UNIVERSITY OF ALBERTA

THE EFFECT OF LITTER ON THE HERBAGE GROWTH CYCLE, SOIL WATER, AND SOIL TEMPERATURE IN THE ASPEN PARKLAND OF ALBERTA

BY

BARRY DAVID IRVING ©

A THESIS
SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH
IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE
OF MASTER OF SCIENCE

IN
RANGE SCIENCE

DEPARTMENT OF PLANT SCIENCE

EDMONTON, ALBERTA
FALL 1992

ISBN 0-315-77084-8

UNIVERSITY OF ALBERTA

RELEASE FORM

NAME OF AUTHOR: BARRY DAVID IRVING

TITLE OF THESIS: THE EFFECT OF LITTER ON THE HERBAGE GROWTH CYCLE, SOIL WATER, AND SOIL TEMPERATURE IN THE ASPEN PARKLAND OF ALBERTA

DEGREE: MASTER OF SCIENCE

YEAR DEGREE GRANTED: 1992

Barry Irving
#14, 51313, Range Road 231
Sherwood Park, Alberta
T8B 1K7

Dated: OCTOBER 7 1992

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 EFFECT OF LITTER ON THE HERBAGE GROWTH CYCLE, SOIL WATER, AND SOIL TEMPERATURE IN THE ASPEN PARKLAND OF ALBERTA here submitted by BARRY DAVID IRVING in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE in RANGE SCIENCE.

....
Arthur Bailey, Supervisor

....
David Chanasyk

....
Jane King

....
Anne Naeth

Dated: 1992

This thesis is dedicated to my father
Cecil Gordon Irving

He didn't say much, but then he didn't have to

ABSTRACT

Historical studies of rangeland productivity have concentrated on the effect of defoliation intensity on peak herbage productivity. Planning for intensive management of rangeland requires knowledge of seasonal herbage production. The purpose of this study was to examine the association between litter accumulation (which is inversely related to defoliation intensity) and seasonal herbage growth, soil water, and soil temperature. Herbage growth, soil water, and soil temperature were studied along a litter gradient in the Neutral Hills, north of Kirriemuir, Alberta, 52°15"N 110°15"W (400 km southeast of Edmonton).

Total litter accumulations were 140 (light), 660 (moderate), and 1490 (heavy) kg/ha. Litter accumulation had a significant effect on plant species composition, mainly because of the effect on the productivity of plains rough fescue (Festuca hallii (Vasey) Piper). Plains rough fescue contributed 75, 44, and 36% of peak herbage production under heavy, moderate, and light litter accumulations, respectively. Litter accumulations resulted in significantly higher peak production of plains rough fescue, total grasses, and total herbage, but had no significant effect on the production of forbs and other grasses. Total herbage production was highest under heavy litter accumulations (1200 kg/ha), medium under moderate litter accumulations (920 kg/ha) and lowest under light litter accumulations (720 kg/ha). Total herbage production was controlled by the productivity of plains rough fescue, which declined from 850 kg/ha (heavy), to 460 kg/ha (moderate), to 260 kg/ha (light litter accumulations).

Soil water and soil temperature were also associated with litter cover. As litter cover decreased, soil water decreased and soil temperature magnitude and amplitude increased, resulting in a less favourable environment for plant growth. Growth of plains rough fescue, other grasses, total grasses, and total herbage were correlated with soil water, while forb growth was correlated with time during

the growing season. Production of plains rough fescue, other grasses, total grasses, and total herbage was highly correlated with soil water, time during the growing season, and litter, while forb production was poorly correlated with litter.

Livestock distribution within an intensively managed series of paddocks was also studied. Utilization by livestock within 130 ha paddocks (0.4 x 3.2 km) can best be described as a wave of defoliation. Areas closest to water were defoliated earliest and heaviest, while areas farther away from water were defoliated later and lighter. Livestock selectivity was not removed by intensive management, but was masked by the rapid rate at which defoliation occurred.

