745 m above sea level with slopes of less than 2%. Soils are Brown Solodized Solonetz and Brown Solod developed on till (Kjearsgaard et al. 1982). Vegetation is of the *Bouteloua-Stipa-Agropyron* (blue grama-spear grass-wheatgrass) faciation dominated by *Bouteloua gracilis, Stipa comata, Agropyron smithii*, and *A. dasystachyum* (Coupland 1961). *Artemisia frigida* and *Selaginella densa* are common forbs. A short grass disclimax dominated by *Bouteloua gracilis* is common as a result of heavy long-term grazing.

Kinsella

The Kinsella site was located in aspen parkland approximately 150 km southeast of Edmonton (53 °N latitude and 111 °W longitude). The climate is dry subhumid (Wonders 1969). Mean annual precipitation is 380 mm; mean annual evapotranspiration is 381 mm. Mean annual temperature is 2 °C, with a July mean of 17 °C and a January mean of -17 °C. Elevation averages 685 m above sea level with gently rolling to hilly topography (Howitt 1988). Grassland soils are dominated by Orthic Black Chernozems developed on till. Vegetation consists of grass and shrub communities with aspen groves occurring at irregular intervals (Moss 1955). *Festuca hallii* (Vasey) Piper (Pavlick and Looman 1984) dominates open undisturbed grasslands and *Stipa curtiseta* co-dominates on grazed areas (Wheeler 1976). Various forbs are a common component of the vegetation.

Stavely

The Stavely site was located in foothills fescue grassland approximately 100 km south-southwest of Calgary (50 °N latitude and 1[illegible] °W longitude). The climate is subhumid without marked deficiency of precipitation. Mean annual precipitation is 550 [illegible]. Mean annual temperature is 5 °C, with a July mean of 16 °C and a January mean of -10 °C. Elevation averages 1350 m above sea level and topography is gently rolling to hilly. Soils are Orthic Black Chernozems developed on till (Johnston et al. 1971). Vegetation is of the fescue grassland association (Looman 19[illegible]) with *Festuca campestris* Rydb. dominating in the undisturbed and lightly grazed areas. *Danthonia parryi* and *Festuca idahoensis* are codominants in the grazed areas. Under heavy grazing regimes, *Festuca campestris* is replaced by annual invaders and *Poa* species.

Grazing Treatments

At Brooks, three grazing treatments were studied within a community pasture that had been established in 1964 (B. Shanks, personal communication, September 1981). The treatments included: (1) early season grazing from May 1 through July; (2) late season grazing from August through October; and (3) a control on an adjacent highway right-of-way that had not been grazed for 25 years. The 0.9 AUM ha^{-1} stocking rate for the grazed treatments was considered heavy for the area.

At Kinsella, five grazing treatments established in 1973 on the University of Alberta ranch were studied (Bailey et al. 1987). The treatments included: (1) light June grazing from June 1 to 30 at 1.5 AUM ha^{-1} with approximately 35% herbage utilized; (2) heavy June grazing from June 1 to 30 at 4.4 AUM ha^{-1} with approximately 75% herbage utilized; (3) heavy autumn grazing from September 15 to October 15 at 4.4 AUM ha^{-1} with approximately 75% herbage utilized; (4) light autumn grazing from September 15 to October 15 at 1.5 AUM ha^{-1} with approximately 35% herbage utilized; and (5) a control that had not been grazed since 1942. Each grazing treatment included 5.5 ha of grassland and a variable area of shrub and forest. Two 10 by 20 m permanent exclosures, randomly located in each treatment, were also studied.

At Stavely, five grazing treatments established in 1949 on an Agriculture Canada Range Research Substation were studied (Johnston 1961). Treatments were grazed from May to October and included: (1) very heavy grazing with 16.2 ha stocked at 4.8 AUM ha^{-1}; (2) heavy grazing with 32.4 ha stocked at 2.4 AUM ha^{-1}; (3) moderate grazing with 48.6 ha stocked at 1.6 AUM ha^{-1}; (4) light grazing with 64.8 ha stocked at 1.2 AUM ha^{-1}; and (5) a control comprised of permanent exclosures of 0.66, 0.41, 0.76, and 0.23 ha in the light, moderate, heavy, and very heavy treatments, respectively.

Experimental Design

The experimental design within each site was a hierarchical (subsampling) arrangement. Within each treatment, three 0.1 ha areas were randomly established. Within each of these 0.1 ha areas, points were randomly selected from which samples were collected or measurements were made.

Litter And Soil Organic Matter Sampling And Analyses

For this study, litter refers to all dead organic matter not incorporated with mineral soil and occurring above soil mineral horizons. Soil organic matter refers to the organic fraction of soil including plant and animal residues at various stages of decomposition, cells and tissues of soil organisms, and substances synthesized by the soil population as defined by the Canada Department of Agriculture (1979).

Sampling was conducted in late August of 1985 and 1986. At each site, in each treatment, in each 0.1 ha area, 10 randomly located 0.1 m^2 quadrats (30 per treatment), with inner dimensions of 20 by 50 cm, were used to collect the samples. In each quadrat, all live vegetation, including dried tips of live plants, was removed with scissors at ground level. Standing litter was removed in the same way. The remaining litter was removed from the soil surface with hand rakes. Soil organic matter was lifted as a slab, after an edging shovel was used to cut down to a mineral soil horizon where a color and texture change indicated the bottom of the Ah horizon. Remaining litter and soil were removed from the sample hole with a brush. Sampling depths varied with site and treatment but averaged approximately 5 to 8 cm at Brooks (no difference in depth among treatments) and 10 to 15 cm at Kinsella (no difference in depth among treatments) and Stavely (the very heavy treatment was shallower than the other treatments).

Live vegetative material was oven dried at 65 °C for 24 hours, then weighed. Litter and organic matter samples were air dried for two weeks then sorted into categories on the basis of size using a bank of sieves mounted on an automatic sieve shaker (Tyler RO-TAP Model B) as modified from Coupland (1973). Five minutes of shaking was required to sort the samples without breaking down plant material. Sieves had openings of 2.0, 0.85, and 0.212 mm (Tyler equivalents of 9, 20, and 65 mesh).

The litter and soil organic matter categories were: (1) standing litter recognized and collected in the field as standing litter; (2) coarse litter remaining in the top sieve (2 mm) and recognizable as undecomposed plant parts; (3) medium litter that was partly decomposed and collected in the second sieve (0.85 mm); (4) fine organic matter that was relatively decomposed and collected in the third sieve (0.212 mm); (5) very fine organic matter that was decomposed and collected in the bottom pan; and (6) roots large enough to be easily handled which were removed from the samples before sieving. Categories 4 and 5 contained most living and dead small roots and root hairs. Above ground organic matter was composed of standing, coarse, and medium litter, and live vegetation. Below ground organic matter was composed of roots, fine, and very fine organic matter. Total organic matter included all the above categories.

During 1985 and 1986, nine soil and litter samples to a depth of 76 mm were taken from each treatment with a Uhland core sampler to obtain cylindrical samples 76 mm in diameter and 76 mm long. The top of the core corresponded to the top of the litter layer. These cores represented the relatively undisturbed litter and soil organic matter component of each treatment. The Stavely control and light grazing treatment samples were inadvertently lost.

Water Holding Capacity Analyses

Water holding capacity (WHC) of litter and soil organic matter was determined with modifications to methods outlined by Kittredge (1955) and Bernard (1963). In 1985 and 1986, five randomly selected samples from each litter and soil organic matter category in each 0.1 ha area were used to fill 7 cm high by 7 cm diameter plastic cylinders to a relatively standard weight (15 per treatment). Cotton fabric secured with a rubber band was used to cover the cylinder bottom. Cylinders were soaked for 48 hours then drained on a tray of damp sand for 48 hours. Laboratory temperature was maintained at approximately 18 °C and relative humidity at approximately 35%. Trays were covered with plastic to prevent evaporation and create a stable microenvironment.

The sand mixture used for drainage was 11% gravel, 23% very coarse sand, 38% coarse sand, 22% medium sand, and 6% fine and very fine sand as determined by the dry sieve method (McKeague 1978). The sand was placed in a large plastic tray with a drainage spout for water to drain. The sand had been previously saturated with water and drained for 48 hours. Water content of the sand at the time samples were placed on it was 10.8% (SD 2.1%). After the cylinders drained for 48 hours, water content of the sand was 14% (SD 2.4%).

After draining, the samples were weighed and oven dried at 105 °C for 48 hours then re-weighed. Water holding capacity was determined by subtracting oven dry mass of the cylinder contents from the drained mass, dividing by litter or soil organic matter mass, and multiplying by 100 (g water/g litter (o.d.w.) x 100 = %WHC). Uhland core samples were treated in the same manner as the filled cylinders in order to determine water holding capacity of litter and soil organic matter in a relatively undisturbed state.

Statistical Analyses

Statistical analyses were conducted using variation among the 0.1 ha areas as an appropriate measure of error variation for testing the significance of treatments. Data were tested for homogeneity of variance using Cochran and Bartlett-Box tests. The W test was used to test data for normality of distribution (Shapiro and Wilk 1965). An SPSSx analysis of variance program was used to test for treatment effects. Data with significant F values were further analyzed to separate the means using the Student-Newman-Keul (SNK) test at the 5% level of significance (Steel and Torrie 1980).

Preliminary statistical analyses within each year by treatment combination indicated that variation among the 0.1 ha areas was not significantly different from sampling point variation and therefore in all future analyses, area and sampling point variation were pooled. If additional preliminary statistical analyses within each treatment using the pooled error term indicated significant differences between study years, data were analyzed on a within year basis. Otherwise data from both years were pooled. Sources of variation in the final statistical analysis were treatments and error within treatments.

RESULTS

In all three sites, water holding capacity of litter and soil organic matter in all treatments did not generally differ significantly between 1985 and 1986. Plotted data are means of these two years.

At all three sites, WHC of root, standing, and coarse organic matter were higher than that of medium, fine, and very fine organic matter (statistics not presented). WHC was generally higher in fine than in medium or very fine categories.

WHC of undisturbed cores was affected more by intensity of grazing than by season of grazing (Table 3.1). At Kinsella and Stavely, WHC of undisturbed cores was lower in heavy and very heavy treatments than in the control or moderate treatments. Although the Brooks treatments were heavily grazed, WHC did not differ significantly with treatment.

WHC of organic matter ranged from 68 to 216% of oven dry weight at Brooks (Figure 3.1). At Kinsella, WHC of root, standing, and coarse organic matter ranged from 180 to 258% and that of medium, fine, and very fine organic matter ranged from 80 to 148% (Figure 3.2). WHC in root, standing, coarse, and fine organic matter ranged from 183 to 254%, while that of medium and very fine organic matter ranged from 107 to 139% (Figure 3.3).

Significant treatment effects on WHC of specific organic matter categories varied with site. At all three sites, coarse organic matter had higher WHC in controls and light intensity/late season treatments such as the light autumn treatment at Kinsella. WHC of coarse organic matter was lowest in heavy intensity/early season treatments. WHC of standing organic matter was affected by grazing treatment at Brooks and Kinsella, being highest in the controls and lowest in early season/heavy intensity treatments.

DISCUSSION

The WHC of root, standing, and coarse organic matter was higher than medium, fine, and very fine organic matter because a largamount of organic matter in a relatively undecomposed state was found in these fractions. Soil organic matter occurs as discrete, organic particles and in a molecular form on mineral surfaces (Farmer 1978). At saturation, large organic particles with a wide range of pores hold up to twice as much water per volume as mineral soils. Highly decomposed organic matter in the molecular form would hold less water due to less pore space and less adhesion. Although very fine organic particles have a greater surface area than larger particles and hold more water, the higher porosity of the larger particles tends to offset this. Organic substances adsorbed on mineral particles can confer hydrophobic properties on mineral soils (Debano and Letey 1969), further reducing WHC. Dormaar et al. (1980) isolated a hydrophobic compound, bis (2-ethylhexyl) phthalate (dioctyl phthalate) from native range soils in Alberta, which contributes to the low WHC of below ground organic matter. High WHC of fine organic matter compared to medium and very fine organic matter may also be related to particle size. The fine category contains the majority of smaller roots and thus has a large portion of organic matter in a relatively undecomposed state.

McCalla (1944) found in intial decomposition stages, decreases in dry weight and volume of litter were accompanied by increases in wetting speed. This increase, combined with higher WHC of larger particle sized organic matter, means it could intercept more precipitation than smaller particle sized organic matter. Greater masses of large sized organic matter per unit land area and higher ground cover in control and light intensity grazing treatments (Chapter II) could lead to higher interception than in heavy intensity grazing treatments. Biomass and cover have also been identified as sources of variation in interception by Clark (1940), Haynes (1940), and Thurow et al. (1987).

Grazing treatment effects on WHC of organic matter were influenced by vegetation differences since there were no significant within-site soil textural differences (Appendix II). Differences in plant species composition among treatments were reported at Brooks (Naeth 1985), Kinsella (Bailey et al. 1987), and Stavely (Johnston 1961; Johnston et al. 1971). Significant treatment effects on WHC occurred among treatments with greatest species composition differences: the control and early season grazing treatment at Brooks, the control and heavy grazing treatments at Kinsella, and the control and light grazing treatments compared to the heavy grazing treatments at Stavely. Treatment differences may also reflect decomposition state of organic matter. Higher WHC in the control organic matter may reflect the absence of trampling which can break litter into smaller pieces, create better litter-soil contact, and facilitate more rapid decomposition. Thus there may be more large particle sized litter in the control contributing to higher WHC.

Water holding capacity in this study represents field water capacity and the upper limits for precipitation held in organic matter mass. Although WHC of standing and coarse litter was higher in the control than under early season grazing and WHC of medium and fine organic matter was higher under early season grazing than in the control, the overall effect of treatment on WHC of organic matter at Brooks was likely small, since higher WHC of whole cores was not detected in any treatment. Total organic matter as opposed to amounts of specific types would likely have a more significant effect on overall WHC at this site. At Kinsella and Stavely, whole core values show that WHC of organic matter generally declines with heavy intensity grazing. From a conservation perspective this may be contradictory in that light grazing, which improves overall hydrologic condition, can lead to accumulation of organic matter with higher WHC. However, the more beneficial effects of holding water in organic matter as opposed to it running off the soil surface would tend to negate the effect. Similar conclusions were reached by Lowdermilk (1930) and by Weaver and Rowland (1952). The lack of grazing treatment effect on WHC of the soil organic matter categories would indicate that grazing treatment would not affect overall WHC below ground. However, the higher WHC in the coarse litter at Kinsella under light autumn grazing and in the control, and in the heavy grazing treatment at Stavely would indicate that the above ground litter would have the most effect on overall WHC at a site.

WHC of organic matter categories, plant species composition, and amounts and kinds of organic matter are all key factors in determining the overall WHC of litter and soil organic matter layers in individual grasslands. The amount of large particle sized organic matter relative to small particle sized organic matter is a critical factor in determining the magnitude of WHC.

CONCLUSIONS

WHC of organic matter differed with ecosystem, being lower in mixed prairie than in fescue grasslands. WHC differed with particle size of litter or soil organic matter. WHC of root, standing, and coarse organic matter was approximately 185% at Brooks, 207% at Kinsella, and 215% at Stavely. WHC of medium, fine, and very fine organic matter was 110% at Brooks, 112% at Kinsella, and 140% at Stavely. WHC of undisturbed litter cores was 38% at Brooks, 70% at Kinsella, and 118% at Stavely. Water holding capacity of large particle sized organic matter was higher than that of small particle sized organic matter. Water holding capacity in large particle sized organic matter decreased with heavy intensity/early season grazing, whereas WHC of small particle sized organic matter was less affected by grazing treatment. WHC of undisturbed cores was affected more by intensity than season of grazing.

Table 3.1. Water holding capacity (% oven dry weight) of undisturbed litter and soil core samples (76 mm diameter and depth) at the study sites.

Site	Treatment	Water Holding Capacity
Brooks	Early Season	41.5a
	Late Season	34.9a
	Control	42.7a
Kinsella	Light June	68.6ab
	Heavy June	60.9b
	Heavy Autumn	63.6b
	Light Autumn	74.4ab
	Control	83.9a
Stavely	Moderate	132.6a
	Heavy	102.7b
	Very Heavy	124.2b

Within a site, treatment means with the same letters are not significantly different (P<0.05).

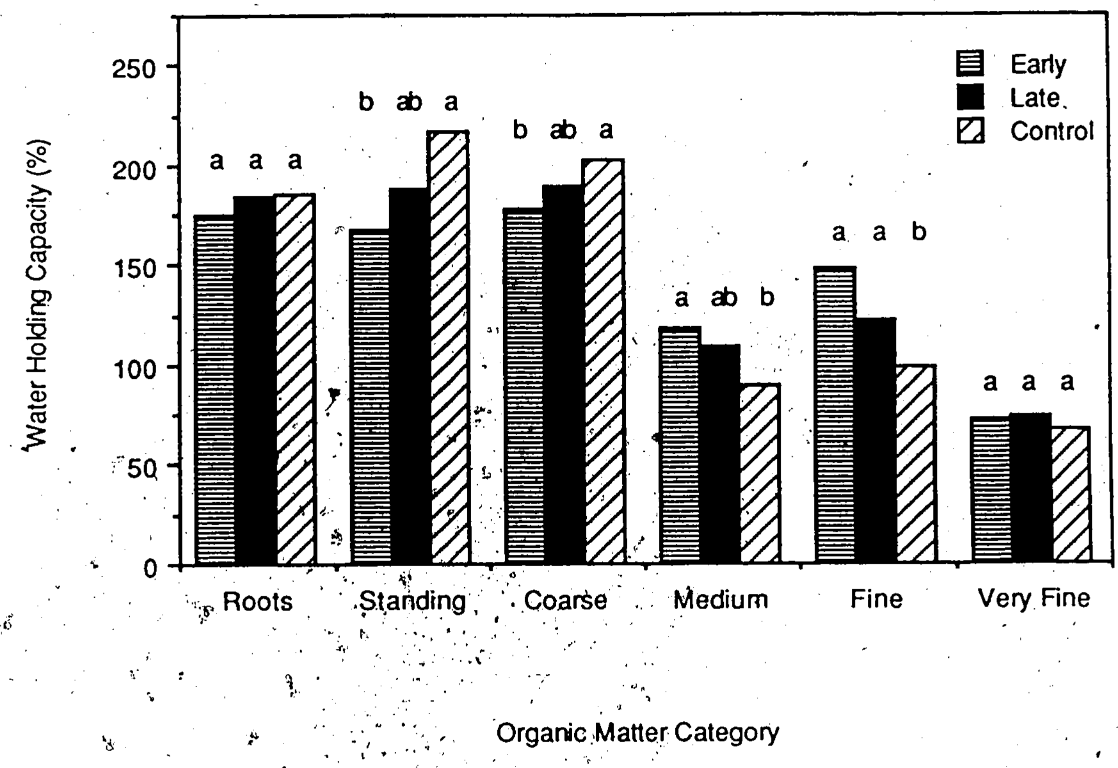


Figure 3.1. Water holding capacity (% oven dry weight) of litter and roots at Brooks. Within category means with the same letters are not significantly different ($P<0.05$).

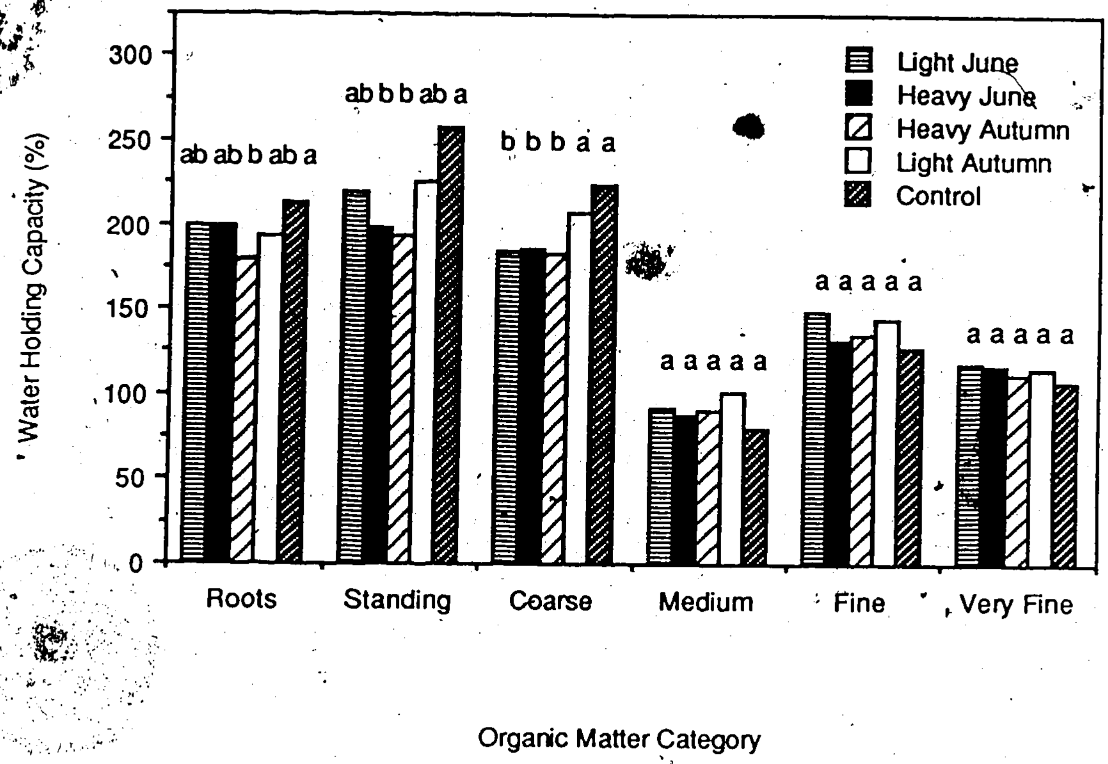


Figure 3.2. Water holding capacity (% oven dry weight) of litter and roots at Kinsella. Within category means with the same letters are not significantly different ($P<0.05$).

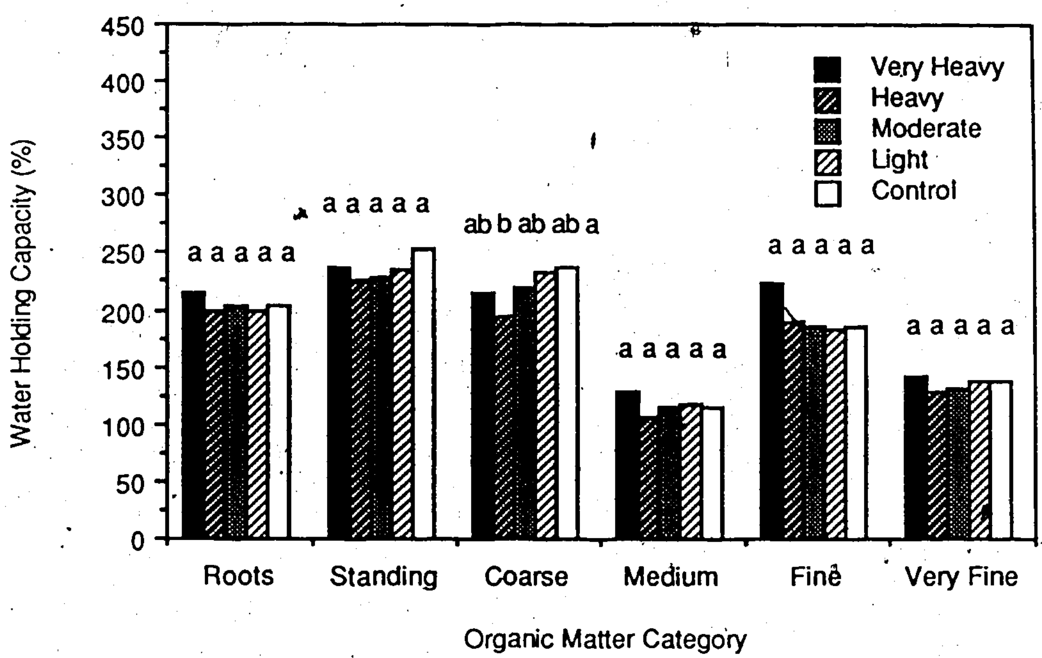


Figure 3.3. Water holding capacity (% oven dry weight) of litter and roots at Stavely. Within category means with the same letters are not significantly different ($P<0.05$).

BIBLIOGRAPHY

Bailey, A.W., Willoughby, M.G., and Irving, B.D. 1987. Effect of grazing on forage and beef production from rough fescue rangeland in central Alberta. Farming for the Future Final Report. Project No. 84-0335. 41 pp.

Bernard, J.M. 1963. Forest floor moisture capacity of the New Jersey pine barrens. Ecology 44:574-576.

Bowser, W.E. 1967. Agroclimatic areas of Alberta. Institute of Pedology. Univ. of Alberta. Edmonton, Alta.

Burgy, R.H. and Pomeroy, C.R. 1958. Interception losses in grassy vegetation. Trans. Amer. Geophys. Union. 39:1095-1100.

Canada Department of Agriculture. 1979. Glossary of terms in soil science. Can. Dept. Agr. Publ. 1459. 44 pp.

Clark, O.R. 1940. Interception of rainfall by prairie grasses, weeds, and certain crop plants. Ecol. Monog. 10:243-277.

Corbett, E.S. and Crouse, R.P. 1968. Rainfall interception by annual grass and chapparal. USDA Forest Serv. Res. Pap. PSW-48. 12 pp.

Coupland, R.T. 1961. A reconsideration of grassland classification in the Northern Great Plains of North America. J. Ecol. 49:136-167.

Coupland, R.T. 1973. I Dynamics of aboveground standing crop. Tech. Rep. No. 27. Canadian Comm. for the International Biological Program. Saskatoon, Sask. 159 pp.

Couturier, D.E. and Ripley, E.A. 1973. Rainfall interception in mixed grass prairie. Can. J. Plant Sci. 53:659-663.

Debano, J.F. and Letey, J. (eds.). 1969. Water-repellent soils. Proc. of the Symp. on water-repellent soils. Univ. of California. Riverside, CA.

Dormaar, J.F., Johnston, A., and Smoliak, S. 1980. Organic solvent-soluble organic matter from soils underlying native range and crested wheatgrass in southeastern Alberta, Canada. J. Range Manage. 33:99-101.

Farmer, V.C. 1978. Water on particle surfaces. In: The chemistry of soil constituents. Greenland, D.J. and Hayes, M.H.B. (eds.). John Wiley and Sons. Chichester. Pp. 405-448.

Flory, E.L. 1936. Comparison of the environment and some physiological responses of prairie vegetation and cultured maze. Ecology 17:67-103.

Haynes, J.L. 1940. Ground rainfall under vegetation canopy of crops. J. Amer. Soc. Agron. 32:176-184.

Helvey, J.D. and Patric, J.H. 1965. Canopy and litter interception of rainfall by hardwoods of eastern United States. Water Resour.Res. 1:193-206.

Howitt, R.W. 1988. Soil survey of the county of Beaver. Alberta Soil Survey Report No. 47. Alberta Research Council Open File Report No. 1987-4. (In press).

Johnston, A. 1961. Comparison of lightly grazed and ungrazed range in fescue grassland of southwestern Alberta. Can. J. Plant Sci. 41:615-622.

Johnston, A., Dormaar, J.F., and Smoliak, S. 1971. Long-term grazing effects on fescue grassland. J. Range Manage. 24:185-188.

Kittredge, J. 1955. Litter and forest floor of the chapparral in parts of the San Dimas Experimental Forest. Hilgardia 23:563-596.

Kjearsgaard, A.A., Peters, T.W., and Pettapiece, W.W. 1982. Soil survey of the County of Newell No. 4, Alberta. Alberta Institute of Pedology Report S-82-41. 197 pp.

Looman, J. 1969. The fescue grasslands of western Canada. Vegetatio Acta Geobotanica 19:127-145.

Lowdermilk, W.C. 1930. The influence of litter on run-off, percolation, and erosion. J. Forest. 28:474-491.

McCalla, T.M. 1944. Changes in the physical properties of straw during the early stages of decomposition. Soil Sci. Soc. Am. Proc. 8:258-262.

McKeague, J.A. 1978. Manual on soil sampling and methods of analysis. Can. Soc. Soil Sci. 212 pp.

Moss, E.H. 1955. The vegetation of Alberta. Bot. Rev. 21:493-587.

Moss, E.H. 1983. Flora of Alberta. 2nd ed. Revised by J.G. Packer. Univ. Toronto Press. Toronto, Ont. 687 pp.

Naeth, M.A. 1985. Ecosystem reconstruction and stabilization following pipeline construction through solonetzic native rangeland in southern Alberta. Unpubl. M.Sc. Thesis. Depts. Soil Sci. and Plant Sci., Univ. of Alberta. Edmonton, Alta. 213 pp.

Pavlick, L.E. and Looman, J. 1984. Taxonomy and nomenclature of rough fescues, *Festuca altaica, Festuca campestris* (*F. scabrella* var. major), and *Festuca hallii*, in Canada and the adjacent part of the United States. Can. J. Bot. 62:1739-1749.

Shapiro, S.S. and Wilk, M.B. 1965. An analysis of variance test for normality (complete samples). Biometrika 52:591-611.

Steel, R.G.D. and Torrie, J.H. 1980. Principles and procedures of statistics: a biometrical approach. 2nd ed. McGraw-Hill, New York. 633 pp.

Thurow, T.L., Blackburn, W.H., Warren, S.D., and Taylor Jr., C.A. 1987. Rainfall interception by midgrass, shortgrass, and live oak mottes. J. Range Manage. 40:455-460.

Weaver, J.E. and Rowland, N.W. 1952. Effects of excessive natural mulch on development, yield, and structure of native grassland. Bot. Gaz. 114:1-19.

Wheeler, G.W. 1976. Some grassland and shrubland communities in the parklands of central Alberta. Unpubl. M.Sc. Thesis. Dept. Plant Science. Univ. of Alberta. Edmonton, Alta. 95 pp.

Wonders, W.C. 1969. Atlas of Alberta. Univ. of Alberta Press in association with Univ. of Toronto Press. Edmonton, Alta. 158 pp.

IV. COMPACTING EFFECTS OF GRAZING REGIME IN MIXED PRAIRIE AND FESCUE GRASSLAND ECOSYSTEMS OF ALBERTA

INTRODUCTION

Researchers have documented compaction of soils by grazing animals in various ecosystems of the world. In the Canadian Northern Great Plains, grazing has caused compaction on loam, silt loam, sand, and clay textured soils in Saskatchewan mixed prairie (Lodge 1954; Martens 1979) but not on loam and sandy loam textured soils in Alberta mixed prairie (Smoliak et al. 1972). Grazing intensity affects compaction, with heavy grazing compacting soils to a 10 cm depth but light and moderate grazing having no effect on bulk density (Lodge 1954). On American rangelands, the susceptibility of a soil to compaction is affected by vegetative cover (Wood and Blackburn 1984), particularly by plant roots (Gifford et al. 1977). Compaction is higher and to a greater depth on coarse textured soils but there is often no effect on fine textured soils (Orr 1960; Van Haveren 1983). Degree of compaction is affected by soil water content (Alderfer and Robinson 1947; Gifford et al. 1977) and is maximum between wilting point and field capacity (Orr 1960). Soil compaction increases as stocking rate increases (Reed and Peterson 1961; Rauzi and Hanson 1966; Warren et al. 1986). In most studies grazing effects on soil bulk density are manifested in the top 6 cm.

The occurrence of compaction in range ecosystems is complex because factors other than trampling may alter soil bulk density and resistance to penetration. Compaction can be affected by vegetation, plant rooting depth, freeze-thaw and wetting-drying cycles, percent organic matter, soil structure, and soil water holding capacity.

It was hypothesized that heavy grazing would compact the soil, especially in treatments where vegetative cover was most affected and in more heavily utilized areas such as cattle paths. It was also hypothesized that defoliation without trampling could reduce root growth. Less root activity could lead to higher bulk densities than in areas that were not defoliated. The objective of this study was to determine the effect of season and intensity of grazing on soil bulk density and penetration resistance in mixed prairie and fescue grassland ecosystems of Alberta. A further objective was to determine the magnitude of heavy trampling, light trampling, and no trampling within a given grazing treatment.

MATERIALS AND METHODS

Study Sites

Three study sites representing major grassland ecosystems of southern and central Alberta rangeland were selected. Each study site had long-term grazing treatments, ungrazed controls, grass dominated vegetation that had never been cultivated, and slopes of less than 2%. (See Appendix I for detailed descriptions). Moss (1983) was used as the botanical authority.

Brooks

The Brooks site was located in mixed prairie approximately 225 km east of Calgary (51 °N latitude and 112 °W longitude). The area has a continental prairie climate and a semiarid moisture regime (Bowser 1967). Mean annual precipitation is 355 mm with an average annual moisture deficit of 227 mm. Mean annual temperature is 4 °C, with a July mean of 19 °C and a January mean of -14 °C. Elevation averages 745 m above sea level with slopes of less than 2%. Soils are Brown Solodized Solonetz and Brown Solod developed on till (Kjearsgaard et al. 1982). Vegetation is of the *Bouteloua-Stipa-Agropyron* (blue grama-spear grass-wheatgrass) faciation dominated by *Bouteloua gracilis, Stipa comata, Agropyron smithii*, and *A. dasystachyum* (Coupland 1961). *Artemisia frigida* and *Selaginella densa* are common forbs. A short grass disclimax dominated by *Bouteloua gracilis* is common as a result of heavy long-term grazing.

Kinsella

The Kinsella site was located in aspen parkland approximately 150 km southeast of Edmonton (53 °N latitude and 111 °W longitude). The climate is dry subhumid (Wonders 1969). Mean annual precipitation is 380 mm; mean annual evapotranspiration is 381 mm. Mean annual temperature is 2 °C, with a July mean of 17 °C and a January mean of -17 °C. Elevation averages 685 m above sea level with gently rolling to hilly topography (Howitt 1988). Grassland soils are dominated by Orthic Black Chernozems developed on till. Vegetation consists of grass and shrub communities with aspen groves occurring at irregular intervals (Moss 1955). *Festuca hallii* (Vasey) Piper (Pavlick and Looman 1984) dominates on undisturbed grasslands and *Stipa curtiseta* co-dominates on grazed areas (Wheeler 1976). Various forbs are a common component of the vegetation.

Stavely

The Stavely site was located in foothills fescue grassland approximately 100 km south-southwest of Calgary (50 °N latitude and 114 °W longitude). The climate is subhumid without marked deficiency of precipitation. Mean annual precipitation is 550 mm. Mean annual temperature is 5 °C, with a July mean of 18 °C and a January mean of -10 °C. Elevation averages 1350 m above sea level and topography is gently rolling to hilly. Soils are Orthic Black Chernozems developed on till (Johnston et al. 1971). Vegetation is of the fescue grassland association (Looman 1969) with *Festuca campestris* Rydb. dominating in undisturbed and lightly grazed areas. *Danthonia parryi* and *Festuca idahoensis* are codominants in grazed areas. With heavy grazing, *Festuca campestris* is replaced by annual invaders and Poa species.

Grazing Treatments

At Brooks, three grazing treatments were studied within a community pasture that had been established in 1964 (B. Shanks, personal communication, September 1, 1981). The treatments included: (1) early season grazing from May 1 through July; (2) late season grazing from August through October; and (3) a control on an adjacent highway right-of-way that had not been grazed for 25 years. The 0.9 AUM ha^{-1} stocking rate was considered heavy for the area.

At Kinsella, five grazing treatments established in 1973 on the University of Alberta ranch were studied (Bailey et al. 1987). The treatments included: (1) light June grazing from June 1 to

30 at 1.5 AUM ha^{-1} with approximately 35% herbage utilized; (2) heavy June grazing from June 1 to 30 at 4.4 AUM ha^{-1} with approximately 75% herbage utilized; (3) heavy autumn grazing from September 15 to October 15 at 4.4 AUM ha^{-1} with approximately 75% herbage utilized; (4) light autumn grazing from September 15 to October 15 at 1.5 AUM ha^{-1} with approximately 35% herbage utilized; and (5) a control that had not been grazed since 1942. Each grazing treatment included 5.5 ha of grassland and a variable area of shrub and forest. Two 10 by 20 m permanent exclosures, randomly located in each treatment, were also studied.

At Stavely, five grazing treatments established in 1949 on an Agriculture Canada Range Research Substation were studied (Johnston 1961). Treatments were grazed from May to October and included: (1) very heavy grazing with 16.2 ha stocked at 4.8 AUM ha^{-1}; (2) heavy grazing with 32.4 ha stocked at 2.4 AUM ha^{-1}; (3) moderate grazing with 48.6 ha stocked at 1.6 AUM ha^{-1}; (4) light grazing with 64.8 ha stocked at 1.2 AUM ha^{-1}; and (5) a control comprised of permanent exclosures of 0.66, 0.41, 0.76, and 0.23 ha in the light, moderate, heavy, and very heavy treatments, respectively.

Experimental Design

The experimental design within each site was a hierarchical (subsampling) arrangement. Within each treatment, three 0.1 ha areas were randomly established. Within each of these 0.1 ha areas, points were randomly selected from which samples were collected or measurements were made.

Soil Analyses And Field Measurements

Soil bulk density and penetration resistance measurements were made in July 1985, 1986, and 1987. At each site, in each treatment, in each 0.1 ha area, three neutron probe access tubes were randomly installed with a hydraulic coring unit (nine tubes per treatment). Soil bulk density measurements were made in each tube with a Campbell Pacific Nuclear 501 combination moisture/density probe. Two 15 second readings were taken at each depth, starting at 15 cm and proceeding in 10 cm increments to 65 cm. Two surface bulk density (0-10 cm) readings were taken adjacent to each access tube with a Campbell Pacific Nuclear MC1-12 surface moisture/density gauge.

Resistance to penetration was measured with a hand-held CN-973 penetrometer with a 30° conical probe, a 3.23 cm^2 base area, and a 0-2069 kPa resistance range. The probe was slowly pushed vertically into the soil and the maximum point resistance encountered was recorded. In each 0.1 ha area, measurements were made in 10 randomly selected locations at the soil surface and at 2.5, 5, 10, 15, and 30 cm depths.

To assess the combined effect of defoliation and trampling on soil compaction, bulk density and penetration resistance were measured on cattle paths where heavy trampling occurred, in the grazing treatment under normal animal traffic, in the exclosure where vegetation was neither trampled nor defoliated, and within the exclosure fence where no trampling occurred but vegetation was defoliated from cattle reaching under the fence. In each 0.1 ha area, in each of these locations, soil compaction was measured with the MC1 and penetrometer in 10 randomly selected locations. These measurements could not be made at Brooks where there were no grazing exclosures adjacent to the treatments.

Soil was analyzed for particle size distribution of sand, silt, and clay by the hydrometer method, and for water retention at -33 and -1500 kPa by the pressure plate extraction method (Appendix II). Litter depth and height were measured and ground cover was assessed with a point frame for percent bare ground, live vegetation, and litter. Litter and soil organic matter masses were measured from determinations of total carbon by dry oxidation (Chapter II).

Statistical Analyses

Statistical analyses were conducted using variation among the 0.1 ha areas as an appropriate measure of error variation for testing the significance of treatments. Data were tested for homogeneity of variance using Cochran and Bartlett-Box tests. The W test was used to test data for normality of distribution (Shapiro and Wilk 1965). An SPSSx analysis of variance program was used to test for treatment effects. Data with significant F values were further analyzed to separate the means using the Student-Newman-Keul (SNK) test at the 5% level of significance (Steel and Torrie 1980).

Preliminary statistical analyses within each year by treatment combination indicated that variation among the 0.1 ha areas was not significantly different from sampling point variation and therefore in all future analyses, area and sampling point variation were pooled. If additional preliminary statistical analyses within each treatment using the pooled error term indicated significant differences between study years, data were analyzed on a within year basis. Otherwise data from both years were pooled. Sources of variation in the final statistical analysis were treatments and error within treatments.

RESULTS

Bulk density and resistance to penetration in a given treatment did not differ among the three study years; plotted data are means of these years. Soil texture and water retention properties at each site did not differ among treatments (Appendix II).

Brooks

Treatment had no significant effect on soil bulk density at any depth (Table 4.1). In the upper 2.5 cm, resistance to penetration was affected by season of grazing, being lowest in the control and highest in the early season treatment (Table 4.2).

Kinsella

Treatment effects on bulk density were evident in the upper 10 cm and between 35 and 55 cm, inclusive (Table 4.3). Near surface bulk density was lowest in the control and highest under heavy June grazing. At 35 to 55 cm, bulk density was lowest in the light autumn treatment.

Penetration resistances from 0-10 cm were lower in the control than in one or more of the grazing treatments (Figure 4.1). At 5 to 10 cm, inclusive, penetration resistances were higher in the autumn treatments than in the control or June treatments. At 15 cm, values were higher in the heavy autumn treatment than in the heavy June treatment.

Bulk density in the top 0-10 cm was not affected by defoliation without trampling but was higher in grazed areas and cattle paths than in the control (exclosure) (Table 4.4). Under light intensity grazing, bulk density in grazed areas was lower than that on cattle paths, whereas under heavy intensity grazing it was the same in the grazed areas and paths.

At all depths, in all treatments, penetration resistances were generally lower in the exclosures than in grazed areas or on cattle paths (Figures 4.2 and 4.3). At the soil surface, penetration resistance on cattle paths was higher than that in grazed areas in autumn treatments but not in June treatments. At 2.5 cm, these two areas had significantly different values in all but the heavy June treatment and at greater depths the differences diminished.

Stavely

Soil bulk density was affected by grazing at all depths to 65 cm, with the exception of 35 cm (Table 4.5). In the surface 0-10 cm, bulk density was lowest in the control and highest under very heavy grazing. At 15 cm, bulk density was highest in the very heavy treatment. At 55 and 65 cm, bulk densities in the heavy and very heavy treatments were higher than those in the other three treatments.

Soil surface penetration resistance increased under grazing (Figure 4.4). With depth, lowest penetration resistances were in the control and highest in the very heavy and/or heavy treatments. At 15 cm and deeper, penetration resistances were not significantly different in the light, moderate, and control treatments.

Higher bulk densities were found in grazed areas and on cattle paths than in untrampled areas (Table 4.6). Bulk densities in defoliated areas and controls (exclosures) were not significantly different. Only under very heavy grazing was bulk density higher on cattle paths than in the regular grazing treatment.

At all depths, in all treatments, penetration resistance was generally lower in the exclosures than on cattle paths or grazed areas (Figures 4.5 and 4.6). The light treatment was the exception, where values did not differ at 15 and 30 cm. Penetration resistance on cattle paths was generally higher than in grazed areas, with the above noted exception and at or below 15 cm in the other treatments. Under very heavy grazing, penetration resistance was not quantifiable on cattle paths below 2.5 cm because values were greater than the 2069 kPa upper limit of the penetrometer.

DISCUSSION

Grazing Effects

Heavy intensity grazing treatments had the most compacting effect. This was evidenced by higher bulk densities and penetration resistances in heavy intensity grazing treatments as compared to controls and lightly grazed treatments. With heavier stocking densities, more surface area is trampled and soil is subjected to more repeated loadings. As vegetation is removed by grazing, its cushioning effects are reduced, making the soil more susceptible to compaction. Smaller amounts of organic matter in heavy treatments would also make it more susceptible to compaction (Chapter II).

The compacting effect of heavy intensity treatments was evidenced by higher surface bulk density in heavy June versus light June treatments at Kinsella and in heavy and very heavy treatments compared to light, moderate, and control treatments at Stavely. Penetration resistances were lowest at the surface in light June and control treatments and at 2.5 cm in the control at Kinsella. However, higher penetration resistances at the surface, 5, and 10 cm under light autumn grazing at Kinsella, did not support this observation. Since the light June treatment had not been grazed for two months when measurements were made, wetting-drying cycles and plant growth may have had ameliorating effects on grazing impacts. However, autumn treatments had not been grazed for a year and should have been affected by the same cycles. No soil textural differences in this treatment could account for the discrepancy. Soil water was lower under light autumn grazing which could affect compaction measurements (Chapter VI).

It was expected that heavy intensity grazing at Brooks would cause compaction compared to the control. High natural bulk densities of the Solonetzic soils and the insensitivity of bulk density to changes within a 10 cm depth increment could have accounted for the lack of differences. Voorhees et al. (1978) found similar results; where bulk density increased 20% or less due to wheel traffic on a silty clay loam, penetration resistance increased by as much as 400%. The results from this study do not support the other studies in Canadian mixed prairie (Lodge 1954; Smoliak et al. 1972; Martens 1979). The heavy continuous grazing regime and higher clay content of the Solonetzic soils in this study could account for the lack of treatment differences. The control could also have been compacted during construction of the adjacent highway and/or railroad.

Early season grazing resulted in more compaction than did late season grazing. Higher organic matter in the heavy autumn treatment compared to the heavy June treatment at Kinsella and in the late season grazed treatment compared to early season grazed treatment at Brooks could lessen compaction. More rainfall occurs when June and early season treatments are grazed than when autumn and late season treatments are grazed (Chapter VII) which could lead to wetter soils that are more susceptible to compaction.

It was hypothesized that defoliation without trampling could lead to reductions in root growth that might affect bulk density. Grazing can reduce root growth and activity, which in turn can have an effect on soil bulk density and penetration resistance. This hypothesis was rejected due to non-significant differences between bulk density under defoliated and non-defoliated areas at Kinsella and Stavely.

Heavy grazing was relatively uniform in its effects on compaction on both cattle path and non-path areas. However, under light grazing, heavier use areas such as the cattle paths were more compacted than were other areas of the treatment. Selective grazing in these lighter grazed treatments led to some areas being utilized less extensively and thus treaded less frequently than others.

Depth Of Compaction

Direct effects of treading on soil compaction are likely to be observed in the top 30 cm of the soil profile where soil bulk density is generally lowest and pressure exerted by a moving animal would have the most impact. Since a heavy tractor with 4 to 5 times the mass of a cow compacts the soil only to a 30 cm depth (Voorhees 1986), it was not expected a cow would compact any deeper taking into account vibration forces, time of loading, and number of loadings.

At Stavely, higher bulk densities in the very heavy treatment from the surface to a 15 cm depth were likely due directly to animal treading. At 55 and 65 cm, increases in bulk density in heavy and very heavy treatments could be an interaction of plant species changes due to grazing, reduced root activity, and treading. As grazing intensity increases, shallow rooted species replace deep rooted species such as *Festuca campestris* (Johnston 1961). Soils were not a significant factor because soil texture did not differ at this depth among the treatments (Appendix II).

Depth of penetration resistance changes between grazed and heavily trampled cattle paths were most affected by heavy intensity/early season grazing. Grazing intensity effects were most evident at Stavely. At Kinsella, surface penetration resistance differed between trampled and grazed areas in autumn but not June treatments. Wetter soil during June grazing may increase compaction but higher organic matter under autumn grazing could reduce compacting effects of grazing. Under heavy June grazing, differences between penetration resistance in cattle paths and regular grazed areas were manifested to a greater depth than under light June grazing. However, differences between these areas under autumn grazing to 15 cm, indicated grazing intensity had less impact late in the growing season.

Effects Of Compaction On Plant Growth

Although the literature contains soil bulk density and penetration resistance ranges which are considered detrimental to plant establishment, growth, and yield, these values are species specific. Russell and Goss (1974) documented that plant roots can exert pressures up to 1000 kPa and that 2000 kPa penetration resistances of soil can reduce root growth up to 50%.

Hakansson et al. (1988) indicated limiting values of penetration resistance for most plant species lie between 2000 and 5000 kPa. Taylor et al. (1966) found no taproots penetrate where soil strength was greater than 2500 kPa, regardless of soil material. Using these values, only in the early season treatment at Brooks and the heavy and very heavy treatments at Stavely were penetration resistance values near 2000 kPa and likely to affect plant growth.

Barley et al. (1970) found as normal point resistance increased above 1000 kPa, primary root elongation rates decreased. Since total root length/unit volume of soil may be one of the most important factors determining uptake of water and nutrients (Barley et al. 1970), penetration resistances above 1000 kPa may affect plant growth and development. The Brooks site would be most affected, since undisturbed soil values are near 1500 kPa below 2.5 cm and increase to 2000 kPa under early season grazing. At Kinsella, only below 30 cm do penetration resistance values increase to greater than 1000 kPa. At Stavely, values in the control are greater than 1000 kPa at 15 cm, and in the grazed treatments are greater below 2.5 cm. The very heavy treatment poses the greatest problem, with penetration resistance as high as 1750 kPa at 2.5 cm.

CONCLUSIONS

Heavy intensity grazing had the greatest compacting effect, increasing bulk densities and penetration resistances. Early season grazing had greater compacting effects than late season grazing. Grazing affected soil bulk density to depths of 10 cm at Kinsella and 65 cm at Stavely, but did not affect soil bulk density at Brooks. Penetration resistance was affected by grazing treatment to 2.5 cm at Brooks, 15 cm at Kinsella, and 30 cm at Stavely. Compaction occurred at greater depths under heavy intensity grazing than under light intensity grazing.

Defoliation without trampling did not increase soil bulk density through changes in root activity. Within a given treatment, heavier trampling on cattle paths compared to the regular grazing treatment caused greater changes in penetration resistance to 30 cm under heavy intensity/early season grazing at Kinsella and Stavely. Under light intensity/late season grazing, differences were not manifested below 10 cm.

Table 4.1. Soil bulk density (Mg m^{-3}) with depth at Brooks.

Depth (cm)	Treatment: Early Season	Late Season	Control
Surface (0-10)	1.07a	1.02a	1.07a
15	1.32a	1.30a	1.31a
25	1.39a	1.32a	1.35a
35	1.35a	1.44a	1.49a
45	1.44a	1.52a	1.57a
55	1.50a	1.55a	1.55a
65	1.49a	1.58a	1.54a

At a given depth, means with the same letters are not significantly different (P<0.05).

Table 4.2. Penetration resistance (kPa) with depth at Brooks.

Depth (cm)	Treatment: Early Season	Late Season	Control
Surface	1648a	1455b	648c
2.5	2013a	1807b	1448c
5.0	2069a	1979a	1875a

At a given depth, means with the same letters are not significantly different (P<0.05).

Table 4.3. Soil bulk density (Mg m^{-3}) with depth at Kinsella.

Depth (cm)	Treatment				
	Light June	Heavy June	Heavy Autumn	Light Autumn	Control
Surface (0-10)	0.96b	1.07a	0.99b	0.95b	0.89c
15	1.24a	1.11a	1.17a	1.12a	1.26a
25	1.41a	1.37a	1.35a	1.30a	1.34a
35	1.52a	1.47a	1.47a	1.34b	1.46a
45	1.50a	1.45a	1.49a	1.35b	1.52a
55	1.55a	1.39ab	1.55a	1.34b	1.55a
65	1.69a	1.54a	1.57a	1.41a	1.58a

At a given depth, means with the same letters are not significantly different (P<0.05).

Table 4.4. Surface (0-10 cm) soil bulk density (Mg m^{-3}) at Kinsella in the exclosure, in areas defoliated but not trampled, in grazed areas, and in heavily trampled areas.

Area	Treatment			
	Light June	Heavy June	Heavy Autumn	Light Autumn
Path	1.01a	1.08a	1.05a	1.00a
Grazed	0.98b	1.10a	1.00a	0.97b
Defoliated	0.85c	0.95b	0.82b	0.90c
Exclosure	0.81c	0.87b	0.82b	0.85c

Within grazing treatment, means with the same letters are not significantly different (P<0.05).

Table 4.5. Soil bulk density (Mg m^{-3}) with depth at Stavely.

Depth (cm)	Treatment				
	Very Heavy	Heavy	Moderate	Light	Control
Surface (0-10)	0.90a	0.83b	0.80b	0.83b	0.75c
15	0.70a	0.48bc	0.40c	0.58b	0.51b
25	0.99a	0.86a	0.66b	0.82a	0.90a
35	1.16a	1.20a	1.09a	1.11a	1.16a
45	1.40a	1.39a	1.19b	1.29ab	1.34a
55	1.62a	1.59a	1.41b	1.41b	1.43b
65	1.68a	1.66a	1.48b	1.51b	1.50b

At a given depth, means with the same letters are not significantly different (P<0.05).

Table 4.6. Surface (0-10 cm) soil bulk density (Mg m^{-3}) at Stavely in the control (exclosure), in areas defoliated but not trampled, in grazed areas, and in heavily trampled areas.

Area	Treatment			
	Light	Moderate	Heavy	Very Heavy
Path	0.92a	0.80a	0.93a	1.04a
Grazed	0.89a	0.82a	0.87a	0.98b
Defoliated	0.77b	0.74b	0.63b	0.81c
Exclosure	0.75b	0.69b	0.74b	0.79c

Within treatment means with the same letters are not significantly different (P<0.05).

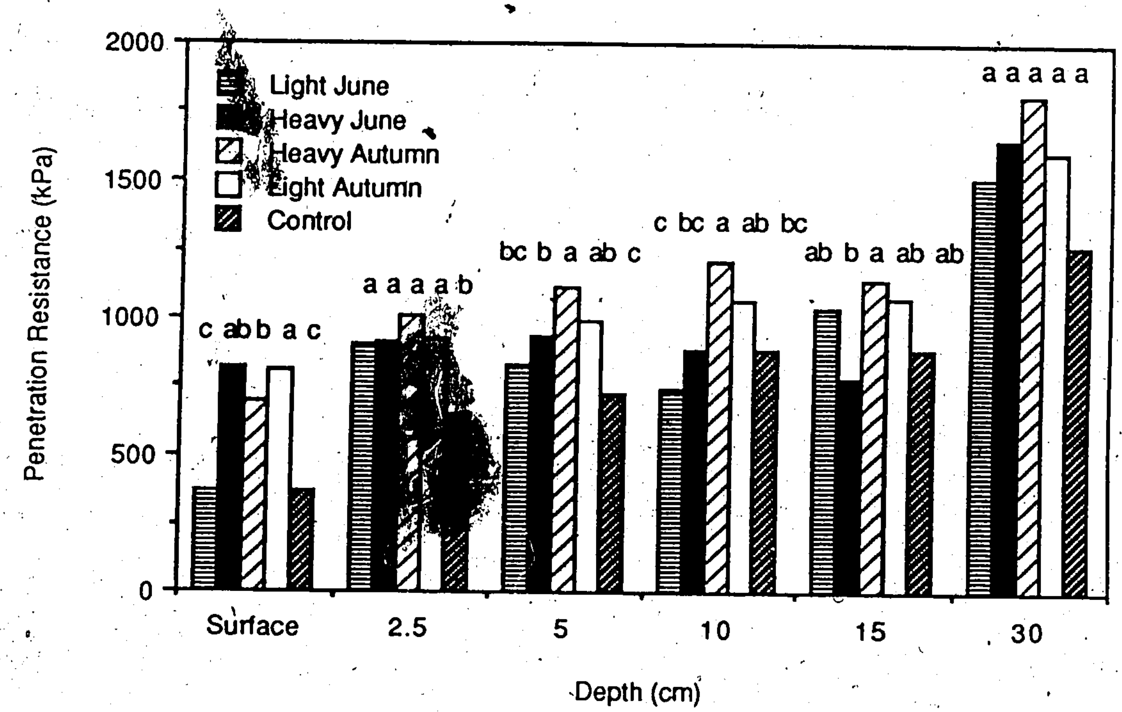


Figure 4.1. Penetration resistance at Kinsella. At a given depth, means with the same letters are not significantly different (P<0.05).

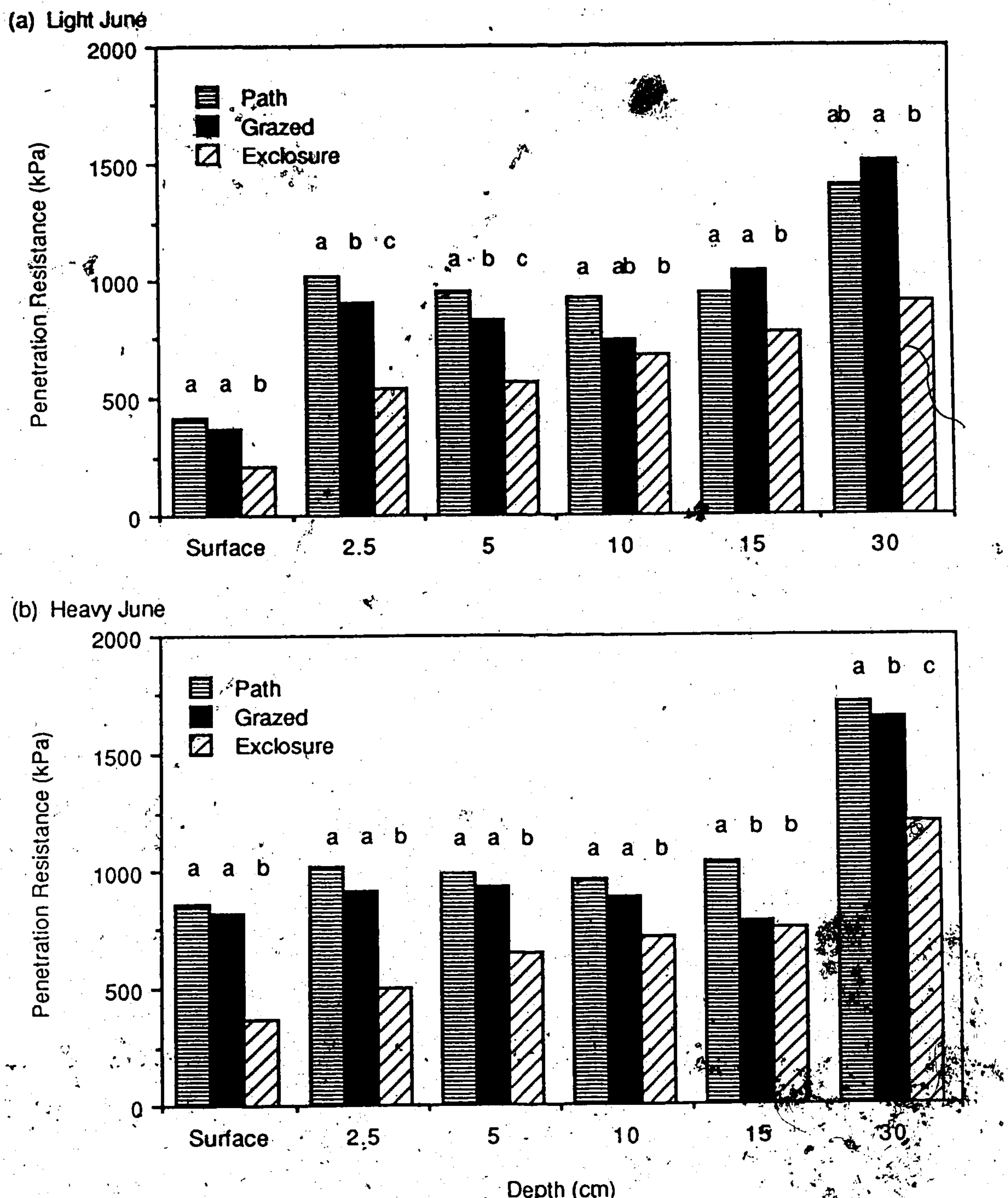


Figure 4.2. Penetration resistance in (a) light June and (b) heavy June treatments at Kinsella. Within treatment and depth means with the same letters are not significantly different ($P<0.05$)

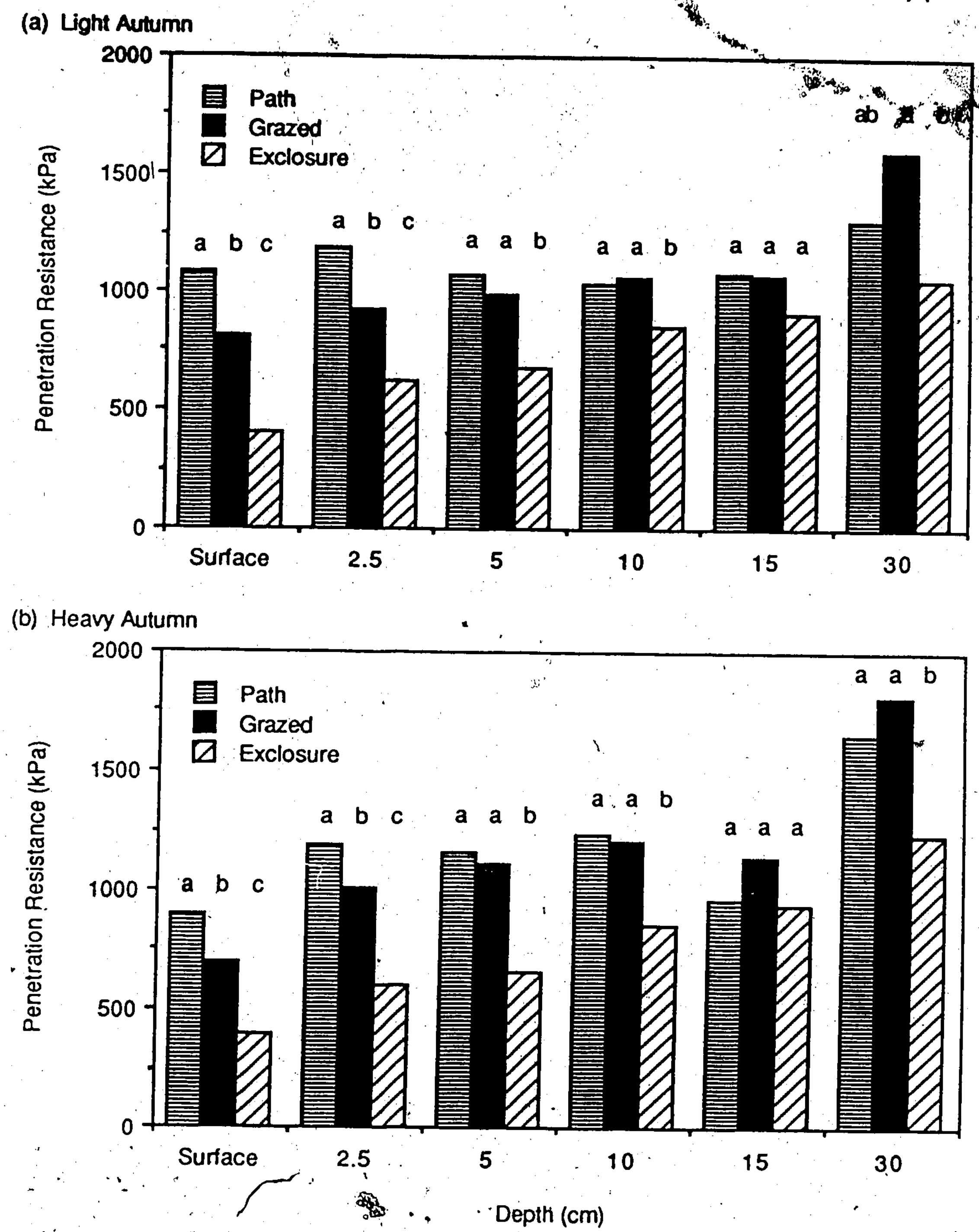


Figure 4.3. Penetration resistance in (a) light autumn and (b) heavy autumn treatments at Kinsella. Within treatment and depth means with the same letters are not significantly different (P<0.05)

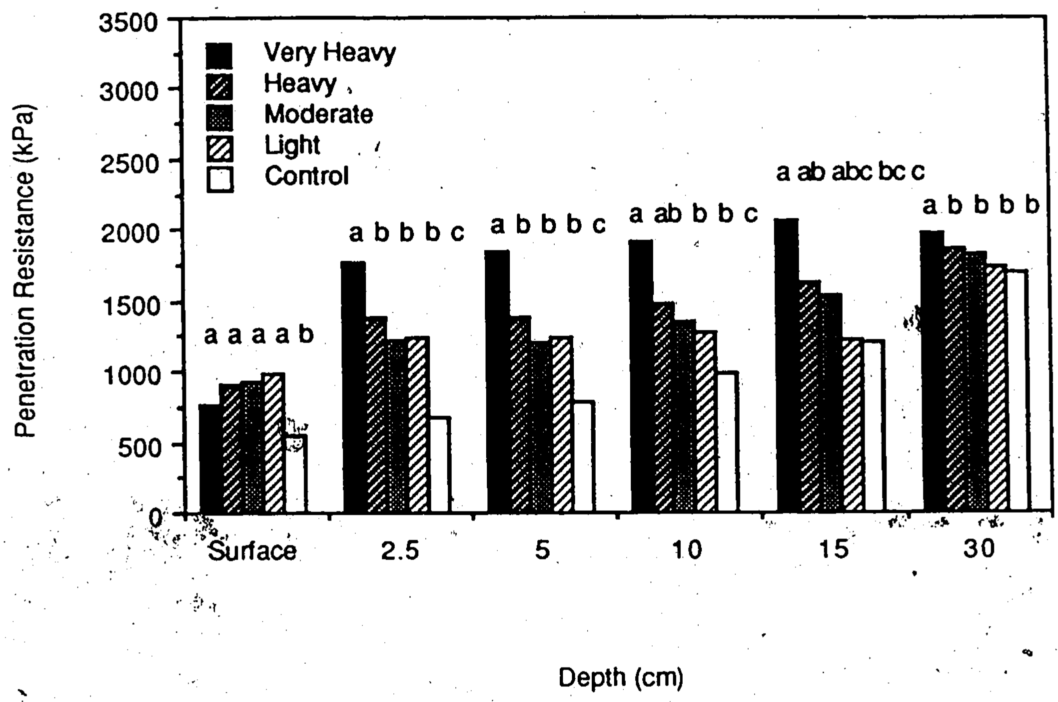


Figure 4.4. Resistance to penetration at Stavely. At a given depth, means with the same letters are not significantly different (P<0.05).