ACKNOWLEDGEMENTS

No thesis is possible without the efforts and support of a great number of people. I would like to thank Dr. Anne Naeth for encouraging me to pursue a graduate degree. She pushed me off the fence, and although there were times when I wondered, I am grateful to her for doing so. To my program supervisor, Dr. A.W. (Art) Bailey, I am eternally grateful. It was because of his flexibility and sacrifice that I was given the opportunity to initiate and complete a graduate program. Well timed words of encouragement and an open willingness to help were a great inspiration. The remaining two members of my committee, Dr. David Chanasyk and Dr. Jane King also made significant contributions to my program. David Chanasyk was very influential in the initial stages of designing and implementing my field study and for that I give him my thanks. Different members of my committee gave varying types of guidance, all of which came together to form a solid advisory team. David Chanasyk and Anne Naeth paid close attention to detail while Art Bailey and Jane King were very helpful in dealing with generalities. The two styles complemented each other nicely.

Field research is very difficult to do alone, and I was fortunate to have enthusiastic, consciencious, personable summer staff to help me collect field data. Julie MacDougall, Brian Olson, and Karen Sundquist were instumental people in the collection of field data. They made my summer tasks easy and enjoyable and for that I am grateful.

Financial support for this project came from matching monies made available through the Government of Alberta for contributions made to the University of Alberta by NOVA Corporation of Alberta. Although the details are complicated, I am grateful to both parties for the funds provided.

I also owe a great deal of thanks to Dr. K.G. Briggs, Chairman of the Department of Plant Science, for allowing me to pursue a graduate degree while maintaining my technologist's position within the Department. Flexibility and understanding on his part were required before this project could even be initiated.

I am forever in debt to Pat and Irene Rutledge. Together, with Shawn and Susan, they showed me the meaning of rural hospitality. The Rutledge Cattle Company is the most innovative livestock operation I have ever witnessed, and that, along with the scale of operation, provided unique research opportunities that simply were not available elsewhere. I learned a great deal from my study, but there are countless insights and experiences not contained in this thesis, that I learned from Pat and the other members of the Rutledge Cattle Company.

Finally, I would like to thank some very important people. My wife, Judy, and two girls, Michelle and Lindsay, endured many lonely days (at least they were lonely for me). Judy was faced with long periods of time where she was the sole recipient of all the stress and frustation that two boisterous children can generate. She never waivered and never complained. I owe her a great deal of thanks for her strong support.

TABLE OF CONTENTS

I. INTRODUCTION ---------- 1
Grazing Behaviour ---------- 1
Grazing Effects ---------- 2
OBJECTIVES ---------- 5
LITERATURE CITED ---------- 7
II. SITE SELECTION AND CHARACTERIZATION
STUDY SITE ---------- 10
Climate ---------- 10
Geology ---------- 10
Soils ---------- 11
Vegetation ---------- 11
Soils-Vegetation Interaction ---------- 12
METHODS FOR SITE CHARACTERIZATION
Site Selection ---------- 13
Data Collection ---------- 14
Data Analysis ---------- 16
RESULTS ---------- 16
DISCUSSION ---------- 18
CONCLUSIONS ---------- 19
LITERATURE CITED ---------- 23
III. THE EFFECT OF LITTER ON HERBAGE GROWTH AND SOIL WATER, AND THEIR INTERACTIONS
INTRODUCTION ---------- 24
OBJECTIVES ---------- 27
STUDY SITE ---------- 28
Climate ---------- 28
Geology ---------- 28
Soils ---------- 29
Vegetation ---------- 29
Soils-Vegetation Interaction ---------- 30
METHODS
Site Selection ---------- 31
Definitions ---------- 32
Data Collection ---------- 33

Data Analysis ---- 34
RESULTS ---- 35
DISCUSSION ---- 38
CONCLUSIONS ---- 43
LITERATURE CITED ---- 50
IV. THE EFFECTS OF LITTER ON SOIL TEMPERATURE
INTRODUCTION ---- 53
STUDY SITE ---- 54
Climate ---- 54
Geology ---- 55
Soils ---- 55
Vegetation ---- 56
Soils-Vegetation Interaction ---- 57
METHODS
Data Collection ---- 57
Data Analysis ---- 58
RESULTS ---- 59
DISCUSSION ---- 61
CONCLUSIONS ---- 63
LITERATURE CITED ---- 69
V. GRASS UTILIZATION AND GRAZING DISTRIBUTION WITHIN INTENSIVELY MANAGED GRAZING PADDOCKS
INTRODUCTION ---- 71
STUDY SITE ---- 72
Climate ---- 72
Geology ---- 72
Soils ---- 73
Vegetation ---- 73
Soils-Vegetation Interaction ---- 74
METHODS
Site Selection ---- 75
Data Collection ---- 76
RESULTS ---- 76
DISCUSSION ---- 77
CONCLUSIONS ---- 80
LITERATURE CITED ---- 84