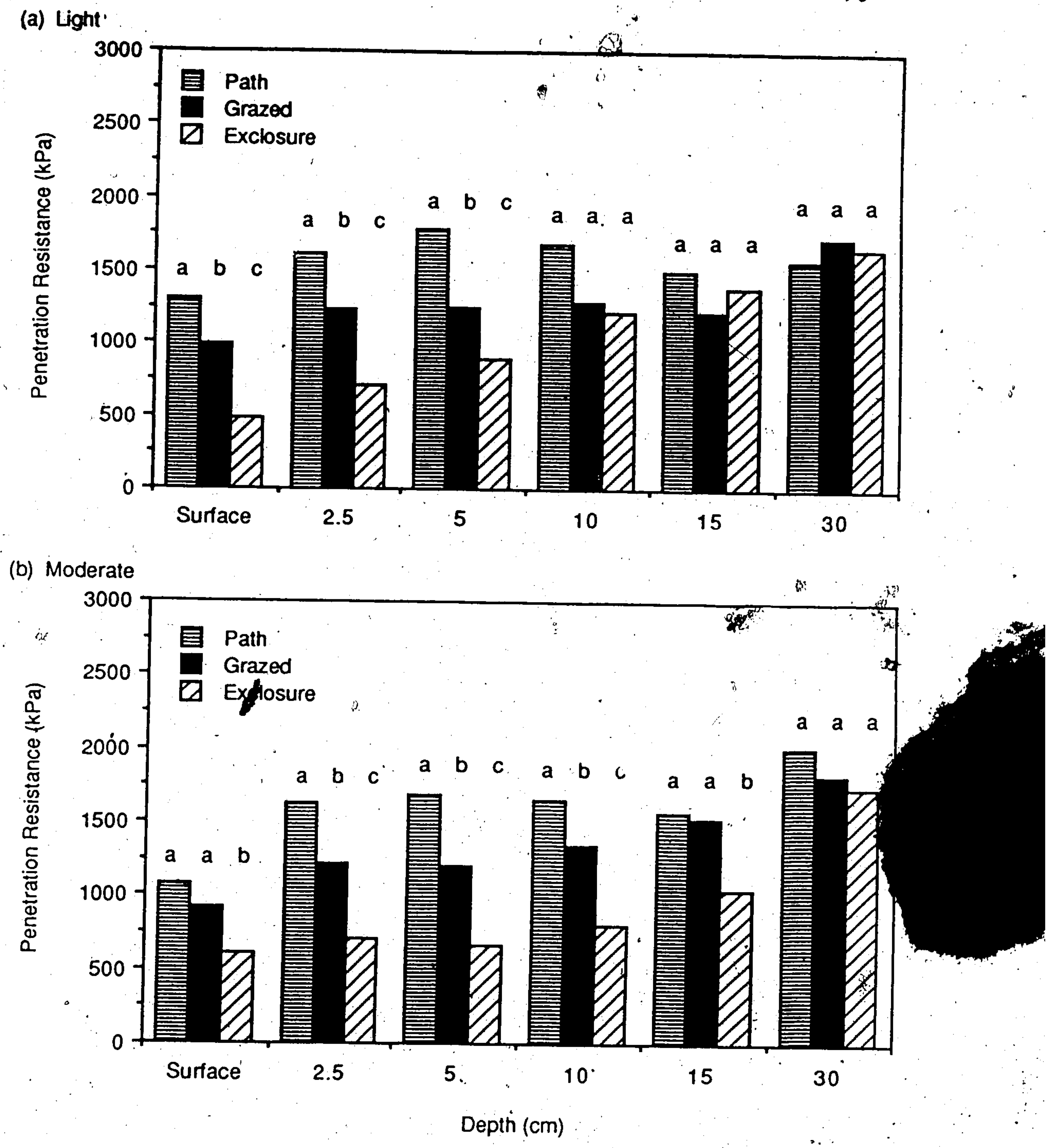


Figure 4.5. Penetration resistance in (a) light and (b) moderate treatments at Stavely. Within treatment and depth means with the same letters are not significantly different ($P<0.05$).

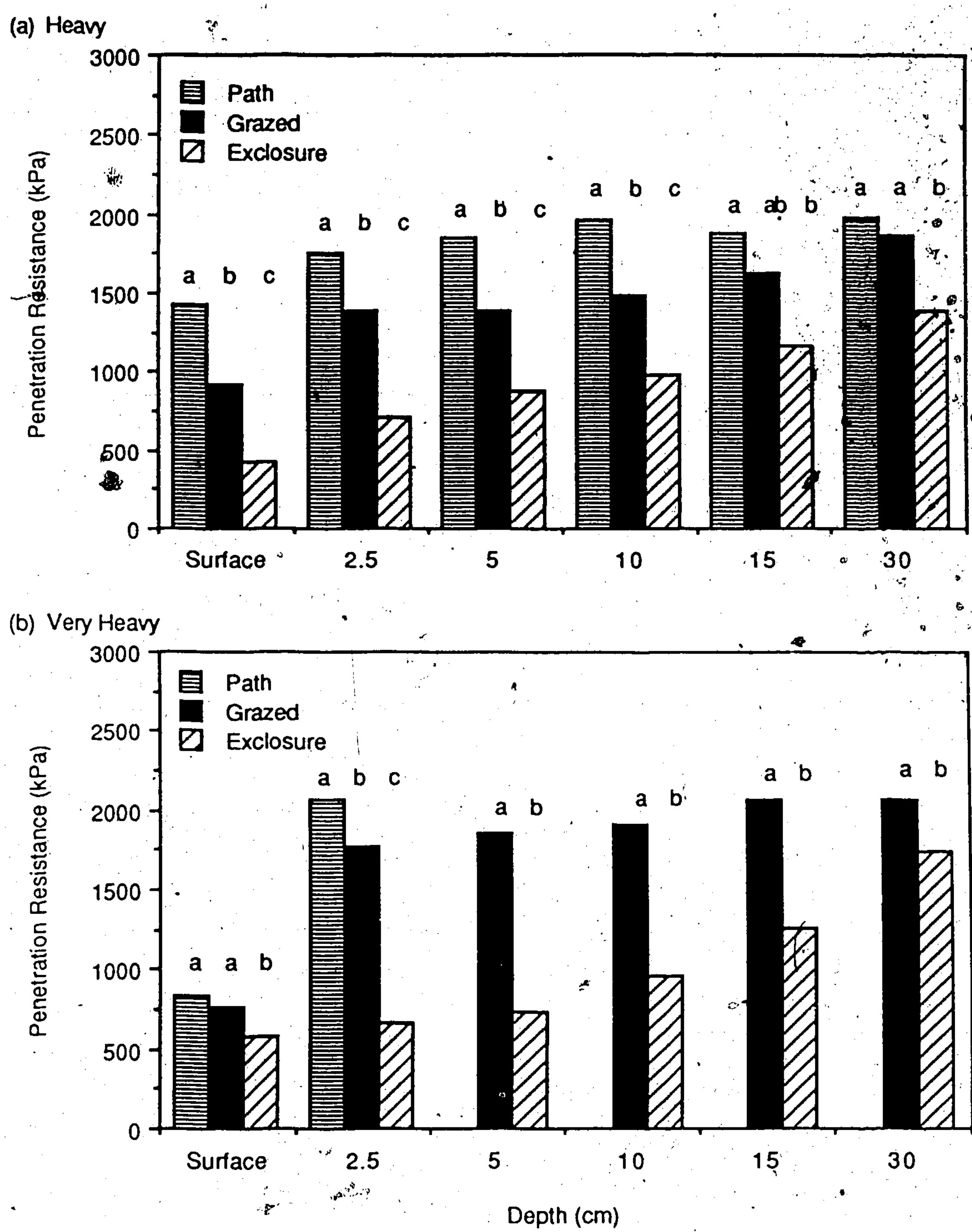


Figure 4.6. Penetration resistance in (a) heavy and (b) very heavy treatments at Stavely. Within treatment and depth means with the same letters are not significantly different ($P<0.05$).

BIBLIOGRAPHY

Alderfer, R.B. and Robinson, R.R. 1947. Runoff from pastures in relation to grazing intensity and soil compaction. J. Amer. Soc. Agron. 39:948-958.

Bailey, A.W., Willoughby, M.G., and Irving, B.D. 1987. Effect of grazing on forage and beef production from rough fescue rangeland in central Alberta. Farming for the Future Final Report. Project No. 84-0335. 41 pp.

Barley, K.P., Farrell, D.A., and Graecen, E.L. 1970. The configuration of the root system in relation to nutrient uptake. Advan. Agron. 22:159-201.

Bowser, W.E. 1967. Agroclimatic areas of Alberta. Institute of Pedology. Univ. of Alberta. Edmonton, Alta.

Coupland, R.T. 1961. A reconsideration of grassland classification in the Northern Great Plains of North America. J. Ecol. 49:136-167.

Gifford, G.F., Faust, R.H., and Coltharp, G.B. 1977. Measuring soil compaction on rangeland. J. Range Manage. 30:459-460.

Hakansson, I., Voorhees, W.B., and Riley, H. 1988. Vehicle and wheel factors influencing soil compaction and crop response in different traffic regimes. Soil and Tillage Res. (In press).

Howitt, R.W. 1988. Soil survey of the county of Beaver. Alberta Soil Survey Report No. 47. Alberta Research Council Open File Report No 1987-4. (In press).

Johnston, A. 1961. Comparison of lightly grazed and ungrazed range in fescue grassland of southwestern Alberta. Can. J. Plant Sci. 41:615-622.

Johnston, A., Dormaar, J.F., and Smoliak, S. 1971. Long-term grazing effects on fescue grassland. J. Range Manage. 24:185-188.

Kjearsgaard, A.A., Peters, T.W., and Pettapiece, W.W. 1982. Soil Survey of the County of Newell No. 4, Alberta. Alberta Institute of Pedology Report S-82-41. 197 pp.

Lodge, R.W. 1954. Effects of grazing on the soils and forage of mixed prairie in southwestern Saskatchewan. J. Range Manage. 7:166-170.

Looman, J. 1969. The fescue grasslands of western Canada. Vegetatio Acta Geobotanica 19:127-145.

Martens, H.E. 1979. Content and distribution of organic matter in natural and managed ecosystems in the mixed prairie grassland region in Saskatchewan. Unpubl. M.Sc. Thesis. Dept. Plant Ecology, Univ. of Saskatchewan. Saskatoon, Sask. 135 pp.

Moss, E.H. 1955. The vegetation of Alberta. Bot. Rev. 21:493-587.

Moss, E.H. 1983. Flora of Alberta. 2nd ed. Revised by J.G. Packer. Univ. of Toronto Press. Toronto, Ont. 687 pp.

Orr, H.K. 1960. Soil porosity and bulk density on grazed and protected Kentucky Bluegrass range in the Black Hills. J. Range Manage. 13:180-186.

Pavlick, L.E. and Looman, J. 1984. Taxonomy and nomenclature of rough fescues, *Festuca altaica, Festuca campestris* (*F. scabrella* var. major), and *Festuca hallii*, in Canada and the adjacent part of the United States. Can. J. Bot. 62:1739-1749.

Rauzi, F. and Hanson, C.L. 1966. Water intake and runoff as affected by intensity of grazing. J. Range Manage. 19:351-356.

Reed, M.J. and Peterson, R.A. 1961. Vegetation, soil, and cattle responses to grazing on Northern Great Plains range. USDA For. Serv. Tech. Bull. No. 1252. 79 pp.

Russell, R.S. and Goss, M.J. 1974. Physical aspects of soil fertility - the response of roots to mechanical impedance. Neth. J. Agr. Sci. 22:305-318.

Shapiro, S.S. and Wilk, M.B. 1965. An analysis of variance test for normality (complete samples). Biometrika 52:591-611.

Smoliak, S., Dormaar, J.F., and Johnston, A. 1972. Long-term grazing effects on *Stipa-Bouteloua* prairie soils. J. Range Manage. 25:246-250.

Steel, R.G.D. and Torrie, J.H. 1980. Principles and procedures of statistics: a biometrical approach. 2nd ed. McGraw-Hill, New York. 633 pp.

Taylor, H.M., Roberson, G.M., and Parker, J.J. 1966. Soil strength-root penetration relations for medium- to coarse-textured soil materials. Soil Sci. 102:18-22.

Van Haveren, B.P. 1983. Soil bulk density as influenced by grazing intensity and soil type on a shortgrass prairie site. J. Range Manage. 36:586-588.

Voorhees, W.B. 1986. The effect of soil compaction on crop yield. SAE Paper No. 860729 ASAE. St. Joseph, MI.

Voorhees, W.B., Senst, C.G., and Nelson, W.W. 1978. Compaction and soil structure modification by wheel traffic in the northern corn belt. Soil Sci. Soc. Am. J. 42:344-349.

Warren, S.D., Nevill, M.B., Blackburn, W.H., and Garza, N.E. 1986. Soil response to trampling under intensive rotation grazing. Soil Sci. Soc. Am. J. 50:1336-1341.

Wheeler, G.W. 1976. Some grassland and shrubland communities in the parklands of central Alberta. Unpubl. M.Sc. Thesis. Dept. Plant Science. Univ. of Alberta, Edmonton, Alta. 95 pp.

Wonders, W.C. 1969. Atlas of Alberta. Univ. of Alberta Press in association with Univ. of Toronto Press. Edmonton, Alta. 158 pp.

Wood, M.K. and Blackburn, W.H. 1984. Vegetation and soil responses to cattle grazing systems in the Texas Rolling Plains. J. Range Manage. 37:303-308.

V. THE IMPACT OF GRAZING REGIME ON INFILTRATION IN MIXED PRAIRIE AND FESCUE GRASSLAND ECOSYSTEMS OF ALBERTA

INTRODUCTION

Infiltration capacity is reduced with increased grazing intensity and reduced range condition, mainly through vegetation and litter removal, soil structure deterioration, and compaction (Reed and Peterson 1961; Branson et al. 1962; Johnston 1962; Rauzi et al. 1968; Gifford and Hawkins 1978; Blackburn 1984). Changes in infiltration rates tend to be incremental to some threshold level at which grazing effects first become significant.

Quantity of living plant material and associated litter are more significantly correlated with infiltration than any other measured variable (Duley and Domingo 1949; Hopkins 1954; Rauzi 1963; Tomanek 1969; Meeuwig 1970). They increase infiltration rates by decreasing the impact of raindrops, improving soil structure through formation of larger soil aggregates, and creating a rougher microtopography that increases infiltration opportunity. Most infiltration studies do not separate influences of live vegetation and litter, although Johnston (1962) found removal of litter reduces infiltration rate more than does removal of current year vegetation. Beke (1969) found soils of the Stavely region have the capacity to transmit water faster than the maximum recorded rainfall intensity and type of cover has little influence on infiltration rate as long as the soil is covered by vegetation.

It was hypothesized that grazing would reduce infiltration capacity, particularly in treatments that caused soil compaction and/or in those that had major effects on vegetative cover, litter mass, and soil organic matter mass. Since the soil surface is a major controlling factor of infiltration, range management practices leading to less compacted surfaces with high litter and organic matter would enhance infiltration capacity. The objective of this study was to determine the effects of season and intensity of grazing on infiltration capacity in mixed prairie and fescue grassland ecosystems of Alberta.

MATERIALS AND METHODS

Study Sites

Three study sites representing major grassland ecosystems of southern and central Alberta rangeland were selected. Each study site had long-term grazing treatments, ungrazed controls, grass dominated vegetation that had never been cultivated, and slopes of less than 2%. (See Appendix I for detailed descriptions). Moss (1983) was used as the botanical authority.

Brooks

The Brooks site was located in mixed prairie approximately 225 km east of Calgary (51 °N latitude and 112 °W longitude). The area has a continental prairie climate and a semiarid moisture regime (Bowser 1967). Mean annual precipitation is 355 mm with an average annual moisture deficit of 227 mm. Mean annual temperature is 4 °C, with a July mean of 19 °C and a January mean of -14 °C. Elevation averages 745 m above sea level with slopes of less than 2%. Soils are Brown Solodized Solonetz and Brown Solod developed on till (Kjearsgaard et al. 1982). Vegetation is of the *Bouteloua-Stipa-Agropyron* (blue grama-spear grass-wheatgrass) faciation dominated by *Bouteloua gracilis, Stipa comata, Agropyron smithii,* and *A. dasystachyum* (Coupland 1961). *Artemisia frigida* and *Selaginella densa* are common forbs. A short grass disclimax dominated by *Bouteloua gracilis* is common as a result of heavy long-term grazing.

Kinsella

The Kinsella site was located in aspen parkland approximately 150 km southeast of Edmonton (53 °N latitude and 111 °W longitude). The climate is dry subhumid (Wonders 1969). Mean annual precipitation is 380 mm; mean annual evapotranspiration is 381 mm. Mean annual temperature is 2 °C, with a July mean of 17 °C and a January mean of -17 °C. Elevation averages 685 m above sea level with gently rolling to hilly topography (Howitt 1988). Grassland soils are dominated by Orthic Black Chernozems developed on till. Vegetation consists of grass and shrub communities with aspen groves occurring at irregular intervals (Moss 1955). *Festuca hallii* (Vasey)

Piper (Pavlick and Looman 1984) dominates open undisturbed grasslands and *Stipa curtiseta* codominates on grazed areas (Wheeler 1976). Various forbs are a common component of the vegetation.

Stavely

The Stavely site was located in foothills fescue grassland approximately 100 km south-southwest of Calgary (50 °N latitude and 114 °W longitude). The climate is subhumid without marked deficiency of precipitation. Mean annual precipitation is 550 mm. Mean annual temperature is 5 °C, with a July mean of 18 °C and a January mean of -10 °C. Elevation averages 1350 m above sea level and topography is gently rolling to hilly. Soils are Orthic Black Chernozems developed on till (Johnston et al. 1971). Vegetation is of the fescue grassland association (Looman 1969) with *Festuca campestris* Rydb. dominating in undisturbed and lightly grazed areas. *Danthonia parryi* and *Festuca idahoensis* are codominants in grazed areas. With heavy grazing, *Festuca campestris* is replaced by annual invaders and *Poa* species.

Grazing Treatments

At Brooks, three grazing treatments were studied within a community pasture that had been established in 1964 (B. Shanks, personal communication, September 1981). The treatments included: (1) early season grazing from May 1 through July; (2) late season grazing from August through October; and (3) a control on an adjacent highway right-of-way that had not been grazed for 25 years. The 0.9 AUM ha^{-1} stocking rate was considered heavy for the area.

At Kinsella, five grazing treatments established in 1973 on the University of Alberta ranch were studied (Bailey et al. 1987). The treatments included: (1) light June grazing from June 1 to 30 at 1.5 AUM ha^{-1} with approximately 35% herbage utilized; (2) heavy June grazing from June 1 to 30 at 4.4 AUM ha^{-1} with approximately 75% herbage utilized; (3) heavy autumn grazing from September 15 to October 15 at 4.4 AUM ha^{-1} with approximately 75% herbage utilized; (4) light autumn grazing from September 15 to October 15 at 1.5 AUM ha^{-1} with approximately 35%

herbage utilized; and (5) a control that had not been grazed since 1942. Each grazing treatment included 5.5 ha of grassland and a variable area of shrub and forest. Two 10 by 20 m permanent exclosures, randomly located in each treatment, were also studied.

At Stavely, five grazing treatments established in 1949 on an Agriculture Canada Range Research Substation were studied (Johnston 1961). Treatments were grazed from May to October and included: (1) very heavy grazing with 16.2 ha stocked at 4.8 AUM ha^{-1}; (2) heavy grazing with 32.4 ha stocked at 2.4 AUM ha^{-1}; (3) moderate grazing with 48.6 ha stocked at 1.6 AUM ha^{-1}; (4) light grazing with 64.8 ha stocked at 1.2 AUM ha^{-1}; and (5) a control comprised of permanent exclosures of 0.66, 0.41, 0.76, and 0.23 ha in the light, moderate, heavy, and very heavy treatments, respectively.

Experimental Design

The experimental design within each site was a hierarchical (subsampling) arrangement. Within each treatment, three 0.1 ha areas were randomly established. Within each of these areas, points were randomly selected from which samples were collected or measurements were made.

Infiltration Tests

Double ring infiltrometers with outside ring diameters of approximately 63 cm and inside ring diameters of approximately 33 cm were used. In each treatment, six infiltration tests were conducted in 1985 and nine in 1986 (2 and 3 per 0.1 ha area, respectively). The rings were driven vertically into the ground. In heavily vegetated areas, a knife was used to cut the sod around the rings before insertion, disturbing the vegetation as little as possible. Where bared ground infiltration tests were conducted, electric clippers were used to remove all standing vegetation and surface litter was raked off with hand rakes. Water was added to the infiltration rings to maintain a relatively constant head between 8 and 10 cm deep in each ring. Float readings were started the first minute after the rings were filled; subsequent readings were taken every minute in the first five minutes, at seven minutes, at 10 minutes, and every five minutes thereafter until a steady infiltration rate was achieved.

Soil And Vegetation Analyses

Measurements of antecedent soil water were made prior to infiltration tests with a Campbell Pacific Nuclear 503 Hydroprobe (Chapter VI). Surface water measurements were taken adjacent to the infiltration site with a hydrogenously shielded neutron probe (Chanasyk and Naeth 1988) and a Campbell Pacific Nuclear MC1-12 surface moisture/density gauge. Bulk density with depth was measured with a Campbell Pacific Nuclear 501 combination moisture/density probe (Chapter IV). Surface density readings were taken with the MC1 to a 10 cm depth adjacent to each test site.

Particle size distribution was determined by the hydrometer method and water retention at -33 and -1500 kPa by the pressure plate extraction method (Appendix II). Litter depth and height were measured and ground cover was determined with a point frame for percent bare ground, live vegetation, and litter. Litter and soil organic matter masses were measured from determinations of total carbon by dry oxidation (Chapter II).

Statistical Analyses

Statistical analyses were conducted using variation among the 0.1 ha areas as an appropriate measure of error for testing treatment significance. Data were tested for homogeneity of variance using Cochran and Bartlett-Box tests. The W test was used to test data for normality of distribution (Shapiro and Wilk 1965). An SPSSx analysis of variance program was used to test for treatment effects. Data with significant F values were further analyzed to separate the means using the Student-Newman-Keul (SNK) test at the 5% level of significance (Steel and Torrie 1980).

Preliminary statistical analyses within each year by treatment combination indicated that variation among the 0.1 ha areas was not significantly different from sampling point variation and therefore in all future analyses, area and sampling point variation were pooled. If additional preliminary statistical analyses within each treatment using the pooled error term indicated significant differences between study years, data were analyzed on a within year basis. Otherwise data from both years were pooled. Sources of variation in the final statistical analysis were treatments and error within treatments.

Infiltration Data

Infiltration tests were run until a constant rate was achieved, usually an hour. Final infiltration rates were calculated as the mean of data from 40 min, inclusive. Cumulative infiltration was derived by multiplying infiltration rate by time period and summing to the time in question.

RESULTS

Within a treatment, infiltration rates at times 2, 3, and 4 min were similar to those at 5 min; rates at 20 and 25 min were similar to those at 15 and 30 min (data not presented). Although infiltration rate for some times differed between years, steady state infiltration at all sites was not significantly different between 1985 and 1986. Antecedent soil water and surface bulk density at the infiltration sites are presented in Table 5.1.

Brooks

High 1 min infiltration rates dropped dramatically by 5 min with 1986 initial rates being higher than those in 1985 (Figure 5.1). Initial infiltration rates in the control were approximately 1.5 times higher than those in the early season treatment. Statistically significant treatment differences occurred at various times throughout the tests with 1986 steady state rates approximately 1.7 times higher in the control than in the early season treatment.

Kinsella

Infiltration rates at 1 min were lowest in the June treatments; 1985 rates were 1.5 to 3 times higher than those in 1986 (Figure 5.2). In 1985, steady state rates were highest in the light autumn and control treatments; in 1986, they were lowest in the light June treatment. In the light autumn treatment steady state infiltration rates on bared ground did not differ from those in the regular treatment as presented in Figure 5.2 (data not shown).

Stavely

In 1985, the 1 min infiltration rate in the very heavy treatment was approximately half that of the control or light treatments (Figure 5.3). Steady state rates were 1.5 to 2 times higher in the light and control treatments than in the moderate, heavy, and very heavy treatments. In 1986, 1 min infiltration rates in the control were 1.5 to 2.3 times higher than in the heavy and very heavy treatments. At any time during the test, approximately twice as much water infiltrated the control as the very heavy treatment. Infiltration rate on bared ground did not differ from that in the light treatment except at 30 and 60 min when it was 40 and 34% lower under bared ground (data not shown). Under very heavy grazing, only steady state infiltration rate under bared ground was significantly different from that in the grazed treatment (13% lower).

Site Comparison

Infiltration rates in the control treatments at Brooks and Kinsella were similar at all times (Figure 5.4). Infiltration rates in the control at Stavely were significantly higher than those in the controls at the other two sites in the first 15-min of the tests. Initial rates at Stavely were 1.7 to 3.5 times higher than those at Brooks and Kinsella. Steady state rates at Stavely were 1.5 to 2 times higher than those at Brooks and Kinsella.

DISCUSSION

Grazing Effects On Infiltration

Infiltration was affected by grazing as indicated by the generally higher infiltration rates in the controls. Lower bulk densities and/or penetration resistances (Chapter IV), less bare ground, greater height of standing and fallen litter, and higher litter and vegetation masses in the controls compared to the grazed treatments (Chapter II) led to surface conditions that were more permeable and conducive to infiltration.

Heavy intensity/early season treatments had the most effect on infiltration as evidenced by low steady state infiltration rates under early season grazing at Brooks in 1986, June and heavy autumn grazing at Kinsella in 1985, and moderate, heavy, and very heavy grazing at Stavely in both 1985 and 1986 compared to light intensity/late season grazing or the controls. Steady state infiltration rates under grazing were reduced by 4.5, 0.7 to 2.7, and 4.8 to 8.4 cm h^{-1} compared to the controls at Brooks, Kinsella, and Stavely, respectively. These results exemplify the importance of vegetation and litter in enhancing infiltration capacity by creating a more permeable soil surface and reducing the effect of trampling on infiltration. Infiltration rates in light and moderate treatments at Stavely were statistically similar. However, the light treatment was closer to the control, differing by 1.4 to 5.1 cm h^{-1}, than it was to the moderate treatment, differing by 2.4 to 4.9 cm h^{-1}. This indicated the effect of grazing from a hydrologic perspective was evident even at very low grazing intensities. The 1 min rates were also lowest under early season/heavy intensity grazing at Brooks, June grazing at Kinsella, and very heavy and heavy grazing at Stavely. At Kinsella, infiltration in the heavy autumn treatment was similar to the June treatments, the controls, and the light autumn treatments, indicating its intermediate nature. Although the heavy autumn treatment was of a heavy intensity, grazing during the dormant season resulted in steady state infiltration rates that were 2 to 6 times higher than rates under June grazing at any intensity.

According to the literature, live and dead vegetation masses have the most effect on infiltration rates. Heights of individual species or standing litter did not differ between grazed treatments at Brooks (Chapter II); however, frequency of grass species is reduced from 25% under late season grazing to 6% under early season grazing (Naeth 1985). Late season grazing increases frequency of taller grasses such as *Stipa* species, *Agropyron* species, and *Koeleria macrantha*. At Kinsella, heights of standing litter for many species were reduced under June and heavy autumn grazing (Chapter II). At Kinsella Bailey et al. (1987) indicated June grazing causes reductions in tall grasses. These changes may have led to more hydrologically favourable conditions in the late season treatments as Rauzi and Smika (1963) and Pluhar et al. (1987) found higher infiltration rates with greater numbers of midgrasses than shortgrasses present. Although interception loss may be higher from tall grasses, the increases in infiltration rates offset this.

Direct comparisons to other studies are difficult due to different soils, vegetation, and methodology. However, trends were similar to those of Rauzi and Smika (1963) who found higher infiltration rates in autumn harvested treatments than in those harvested throughout the growing season. Johnston (1962) found similar trends on fescue rangeland using an infiltrometer. When comparing infiltration rates obtained with infiltration rings, values for the mixed prairie under heavy grazing are comparable to those of Knoll and Hopkins (1959) at 4.01 cm h^{-1}, Reed and Peterson (1961) at 7.19 cm h^{-1}, and Whitman et al. (1964) at 7.87 cm h^{-1}.

Bared Ground Treatments

It had been hypothesized that removing vegetation and litter at the soil surface would cause decreases in infiltration rate. Decreased infiltration would likely result from plugging of soil pores with soil particles. The non-significant differences between bared and untreated infiltration sites at Kinsella indicate that below ground litter, root mass, and soil properties were just as important in the light autumn treatment as were vegetative characteristics above ground. At Stavely, higher infiltration rates in unbared ground under light and very heavy grazing indicated the importance of surface cover. Bared ground would be more important in rainfall simulations, because under ponded conditions, surface changes such as puddling and sealing caused by raindrop impact were not present.

Site Comparison

When comparing controls at the three sites, the importance of both soils and vegetation in determining infiltration capacity is emphasized. The Brooks site was in the poorest hydrologic condition with high bulk densities and high penetration resistances of the Solonetzic soils (Chapter IV) combined with low organic matter (Chapter II). However, lower antecedent soil water and loam soil surface seem to have mitigated the effect of other factors. At Kinsella, the sandy soil surface and less compacted Chernozemic soils combined with the higher litter mass were more conducive to infiltration. However, the high surface soil water, especially in 1986, had the most pronounced effect on infiltration. Mean infiltration values from the two study years for Brooks and Kinsella were similar. At Stavely, higher organic matter and lower bulk densities created the most favourable environment for infiltration and rates were higher than at the other two sites. The study supports that of Dee et al. (1966) who found infiltration rates increase with increasing level of vegetation on the successional scale. This is particularly notable in the very heavy treatment at Stavely that is dominated by invader species. The less permeable Bnt horizon at Brooks likely would have affected steady state infiltration more than Bm or Bt horizons at the other two sites.

Antecedent Surface Soil Water Effects On Infiltration

Under late season grazing at Brooks, soil water was almost twice as high in 1986 as in 1985 contributing to a lower 1 min infiltration rate in 1986. Higher rates under early season grazing in 1986 than in 1985 may be due to modifying effects of increased below ground litter. Higher 10 min infiltration rates in the late season treatment in 1986 indicate vegetative and soil characteristics may be more important than antecedent soil water after the first few min of the test. At Stavely, soil water in 1986 was lowest in the very heavy treatment, yet infiltration rate was lower than in light or moderate treatments. Higher soil water in the light treatment than in the control caused lower infiltration rates only in the first 1 min, also indicating effect of antecedent soil water was important during earlier stages of the tests. Results are similar to those of Rauzi and Smith (1973) who found soil effects significant only during the first 10 min of the infiltration process. After 15 min, grazing influences are detectable, after 20 min, soil and grazing effects are equal.

Management Implications

On Alberta prairie, intense short duration rains are common (Atmospheric Environment Services 1987). Management factors creating a soil surface conducive to absorbing this precipitation are important. Treatments having high initial and 5 min infiltration rates may be used as management models. Although the data in this study were often statistically different among treatments, the practical or physical significance of these differences for short duration showers could be low. Differences were 1.3 to 8.6 cm h^{-1} of water under steady state ponded conditions, much higher than average rainfall intensity for the area. However, the differences in infiltration rate may be of more importance under longer duration, lighter intensity precipitation events.

CONCLUSIONS

Infiltration rate was reduced more by heavy intensity/early season grazing than by light intensity/late season grazing as compared to infiltration rates in the controls. At Stavely, the moderate treatment was intermediate between the heavy and very heavy treatments and the light and control treatments.

Table 5.1. Pre-infiltration soil water and bulk density to10 cm at Brooks, Kinsella, and Stavely.

Site	Treatment	1985		1986	
		Soil Water $cm^3\ cm^{-3}$ x 100	Bulk Density $Mg\ m^{-3}$	Soil Water $cm^3\ cm^{-3}$ x 100	Bulk Density $Mg\ m^{-3}$
Brooks	Early	10.4b	1.16a	13.7b	1.14a
	Late	9.6b	1.06b	17.2a	1.03b
	Control	13.0a	1.11ab	15.5ab	1.09ab
Kinsella	Light June	31.4a	0.95a	43.0a	0.94a
	Heavy June	32.0a	0.97a	40.7b	1.02a
	Heavy Autumn	27.9a	0.98a	39.3b	0.96a
	Light Autumn	16.1b	1.01a	36.6c	0.98a
	Control	17.6b	0.95a	30.0d	0.94a
Stavely	Very Heavy	15.5a	1.00a	16.5c	0.97a
	Heavy	16.3a	0.90ab	20.8a	0.87b
	Moderate	14.8a	0.92ab	19.6b	0.86b
	Light	14.9a	0.93ab	22.7a	0.83b
	Control	15.0a	0.83b	20.3b	0.79c

Within year and treatment means with the same letters are not significantly different ($P<0.05$).

Within treatment soil bulk density did not differ between years at Brooks and Kinsella; differences occurred in the moderate treatment at Stavely ($P<0.05$).

Within treatment soil water was significantly different between years at Brooks and Kinsella; it differed only in the very heavy treatment at Stavely ($P<0.05$).

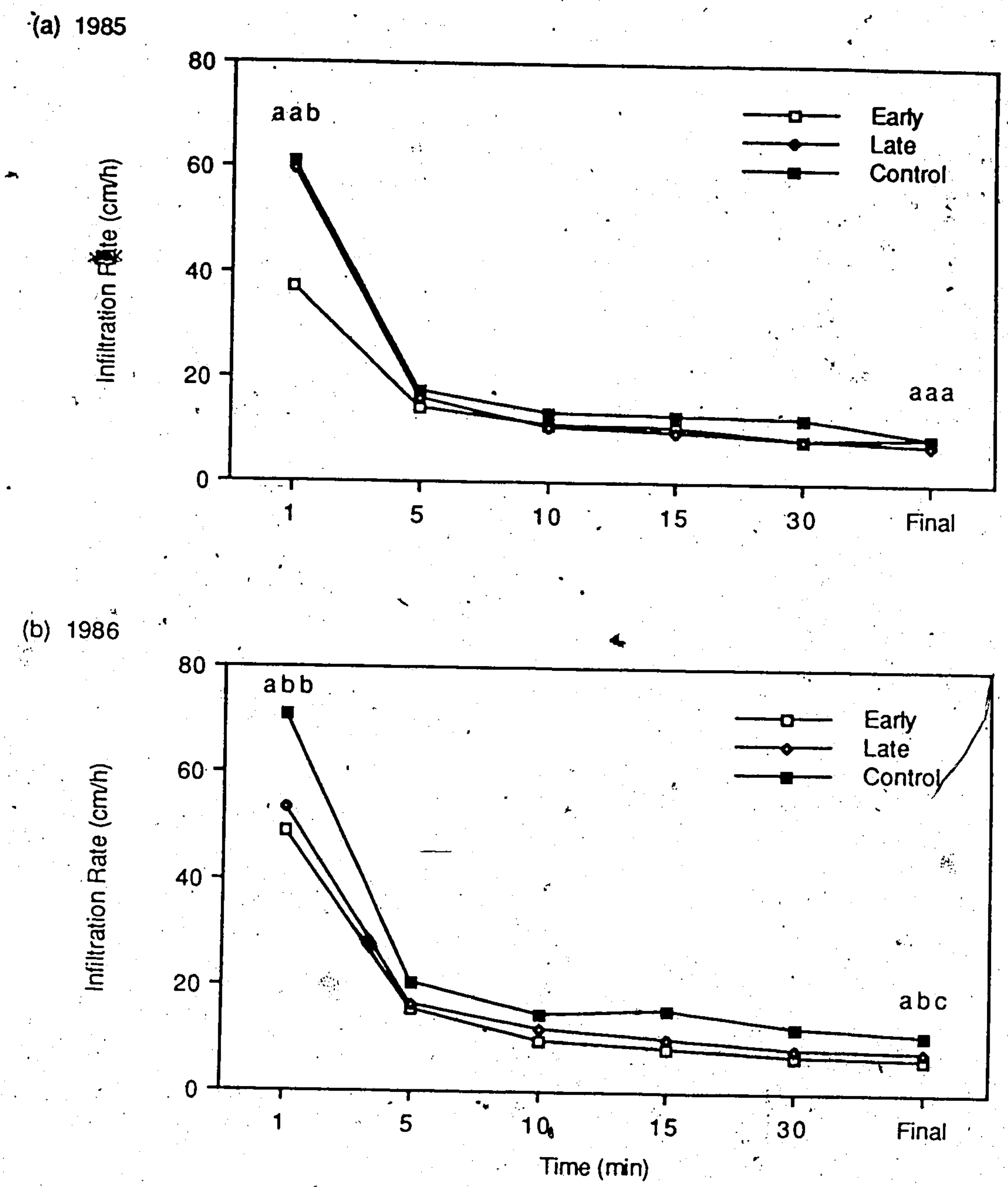
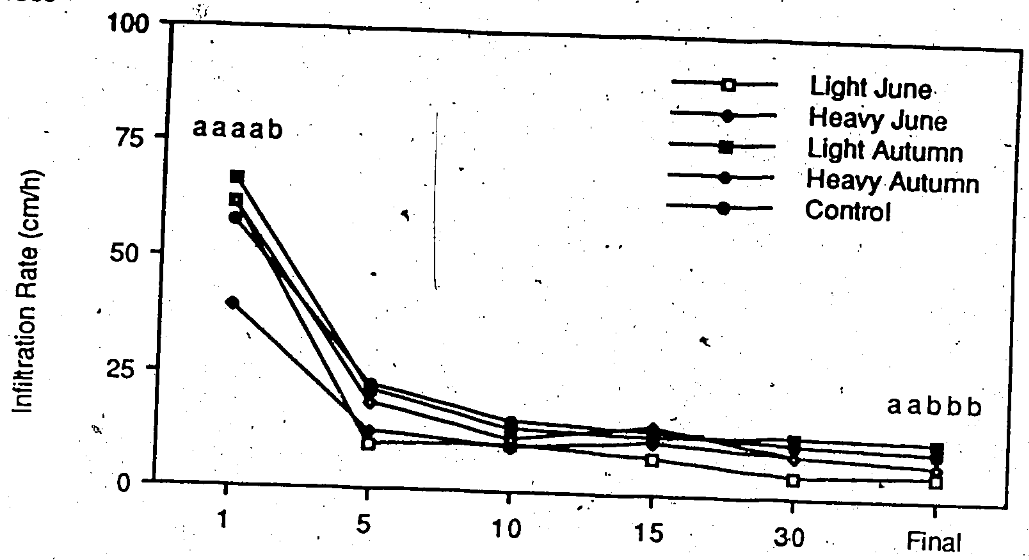


Figure 5.1. Infiltration rate at Brooks in (a) 1985 and (b) 1986. Within year, at a given time, means with the same letters are not significantly different ($P<0.05$).

(a) 1985



(b) 1986

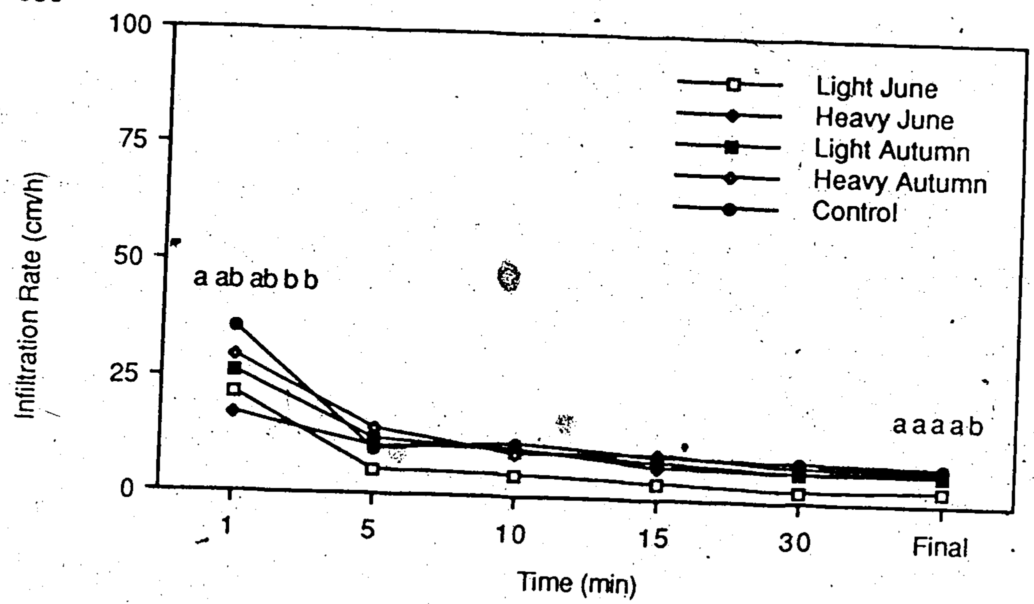
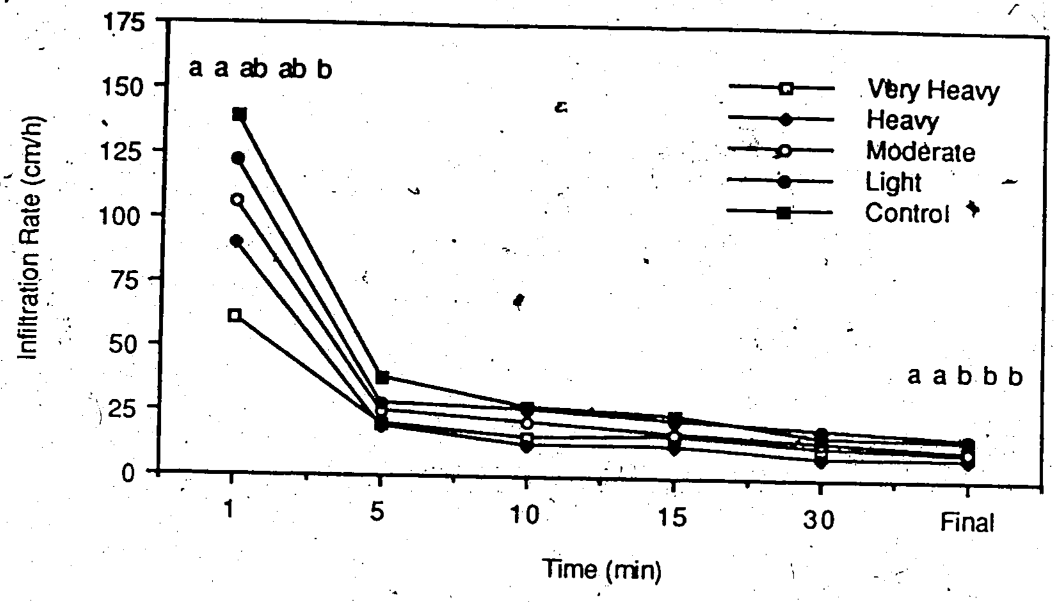


Figure 5.2. Infiltration rate at Kinsella in (a) 1985 and (b) 1986. Within year, at a given time, means with the same letters are not significantly different ($P<0.05$).

(a) 1985



(b) 1986

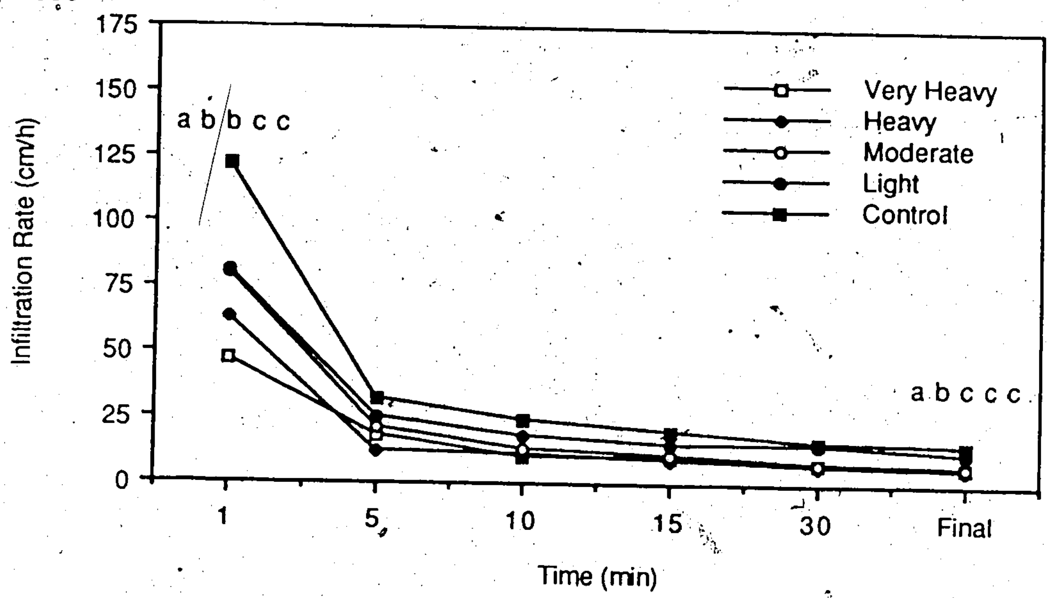


Figure 5.3. Infiltration rate at Stavely in (a) 1985 and (b) 1986. Within year, at a given time, means with the same letters are not significantly different (P<0.05).

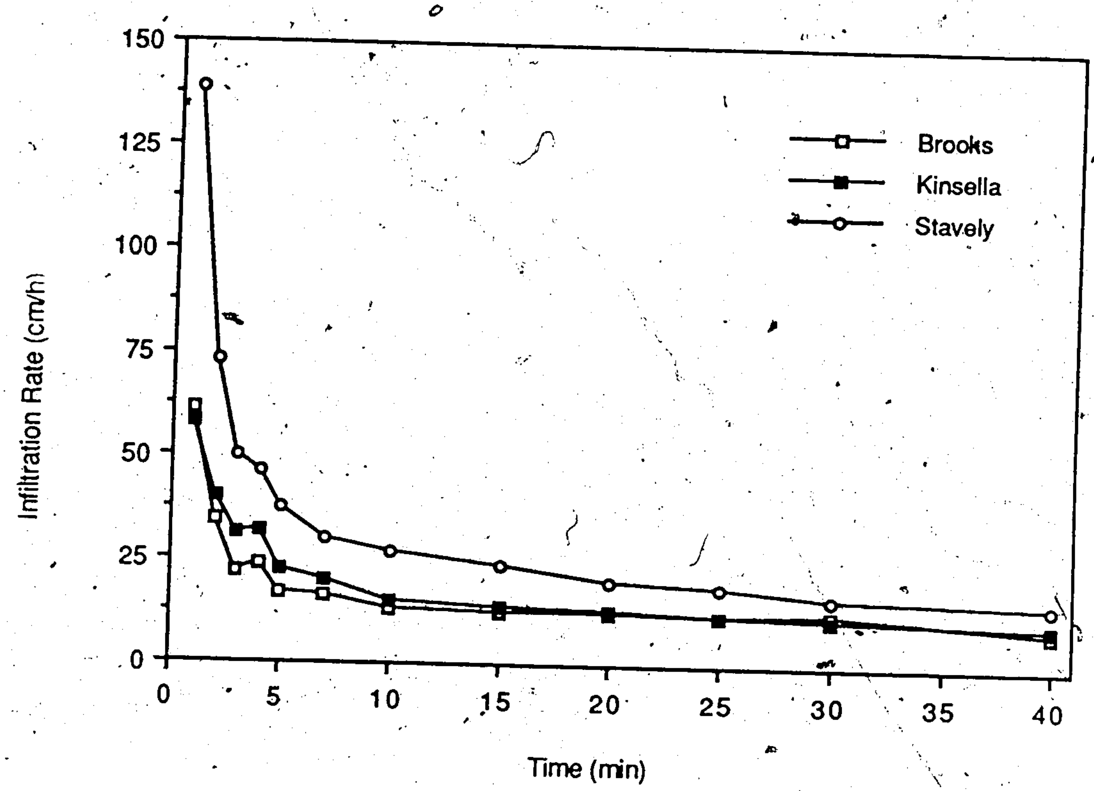


Figure 5.4. Infiltration rate in the control treatments at Brooks, Kinsella, and Stavely in 1985.

BIBLIOGRAPHY

Atmospheric Environment Services. 1987. Monthly record: meteorological observations in western Canada. Vol. 72. Environment Canada.

Bailey, A.W., Willoughby, M.G., and Irving, B.D. 1987. Effect of grazing on forage and beef production from rough fescue rangeland in central Alberta. Farming for the Future Final Report. Project No. 84-0335. 41 pp.

Beke, G.J. 1969. Soils of 3 experimental watersheds in Alberta and their hydrologic significance. Unpubl. Ph.D. Thesis, Dept. Soil Sci., Univ. of Alberta. Edmonton, Alta. 456 pp.

Blackburn, W.H. 1984. Impacts of grazing intensity and specialized grazing systems on watershed characteristics and responses. In: Developing strategies for rangeland management. NRC/NAS. Westview Press/Boulder and London. Pp. 927-983.

Bowser, W.E. 1967. Agroclimatic areas of Alberta. Institute of Pedology, Univ. of Alberta. Edmonton, Alta.

Branson, F.A., Miller, H.F., and McQueen, I.S. 1962. Effects of contour furrowing, grazing intensities and soil on infiltration rates, soil moisture and vegetation near Fort Peck, Montana. J. Range Manage. 15:151-158.

Chanasyk, D.S. and Naeth, M.A. 1988. Measurement of near-surface soil moisture with a hydrogenously shielded neutron probe. Can. J. Soil Sci. 68:171-176.

Coupland, R.T. 1961. A reconsideration of grassland classification in the Northern Great Plains of North America. J. Ecol. 49:136-167.

Dee, R.F., Box, T.W., and Robertson, E. Jr. 1966. Influence of grass vegetation on water intake of Pullman silty clay loam. J. Range Manage. 19:77-79.

Duley, F.L. and Domingo, C.E. 1949. Effect of grass on intake of water. Univ. Nebraska Agr. Exp. Sta. Res. Bull. 159 pp.

Gifford, G.F. and Hawkins, R.H. 1978. Hydrologic impact of grazing on infiltration: a critical review. Water Resour. Res. 14:305-313.

Hopkins, H. 1954. Effects of mulch upon certain factors of the grassland environment. J. Range Manage. 7:255-258.

Howitt, R.W. 1988. Soil survey of the county of Beaver. Alberta Soil Survey Report No. 47. Alberta Research Council Open File No. 1987-4. (In press).

Johnston, A. 1961. Comparison of a lightly grazed and ungrazed range in fescue grassland of southwestern Alberta. Can. J. Plant Sci. 41:615-622.

Johnston, A. 1962. Effects of grazing intensity and cover on the water-intake rate of fescue grassland. J. Range Manage. 15:79-82.

Johnston, A, Dormaar, J.F., and Smoliak, S. 1971. Long-term grazing effects on fescue grassland soils. J. Range Manage. 24:185-188.

Kjearsgaard, A.A., Peters, T.W., and Pettapiece, W.W. 1982. Soil Survey of the County of Newell No. 4, Alberta. Alberta Institute of Pedology Report S-82-41. 197 pp.

Knoll, G. and Hopkins, H.H. 1959. The effects of grazing and trampling upon certain soil properties. Trans. Kansas Acad. Sci. 62:221-231.

Looman, J. 1969. The fescue grasslands of Western Canada. Vegetatio Acta Geobotanica 19:127-145.

Meeuwig, R.O. 1970. Infiltration and soil erosion as influenced by vegetation and soil in northern Utah. J. Range Manage. 23:183-188.

Moss, E.H. 1955. The vegetation of Alberta. Bot. Rev. 21:493-567.

Moss, E.H. 1983. Flora of Alberta. 2nd ed. Revised by J.G. Packer. Univ. of Toronto Press. Toronto, Ont. 687 pp.

Naeth, M.A. 1985. Ecosystem reconstruction and stabilization following pipeline construction through solonetzic native rangeland in southern Alberta. Unpubl. M.Sc. Thesis. Depts. Soil Sci. and Plant Sci., Univ. of Alberta. Edmonton, Alta. 213 pp.

Pavlick, L.E. and Looman, J. 1984. Taxonomy and nomenclature of rough fescues, *Festuca altaica, Festuca campestris* (*F. scabrella* var. major), and *Festuca hallii*, in Canada and the adjacent part of the United States. Can. J. Bot. 62:1739-1749.

Pluhar, J.J., Knight, R.W., and Heitschmidt, R.K. 1987. Infiltration rates and sediment production as influenced by grazing systems in the Texas Rolling Plains. J. Range Manage. 40:240-243.

Rauzi, F. 1963. Water intake and plant composition as affected by differential grazing on rangeland. J. Soil Water Conserv. 18:114-116.

Rauzi, F. and Smika, D.E. 1963. Water intake on rangeland as affected by simulated grazing and fertilization. J. Range Manage. 16:125-128.

Rauzi, F. and Smith, F.M. 1973. Infiltration rates: three soils with three grazing levels in northeastern Colorado. J. Range Manage. 26:126-129.

Rauzi, F., Fly, C.L., and Dyksterhuis, E.J. 1968. Water intake on mid-continental rangelands as influenced by soil and plant cover. USDA Tech. Bull. 1390. 58 pp.

Reed, M.J. and Peterson, R.A. 1961. Vegetation, soil and cattle responses to grazing on Northern Great Plains range. USDA Tech. Bull. 1252. 79 pp.

Shapiro, S.S. and Wilk, M.B. 1965. An analysis of variance test for normality (complete samples). Biometrika 52:591-611.

Steel, R.G.D. and Torrie, J.H. 1980. Principles and procedures of statistics: a biometrical approach. 2nd ed. McGraw-Hill, New York. 633 pp.

Tomanek, G.W. 1969. Dynamics of mulch layer in grassland ecosystems. In: The grassland ecosystem. R.L. Dix and R.G. Beidleman (eds.). Range Sci. Dept. Sci. Series No. 2. Colo. State Univ., Fort Collins, Colo. Pp. 225-240.

Wheeler, G.W. 1976. Some grassland and shrubland communities in parklands of central Alberta. Unpubl. M.Sc. Thesis. Dept. Plant Science. Univ. of Alberta. Edmonton, Alta. 95 pp.

Whitman, W.C., Zeller, D., and Bjugstad, A.J. 1964. Influence of grazing on factors affecting water intake rates of range soils. Proc. N. Dakota Acad. Sci. 18:71.

Wonders, W.C. 1969. Atlas of Alberta. Univ. of Alberta Press in association with Univ. of Toronto Press. Edmonton, Alta. 158 pp.

VI. THE IMPACT OF GRAZING REGIME ON SOIL WATER IN MIXED PRAIRIE AND FESCUE GRASSLAND ECOSYSTEMS OF ALBERTA

INTRODUCTION

Soil water may be lost through transpiration, through evaporation from the soil surface, or to groundwater through deep percolation. Evapotranspiration varies with plant species and grassland ecosystem (Brown and Thompson 1965; Conard and Youngman 1965; Branson et al. 1970). However, Doss et al. (1962) and Bennett et al. (1964), studying annual and perennial forage species, found water use depended more on soil water available than on plant species.

Through removal of herbage, grazing may result in less soil water extraction and reduced evapotranspiration, creating a potential for increased soil water (Baker and Hunt 1961; Van Riper and Owen 1964; Buckhouse and Coltharp 1976). Reduced soil water under grazing is attributed to altered infiltration rates as livestock trampling compacts and seals the soil surface and reduces root channels through the soil (Hagan and Peterson 1953; Llacos 1962). Grazing can reduce litter which also affects soil water through increased evaporation and reduced infiltration (Stephenson and Schuster 1945; Barkley et al. 1965; Tomanek 1969). In Alberta, with increased grazing pressure, soil water to 10 cm depths can decrease in mixed prairie (Smoliak et al. 1972) and to 30 cm in foothills rough fescue (Johnston 1961; Johnston et al. 1971) but there is no reported effect of grazing in Saskatchewan mixed prairie (Lodge 1954).

Soil water is affected by season, being lower in grazed than ungrazed prairie from the beginning of the growing season to the end of summer, after which it is higher in grazed prairie (Kucera 1958). Season of active growth and water use by warm season grasses is May to September and for cool season grasses is April to November (Conard and Youngman 1965). In Saskatchewan mixed prairie with both warm and cool season grasses, soil water extraction begins in mid-April and continues to mid-September or later (de Jong and MacDonald 1975). Most rapid water use is from May to July with soil water often limiting plant growth by August.

It was hypothesized that soil water would decrease under grazing during the early part of the growing season due to reductions in infiltration capacity, but would increase later in the growing season due to reduced vegetation mass and subsequent reduced evapotranspiration. Effects would be most pronounced in treatments with the most changed vegetative cover. The objective of this study was to determine the effects of season and intensity of grazing on soil water at different depths and at different times of the year in mixed prairie and fescue grassland ecosystems of southern and central Alberta.

MATERIALS AND METHODS

Study Sites

Three study sites representing major grassland ecosystems of southern and central Alberta rangeland were selected. Each study site had long-term grazing treatments, ungrazed controls, grass dominated vegetation that had never been cultivated, and slopes of less than 2%. (See Appendix I for detailed descriptions). Moss (1983) was used as the botanical authority.

Brooks

The Brooks site was located in mixed prairie approximately 225 km east of Calgary (51 ^{o}N latitude and 112 ^{o}W longitude). The area has a continental prairie climate and a semiarid moisture regime (Bowser 1967). Mean annual precipitation is 355 mm with an average annual moisture deficit of 227 mm. Mean annual temperature is 4 ^{o}C, with a July mean of 19 ^{o}C and a January mean of -14 ^{o}C. Elevation averages 745 m above sea level with slopes of less than 2%. Soils are Brown Solodized Solonetz and Brown Solod developed on till (Kjearsgaard et al. 1982). Vegetation is of the *Bouteloua-Stipa-Agropyron* (blue grama-spear grass-wheatgrass) faciation dominated by *Bouteloua gracilis*, *Stipa comata*, *Agropyron smithii*, and *A. dasystachyum* (Coupland 1961). *Artemisia frigida* and *Selaginella densa* are common forbs. A short grass disclimax dominated by *Bouteloua gracilis* is common as a result of heavy long-term grazing.

Kinsella

The Kinsella site was located in aspen parkland approximately 150 km southeast of Edmonton (53 °N latitude and 111 °W longitude). The climate is dry subhumid (Wonders 1969). Mean annual precipitation is 380 mm; mean annual evapotranspiration is 381 mm. Mean annual temperature is 2 °C, with a July mean of 17 °C and a January mean of -17 °C. Elevation averages 685 m above sea level with gently rolling to hilly topography (Howitt 1988). Grassland soils are dominated by Orthic Black Chernozems developed on till. Vegetation consists of grass and shrub communities with aspen groves occurring at irregular intervals (Moss 1955). *Festuca hallii* (Vasey) Piper (Pavlick and Looman 1984) dominates open undisturbed grasslands and *Stipa curtiseta* co-dominates on grazed areas (Wheeler 1976). Various forbs are a common component of the vegetation.

Stavely

The Stavely site was located in foothills fescue grassland approximately 100 km south-southwest of Calgary (50 °N latitude and 114 °W longitude). The climate is subhumid without marked deficiency of precipitation. Mean annual precipitation is 550 mm. Mean annual temperature is 5 °C, with a July mean of 18 °C and a January mean of -10 °C. Elevation averages 1350 m above sea level and topography is gently rolling to hilly. Soils are Orthic Black Chernozems developed on till (Johnston et al. 1971). Vegetation is of the fescue grassland association (Looman 1969) with *Festuca campestris* Rydb. dominating in undisturbed and lightly grazed areas. *Danthonia parryi* and *Festuca idahoensis* are codominants in the grazed areas. With heavy grazing intensities, *Festuca campestris* is replaced by annual invaders and Poa species.

Grazing Treatments

At Brooks, three grazing treatments were studied within a community pasture that was established in 1964 (B. Shanks, personal communication, September 1981). The treatments included: (1) early season grazing from May 1 through July; (2) late season grazing from August through October; and (3) a control on an adjacent highway right-of-way that had not been grazed for 25 years. The 0.9 AUM ha^{-1} stocking rate of the grazed treatments was considered heavy for the area.

At Kinsella, five grazing treatments established in 1973 on the University of Alberta ranch were studied (Bailey et al. 1987). The treatments included: (1) light June grazing from June 1 to 30 at 1.5 AUM ha^{-1} with approximately 35% herbage utilized; (2) heavy June grazing from June 1 to 30 at 4.4 AUM ha^{-1} with approximately 75% herbage utilized; (3) heavy autumn grazing from September 15 to October 15 at 4.4 AUM ha^{-1} with approximately 75% herbage utilized; (4) light autumn grazing from September 15 to October 15 at 1.5 AUM ha^{-1} with approximately 35% herbage utilized; and (5) a control that had not been grazed since 1942. Each grazing treatment included 5.5 ha of grassland and a variable area of shrub and forest. Two 10 by 20 m permanent exclosures, randomly located in each treatment, were also studied.

At Stavely, five grazing treatments established in 1949 on an Agriculture Canada Range Research Substation were studied (Johnston 1961). Treatments were grazed from May to October and included: (1) very heavy grazing with 16.2 ha stocked at 4.8 AUM ha^{-1}; (2) heavy grazing with 32.4 ha stocked at 2.4 AUM ha^{-1}; (3) moderate grazing with 48.6 ha stocked at 1.6 AUM ha^{-1}; (4) light grazing with 64.8 ha stocked at 1.2 AUM ha^{-1}; and (5) a control comprised of permanent exclosures of 0.66, 0.41, 0.76, and 0.23 ha in the light, moderate, heavy, and very heavy treatments, respectively.

Experimental Design

The experimental design within each site was a hierarchical (subsampling) arrangement. Within each treatment, three 0.1 ha areas were randomly established. Within each of these 0.1 ha areas, points were randomly selected from which samples were collected or measurements were made.

Precipitation And Soil Water Measurements

Precipitation data were obtained from Atmospheric Environment Services (1985-1987) for the closest data collection centre to each of the study sites. Long-term data were also obtained.

In each treatment, in each 0.1 ha area, three neutron probe access tubes were installed to a depth of 1.0 m (9 tubes per treatment). Two 15 sec soil water readings were taken at each depth in these tubes with a Campbell Pacific Nuclear 503 Hydroprobe, starting at 15 cm and proceeding in 10 cm depth increments. Two surface (0-10 cm) water measurements were taken adjacent to each access tube with a hydrogenously shielded neutron probe (Chanasyk and Naeth 1988) and a Campbell Pacific Nuclear MC1-12 surface moisture/density gauge. Soil water measurements were made approximately every month from April through October, 1985-1987.

Soil And Vegetation Analyses

Particle size distribution was determined by the hydrometer method and water retention at -33 and -1500 kPa by the pressure plate extraction method (Appendix II). Litter depth and height were measured and ground cover was determined with a point frame for percent bare ground, live vegetation, and litter. Litter and soil organic matter masses were measured from determinations of total carbon by dry oxidation (Chapter II) and water holding capacity of the litter was determined (Chapter III). Soil bulk density and resistance to penetration were measured each year of the study (Chapter IV) and infiltration tests were conducted in 1985 and 1986 (Chapter V).

Water Budget Calculations

An estimate of evapotranspiration was calculated using a simple hydrologic model. Since slopes at the study sites were less than 2%, it was assumed that runoff would be negligible. Although deep percolation likely occurred at each of the sites it is not quantified and was also assumed to be negligible to simplify the above calculations. The model was evapotranspiration equals precipitation minus change in soil water storage (ET = P - SW). The 0-80 cm depth increment was used for calculating soil water storage.

Statistical Analyses

Statistical analyses were conducted using variation among the 0.1 ha areas as an appropriate measure of error variation for testing the significance of treatments. Data were tested for homogeneity of variance using Cochran and Bartlett-Box tests. The W test was used to test data for normality of distribution (Shapiro and Wilk 1965). An SPSSx analysis of variance program was used to test for treatment effects. Data with significant F values were further analyzed to separate the means using the Student-Newman-Keul (SNK) test at the 5% level of significance (Steel and Torrie 1980).

Preliminary statistical analyses within each year by treatment combination indicated that variation among the 0.1 ha areas was not significantly different from sampling point variation and therefore in all future analyses, area and sampling point variation were pooled. Additional preliminary statistical analyses within each treatment using the pooled error term indicated significant differences between study years, therefore data were analyzed on a within year basis. Sources of variation in the final statistical analysis were treatments and error within treatments.

RESULTS

Brooks

Total precipitation in 1985, 1986, and 1987 was 407, 388, and 278 mm, respectively (Appendix III). The long-term 1951-1980 average was 335 mm.