VI. GENERAL DISCUSSION
LITTER ACCUMULATIONS -- 86
Management Implications -- 86
LIVESTOCK DISTRIBUTION -- 87
Management Implications -- 87
APPENDIX A. SCHEMATIC MAPS OF THE STUDY AREA. -------------- 88
APPENDIX B. DETAILED SOIL WATER DATA. ---------------------------- 89

LIST OF TABLES

II-1 Litter accumulation (kg/ha). ---------- 20
II-2 Percent plant species composition (by weight). ---------- 21
II-3 Soil bulk density (Mg/m^3). ---------- 21
II-4 Particle size distribution (%) and soil organic matter (%) for the upper 15 cm. ---------- 22
II-5 Precipitation (mm) for the 1990 and 1991growing seasons. ------ 22
III-1 Peak (1 August) herbage production (kg/ha) by herbage group. 44
III-2 Volumetric soil water (%) at two depth intervals. ---------- 45
III-3 Depletion of soil water (cm) at selected depth intervals between May 1 and October 1 averaged over 1990 and 1991. ---------- 47
III-4 Herbage growth as related to volumetric soil water and time. ---- 48
III-5 Herbage production as related to soil water, time, and litter. ----- 49
V-1 Herbage (kg/ha) at the beginning of the grazing period and utilization (percent disappearance measured by clipping at the end of the grazing period) by distance from water. ---------- 81
V-2 Comparison of clipped and visual estimates of utilization at the end of the grazing period. ---------- 83

LIST OF FIGURES

III-1 Soil water (%) at two depth intervals and herbage production by month for three accumulations of litter. ---------------------------- 46

IV-1 Total grass and total herbage production from 1 May to 1 October, 1991, under two levels of litter accumulation. ------------- 64

IV-2 Soil water at the surface and 15-40 cm depth interval for two levels of litter accumulation (1991 only). ------------------------------ 65

IV-3 Running (three day) average daily mean temperature (C) for air and soil at two depths under two levels of litter accumulation (1990 and 1991 averaged). ---------------------------- 66

IV-4 Diurnal air and soil temperatures (5 and 15-cm depth) for early, middle, and late growing season under moderate and heavy litter accumulations (1990 and 1991 averaged). ------- 67

IV-5 Diurnal air and soil temperatures (5 and 15-cm depth) for days with maximum daily temperatures exceeding 30^{0}C under moderate and heavy litter accumulations. -------------------- 68

V-1 Percent utilization (visually estimated) by distance from water and day of grazing in intensively managed paddocks. ----- 82

I. INTRODUCTION

Specialized grazing systems are gaining support for increasing range productivity while maintaining range condition through improved livestock distribution and control of the intensity, season, and duration of defoliation. With the promotion of more intensive grazing systems comes the need for more detailed information concerning herbage growth and the effects of utilization. Historical productivity studies have concentrated on comparisons of peak production, with little attention paid to variations in production occuring within seasons (Van Poolen and Lacey 1979). Intensive management requires knowledge of the herbage growth cycle, yet this information is lacking for major Alberta range types. Little research examined the effect of livestock selectivity on grazing intensity gradients within individual fields. How and if utilization gradients affect subsequent herbage production and growth is not well understood. Knowledge of the herbage growth cycle, and how it may be affected by utilization gradients is extremely important for effective management and long term planning of Alberta rangelands.

Grazing Behaviour

Slope length and steepness, distance from water, and the presence of brush have all been listed as factors affecting livestock distribution on rangeland (Mueggler 1965, Cook 1966, Roath and Krueger 1982, Gillen, Krueger, and Miller 1984). It is difficult to separate the factors and evaluate them individually (Cook 1966). Gillen, Krueger, and Miller (1984) found that cattle preferred areas within 200 m of water and avoided areas farther than 600 m away from water. A change from continuous grazing to deferred-rotational grazing did not appreciably change the grazing pattern. Roath and Krueger (1982) speculated that when other factors influencing livestock distribution were not limiting, distance from water ultimately controlled the outer limits of vegetation utilization. They found that utilization approached zero at a distance of about 1900 m from water, on relatively level rangeland. In areas of steeper terrain and variable vegetation types, the distance from water of zero utilization would be reduced. Recently, the use of short duration grazing (SDG) has become popular as a method to evenly distribute grazing pressure. Increased stock density has been associated with (although not quantified) more even utilization in intensively managed grazing systems (Kothmann 1980). Kirby, Pessin, and Clamby (1986) found that grazing uniformity in pastures containing five major plant communities did not differ significantly between SDG and repeated season-long grazing treatments. The effects of field size and varying vegetation on grazing distribution requires further research.