In the surface 0-10 cm, soil water fluctuated widely with year and season (Table 6.1). Values were generally higher in the control than in the grazed treatments from April through July, with July 1986 and April and May 1987 being the exceptions. Significant treatment differences often did not occur in August, September, and October, although there was a trend towards higher values in the early season treatment by October.

Soil water for 0-30 cm was generally higher in the control than under early season grazing (Figure 6.1). Water content for the grazed treatments was similar but higher in the late season treatment from September to October 1985 and from May to June 1987. Soil water for 30-50 cm remained relatively constant for all treatments from July 1985 to August 10 1986, then rose dramatically, peaked April 14, 1987, and declined thereafter. Soil water in the control was highest and generally different from that in the early season treatment. For 50-80 cm, soil water status was similar for all treatments until August 10, 1986, after which the control had higher values than the grazed treatments. The 159 mm of precipitation between August 10 and October 18, 1986 recharged the control to 80 cm more effectively than it did the grazed treatments. At 0-30 cm, recharge was equal across treatments and at 30-50 cm, recharge was least effective in the early season treatment.

Water for 0-30 cm was near wilting point most of the year except October 1986 and April 1987 when it was near field capacity (Appendix III). For 30-50 and 50-80 cm, water was below wilting point except in autumn 1986 and spring 1987.

Kinsella

Total precipitation in 1985, 1986, and 1987 was 376, 395, and 344 mm, respectively (Appendix III). The long-term average was 422 mm.

In the surface 0-10 cm, soil water was generally lowest in the control (Table 6.2). The heavy treatments were similar to each other 75% of the time; the light treatments were similar 50% of the time. The autumn treatments were similar 33% of the time; the June treatments 60% of the time.

Soil water in the uppermost 30 cm was similar for all treatments, generally being within 15-20 mm of each other (Figure 6.2). For depth increments of 30-50 and 50-80 cm, soil water was relatively constant being highest in the control and lowest in the light autumn treatment. There was little variation between the two heavy treatments, whereas in the light treatments there was a 20-30 mm difference. Major recharge occurred twice in 1987, although the effect of precipitation was only slightly evidenced in the 30-50 and 50-80 cm zones.

Soil water for 0-30 cm was near field capacity in September and October 1985, April and May 1986, and April and August 1987 (Appendix III). Values were below wilting point in July 1985, August 1986, and June and October 1987. At 30-50 and 50-80 cm, soil water was near wilting point on all dates monitored.

Stavely

Total precipitation in 1985, 1986, and 1987 was 365, 435, and 337 mm, respectively (Appendix III). The long-term average was 476 mm.

In the surface 0-10 cm, soil water fluctuated in all three years (Table 6.3). Lowest surface water was most often in the control which was more similar to heavy and very heavy treatments than to light and moderate treatments. The moderate treatment was intermediate between the heavy and light treatments.

Soil water for 0-30 cm was similar for all treatments, with autumn 1985 and 1986 and spring 1987 being times of significant recharge (Figure 6.3). Trends for 30-50 and 50-80 cm were subdued versions of those for 0-30 cm with highest soil water generally in the control and light treatments and lowest values in the very heavy treatment.

Soil water for 0-30 cm was at or above field capacity in September and October 1985, April, May, and October 1986, and April 1987 (Appendix III). At this depth, soil water was below wilting point in August 1985, July and August 1986, and most of 1987. This trend was similar for soil water at 30-50 and 50-80 cm.

Profile Water

Profile soil water was plotted at the time of lowest and highest soil water in 1987 (Figures 6.4 and 6.5, respectively). At Brooks, highest water content at and below 25 cm was in the control and the lowest was in the early season treatment. Treatment responses were similar during dry and wet periods. At Kinsella, during a dry period, highest soil water at and below 15 cm was in the light June treatment and lowest values were in the light autumn treatment. Water profiles in the heavy treatments were similar. During a wet period, highest soil water was in the control and all grazed treatments were similar between 15 and 65 cm. At Stavely, during a dry period, highest soil water at and below 15 cm was in the control, lowest values were in the very heavy treatment. Water in the moderate and heavy treatments was similar to 55 cm. In a wet period, highest soil water was in light and moderate treatments and lowest in very heavy and heavy treatments.

Brooks was the driest site in the uppermost 25 cm. Kinsella had the greatest treatment separation in water content at depth. Among treatment differences in water content at 75 cm ranged from 8% at Brooks to 12% at Kinsella (absolute).

Water Budget

At Brooks, changes in soil water for 0-80 cm in the control were 12 to 62 mm lower than in grazed treatments (Table 6.4). Average evapotranspiration rates for all treatments were 1.9, 1.4, and 2.1 mm per day for 1985, 1986, and 1987, respectively. At Kinsella, there were no distinct treatment trends (Table 6.5). Average evapotranspiration rates for all treatments were 1.0, 1.9, and 2.3 mm per day for 1985, 1986, and 1987, respectively. At Stavely, soil water changes in the control and light treatments were lowest (Table 6.6). Average evapotranspiration rates for all treatments were 1.1, 1.4, and 2.0 mm per day for 1985, 1986, and 1987, respectively. Treatment-averaged, complete season (April to October 1986) evapotranspiration was 350 mm for Kinsella, 237 mm for Brooks (during a wet year), and 364 mm for Stavely. ET values are sometimes twice as high as precipitation for the time period, however if values were calculated for long periods soil water storage wouldbe near zero and ET values would be lower. Parton et al. (1981) found water loss was generally equal to water input for a *Bouteloua gracilis* grassland in Colorado. The above calculated values are in agreement with the 3 mm per day consumptive use of water by grasses in the Stavely region reported by Singh (as cited by Johnston et al. 1971).

DISCUSSION

Grazing Effects

Grazing affected soil water as evidenced by higher soil water in controls compared to grazed treatments at all three sites. Heavy intensity grazing affected soil water more than light intensity grazing as exemplified at Stavely where soil water was highest in the control and lowest in the very heavy treatment. The intermediate nature of the moderate treatment at Stavely indicates that grazing of any intensity greater than light decreased soil water but the decrease was generally proportional to grazing intensity.

Higher infiltration capacities of the controls and light intensity/late season treatments could account for higher soil water, especially at the beginning of the growing season (Chapter V). During the growing season, more vegetation in the controls (Chapter II) extracted more soil water. Deeper rooted species in controls at Brooks (Naeth 1985), Kinsella (Bailey et al. 1987), and Stavely (Johnston et al. 1971) and in the light autumn treatment at Kinsella could have increased water use. However, more water was added by increased infiltration than was utilized by increased vegetation. By the end of the growing season, shallower rooted species in heavy intensity/early season grazed treatments would not have used as much soil water and/or summer and autumn rains would not have infiltrated as rapidly due to lower infiltration capacity (Chapter V).

Similar soil water at all depths in the heavy treatments at Kinsella is evidence that season of grazing had less of an effect on soil water than did intensity of grazing. Although infiltration was often higher in the heavy autumn treatment than in the heavy June treatment at Kinsella (Chapter V), increased biomass in the heavy autumn treatment (Chapter II) could account for higher water use; the two factors would account for lack of treatment differences. Litter accumulation was similar in heavy treatments, but live vegetation and infiltration capacity were higher in the heavy autumn treatment than in the heavy June treatment. Increased vegetation in the heavy autumn treatment could have led to increased water extraction and subsequent similarities in soil water.

Results from this study for the mixed prairie were similar to those of Kucera (1958) and Smoliak et al. (1972) who worked in Alberta mixed prairie, but contradicted those of Lodge (1954) who found no difference in soil water with grazing in Saskatchewan. Hanson and Lewis (1978) found autumn soil water on South Dakota mixed prairie was inversely proportional to range condition due to changes in vegetation with grazing. Results to 30 cm at Stavely are similar to those of Johnston (1961), however, below this depth he found no effect of grazing. Contrary to results from this study Johnston et al. (1971) found soil water decreased under grazing to a depth of 10-15 cm. However, Johnston did not examine seasonal differences or utilize long-term data.

High surface soil water may be due to the protective effect of high litter mass which reduced evaporation. Low surface water may reflect more water extraction at shallower depths by shallower rooted species. The greater similarity between heavy treatments than between light treatments at Kinsella may reflect litter and evaporation interactions since the light autumn treatment had more litter than the light June treatment, but litter accumulation under the heavy treatments was similar (Chapter II). The frequently low surface soil water in the controls at Stavely and Kinsella is difficult to explain. It was expected that higher litter would reduce evaporation and increase soil water at the surface. However, increased rooting depth could increase percolation of infiltrated surface water. In the control there is not a consistently good litter-soil interface due to bulky untrampled litter, increasing potential evaporation of water held in litter. A technicality of surface water measurement may also be a factor: good ground-probe contact in the control was difficult to achieve due to the large litter mass. This may have caused low surface water readings in the control. The sometimes lower soil water at the surface of the heavy treatment is likely a function of water extraction by very shallow rooted species, lower litter mass, and higher evaporation potential. Storage opportunity is reduced due to reduced water extraction by the lower vegetation mass. The litter in the very heavy treatment has a lower water holding capacity (Chapter III) than the other treatments which could account for more water entering the soil surface from short duration precipitation events as opposed to being held in the litter layer and subsequently evaporated.

Although it was expected June treatments would have an increased number of shallow rooted species compared to autumn treatments, it was not reflected in similarities of soil water at 30-50 cm depths to which these species root (Coupland and Johnson 1965). The similarity of soil water at 50-80 cm between the autumn treatments reflects the increase in more deeply rooted species in both these treatments. The similarity in soil water between light autumn and control treatments at 0-30 cm would likely indicate the dominant influence of litter on infiltration and evaporation retardation, since litter masses were higher in these two treatments. These two treatments also had similar evapotranspiration rates for 1985 and 1986. The lower soil water in the light autumn treatment even during times of recharge may reflect the high infiltration rate and therefore the lower soil water must relate to plant use. The light autumn treatment should have the most vigorous growing plants since it is least affected by grazing.

Soil Water Recharge

Higher soil water at the study sites in April, September, and/or October indicate times of soil water recharge. This supports de Jong and MacDonald (1975) who documented some recharge occurs between September and January, but the time of maximum recharge is late March and early April. Approximately 67% of annual precipitation occurs from April through September, with maximum precipitation occurring in June (Atmospheric Environment Services 1987) coinciding with the time of most rapid water extraction by grassland plants (de Jong and MacDonald 1975). Most grass species, especially at Kinsella and Stavely, are cool season grasses, which use early spring and autumn soil water more rapidly (Conard and Youngman 1965). Reserves would not accumulate unless precipitation was above normal.

Snow could be important in soil water recharge at spring melt especially at Kinsella and Stavely where snow accounts for 27 and 40% of the annual precipitation, respectively. This is evidenced by large increases in soil water at Brooks and Kinsella in April 1987 and at Stavely in April 1986 and 1987. However, heavy rainfall also effectively recharged soil water at Brooks in July 1986, Kinsella in May 1986 and July 1987, and Stavely in September 1985. Greater litter mass and height of standing litter in the less intensively grazed treatments would be most effective for snow trapping.

Permanent Wilting Point

Soil water in this study was often at or below theoretical wilting point. The significance of this is questionable as wilting point is species dependent. Many grassland species have higher wilting points than agronomic species and would thus survive in arid grassland ecosystems (Sosebee

1977). During a typical drying cycle in arid grasslands, soil water potential can decrease from 0 to -6500 kPa by the end of the drying cycle. Wilting point of several common range grasses ranges from -800 to -3860 kPa. Llacos (1962) also reported that soil water potential was often below wilting point at all depths monitored.

CONCLUSIONS

Grazing affected soil water with heavy intensity/early season treatments having more impact than light intensity/late season treatments. Season of grazing was more important under light grazing intensities than under heavy grazing intensities. Under grazing intensities heavier than moderate, soil water for 0-80 cm was reduced with reductions increasing with grazing intensity. Soil water was not lower in the controls during the latter part of the growing season due to increased plant use as hypothesized; it is assumed that the higher infiltration rates in the controls made up for the higher consumptive use. Surface soil water at Brooks and Kinsella was less affected by grazing than was soil water at depth. At Stavely the most consistent treatment effect was lower soil water in the control and very heavy treatments.

Table 6.1. Surface (0-10 cm) soil water (mm) at Brooks.

Year	Date	Treatment		
		Early	Late	Control
1985	July 23	10.4b	10.4b	14.7a
	Aug 8	0.9a	2.1a	2.0a
	Sept 22	4.4b	9.3a	9.3a
	Oct 20	13.1a	11.0b	10.2b
1986	Apr 16	5.4b	3.7b	10.1a
	May 2	3.3b	2.3b	11.1a
	May 20	13.5b	13.9b	18.5a
	July 17	9.1a	8.9a	10.7a
	Aug 10	3.8a	0.1c	2.7b
	Oct 18	19.8a	18.5a	16.1b
1987	Apr 14	24.4a	23.2a	18.9b
	May 17	3.3a	3.0a	3.1a
	June 18	4.3b	3.5b	8.0a
	July 17	11.3ab	9.3b	12.1a
	Aug 10	4.4a	3.4a	3.7a
	Oct 18	2.9a	2.0a	2.2a

Within date means with the same letters are not significantly different (P<0.05).

Table 6.2. Surface (0-10 cm) soil water (mm) at Kinsella.

Year	Date	Treatment				
		Light June	Heavy June	Heavy Autumn	Light Autumn	Control
1985	July 22	9.7a	8.9a	8.6a	5.9b	4.1c
	Aug 13	14.9b	17.2a	14.5b	14.6b	17.8a
	Sept 25	33.3a	26.5b	29.5b	34.9a	28.7b
	Oct 23	21.3b	22.6b	27.7a	21.4bc	18.4c
1986	Apr 21	27.4a	19.7b	20.6b	14.4c	14.0c
	May 6	16.2a	16.0a	14.3a	17.1a	8.4b
	May 23	34.3a	30.7b	28.5b	20.7c	23.9c
	July 22	28.6a	27.3ab	25.4ab	24.2b	13.5c
	Aug 13	11.1a	11.0a	9.7a	10.9a	6.1b
	Sept 25	21.9b	20.99a	31.0a	19.9b	20.6b
	Oct 23	17.2ab	15.2b	16.3ab	16.6ab	18.3a
1987	Apr 16	26.4bc	37.6a	28.6b	27.1bc	22.2c
	May 15	14.9a	15.4a	15.6a	11.5b	10.1b
	June 24	17.9a	18.5a	17.7a	15.3b	11.0c
	Aug 6	31.6a	32.4a	32.1a	27.2b	22.1c
	Oct 14	12.6b	12.0b	15.9a	8.9c	7.6c

Within date means with the same letters are not significantly different ($P<0.05$).

Table 6.3. Surface (0-10 cm) soil water (mm) at Stavely.

Year	Date	Treatment				
		Very Heavy	Heavy	Moderate	Light	Control
1985	July 27	11.8a	6.3b	6.6b	3.9b	6.6b
	Aug 7	6.4a	3.6b	4.2b	2.7b	6.9a
	Sept 20	25.4a	30.3a	25.8a	28.9a	26.3a
	Oct 19	27.1a	20.8b	21.1b	11.6c	10.5c
1986	Apr 16	17.3b	14.3bc	23.0a	24.3a	10.3c
	May 26	15.8a	16.2ab	18.5a	12.6b	9.4c
	July 16	4.5c	8.6ab	6.8bc	12.9a	6.0bc
	Aug 7	12.7a	8.9b	6.5b	7.3b	4.7c
	Oct 19	20.5a	14.4b	15.9b	12.9a	7.0c
1987	Apr 14	29.3b	33.6a	38.0a	37.3a	35.0a
	May 16	13.6a	13.1ab	10.0bc	10.1bc	8.7c
	June 18	15.4ab	17.8a	17.2a	17.3a	12.9b
	July 7	16.0bc	15.4bc	18.1ab	20.1a	13.5c
	Aug 3	11.6ab	12.1ab	14.5a	11.2ab	9.4b
	Oct 9	6.1c	9.9b	13.4a	12.7a	7.3c

Within date means with the same letters are not significantly different ($P<0.05$).

Table 6.4. Water budget parameters (mm) at Brooks.

Time Period	Treatment	Precipitation	Soil Water Change	Evapotranspiration
July 23 to	Early	158	+18	140
Oct 20	Late	158	+13	145
1985	Control	158	+1	157
April 16 to	Early	325	+98	227
Oct 18	Late	325	+103	222
1986	Control	325	+63	262
April 14 to	Early	125	-126	251
Aug 10	Late	125	-116	241
1987	Control	125	-138	263

Table 6.5. Water budget parameters (mm) at Kinsella.

Time Period	Treatment	Precipitation	Soil Water Change	Evapotranspiration
July 22 to Oct 23 1985	Light June	146	+40	106
	Heavy June	146	+51	95
	Heavy Autumn	146	+69	77
	Light Autumn	146	+62	84
	Control	146	+54	92
Apr 21 to Oct 23 1986	Light June	306	-40	346
	Heavy June	306	-48	354
	Heavy Autumn	306	-66	372
	Light Autumn	306	-35	341
	Control	306	-31	337
June 25 to Aug 6 1987	Light June	160	+57	103
	Heavy June	160	+85	75
	Heavy Autumn	160	+73	87
	Light Autumn	160	+58	102
	Control	160	+28	132

Table 6.6. Water budget parameters (mm) at Stavely.

Time Period	Treatment	Precipitation	Soil Water Change	Evapotranspiration
	Very Heavy	239	+154	85
July 27 to	Heavy	239	+149	90
Oct 19	Moderate	239	+166	73
1985	Light	239	+137	102
	Control	239	+126	113
	Very Heavy	227	+133	94
July 16 to	Heavy	227	+100	127
October 19	Moderate	227	+94	133
1986	Light	227	+74	153
	Control	227	+75	152
	Very Heavy	196	-168	364
Apr 14 to	Heavy	196	-170	366
Oct 9	Moderate	196	-195	391
1987	Light	196	-160	356
	Control	196	-148	344

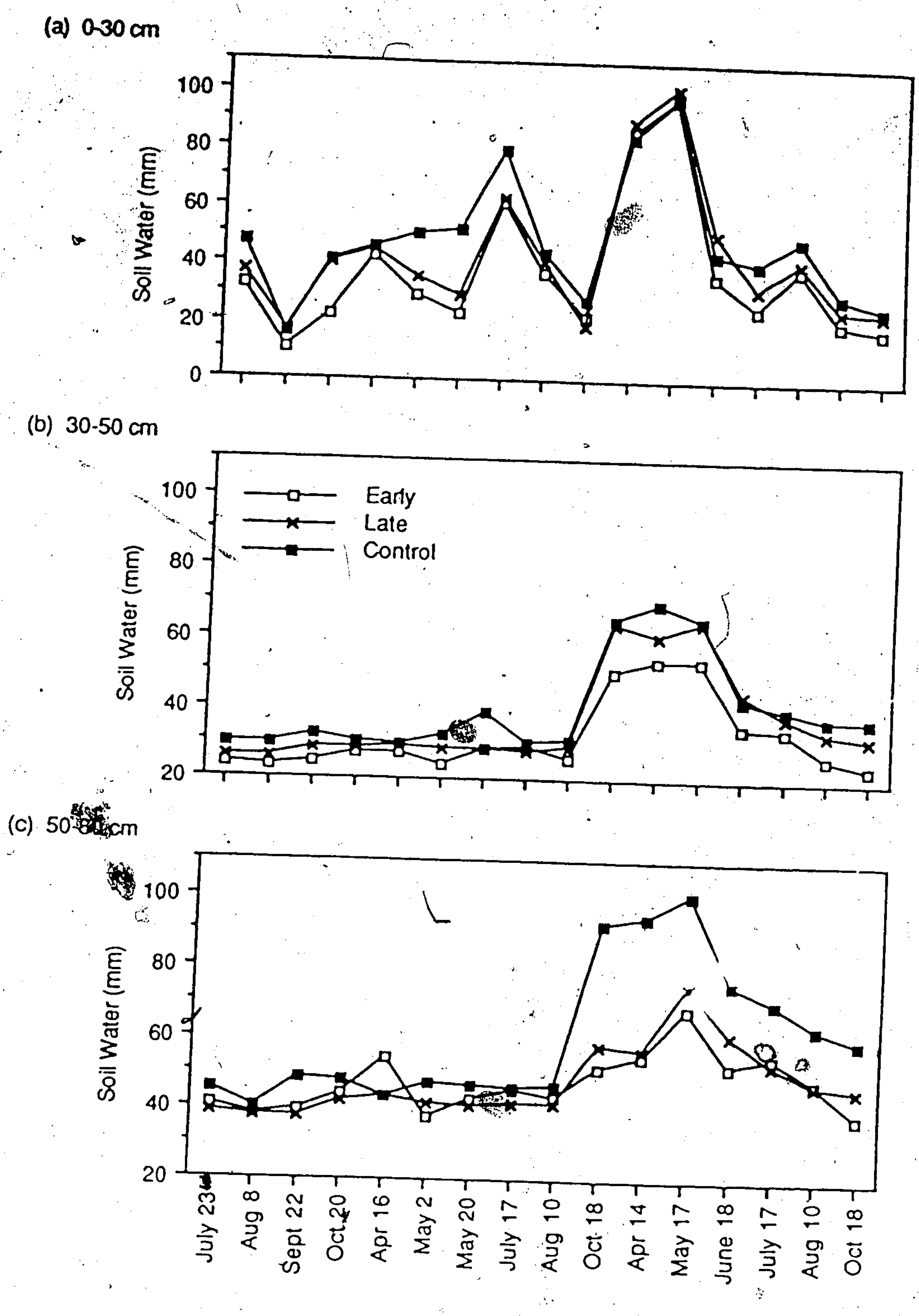


Figure 6.1. Soil water at Brooks from July 23, 1985 to October 18, 1987 for (a) 0-30, (b) 30-50, and (c) 50-80 cm.

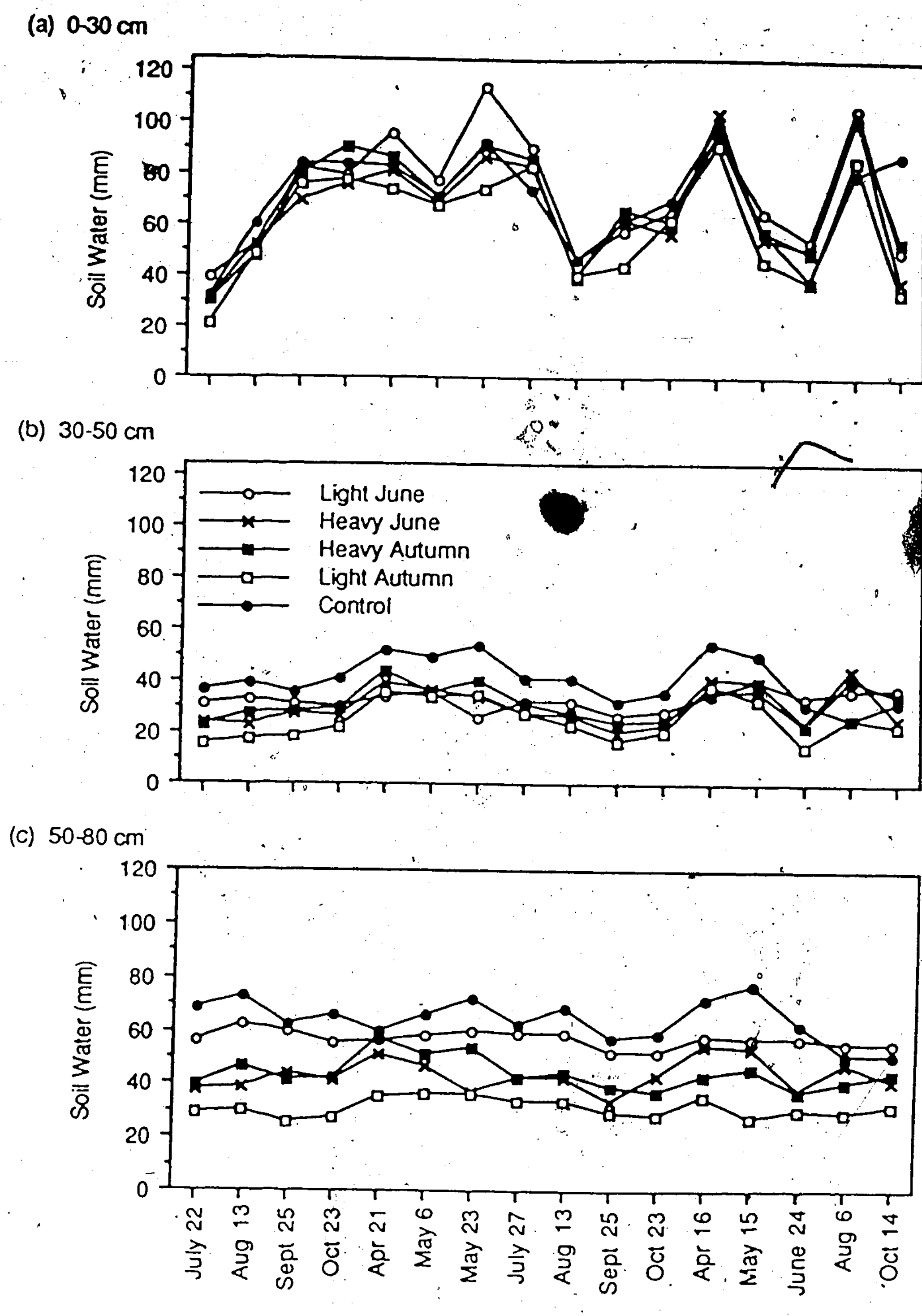


Figure 6.2. Soil water at Kinsella from July 22, 1985 to October 14, 1987 for (a) 0-30, (b) 30-50, and (c) 50-80 cm.

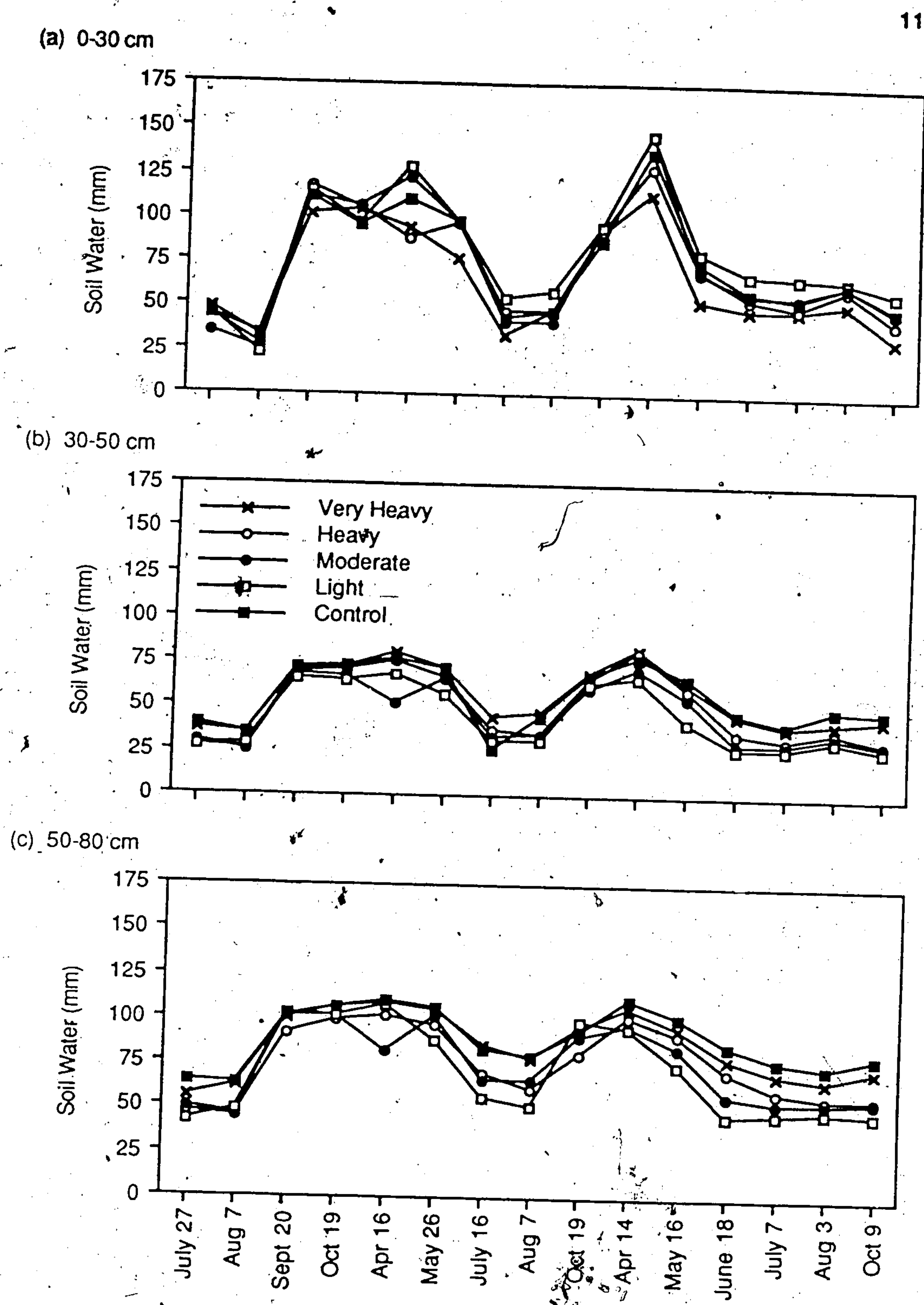


Figure 6.3. Soil water at Stavely from July 27, 1985 to October 9, 1987 for (a) 0-30, (b) 30-50, and (c) 50-80 cm.

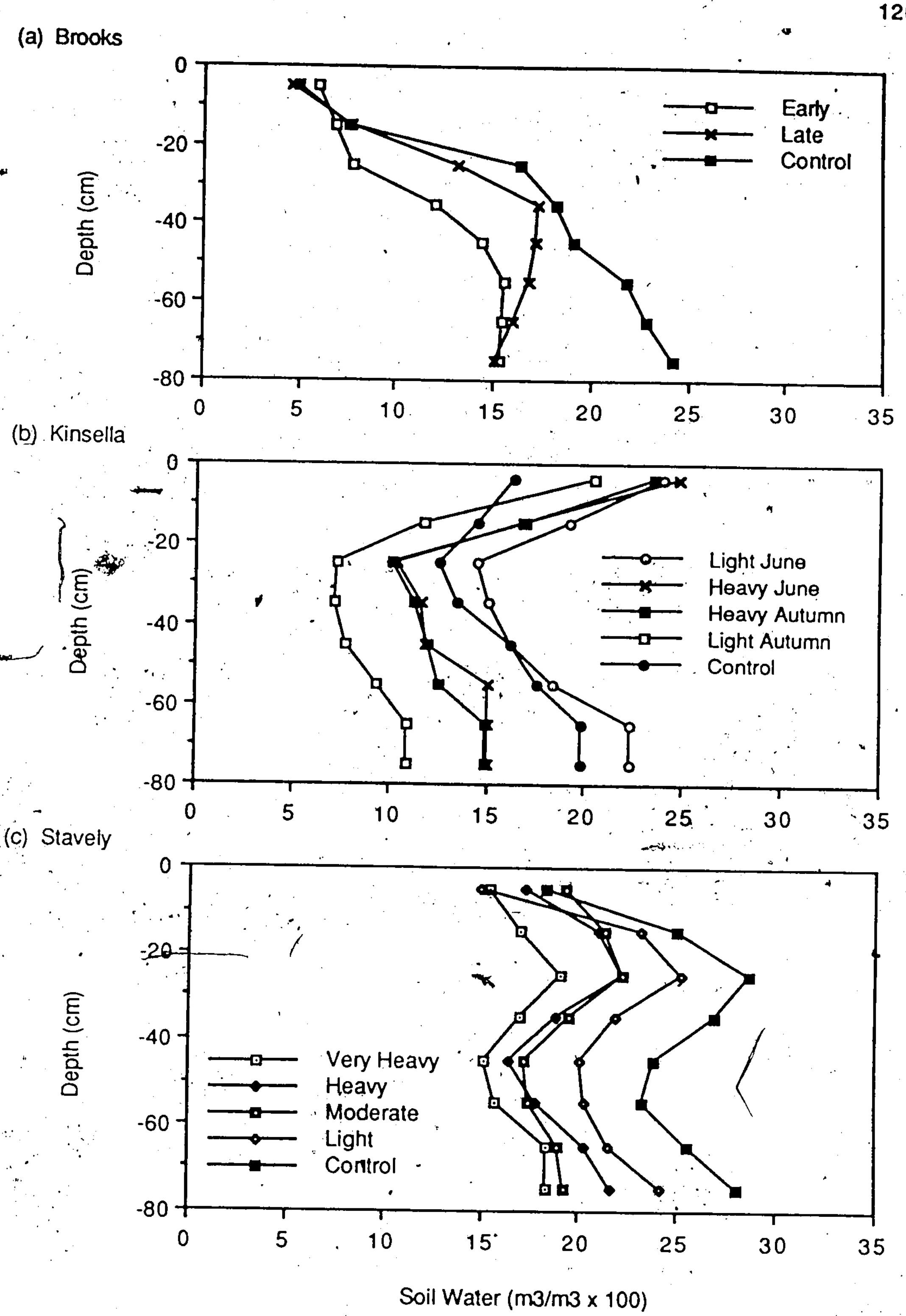


Figure 6.4. Lowest values for profile soil water at (a) Brooks on August 10, 1987, (b) Kinsella on June 24, 1987, and (c) Stavely on August 3, 1987.

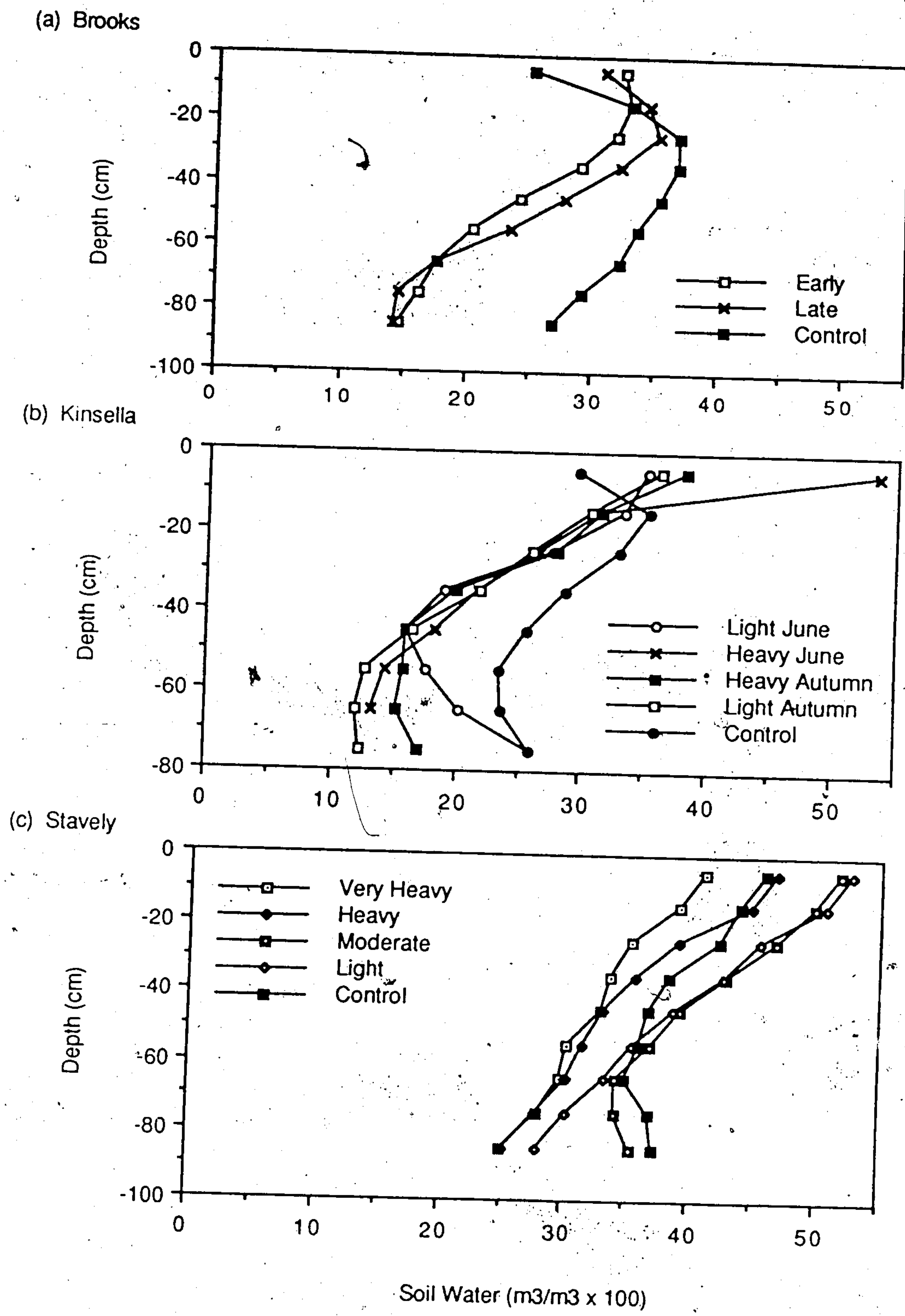


Figure 6.5. Highest values for profile soil water at (a) Brooks on April 14, 1987, (b) Kinsella on April 16, 1987, and (c) Stavely on April 14, 1987.

BIBLIOGRAPHY

Atmospheric Environment Services. 1985-1987. Monthly record: meteorological observations in western Canada. Vols. 70, 71, 72. Environment Canada.

Bailey, A.W., Willoughby, M.G., and Irving, B.D. 1987. Effect of grazing on forage and beef production from rough fescue rangeland in central Alberta. Farming for the Future Final Report. Project No. 84-0335. 41 pp.

Baker, J.N. and Hunt, O.J. 1961. Effects of clipping treatments and clonal differences on water requirements of grasses. J. Range Manage. 14:216-219.

Barkely, D.G., Blaser, R.E., and Schmidt, R.E. 1965. Effect of mulches on microclimate and turf establishment. Agron. J. 57:189-192.

Bennett, O.L., Doss, B.D., Ashley, D.A., Kilmer, V.J., and Richardson, E.C. 1964. Effects of soil moisture regime on yield, nutrient content, and evapotranspiration for three annual forage species. Agron. J. 56:195-198.

Bowser, W.E. 1967. Agroclimatic areas of Alberta. Institute of Pedology. Univ. of Alberta. Edmonton, Alta.

Branson, F.A., Miller, R.F., and McQueen, I.S. 1970. Plant communities and associated soil water factors on shale-derived soils in northeastern Montana. Ecology 51:391-407.

Brown, H.E. and Thompson, J.R. 1965. Summer water use by aspen, spruce, and grassland. J. Forest. 63:756-760.

Buckhouse, J.C. and Coltharp, G.B. 1976. Soil moisture responses to several levels of foliage removal on two Utah ranges. J. Range Manage. 29:313-315.

Chanasyk, D.S. and Naeth, M.A. 1988. Measurement of near-surface soil moisture wit' a hydrogenously shielded neutron probe. Can. J. Soil Sci. 68:171-176.

Conard, E.C. and Youngman, V.E. 1965. Soil moisture conditions under pastures of cool-season and warm-season grasses. J. Range Manage. 18:74-78.

Coupland, R.T. 1961. A reconsideration of grassland classification in the Northern Great Plains of North America. J. Ecol. 49:136-167.

Coupland, R.T. and Johnson, R.E. 1965. Rooting characteristics of native grassland species in Saskatchewan. J. Ecol. 53:475-507.

De Jong, E. and MacDonald, K.B. 1975. The soil moisture regime under native grassland. Geoderma 14:207-221.

Doss, B.D., Bennett, O.L., Ashley, D.A., and Weaver, H.A. 1962. Soil moisture regime effect on yield and evapotranspiration from warm season perennial forage species. Agron. J. 54:239-242.

Hagan, R.M. and Peterson, M.L. 1953. Soil moisture extraction by irrigated pasture mixtures as influenced by clipping frequency. Agron. J. 45:288-292.

Hanson, C.L. and Lewis, J.K. 1978. Winter runoff and soil water storage as affected by range condition. In: Proc. 1st Int. Rangeland Congr. Hyder, D.N. (ed.). Denver, Colo. Aug 14-18, 1978. Pp. 284-287.

Howitt, R.W. 1988. Soil survey of the county of Beaver. Alberta Soil Survey Report No. 47. Alberta Research Council Open File Report No 1987-4. (In press).

Johnston, A. 1961. Comparison of lightly grazed and ungrazed range in fescue grassland of southwestern Alberta. Can. J. Plant Sci. 41:615-622.

Johnston, A., Dormaar, J.F., and Smoliak, S. 1971. Long-term grazing effects on fescue grassland soils. J. Range Manage. 24:185-188.

Kjearsgaarsd, A. A., Peters, T.W., and Pettapiece, W.W. 1982. Soil Survey of the County of Newell No. 4, Alberta. Alberta Institute of Pedology Report S-82-41. 197 pp.

Kucera, C.L. 1958. Some changes in the soil environment of a grazed prairie community in central Missouri. Ecol. 39:538-540.

Llacos, L.G. 1962. Water yield as influenced by degree of grazing in the California winter grasslands. J. Range Manage. 15:34-42.

Lodge, R.W. 1954. Effects of grazing on the soils and forage of mixed prairie in southwestern Saskatchewan. J. Range Manage. 7:166-170.

Looman, J. 1969. The fescue grasslands of western Canada. Vegetatio Acta Geobotanica 19:127-145.

Moss, E.H. 1955. The vegetation of Alberta. Bot. Rev. 21:493-58

Moss, E.H. 1983. Flora of Alberta. 2nd ed. Revised by J.G. Packer. Univ. of Toronto Press. Toronto, Ont. 687 pp.

Naeth, M.A. 1985. Ecosystem reconstruction and stabilization following pipeline construction through solonetzic native rangeland in southern Alberta. Unpubl. MSc. Thesis. Depts. Soil Sci. and Plant Sci., Univ. of Alberta. Edmonton, Alta. 213 pp.

Parton, W.J., Lauenroth, W.K., and Smith, F.M. 1981. Water loss from a shortgrass steppe. Agric. Meteor. 24:97-109.

Pavlick, L.E. and Looman, J. 1984. Taxonomy and nomenclature of rough fescues, *Festuca altaica, Festuca campestris*, (*F. scabrella* var. major), and *Festuca hallii*, in Canada and the adjacent part of the United States. Can. J. Bot. 62:1739-1749.

Shapiro, S.S. and Wilk, M.B. 1965. An analysis of variance test for normality (complete samples). Biometrika 52:591-611.

Smoliak, S., Dormaar, J.F., and Johnston, A. 1972. Long-term grazing effects on *Stipa-Bouteloua* prairie soils. J. Range Manage. 25:246-250.

Sosebee, R.E. 1977. Rangeland plant physiology. Soc. Range Manage. Range Sci. Series No. 4. Denver, Colo. 290 pp.

Steel, R.G.D. and Torrie, J.H. 1980. Principles and procedures of statistics: a biometrical approach. 2nd ed. McGraw-Hill, New York. 633 pp.

Stephenson, R.E. and Schuster, C.E. 1945. Effects of mulches on soil properties. Soil Sci. 59:219-230.

Tomanek, G.W. 1969. Dynamics of mulch layer in grassland ecosystems. In: The grassland ecosystem. Dix, R.L. and Beidleman, R.G. (eds.). Range Science Dept. Sci. Series No. 2. Colo. State Univ. Fort Collins, Colo. Pp. 225-240.

Van Riper, G.E. and Owen, F.G. 1964. Effect of cutting height on alfalfa and two grasses as related to production, persistence, and available soil moisture. Agron. J. 56:291-295.

Wheeler, G.W. 1976. Some grassland and shrubland communities in the parklands of central Alberta. Unpubl. M.Sc. Thesis. Dept. Plant Science. Univ. of Alberta. Edmonton, Alta. 95 pp.

Wonders, W.C. 1969. Atlas of Alberta. Univ. of Alberta Press in association with Univ. of Toronto Press. Edmonton, Alta. 158 pp.

VII. A NOTE ON USING THE KOSTIAKOV INFILTRATION EQUATION IN MIXED PRAIRIE AND FESCUE GRASSLAND ECOSYSTEMS OF ALBERTA.

INTRODUCTION

Researchers have attempted to express results of field infiltration tests in terms of specific models or equations. The Kostiakov equation is a simple empirical model relating infiltration to time as a power function (Kostiakov 1932). Gifford (1978) found coefficients in Kostiakov's equation were related to vegetation factors more than soil factors in Utah pinyon-juniper sites. Gifford (1976) found the Kostiakov equation did not fit infiltrometer data from semi-arid rangelands in Australia or the United States; point measure variability of short-term infiltration rates was not satisfactorily accounted for. The objective of this study was to investigate the suitability of the Kostiakov equation for characterizing infiltration in Alberta mixed prairie and fescue grasslands.

MATERIALS AND METHODS

Infiltration data were collected using double ring infiltrometers at three study sites (Chapter IV). Surface (0-10 cm) water and bulk density were measured at the time of the infiltration tests.

A best fit regression line for the averaged data from each treatment was fit for log infiltration rate versus log time, up to an elapsed time of 40 min. The c and n parameters of the Kostiakov equation for infiltration ($f=cnT^{n-1}$) were calculated from the intercept (cn) and slope (n-1) of these regression lines. The slope of the accumulated water intake curve is n; the intercept is c.

RESULTS

The infiltrartion data fit the Kostiakov equation quite well. Average R^2 for data at a site was 0.931 for Brooks, 0.857 for Kinsella, and 0.938 for Stavely. 1986 control data at each site represent best fit curves (Figure 7.1). Slope and intercept of best fit regression lines for a given treatment at Brooks were similar for 1985 and 1986 (Table 7.1). The control had the lowest slope; the early season treatment had the lowest intercept. At Kinsella, control and light autumn treatments had highest intercepts and the heavy June treatment had the lowest (Table 7.2). The heavy June treatment had the lowest slope both years. Slope and intercept were lower in 1986 than in 1985. At Stavely, intercept declined with increasing grazing intensity both study years (Table 7.3). Slopes were generally higher in 1986 than in 1985.

Average slopes were similar at Brooks both years, and for all sites in 1985 (Table 7.4). In 1986, average slope dropped at Kinsella. Average intercept at Brooks was similar both years and lower at Kinsella and Stavely in 1986 than in 1985. Stavely had the highest intercept both years.

DISCUSSION

The Kostiakov equation can be used to describe infiltration as a process rather than at discrete times. It can also be used to predict infiltration rates at times other than those monitored.

At Brooks, the similarity of slope and intercepts in 1985 and 1986 was due to similar surface water contents at the time of the infiltration tests. At Kinsella, high intercepts for control and light autumn treatments indicate a high initial infiltration rate. Low slopes for the heavy June treatment indicate a relatively constant infiltration rate with time. Higher soil water in 1986 than 1985 likely reduced slope and intercept for all treatments. Declining intercepts with increased grazing intensity at Stavely demonstrate negative effects of heavy grazing on initial infiltration rate. Similar slopes at all sites in 1985 is coincidence. The high intercept at Stavely indicates this site had the highest 1 min infiltration rate in both years. The low infiltration rate for Kinsella in 1986 shows the dramatic effect of increased antecedent soil water on infiltration rate.

These data do not support Gifford (1976) who found the Kostiakov equation did not fit infiltration data for United States and Australian rangelands. This may be due to differences in ecosystems or that ponded infiltration was evaluated in this study, whereas Gifford used data obtained from rainfall simulators.

CONCLUSIONS

Infiltration data for Alberta mixed prairie and fescue grasslands fit the Kostiakov equation well.

Table 7.1. Infiltration equation parameters at Brooks.

Year	Parameter	Early Season	Late Season	Control
1985	slope	-0.495	-0.573	-0.437
	intercept	36.3	46.3	43.7
	n	0.505	0.427	0.563
	c	71.9	108.5	77.5
1986	slope	-0.522	-0.531	-0.447
	intercept	37.7	47.0	49.0
	n	0.478	0.469	0.553
	c	78.8	100.2	88.6

example: 1985 early season treatment

$f=(\text{intercept})T^{\text{slope}}$ $f=36.3T^{-0.495}$ or $f=cnT^{n-1}$ $f=71.9(0.505)T^{0.505-1}$

Table 7.2. Infiltration equation parameters at Kinsella.

Year	Parameter	Light June	Heavy June	Light Autumn	Heavy Autumn	Control
1985	slope	-0.655	-0.364	-0.537	-0.476	-0.496
	intercept	43.8	27.7	49.1	51.9	55.2
	n	0.345	0.636	0.463	0.524	0.504
	c	126.8	43.5	106.0	99.0	109.5
1986	slope	-0.494	-0.189	-0.309	-0.354	-0.316
	intercept	13.4	13.6	18.5	23.8	22.9
	n	0.506	0.811	0.691	0.646	0.684
	c	26.5	16.7	26.8	36.8	33.4

Table 7.3. Infiltration equation parameters at Stavely.

Year	Parameter	Very Heavy	Heavy	Moderate	Light	Control
1985	slope	-0.453	-0.598	-0.497	-0.436	-0.561
	intercept	48.4	61.1	71.3	73.8	105.7
	n	0.547	0.402	0.503	0.564	0.439
	c	88.5	152.0	141.7	130.9	240.8
1986	slope	-0519	-0.624	-0.575	-0. 444	-0.493
	intercept	40.8	54.6	56.4	58.3	84.3
	n	0.481	0.376	0.425	0.556	0.507
	c	84.8	145.2	137.0	104.9	166.3

Table 7.4. Average infiltration equation parameters.

Year	Parameter	Brooks	Kinsella	Stavely
1985	slope	-0.502	-0.506	-0.509
	n	0.498	0.494	0.491
	intercept	42.1	45.5	72.1
	c	86.0	97.0	150.8
1986	slope	-0.500	-0.332	-0.535
	n	0.500	0.668	0.465
	intercept	44.6	18.4	58.5
	c	89.2	28.0	127.5

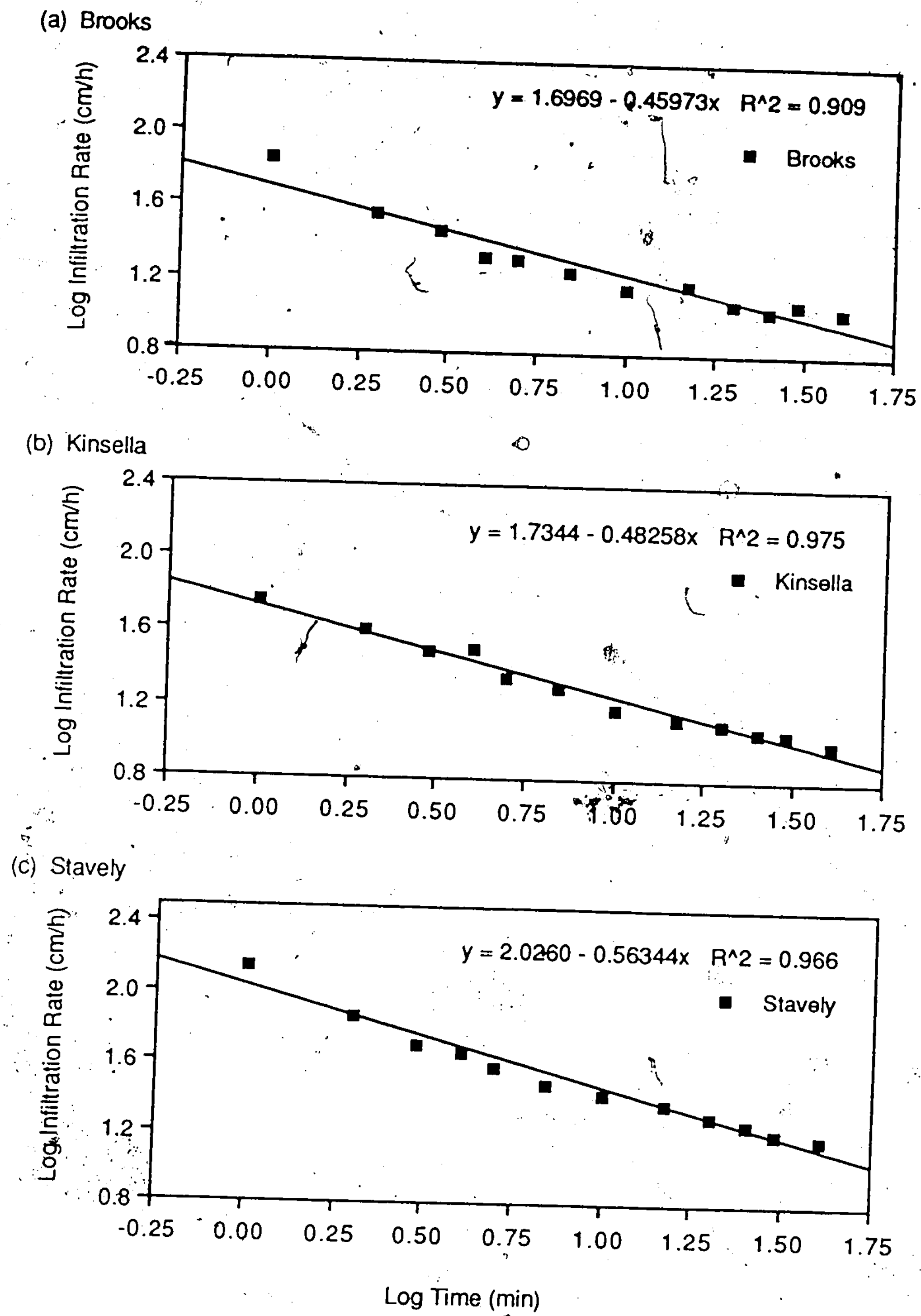


Figure 7.1. Best fit infiltration line for (a) Brooks, (b) Kinsella, and (c) Stavely in 1986.

BIBLIOGRAPHY

Gifford, G.F. 1976. Applicability of some infiltration formulae to rangeland infiltrometer data. J. Hydrol. 28:1-11.

Gifford, G.F. 1978. Use of infiltration equation coefficients as an aid in defining hydrologic impacts of range management schemes. J. Range Manage. 31:115-117.

Kostiakov, A.N. 1932. On the dynamics of the coefficient of water-percolation in soils and on the necessity for studying it from a dynamic point of view for purposes of amelioration. In: Trans. 6th Comm. Int. Soc. Soil Sci. Russian Part A:17-21.

VIII. GENERAL DISCUSSION AND CONCLUSIONS

Hydrologic Condition And Stability

The major objective in the hydrologic management of rangelands should be to optimize infiltration capacity in order to enhance forage productivity on a sustained basis and minimize soil and water losses through erosion processes. Infiltration capacity is mainly affected by inherent soil and vegetative properties which may be altered by grazing. Thus optimization of infiltration capacity can be achieved by maintaining the rangeland in good hydrologic condition through manipulation of the grazing animal in space and time. Although not generally defined, the term good hydrologic condition implies that the rangelands have soil and vegetative characteristics that optimize infiltration and minimize runoff and erosion. A rangeland in good hydrologic condition has soil surface conditions that ensure infiltration at a rate equal to or exceeding precipitation intensity of moderate frequency. The rangeland is hydrologically stable; soil, vegetative, and hydrologic characteristics are not easily negatively altered by the grazing regime imposed on the system.

Properties of the ground surface are important in determining soil water dynamics. The soil surface must be permeable, well-aggregated, non-crusted, and of a low bulk density. Live vegetation and litter should cover the ground to reduce bare ground and keep organic matter at levels that aid in maintaining the ideal soil surface conditions noted above. Organic matter cover reduces the force of falling raindrops, reduces puddling and slaking, and helps to maintain soil surface permeability. Trampling can increase soil bulk density and penetration resistance which in turn affects infiltration. Vegetation can cushion the soil from trampling and can promote good root growth and organic matter incorporation that tends to reduce bulk density and resistance to penetration. More permeable soil conditions facilitate greater root penetration which further increases permeability. Taller standing litter can increase the snow trapping potential of the rangelands, increasing snowmelt recharge in spring. Not only is the quantity of vegetative cover important, but also the type of cover. Infiltration rates increase with increasing position of the plant on the successional scale (Dee et al. 1966). Bunch type grasses enhance infiltration and are better at controlling erosion compared to sod grasses (Branson et al. 1981; McCalla et al. 1984; Blackburn et al. 1986; Pluhar et al. 1987) and water intake rates are more closely correlated with mid-grasses than short-grasses (Rauzi and Smika 1963). Results from this study confirmed a tenet of range management that overgrazing can lead to the creation of a less hydrologically stable and poorer condition rangeland.

Satterlund (1972) stated that for every site there exists a critical point of deterioration due to surface erosion. Beyond this critical point, erosion continues at an accelerated rate which cannot be overcome by natural vegetation and soil stabilizing forces. Blackburn et al. (1986) have reviewed the literature and concluded that sites differ in the amount of disturbance necessary to reach this critical point. They further conclude that the amount of vegetation is the primary controlling factor if the site is not near the critical point. If the site is near the critical point then the kind of vegetation has the potential to influence the erosion rate curve. As outlined previously, stabilizing vegetation would include more bunch grasses and mid-grasses than sod grasses and short-grasses. There is considerable uncertainty about amounts of vegetative cover to prevent excessive overland flow and erosion under the diverse topography and soil characteristics of most rangelands but that soils with a high inherent erodibility need more protective cover than soils with a low inherent erodibility (Meeuwig 1970).

The effect of grazing on hydrologic parameters is not linear, but rather the effects are manifested at some critical level. Whereas Satterlund (1972) talks about a critical *point* at which soil erosion processes are no longer reversible by removing the source of the disturbance, this critical *level* can be used to determine the point at which grazing effects are first significant from a physical perspective. Knowledge of this level can then be used to develop management strategies that will reduce the negative impacts of grazing and reinforce the fact that not all grazing regimes will lead to deterioration of the grassland ecosystem.

The rapidity with which an ecosystem responds to change or the degree of disturbance needed to bring about a change in terms of hydrologic stability is important in order to understand how anthropogenic disturbances such as grazing and natural resource exploration will affect the rangeland ecosystem. Since organic matter mass as live vegetation, litter, and soil organic matter have been cited in Chapter II as the most important factor in hydrologic condition of rangelands, its response to disturbance may be used as an indicator of how close to the critical level an ecosystem is. Other indicators may be resistance to penetration and soil bulk density since these soil characteristics affect both plant growth and infiltration and are in turn affected by plant growth.

Dormaar et al. (1977) emphasized the fragility of the equilibrium under which soil organic matter of heavily grazed prairie forms and exists. Organic matter content in mixed prairie is inherently low and has little resistance to ecological change. It is more fragile in its response to grazing-induced changes than is foothills fescue grassland. Other research by Dormaar (1975) indicated that organic matter of Brown Chernozemic soils, upon which most mixed prairie developed, is less resistant to biological breakdown than that of Black Chernozemic soils. Dormaar et al. (1984) found that resistance to breakdown of *Bouteloua gracilis* roots was lower than that of *Festuca campestris* roots. Since *Bouteloua gracilis* is the dominant species in the mixed prairie site, it would appear that the breakdown of mixed prairie roots would occur more rapidly than that in fescue grassland, creating a less stable environment.

Hydrologic Impacts Of Grazing

This study was designed to determine the hydrologic impact of common grazing regimes in mixed prairie and fescue grassland ecosystems of southern and central Alberta in terms of which hydrologic parameters were affected. Although quantitative determinations could not always be given, an attempt was made to assess the range of values for key hydrologic parameters at which the critical level in response to grazing was reached.

In this study it was shown long-term early season/heavy intensity grazing had the greatest effect on hydrologic characteristics of rangelands in Alberta. Patterns of response for hydrologic values were not linear, but tended to be incremental and first significant at grazing intensities greater than moderate, particularly if they occurred during the growing season. From a physical perspective, hydrologic changes brought about by common grazing practices involved only a few mm of soil water or less than 8.5 cm h^{-1} in infiltration rates. Steady state infiltration was reduced by 4.5 (Brooks), 0.7-2.7 (Kinsella), and 4.8-8.5 (Stavely) cm h^{-1} compared to the respective controls. The changes were on a very small scale compared to the amount of precipitation the rangelands receive. Based on 20 years of data for the study region, a 60 minute precipitation event with a 2 year return period has an intensity of 1.5 cm h^{-1}, with values for 5, 10, 25, 50, and 100 year return periods of 2.3, 2.8, 3.4, 3.8, and 4.1 cm h^{-1}, respectively (Atmospheric Environment Services 1987). Compacting effects of grazing were present, but values were not of a magnitude expected to cause serious plant growth problems. Only at Brooks under early season grazing and at Stavely under heavy and very heavy grazing intensities were penetration resistance values near 2000 kPa, the lower point of the range assumed to cause plant growth problems (Hakansson et al. 1988). However, the negative effects of long-term, heavy intensity/early season grazing should be kept in mind when developing management strategies to optimize the rangeland resource on a sustained yield basis.

Brooks

Percent ground cover and specific mass of above ground organic matter were not significantly affected by grazing disturbance but height of standing and fallen litter and specific mass of live vegetation were significantly decreased under both early and late season continuous grazing. Overall, the specific mass of organic material was not detrimentally changed by grazing. Grazing during any season significantly increased resistance to penetration, indicating that the system was responding to this type of disturbance more so than to organic matter reductions.

Early season grazing had more effect on hydrologic characteristics than late season or no grazing. Under early season grazing, total and below ground organic matter masses were reduced, bare ground increased, fallen and standing litter height was reduced, and penetration resistance to 2.5 cm was increased relative to that under late season grazing and the control. These factors combined to create less permeable soil surface conditions and resulted in reduced initial infiltration rates and reduced soil water to 80 cm depths. The effect of grazing on final infiltration rate was less than 8.5 cm h^{-1}. Final rates were also likely limited by the Bnt horizon of the Solonetzic soils.

Kinsella

In general, season of grazing effects were often more pronounced than intensity of grazing effects. The June treatments had the most effect on hydrologic characteristics, especially if under a heavy grazing intensity. Bare ground increased, height of standing and fallen litter decreased, and surface bulk density and penetration resistance increased, resulting in lower initial infiltration rates compared to autumn treatments and the control. The light autumn had the least hydrologic impact and was most similar to the control. In most respects heavy treatments were more similar to each other than were light treatments.

Stavely

The grazing treatments were the oldest of the three sites and give a good indication of the long-term effect of grazing. In general, hydrologic condition decreased with grazing intensities heavier than moderate. Light and control treatments were similar to each other as were heavy and very heavy treatments. The moderate treatment was intermediate. Under heavy and especially very heavy grazing, bare ground increased, live vegetative and litter cover were reduced, fallen and standing litter height were reduced, live vegetation and below ground organic matter masses decreased, bulk density to 15 cm increased, and resistance to penetration increased and was manifested to greater depths. These factors led to reduced initial infiltration rates and lower soil water, although final rates were reduced by 4.5 to 8.5 cm h^{-1}.

Range Management Implications

For range management purposes, data from all three sites confirm the importance of a permeable well vegetated ground surface to promote good hydrologic condition. Grazing of any intensity during any season had some effect on infiltration although these differences were often small. Although total litter accumulation was not always altered significantly by grazing, height of standing and fallen litter were often reduced. In most cases significant increases in resistance to penetration and/or bulk density occurred with grazing. The magnitude of these changes was not high enough to affect plant growth in most instances.

In mixed prairie at Brooks, continuous grazing had an overall negative effect on hydrologic parameters. Infiltration rate was reduced, especially in the early season treatment. Soil water was higher in the control during soil water accretion times and was often higher during depletion times as well. Again, the effects were more pronounced in the early season treatment than in the late season treatment. From a management perspective grazing in the dormant season is the best alternative. However, if the range is grazed during the growing season, the stocking rate should be reduced to that of a moderate intensity. Since resistance to penetration is highly affected by grazing, some measure to reduce the compacting influence of grazing may be taken. Gill and Reaves (1956) have indicated that 90% of the compaction occurs with the first pass. The cattle on large mixed prairie ranges must walk long distances to water; reducing field size and decreasing travel distance to water would help lessen concentration of compaction within small areas.

Although the infiltration rates are not reduced to the point where runoff could be a major problem, the overall negative effect of heavy and early season grazing would indicate the importance of eliminating such a grazing regime from common practice in the aspen parkland. It would appear that from a hydrologic perspective the reduction of June or early growing season grazing to a minimum would be advisable. Moderate grazing in autumn would be the best grazing regime to employ. Perhaps the most feasible alternative would be to graze in the early part of the growing season on a rotational basis, such as every second year, or to rotationally graze during the middle of the growing season.

Grazing foothills fescue grasslands at a light or moderate rate would appear to be the least hydrologically detrimental. Although moderate grazing was not significantly different from heavy and very heavy grazing with respect to final infiltration rate under ponded conditions, it was not significantly different from the control for at least the first 5 min of the infiltration test. Because there is evidence of much selective grazing in this treatment, reducing the size of the fields and decreasing the length of grazing time may be a means of increasing effectiveness of the treatment both from a hydrologic perspective and an economic one. From this site, it is also indicated that grazing on a continuous basis throughout the growing season at a moderate rate is a viable alternative to rotational or deferred grazing. This may be of particular interest in the foothills grasslands where low management inputs on very large ranches are of economic importance. These conclusions are similar to those of Wood (1980) who reviewed the literature and found heavy intensity/low frequency grazing may not influence vegetation and soil characteristics for watershed improvement more favourably than light or moderate continuous grazing.

Results from this study do not provide absolute values of amounts of organic matter mass, penetration resistances, or bulk density necessary for adequate infiltration and soil water levels. However they identify those site factors that exert important influences on hydrologic stability and are affected by grazing. They provide qualitative criteria for estimating adequate levels. They furnish a basis for comparing hydrologic condition at different sites and under different grazing regimes. They also provide the basis for determining changes in influential site factors that must be achieved by management to ensure infiltration rate potentials considered acceptable are not reduced.

If infiltration ca[acity is used as an overall indicator of hydrologic condition, then the following values are ranges within which a critical level leading to deterioration of hydrologic condition is reached. This means for example, that somewhere between the upper and lower values of the range given, the hydrologic impact of grazing will be negative in terms of how the parameter in question affects infiltration rate. Percent bare ground at Brooks was not a factor because of the large cover of *Selaginella densa*. Nor was it a factor at Kinsella, where the treatment in the poorest hydrologic condition had only 2% bare ground. Overall, litter was not significantly affected by grazing at Brooks or Kinsella. At Stavely, the critical range for above ground litter was between 1.7

and 2 kg m^{-2}. Fallen litter was substantially reduced at all sites, with the critical level somewhere between 0.2 and 4.9 cm. It was concluded that compaction was not a major problem in terms of its effects on infiltration but that the increase in bulk density and penetration resistance under early season/heavy intensity grazing regimes would combine with other factors such as vegetative cover to affect infiltration rates. Thus any critical levels could not be determined based on this study.

Rangeland Reclamation Under Grazing

Successful range renovation and reclamation efforts associated with industrial disturbances such as pipeline installation or mining operations require a considerable knowledge of the impacts of grazing on a rangeland ecosystem. To assess the impact of a particular reclamation or revegetation practice, the superimposed effect of grazing regime must be considered (Naeth 1985). When selecting plant species for revegetation in rangelands, resistance to grazing, the effect of season of defoliation, and the impact of grazing on hydrologic parameters of an ecosystem must be considered. In Alberta rangelands that are overgrazed, anthropogenic disturbances are more likely to cause "problems" than similar disturbances would on less heavily grazed ecosystems. Assessing infiltration rates and erosion potential under grazing can aid in predicting erosion problems during reclamation.

Revegetating native rangelands after linear disturbances poses a specific problem. Cattle are attracted to the right-of-way (r-o-w) with lush new growth that is more palatable than the native range, particularly if it is fertilized (Naeth 1985). R-o-w species are often later maturing and thus more palatable when native species have formed seed heads or gone into dormancy. Introduced species are often more productive than the native range which further enhances their desirability. The cattle on a range tend to move into the r-o-w when they are put into the field each spring. This attraction leads to excessive defoliation which can result in plant cover loss from the r-o-w as young seedlings are grazed in spring before they can develop a sufficient root system to resist grazing. Cattle overuse of the r-o-w is also associated with trampling and compaction of the soil surface can lead to crusting and sealing resulting in reduced infiltration capacity and associated runoff and erosion. Litter is often removed with pipeline installation and is not built up for many years if the r-o-w is grazed. The effect of litter on the hydrologic parameters of specific range types as well as the response of litter to grazing regime suggests the beneficial effects of using a mulch on the r-o-w to enhance revegetation efforts.

Data from this research can be used to identify grazing regimes that are potentially hydrologically detrimental and thus revegetation strategies can be adapted to the grazing regime or the grazing regime altered until a suitable ground cover has been established. The Brooks study site may be the most fragile with respect to reclamation related disturbances. Since the amount of organic matter is already low, further reduction of organic matter during natural resources exploration may present problems, especially if the operation occurs in an early season grazed location. However, since the topography is relatively flat, erosion potential would likely be minimal. Heavy June grazing at Kinsella could pose problems to reclamation efforts since there is more bare ground and greater potential for erosion. In foothills fescue grassland, reclamation practices in very heavy grazed areas would present the greatest potential for erosion due to large amounts of bare ground already present. The rougher topography of the fescue grasslands would also enhance erosion potential under bared ground. At all three sites, soils compact under light grazing treatments, indicating a high potential for compaction problems when large equipment is involved.

Model Development

A model will be developed to utilize the data from this study and to simulate and integrate key hydrologic processes influencing and/or being influenced by production, utilization, and management of rangelands. Such a model could reveal more clearly interactions between climate, soil, vegetation, and range management practices that affect the hydrologic regime, which in turn would allow researchers to devise more efficient and reliable methods of range management. It could be used more directly to predict the impact of other defoliation disturbances such as pipeline construction and mining operations on rangelands. It could provide early warnings of potentially serious damage such as decreased ground cover, so effective counter measures such as reduced grazing intensity and duration can be undertaken. In reclamation, the model could help to predict potential erosion problems. The timing of herbicide application for weed control and revegetation treatments for range improvement is often based on the assessment of available water for plant growth and herbicide translocation. A model could provide valuable input data for decision making. The model might also be used to determine optimum carrying capacity for a specific range condition.

BIBLIOGRAPHY

Atmospheric Environment Services. 1987. Monthly record: meteorological observations in Western Canada. Vol 72. Environment Canada.

Blackburn, W.H., Thurow, T.L., and Taylor Jr, C.A. 1986. Soil erosion on rangeland. In: Use of cover, soils, and weather data in rangeland monitoring Symp. Proc. February 12, 1986. Kissimmee, Florida. Society for Range Management. Denver, Colo. Pp. 31-39.

Branson, F.A., Gifford, G.F., Renard, K.G., and Hadley, R.F. 1981. Rangeland Hydrology. Range Science Series No. 1. Society for Range Management. Kendall/Hunt Publ. Toronto, Ont. 340 pp.

Dee, R.F., Box, T.W., and Robertson, E. Jr. 1966. Influence of grass vegetation on water intake on Pullman silty clay loam. J. Range Manage. 19:77-79.

Dormaar, J.F. 1975. Susceptibility of organic matter of Chernozemic Ah horizons to biological decomposition. Can. J. Soil Sci. 55:473-480.

Dormaar, J.F. Johnston, A., and Smoliak, S. 1977. Seasonal variations in chemical characteristics of soil organic matter of grazed and ungrazed mixed prairie and fescue grassland. J. Range Manage. 30:195-198.

Dormaar, J.F. Johnston, A., and Smoliak, S. 1984. Seasonal changes in carbon content, dehydrogenase, phosphatase, and urease activities in mixed prairie and fescue grassland Ah horizons. J. Range Manage. 37:31-35.

Gill, W.R. and Reaves, C.A. 1956. Compaction problems of smooth rubber tyres. Agric. Eng. 37:677-680.

Hakansson, I., Voorhees, W.B., and Riley, H. 1988. Vehicle and wheel factors influencing soil compaction and crop response in different traffic regimes. Soil and Tillage Res. (in press).

McCalla, G.R. II, Blackburn, W.H., and Merrill, L.B. 1984. Effects of livestock grazing on infiltration rates, Edwards Plateau of Texas. J. Range Manage. 37:265-269.

Meeuwig, R.O. 1970. Infiltration and soil erosion as influenced by vegetation and soil in northern Utah. J. Range Manage. 23:183-188.

Naeth, M.A. 1985. Ecosystem reconstruction and stabilization following pipeline construction through solonetzic native rangeland in southern Alberta. Unpubl. MSc. Thesis. Depts. Soil Sci. and Plant Sci., Univ. of Alberta, Edmonton, Alta. 213 pp.

Pluhar, J.J., Knight, R.W., and Heitschmidt, R.K. 1987. Infiltration rates and sediment production as influenced by grazing systems in the Texas Rolling Plains. J. Range Manage. 40:240-243.

Rauzi, F. and Smika, D.E. 1963. Water intake on rangeland as affected by simulated grazing and fertilization. J. Range Manage. 16:125-128.

Satterlund, D.R. 1972. Wildland watershed management. Ronald Press Co. New York. 370 pp.

Wood, M.K. 1980. Impacts of grazing systems on watershed values. In: Proc. Grazing Management Sytems for Southwest Rangelands Symp. April 1-2, 1980. Albuquerque, New Mexico. New Mexico State Univ. Las Cruces, NM. Pp. 163-170.

APPENDIX I. STUDY SITE DESCRIPTIONS

BROOKS

Location and History

The mixed prairie study site was located approximately 225 km east of Calgary, in the N 15-20-11-W4 and N 16-20-11-W4. Approximate latitude is 51 ^{o}N and longitude is 112 ^{o}W. In 1964, the Eastern Irrigation District Grazing Association assumed management, at which time the range was divided and the present grazing regime established.

Climate

The area has a continental prairie climate characterized by warm summers, cold winters, and low precipitation (Bowser 1967; Kjearsgaard et al. 1982). The soil moisture regime is semiarid. Major storms track south of the area in winter and north of the area in summer, resulting in lowest summer and winter precipitation totals in the province. Mean annual precipitation is 355 mm, with approximately 224 mm falling as rain from May to September. Average snowfall is 106 cm. Moisture is a moderate to severe limiting factor to crop growth. High potential evapotranspiration and a large moisture deficit (227 mm) result from high summer temperatures, low precipitation, and strong winds. Prevailing winds are from the west to northwest with strongest winds from the south. Average wind velocity is 12 km h^{-1}. Average number of Chinook days is 20. Low winter temperature and shallow snow cover subject vegetation to harsh winter conditions. Annual mean temperature is 4 ^{o}C. The warmest month is July with a mean temperature of 19 ^{o}C and the coldest month is January with a mean temperature of -14 ^{o}C. The average growing season with mean temperatures above 5.6 ^{o}C is 183 days and the average frost free period is 116 days.

Physiography, Relief, and Drainage

The study area is in the Alberta Plains Physiographic Region, surrounded by the Rainy Hills Sheet (Wyatt et al. 1937; Kjearsgaard et al. 1982). The study sites were located in the eastern portion of the Kininvie Plain, which is mainly undulating moraine with common occurrences of flats and meadows. Surface elevations range from 730 to 760 m. The plain is capped with a thin to absent veneer of till through which underlying saline soft rock outcrops. The area is situated between the Red Deer and Bow Rivers and is drained by Matzhiwin, Onetree, and Little Sandhill Creeks.

Surficial and Bedrock Geology

The Horseshoe Canyon, Bearpaw, Oldman, and Foremost formations, all of Upper Cretaceous age, form the uppermost geologic deposits (Wyatt et al. 1937; Kjearsgaard et al. 1982). The study site is underlain by the Oldman formation and the surrounding area is underlain by the Bearpaw formation.

The Oldman is a nonmarine formation composed of pale gray, thick bedded, medium to coarse grained feldspathic sandstone; green and gray mudstone; dark gray and brown carbonaceous shale; and ironstone concretionary beds. The Bearpaw formation is of marine origin and composed of dark gray blocky shale and silty shale; greenish glauconite and clayey sandstone; thin concretionary ironstone and bentonite beds.

The most common surficial materials are till and fluvial-lacustrine followed by fluvial, fluvial-eolian outwash gravels, and soft rock. Some glacial drift was likely brought in from the Hudson Bay region, whereas some originated from underlying sandstone and shales.

Soils

Soils in the western portion of the study area were identified as 60% Steveville, 30% Hemaruka, and 10% Halliday series while the more eastern portion was composed of 60% Hemaruka, 20% Steveville, and 20% Halliday (Kjearsgaard et al. 1982). Several areas of Solonetzic soils in the study area were comprised of 75% Brown Solodized Solonetz and 25% Brown Solods (Norwest Soil Research Ltd. 1981). Blowout areas were common.

The Steveville series is a Brown Solodized Solonetz with a common horizon sequence of Ah, Ae, Bnt, Csk. Surface horizons are brown and weakly structured, especially the Ae. The Bnt has a hard columnar structure. Subsoil texture is loam to clay loam with an alkaline pH. Lime occurs near the 40 cm depth. These soils, formed on fine loamy soft rock, are very stony and have numerous eroded pits. Steveville soils are found on undulating to rolling topography with slopes of 2 to 15%. They are moderately well drained with little or no potential for cultivated agriculture. Grazing capacity is 19 to 24 ha AUY^{-1}.

The Halliday series is a Brown Solod with a common horizon sequence of Ah, Ae, AB, Bnt, BC, Cca, Csk. The A horizon is brown to gray-brown and slightly acidic. The Ae and AB horizons are very distinct. The series is characterized by a transitional AB horizon, retaining the round-topped form but losing any strong secondary structure, and is easily broken into subangular blocky peds. The transition to the columnar structured Bnt horizon is gradual in both colour and texture. The Bnt horizon is generally of clay loam texture and dark brown in colour. The structural characteristics gradually become less obvious through the BC horizon and disappear entirely in the Cca horizon at 45 to 55 cm. The mildly alkaline pH of the B horizon increases to moderately alkaline in the C horizon. These soils developed on fine loamy till, occurring in lower slope positions in undulating and hummocky areas. Slopes range from 2 to 15%. The soils are moderately well drained and rated poor for irrigation due to their Solonetzic B structure and subsurface salts. Agricultural capability is rated as marginal and grazing capacity is 14 to 19 ha AUY^{-1}. Under continued dryland farming, medium to strongly acidic conditions can develop in the A horizon to the point where crop growth is affected.

The Hemaruka series is a Brown Solodized Solonetz with a common horizon sequence of Ah, Ae, Bn or Bnt, Csk. The A horizon has a distinct Ah of approximately 8 cm and an Ae of approximately 3 cm. The brown to grayish-brown A horizon has a loam texture with a neutral to slightly acidic pH. The Bnt horizon is characterized by a hard, columnar round-topped structure, highly resistant to breakdown. It is generally clay loam to clay in texture, dark grayish-brown in colour, and of a neutral to mildly alkaline pH. The lower B tends to be more weakly structured and gradually decreases in alkalinity at depths of 35 cm below the surface. The C horizon is characterized by lighter colours, a moderately alkaline pH, and a clay loam texture. Sand lenses are common in till materials. Soils of the Hemaruka series developed on fine loamy till. They occur on undulating and hummocky topography, most often occupying lower slope positions. Slopes range from 2 to 25%. Eroded pits and slight stoniness are common features. These soils are moderately well drained, marginal for agricultural capability, and poor for irrigated agriculture. The grazing capacity has been assessed at 16 to 24 ha AUY^{-1}.

Vegetation

The study area supports vegetation of the *Stipa-Bouteloua-Agropyron* faciation (Coupland 1961). Dominant grasses are *Bouteloua gracilis, Stipa comata*, and *Agropyron smithii. Stipa curtiseta* and *Agropyron dasystachyum* are found in moister areas. Forbs are abundant and shrubs are limited. The dominant shrub is *Artemisia cana*, the dominant suffratescent shrub is *Artemisia frigida*, and the most abundant forbs are *Phlox hoodii* and *Selaginella densa. Koeleria macrantha* and *Poa sandbergii* are principle subordinate grasses and *Carex stenophylla* and *C. filifolia* are principle subordinate sedges.

Extended overgrazing results in a short grass disclimax, often a *Bouteloua-Stipa faciation* (Coupland 1961). During moist years a *Stipa-Bouteloua* or *Bouteloua-Stipa* character is retained in some sites while others swing towards *Stipa-Agropyron*. Areas of *Bouteloua-Agropyron* are common on Solonetzic soils with large blowout areas and are considered as serules representing a stage in succession. Here *Agropyron* species occupy blowout areas and *Bouteloua* occupies areas with topsoil.

Vegetation has been classified as short grass prairie dominated by *Bouteloua gracilis* with secondary occurrences of *Stipa comata* (Strong and Leggat 1981; Walker 1981; Kjearsgaard et al. 1982). Classifications as short grass prairie were likely based on the overgrazed conditions which tend to favour the increase of short grass species.

KINSELLA

Location and History

The aspen parkland study area was located on the University of Alberta ranch, near Kinsella, 157 km southeast of Edmonton. The study site is in the NW-28-47-11-W4. Approximate latitude is 53 02 ^{O}N and longitude is 111 33 ^{O}W.

Section 28 of the University ranch had been unfenced for many years and was heavily grazed from 1916 to 1944 by local ranchers. From 1944 until 1970 hay was cut on an alternate year basis. In 1970 the land was purchased by the province and leased to the University of Alberta; in 1973 grazing treatments were established.

Climate

The Kinsella area has a dry subhumid climate with cold winters and mild dry summers (Wonders 1969). Average annual precipitation is 380 mm. Average annual evapotranspiration is 356 to 406 mm. Approximately 67% of the annual precipitation falls as rain during May to September; 50% falls during June, July, and August. Average monthly precipitation maximum is in July (860 mm) and minimum is in October and November (150 mm). Snow accounts for 27% of the annual precipitation. Most snow falls between December and February but may occur between September and April. Mean annual temperature is 2 ^{O}C. The warmest month is July with a monthly maximum temperature of 19 ^{O}C, a minimum of 8 ^{O}C, and a mean of 17 ^{O}C. January has the coldest temperatures; with a monthly maximum temperature of -13 ^{O}C, a minimum of -23 ^{O}C, and a mean of -17 ^{O}C. There are approximately 90 frost free days. Prevailing winds are from the west to northwest (Wyatt et al. 1944).

Physiology, Relief, and Drainage

The study site is in the Eastern Alberta Plain, in the Viking upland (Howitt 1988). The Viking upland is of hummocky moraine characterized by hummocks with short steep slopes interspersed by numerous pothole lakes as a result of melting and disintegrating stagnant glacial ice masses.

Elevation ranges from 670 to 700 m. A meltwater channel traverses north to south through the district. Several lakes have formed in association with this channel but there are no major creeks.

Surficial and Bedrock Geology

About 15,000 years ago the recession of the Kehewin ice sheet deposited heavy textured till of the Viking moraine from which soils of the Kinsella area developed (Wonders 1969). Where erosive agents removed this till, bedrock is the original parent material. Bedrock is of the Belly River formation, of upper cretaceous sediments composed of sandstone, mudstones, and siltstones, with concretionary ironstone beds (Howitt 1988). Sand and gravel deposits occur throughout the area.

Soils

Soils are fine loamy till dominated by Orthic Black Chernozems with poorly drained Humic Gleysols in scattered depressions (Howitt 1988). Some gleyed subgroups, Regosols, and Solonetzic soils are also present in small amounts. Steeply sloping land is dominated by undifferentiated black grassland soils. Most soils are of the Elnora series

Elnora is a thin, well drained, Orthic Black grassland soil. Till material is fine loamy to fine clayey, containing less than 5% coarse fragments; it is 8 to 30 m thick and moderately calcareous. Sand and gravel lenses are common. The black loamy surface horizon is 10 to 15 cm thick, underlain by a yellowish brown, weakly prismatic B horizon. Unaltered parent material occurs at 40 to 60 cm with calcium carbonate, pebbles, coal flecks, and iron stains. The surface horizon is slightly acidic to neutral and subsurface horizons are neutral to mildly alkaline. Elnora is moderately pervious and has adequate moisture retention. Most rainfall infiltrates but surface runoff occurs on steep slopes or during heavy rainfall. Elnora is suitable for grain and forage production. Sloped areas are used for grazing and improved pasture. Moderate to severe limitations to crop production result from steep slopes and associated sloughs and wet soils.

Vegetation

The ranch is located in the aspen parkland of east-central Alberta, consisting of grasslands and/or shrub communities with aspen groves occurring at irregular intervals (Moss 1955). Plant associations vary with topography, soils, moisture, and range condition. Six distinct range types occur: *Stipa-Agropyron*, *Festuca-Stipa*, *Symphoricarpos* shrub, *Populus tremuloides* forest, sedge meadows, and salt grass meadows.

The grasslands and shrublands at and surrounding Kinsella have been classified into five different communities including *Symphoricarpos*, *Symphoricarpos-Festuca*, *Festuca-Stipa*, *Stipa-Festuca*, and *Stipa-Agropyron* (Wheeler 1976). The area is further classified into nine communities including *Carex* wetlands, *Salix* wetlands, aspen forest, shrublands, open grassland, forest edge phase grassland, snowberry phase grassland, silverberry phase grassland, and brushed fencelines (Arthur 1984).

Historically, the land was virgin fescue grassland with *Festuca hallii* as the sole dominant. Grazing and fire modified the grassland, increasing *Agropyron trachycaulum*, *A. dasystachyum*, *A. subsecundum*, *Stipa curtiseta*, *Koeleria macrantha*, and *Danthonia parryi*. Today open grasslands are dominated by *Festuca hallii* on mesic undisturbed sites. On grazed areas *Stipa curtiseta* is a co-dominant. Subdominants include *Agropyron subsecundum*, *A. dasystachyum*, *Solidago* species, *Cerastium arvense*, *Achillea millifolium*, *Fragaria virginiana*, *Artemisia ludoviciana*, *A. frigida*, and *Galium boreale*. *Aster laevis* and *Solidago missouriensis* are the most common palatable forbs.

Shrubs and trees are found on moister, lower slope positions. Major species include *Populus tremuloides*, *Symphoricarpos occidentalis*, and *Elaeagnus commutata*. Other common species include *Amelanchier alnifolia*, *Rosa woodsii*, *R. acicularis*, *Rubus idaeus*, and *Salix* species. In shrub communities, the herb layer includes *Rubus pubescens*, *Aster* species, *Vicia americana*, *Lathyrus ochroleucus*, *Pyrola secunda*, *Fragaria virginiana*, *Galium boreale*, *Epilobium angustifolium*, *Viola adunca*, *Smilacina stellata*, *Thalictrum venulosum*, *Calamagrostis* species, *Anemone canadensis*, and *Agropyron trachycaulum* .

Major species in wetland communities are *Carex* species, *Calamagrostis canadensis*, *Glyceria grandis*, *Bechmannia syzigachne*, and *Sium suave*. Common willows are *Salix petiolaris* and *Salix discolor*.

The area is facing a *Populus tremuloides* invasion of 7.6 m km^{-1} y^{-1} (Scheffler 1976) which had been historically checked by lightning and Indian fires.

STAVELY

Location and History

The study site is located in sections 21 and 22-14-29-W4, approximately 100 km south southwest of Calgary in the Porcupine Hills. Approximate latitude is 50 ^{o}N and longitude is 114 ^{o}W. The area was moderately stocked with cattle for summer grazing from 1884 to 1908, with horses from 1908 to 1920, then again with cattle from 1920 to 1944 (Johnston 1961). It was heavily grazed during the drought years of the thirties. In 1944 the area became part of a large ranch and was lightly used as winter range until 1949. In 1949, the Alberta government leased 390 ha of range to the federal government and called the site the Stavely Grassland Substation. Three fields were established, corresponding to the light, moderate, and heavy grazing treatments. In 1951, the very heavy grazing treatment was established. In 1965 the name was changed to Range Research Station, Stavely, Alberta and carrying capacity and other studies were started.

Climate

The climate is moist subhumid without marked deficiency of precipitation (Johnston 1961). Annual precipitation is approximately 550 mm with approximately 40% of this occurring as snow. May to September precipitation is 230 to 370 mm (Strong and Leggat 1981). During the winter, Chinook winds moderate the climate. Temperature tends to fluctuate widely at all seasons. Mean annual temperature is 5 ^{o}C, with January means of -10 ^{o}C and July means of 18 ^{o}C. There are approximately 230 growing days and the frost free period is 25 days.

Physiology, Relief, and Drainage

The topography ranges from gently rolling to hilly. The gently rolling areas comprise only a small percentage of the total area and are located near drains. The rolling area consists of half the remaining area and is made up of flat bench lands and less steep slopes. The remaining land is hilly, consisting of steeper slopes to drains and rough higher land to the north and northwest with altitudes up to 1402 m (Johnston 1961).

The Porcupine Hills are generally poorly watered although the study area is supplied with water. A creek, which is supplied by a good spring, runs along the west side of section 21 and another creek which appears to be intermittent, is located between sections 21 and 22. A small spring runs into this creek from the north.

Surficial Bedrock and Geology

Bedrock consists of sandstone which outcrops frequently, resulting in shallow, infertile soils along many hillsides. The area had been glaciated by ice originating near the Hudson Bay and over the Rocky Mountains, the Laurentide, and Cordilleran ice sheets (Beke 1969). Glacial till surficial deposits are common and range in thickness from less than 20 feet on ridges to more than 100 feet above sea level. Laurentide drift material covers Cordilleran drift throughout most of the Porcupine Hills.

Soils

The soil is an Orthic Black Chernozem and has a clay loam to loam texture (Johnston 1961). The uplands and steeper slopes tend to be of heavy loam texture, while lower areas and less steep slopes are mostly loams. Depth of Ah horizons average 8 to 10 cm with 5 cm on uplands and 15 to 18 cm in gently rolling flats. The C horizon occurs at approximately 60 cm. Soils are generally quite fertile, well drained, with normal, non-Solonetzic profiles.

Soils are dominated by the Dunvargon series (Walker and Brierly 1988). Dunvargon is an Orthic Black Chernozem with a common horizon sequence of Ah, Bm_1, Bm_2, BCk, Ck. The series is characterized by a thick clay loam Ah usually greater than 15 cm. The Bm horizons are dark yellowish brown of clay loam to loam texture, occurring at depths of 14 to 35 and 35 to 53 cm. Carbonates are found below 50 cm. The soil developed from moderately calcareous, medium textured, continental till overlying sandstone. Sandstone ghosts are present throughout the B horizon. Gravel to cobble size quartzitic stones are present throughout the profile.

Johnston et al. (1971) documented changes in soil due to grazing treatments. The soil was black under light grazing, dark gray under moderate grazing, dark grayish-brown under heavy grazing, and dark brown under very heavy grazing. Percent organic matter and total phosphorus decreased as grazing intensity increased, while $NaHCO_3$ soluble phosphorus increased.

Vegetation

Vegetation is of the fescue grassland association (Moss and Campbell 1957; Looman 1969). *Festuca campestris* is the dominant species in undisturbed and lightly grazed areas. *Danthonia parryi* forms a disclimax under heavy utilization and an edaphic subclimax on exposed sites. Subdominant grasses which increase with grazing include: *Festuca idahoensis, Danthonia intermedia, Agropyron subsecundum, A. trachycaulum, Koeleria macrantha,* and *Helictotrichon hookeri.* Common forbs include *Geranium viscosissimum, Cerastium arvense, Galium boreale, Solidago glabberina, Anemone patens, Aster laevis, A. ericoides, Hedysarum alpinum, Geum triflorum, Lithospermum ruderale, Lupinus argenteus,* and *Achillea millifolium.* Common shrubs include *Potentilla fruticosa, Rosa arkansana,* and *Artemisia frigida* (a suffratescent shrub). With heavy grazing *Festuca* and *Danthonia* species are replaced by invaders such as *Taraxacum officinale, Lappula redowskii* and *Poa* species.

Under light grazing, *Festuca campestris* was the dominant grass with *Danthonia parryi* dominating heavy grazed fields (Johnston et al. 1971). Under very heavy grazing, *Festuca* *campestris* was eliminated, litter almost disappeared, and various annual species invaded.

Populus tremuloides had encroached upon grassland in the lightly and moderately grazed fields.

BIBLIOGRAPHY

Arthur, R.L. 1984. Forage selection by cattle on aspen parkland. Unpubl. M.Sc. Thesis. Dept. Plant Science, Univ. of Alberta. Edmonton, Alta. 192 pp.

Beke, G. 1969. Soils of three experimental watersheds in Alberta and their hydrologic significance. Unpubl. Ph.D. Thesis. Dept. Soil Sci., Univ. of Alberta. Edmonton, Alta. 456 pp.

Bowser, W.E. 1967. Agroclimatic areas of Alberta. Institute of Pedology, Univ. of Alberta. Edmonton, Alta.

Coupland, R.T. 1961. A reconsideration of grassland classification in the northern Great Plains of North America. J. Ecol. 49:136-167.

Howitt, R.W. 1988. Soil survey of the County of Beaver. Alberta Soil Survey Report No. 47. Alberta Research Council Open File Report No. 1987-4. In press.

Johnston, A. 1961. Comparison of a lightly grazed and ungrazed range in the fescue grassland of southwestern Alberta. Can. J. Plant Sci. 41:615-622.

Johnston, A., Dormaar, J.F., and Smoliak, S. 1971. Long-term grazing effects on fescue grassland soils. J. Range Manage. 24:185-188.

Kjearsgaard, A.A., Peters, T.W., and Pettapiece, W.W. 1982. Soil survey of the County of Newell No. 4, Alberta. Alberta Institute of Pedology Report S-82-41. 197 pp.

Looman, J. 1969. The fescue grasslands of Western Canada. Vegetatio Acta Geobotanica 19:127-145.

Moss, E.H. 1955. The vegetation of Alberta. Bot. Rev. 21:493-567.

Moss, E.H. and Campbell, J.A. 1957. The fescue grassland of Alberta. Can. J. Res. Sect. C, Bot. Sci. 25:209-227.

Norwest Soil Research Ltd. 1981. Exploratory soil survey of selected areas on the Eastern leg (Zones 6 and 9) of the Alaska Highway gas pipeline project. A report prepared for the Alaska Project Division of NOVA, An Alberta Corporation. Calgary, Alta. 47 pp.

Scheffler, E.J. 1976. Aspen forest invasion in a portion of the east central Alberta parklands. Unpubl. M.Sc. Thesis. Dept. Plant Science, Univ. of Alberta. Edmonton, Alta. 160 pp.

Strong, W.L. and Leggat, K.R. 1981. Ecoregions of Alberta. Alta. Energy and Natural Resources. 64 pp.

Walker, D. and Associates Ltd. 1981. Revegetation procedures and line log. 1981. Construction Zone 6. Alaska Highway gas pipeline project. Prepared for: The Alaska Project Division of NOVA, An Alberta Corporation - Agent for Foothills Pipelines (Alta.) Ltd. 25 pp.

Walker, B.D. and Brierley, J.A. 1988. Soil survey of the Pincher Creek - Crowsnest Pass area. In preparation.

Wheeler, G.W. 1976. Some grassland and shrubland communities in the parklands of central Alberta. Unpubl. M.Sc. Thesis. Dept. Plant Science, Univ. of Alberta. Edmonton, Alta. 95 pp.

Wonders, W.C. 1969. Atlas of Alberta. Univ. of Alberta Press in association with Univ. of Toronto Press. Edmonton, Alta. 158 pp.

Wyatt, F.A., Newton, J.D., Bowser, W.E., and Odynsky, W. 1944. Soil survey of Wainwright and Vermilion sheets. Univ. of Alberta College of Agriculture Bull. No. 42. Edmonton, Alta.

Wyatt, F.A., Newton, J.D., Bowser, W.E., and Odynsky, W. 1937. Soil survey of Rainy Hills sheet. Univ. of Alberta, College of Agriculture Bull. No. 28. Edmonton, Alta. 56 pp.

APPENDIX II. PARTICLE SIZE AND WATER RETENTION OF STUDY SITE SOILS

SOIL SAMPLING

The experimental design within each study site was a hierarchical (subsampling) arrangement. Within each treatment, three 0.1 ha areas were randomly chosen. Within each of these areas, sample points were randomly selected from which soil samples were taken in May 1986. In each 0.1 ha area, three soil samples (9 per treatment) were obtained approximately 15 m apart with a hydraulic coring unit. Samples were separated into depth increments of 0-5, 5-15, 15-30, 30-45, 45-60, and 60+ cm.

Water retention was determined using a No. 1600 pressure plate extractor and a ceramic No. 1500 plate extractor (both from Soil Moisture Equipment Corp., Santa Barbara, California) for -33 kPa and -1500 kPa, respectively (McKeague 1978). The retainer ring was 5 cm in diameter; the crushed and ground (2 mm) soil sample mass was approximately 10 g. Available water capacity was calculated by subtracting water content at -1500 kPa from that at -33 kPa.

Sand, silt, and clay contents were determined using the hydrometer method (McKeague 1978). Pretreatment for removal of organic matter was conducted as outlined in McKeague in section 2.111B using hydrogen peroxide. Pretreated samples included Kinsella samples from 0-5 cm and Stavely samples from 0-5 and 5-15 cm. Soil textural classes were assigned according to the Canada Soil Survey Committee (1978) textural triangle.

STATISTICAL ANALYSES

Statistical analyses were conducted using variation among 0.1 ha areas as an appropriate measure of error variation for testing the significance of treatments. Data were tested for homogeneity of variance using Cochran and Bartlett-Box tests for homogeneity. The W test was used to test data for normality of distribution (Shapiro and Wilk 1965). An SPSSx analysis of variance program was used to test for treatment effects. Data with significant F values were further analyzed to separate means using the Student-Newman-Keul (SNK) test at the 5% level of significance (Steel and Torrie 1980).

Preliminary statistical analyses indicated that variation among the 0.1 ha areas was not significantly different from sampling point variation and therefore in all future analyses, area and sampling point variation were pooled. The sources of variation in the final statistical analysis were treatments and error within treatments.

Table II.1. Soil texture with depth at Brooks.

Depth (cm)	Early	Late	Control
0-5	L	L	L
5-15	L	L	L
15-30	L	L-CL	L
30-45	CL	CL	CL
45-60	CL	CL	CL
60+	L-CL	CL	CL

L = loam
SL = sandy loam
SCL = sandy clay loam
CL = clay loam

Table II.2. Soil texture with depth at Kinsella.

Depth (cm)	Light June	Heavy June	Heavy Autumn	Light Autumn	Control
0-5	SCL	SCL	SCL	SCL	SCL
5-15	L	L	L	SL	L-SL
15-30	SL	SL	L	SL	L
30-45	SL	SCL-SL	SCL	SCL	L
45-60	SCL	L	SCL-SL	L	L
60+	SCL	L	L	SCL	SCL

Table II.3. Soil texture with depth at Stavely.

Depth (cm)	Very Heavy	Heavy	Moderate	Light	Control
0-5	SCL	CL	CL	CL	CL
5-15	CL	CL	C	CL	CL
15-30	CL	L	CL	CL	L
30-45	L	CL	CL	L	CL
45-60	L	CL-L	CL	L	CL
60+	L	CL	CL	L	CL

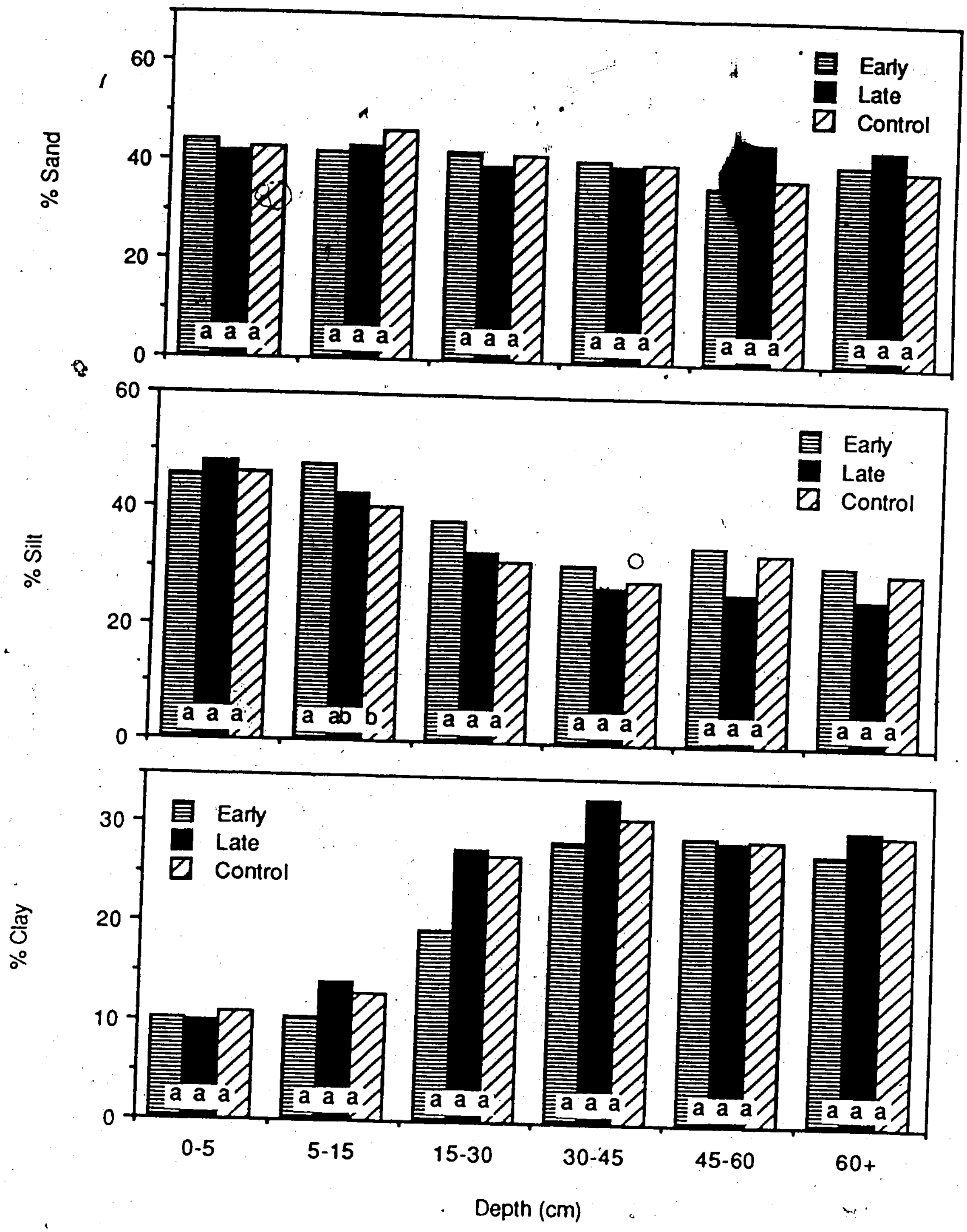


Figure II.1. Percent sand, silt, and clay in the soil profile at Brooks. Within parameter and depth means with the same letters are not significantly different (P<0.05).

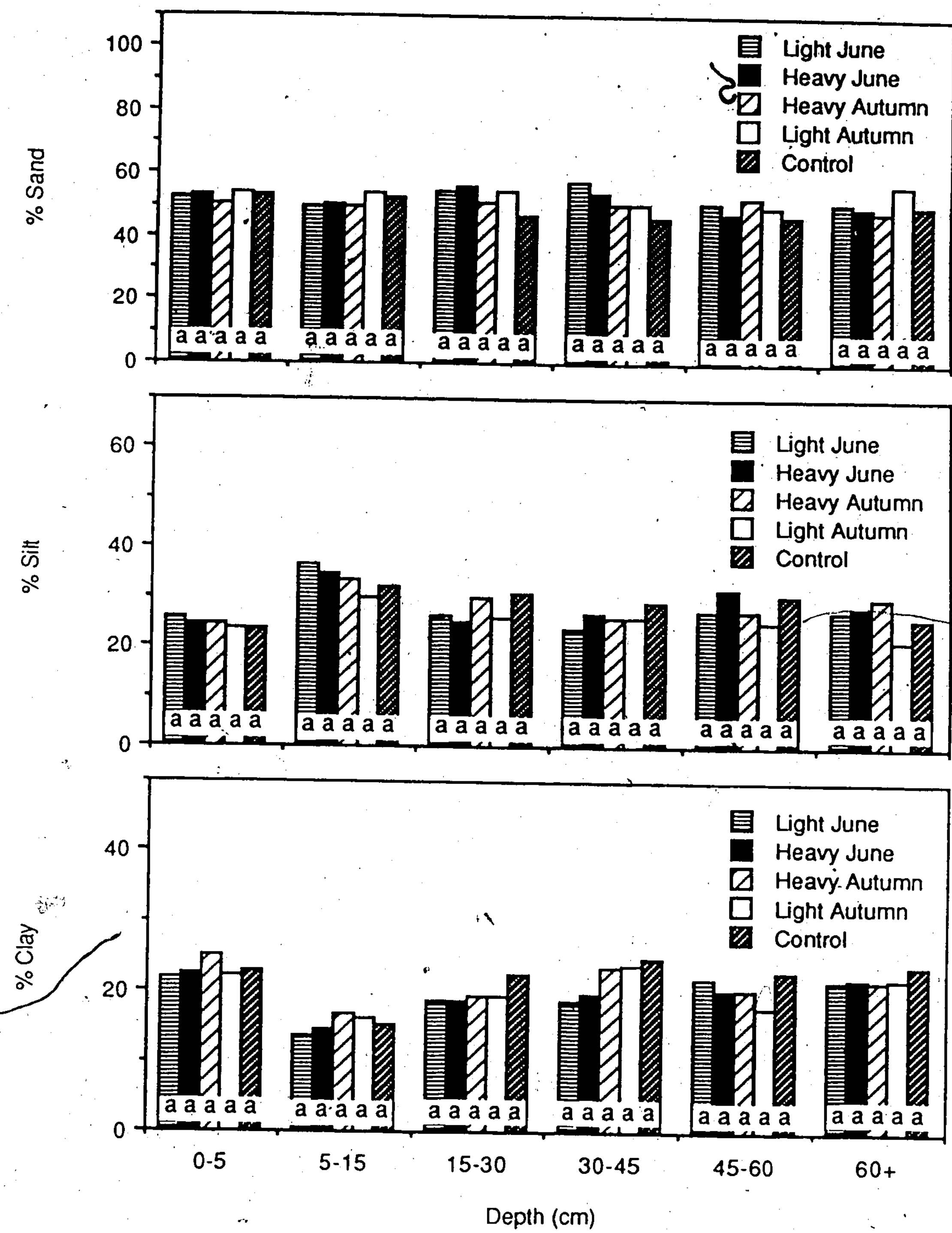


Figure II.2. Percent sand, silt, and clay in the soil profile at Kinsella. Within parameter and depth means with the same letters are not significantly different ($P<0.05$).

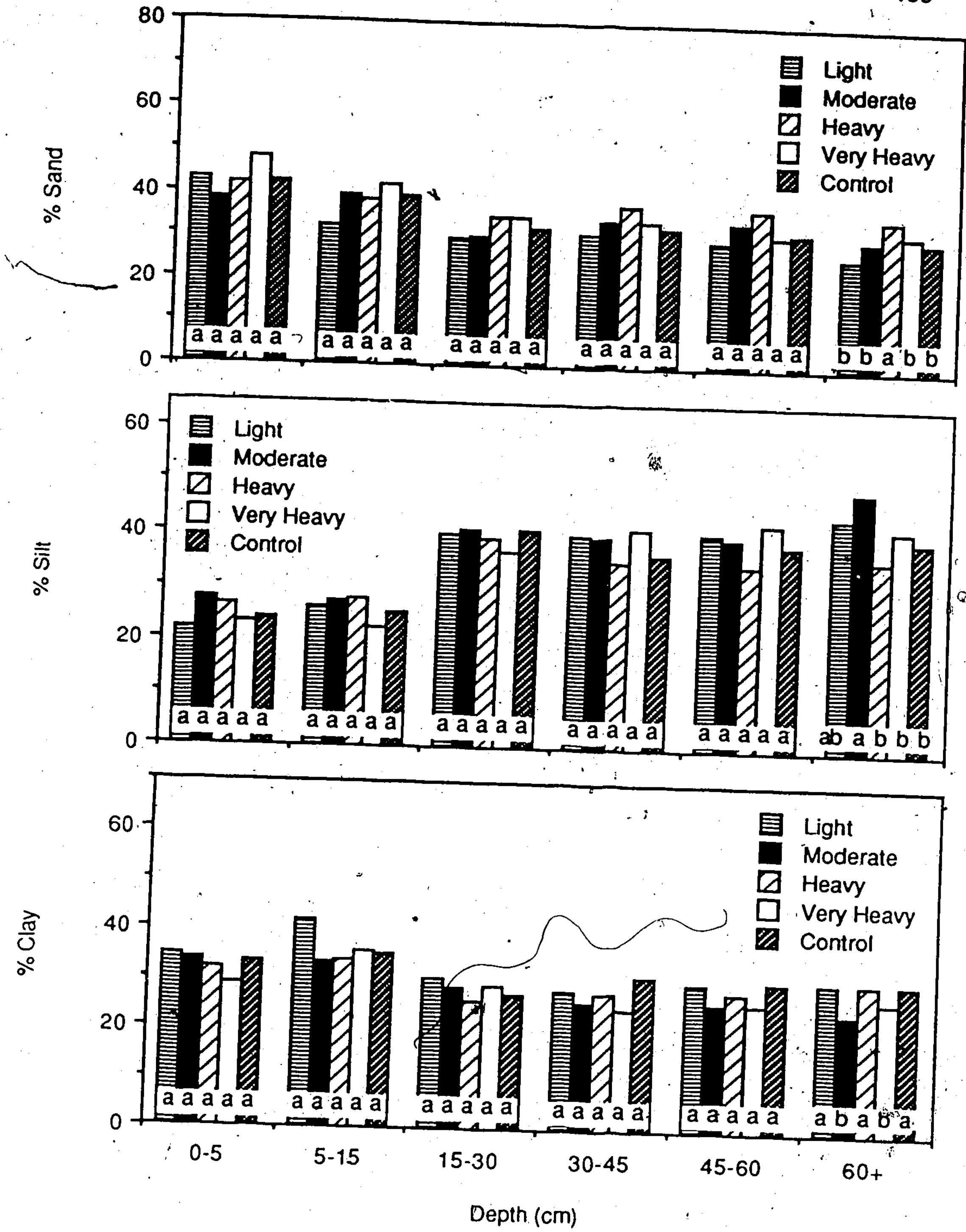


Figure II.3. Percent sand, silt, and clay in the soil profile at Stavely. Within parameter and depth means with the same letters are not significantly different (P<0.05).

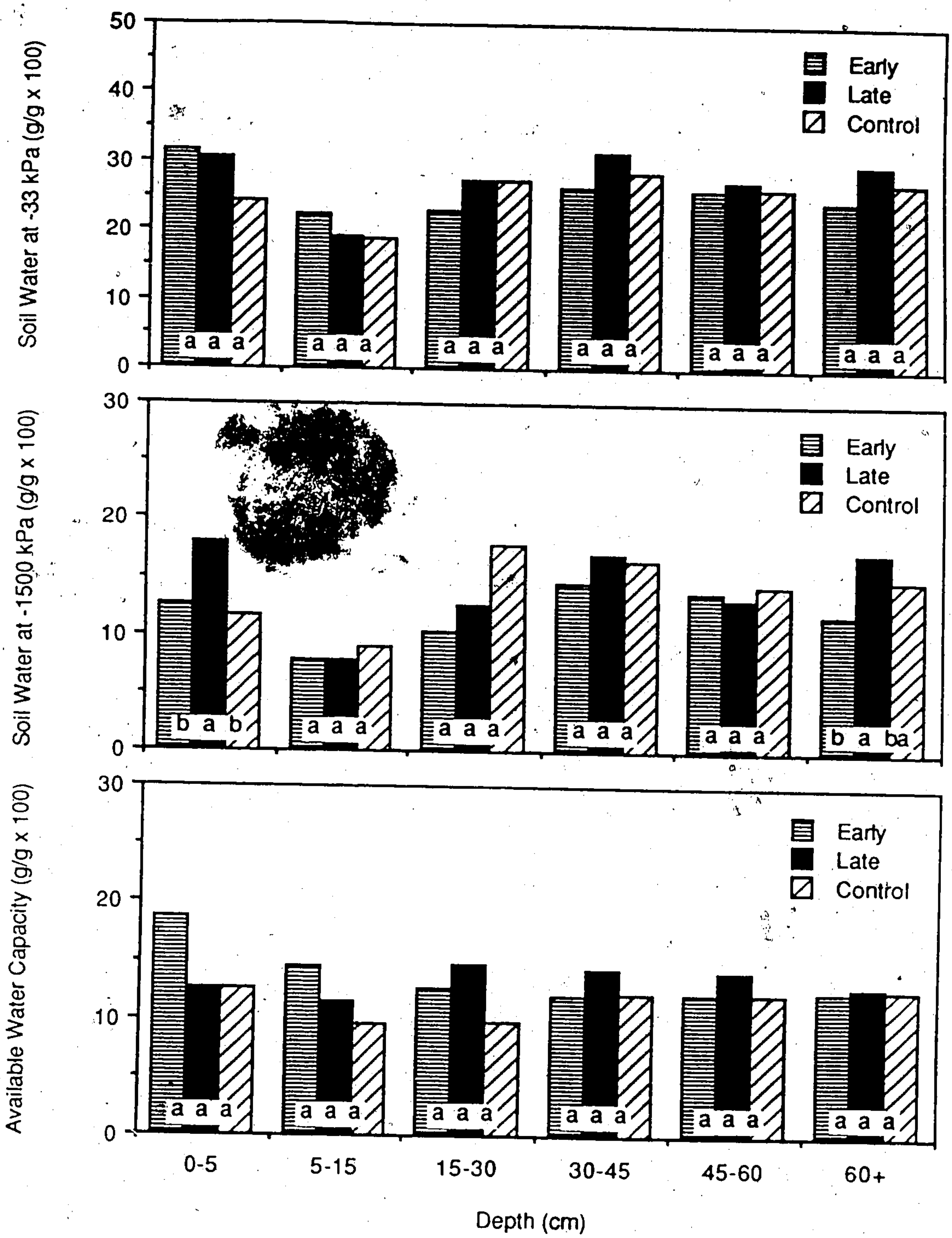


Figure II.4. Water retention properties in the soil profile at Brooks. Within parameter and depth means with the same letters are not significantly different (P<0.5).

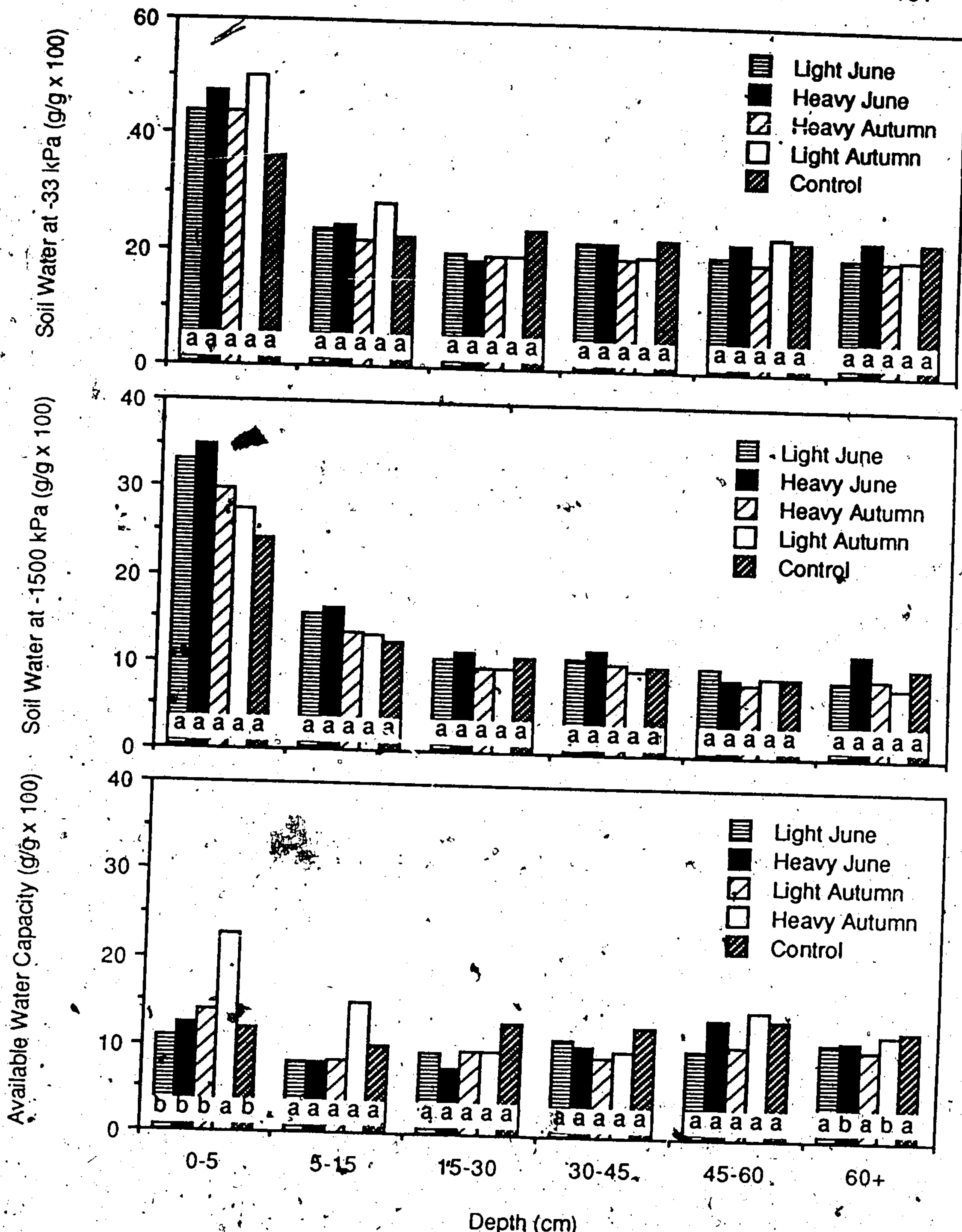


Figure II.5. Water retention properties in the soil profile at Kinsella. Within parameter and depth means with the same letters are not significantly different (P<0.5).

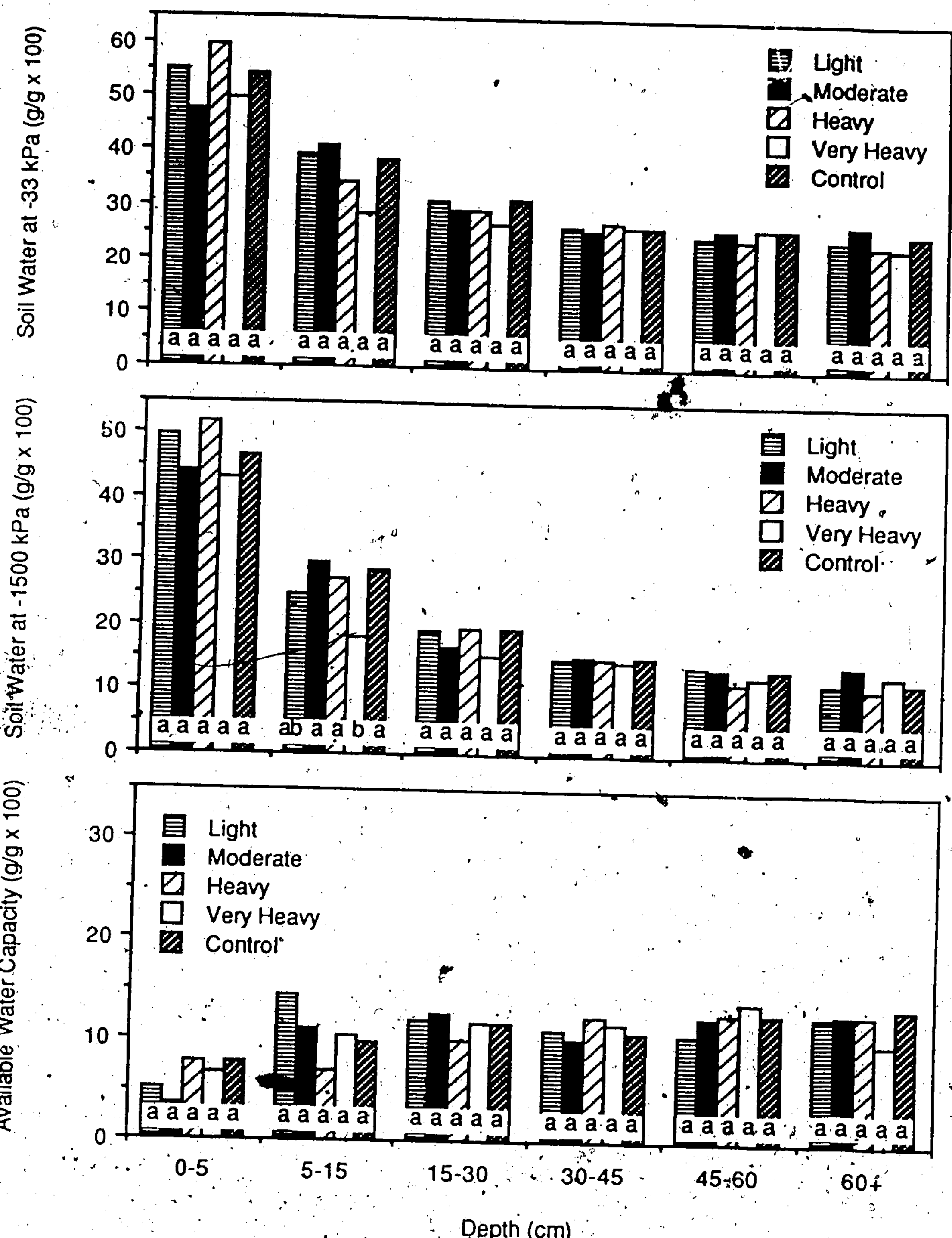


Figure II.6. Water retention properties in the soil profile at Stavely. Within parameter and depth means with the same letters are not significantly different (P<0.5).

BIBLIOGRAPHY

Canada Soil Survey Committee, Subcommittee on Soil Classification. 1978. The Canadian system of soil classification. Can. Dept. Agr. Publ. 1646. 164 pp.

McKeague, J.A. 1978. Manual on soil sampling and methods of analysis. Can. Soc. Soil Sci. 212 pp.

Shapiro, S.S. and Wilk, M.B. 1965. An analysis of variance test for normality (complete samples). Biometrika 52:591-611.

Steel, R.G.D. and Torrie, J.H. 1980. Principles and procedures of statistics: a biometrical approach. 2nd ed. McGraw-Hill, New York. 633 pp.

APPENDIX III. CLIMATIC DATA FOR THE STUDY SITES

METEOROLOGICAL DATA

Campbell Scientific CR21X dataloggers were used to collect meteorological data at each study site from April through October, 1985 to 1987. Data included: precipitation with a tipping bucket rain gauge, air temperature, relative humidity, and wind speed. Problems with these meteorological stations sometimes led to loss of data. Missing data were obtained from Atmospheric Environment Services (1985-1987) for the closest meteorological data collection centre to each of the study sites. These centres were Brooks AHRC, Kinsella Ranch, and Claresholm Waterworks, for the Brooks, Kinsella, and Stavely study sites, respectively.

EVAPOTRANSPIRATION AND WATER DEFICIT

Monthly potential evapotranspiration (PET) values were calculated using the Thornthwaite equation, correcting for latitude (Withers and Vipond 1980). Monthly precipitation was subtracted from monthly PET to obtain monthly deficit. Monthly values of PET, precipitation, and deficit were summed for April to October, inclusive, to obtain growing season values. These values were compared to the long-term normals (1951-1980).

The growing season deficits at Brooks for 1985 and 1986 were 111 and 92 mm lower than the long-term average of 312 mm, largely due to above normal precipitation in August, September, and October (133, 319, and 200% of the normal, respectively). The growing season deficits for Claresholm airport (approximately 32 km from the Stavely study site) in 1985 and 1986 were 233 and 187 mm, respectively, compared to the long-term average of 204 mm. Precipitation at Claresholm in 1985 was below normal for the entire period April to July, inclusive (97, 53, 15, and 60% of the long-term normal) and then above normal for August to October, inclusive (119, 193, and 110%, respectively). Air temperature followed an inverse trend to that of precipitation for the same period.

CALCULATION OF FIELD CAPACITY AND WILTING POINT

Field capacity and wilting point for a given depth increment were calculated by depth weighting of appropriate -33 and -1500 kPa values. For these increments bulk density was also depth weighted. For example: to obtain field capacity of the uppermost 10 cm, the -33 kPa value for the 0-5 cm depth increment and half the value for the 5-15 cm depth increment were summed. For a given depth increment, field capacity and wilting point were expressed as mm of water by multiplying depth weighted -33 kPa values and -1500 kPa values, respectively by depth increment by bulk density divided by density of water (1 Mg m^{-3}). Values for greater increments were determined by summing constituent increments. For example, the 0-80 cm value was the sum of 0-30, 30-50, and 50-80 cm values.

Table III.1. Monthly temperature (°C) for the Brooks study site.

Month	1951-1980 Average	1985	1986	1987
January	-14.2	-12.5	-1.8	-3.0
February	-9.5	-12.6	-10.6	-1.7
March	-4.1	-0.8	3.7	-0.4
April	4.6	6.3	4.8	8.8
May	11.1	12.8	12.0	13.2
June	15.6	14.6	17.2	18.0
July	18.6	19.7	16.4	17.9
August	17.3	16.0	17.9	14.7
September	11.9	7.9	8.8	13.5
October	6.3	5.8	7.6	6.9
November	-3.1	-13.7	-5.9	1.0
December	-9.4	-6.9	-3.3	-3.9
Annual mean	3.8	3.1	5.7	7.1

Table III.2. Monthly precipitation (mm) for the Brooks study site.

Month	1951-1980 Average	1985	1986	1987
January	21.9	3.4	0.6	4.3
February	14.4	15.1	19.5	4.3
March	16.0	11.3	11.5	28.1
April	26.0	79.9	10.8	11.6
May	38.3	13.2	54.3	26.8
June	65.7	22.0	30.5	22.1
July	32.2	38.8	62.9	43.2
August	40.1	53.4	12.8	102.6
September	33.8	123.5	140.6	15.7
October	13.4	26.8	25.4	6.8
November	14.9	18.1	15.4	6.0
December	18.7	1.6	3.4	6.4
Annual total	335.4	407.1	387.6	277.9

Table III.3. Monthly temperature (^{o}C) for the Kinsella study site.

Month	1951-1980 Average	1985	1986	1987
January	-16.9	-10.7	-6.6	-7.1
February	-11.4	-13.5	-14.0	-5.4
March	-6.9	-2.3	0.1	-6.0
April	3.2	5.1	3.6	7.1
May	10.4	12.1	11.9	12.3
June	14.2	12.5	14.9	17.0
July	16.7	17.9	15.0	16.9
August	15.6	14.5	16.3	13.2
September	10.4	6.9	8.5	13.3
October	4.9	3.6	6.8	5.5
November	-5.2	-14.2	-9.3	0.2
December	-12.4	-7.8	-6.8	-6.1
Annual mean	1.9	2.0	3.4	5.1

Table III.4. Monthly precipitation (mm) for the Kinsella study site.

Month	1951-1980 Average	1985	1986	1987
January	19.6	21.8	12.6	1.3
February	11.8	10.0	8.0	18.4
March	15.7	3.2	23.2	15.7
April	26.2	23.8	17.8	28.6
May	40.3	59.0	24.7	24.8
June	82.3	56.2	60.4	33.8
July	75.8	22.0	115.5	83.9
August	60.0	70.5	20.8	79.8
September	38.6	32.6	62.7	31.0
October	16.7	46.0	16.0	11.0
November	15.7	14.9	24.0	6.8
December	18.9	36.2	9.0	9.0
Annual total	421.6	376.2	394.7	344.1

Table III.5. Monthly temperature (^{o}C) for the Stavely study site.

Month	1951-1980 Average	1985	1986	1987
January	-9.9	-5.7	1.6	-1.0
February	-5.4	-7.1	-7.9	-0.2
March	-2.1	0.8	5.6	0.1
April	4.4	7.1	5.6	8.7
May	10.6	12.6	11.4	12.2
June	14.8	14.0	16.2	16.7
July	18.1	19.9	15.5	16.2
August	16.9	15.6	17.2	13.6
September	12.0	8.3	8.1	13.5
October	7.2	6.0	8.5	7.3
November	-0.9	-12.6	-3.5	2.9
December	-5.8	-3.1	0.3	-2.5
Annual mean	5.0	4.7	6.6	7.3

Table III.6. Monthly precipitation (mm) for the Stavely study site.

Month	1951-1980 Average	1985	1986	1987
January	29.4	6.5	1.0	7.0
February	20.9	20.0	35.6	3.0
March	27.2	16.4	10.4	33.0
April	49.6	46.5	19.6	16.2
May	46.3	30.3	65.2	11.9
June	81.7	11.0	52.9	34.7
July	45.8	23.0	43.1	109.8
August	67.6	61.8	34.3	78.6
September	37.8	65.4	123.0	16.1
October	19.5	20.6	15.9	7.4
November	21.6	46.6	30.8	9.2
December	28.6	17.0	3.0	9.6
Annual total	476.0	365.1	434.8	336.5

Table III.7. Water (mm) at field capacity and wilting point for the three study sites.

	Brooks		Kinsella		Stavely	
Depth Increment (cm)	Field Capacity	Wilting Point	Field Capacity	Wilting Point	Field Capacity	Wilting Point
0-10	26	12	33	21	37	30
0-30	93	44	91	53	79	56
30-50	83	46	62	30	65	36
50-80	125	66	97	43	115	58
0-80	301	156	250	126	259	150

BIBLIOGRAPHY

Atmospheric Environment Services. 1985-1987. Monthly record: meteorological observations in western Canada. Vols. 70, 71, 72. Environment Canada.

Withers, B. and Vipond, S. 1980. Irrigation design and practice. Cornell Univ. Press. Ithaca, NY. 306 pp.