Grazing Effects

The direct effects of grazing intensity on plant development have been well documented for several species. Variable plant responses caused by the interaction among intensity, season, frequency, and distribution of livestock use makes interpretation of plant responses difficult (Ogden 1980). It has generally been accepted that heavy defoliation during the active growing period is detrimental to individual plant vigor. Heavy grazing during the growing season of Festuca-Stipa grassland reduces productivity and lowers range condition (Bailey, Willoughby, and Irving 1987). Herbage yield, vigor, and total non-structural carbohydrates of western wheatgrass were all detrimentally affected by heavy utilization (Buwai and Trlica 1976). Rest following heavy grazing may compensate for the negative effects (Trlica, Buwai, and Menke 1977) with the amount of rest required for full recovery proportional to the degree of defoliation (modified by the timing of defoliation). Severely defoliated plants may require in excess of one full growing season for complete recovery, while moderately defoliated plants recover rapidly. In a comprehensive review, Van Poollen and Lacey (1979) concluded that adjustments in livestock numbers (synonymous with grazing intensity) had a greater effect on herbage productivity than did the implementation of a grazing system. They concluded that reducing grazing intensity was more beneficial than alternating the season of defoliation or providing rest from grazing. Grazing intensity was the primary factor limiting (controlling) rangeland productivity. In northern regions, where the growing season is compressed into 6-8 weeks, knowledge of the the herbage growth cycle is crucial for proper range management. Frank and Kofmann (1989) demonstrated that accumulated dry matter production on moderately grazed pastures exceeds that of heavily grazed pastures at all times during the growing season.

Soil water is affected by the processes of infiltration, evapotranspiration, and percolation. Grazing, because it directly affects the characteristics of the soil surface and indirectly affects the subsurface, affects the processes that control soil water. The effect of heavy stocking on infiltration capacity has been well documented (Johnston 1962, Rhoades et al. 1964, Rauzi and Smith 1973, Weltz and Wood 1986, Pluhar, Knight, and Heitschmidt 1987, Naeth et al. 1990b). Although ungrazed areas generally have a higher infiltration rate than do grazed areas, there is not a definite reduction in infiltration rates until heavy levels of grazing are reached (Gifford and Hawkins 1978); moderate and light grazing intensities have similar infiltration rates. Soil compaction caused by grazing reduces infiltration capacity (Naeth et al. 1990a). Heavy grazing, associated with higher animal impacts and spring grazing, associated with higher soil water (more susceptible to compaction) both cause higher levels of soil compaction (Naeth et al. 1990a) and lower infiltration capacities (Naeth et al. 1990b). Several studies have documented an inverse relationship between plant biomass and runoff (Branson and Owen 1970, Marston 1952, Hanson et al. 1970). Light or moderate grazing may actually increase soil water (compared to no grazing) by maintaining ground cover (and thus maintaining infiltration capacity) while reducing the transpiring surface (Liacos 1962a,b, Hanson et al. 1970, Lusby 1970, Naeth et al. 1991). Sharrow and Wright (1977) found burning of tobosagrass rangeland reduced the water content of the soil; they attributed this reduction to increased transpiration caused by increased herbage production. Clearly, soil water and herbage productivity are closely related, with variations occurring between vegetation types and defoliation regimes.

Litter (dead, relatively undecomposed plant material) accumulation on semi-arid grasslands modifies the soil climate and has corresponding effects on soil temperature. Grazing reduces litter accumulation through a combination of herbage removal and physical compaction (hoof action). Litter acts as an insulating layer and prevents high surface temperature (Hopkins 1954, Sharrow and Wright 1977). Uresk, Cline, and Rickard (1979) classified cheatgrass growth response into three temperature phases; limited, relatively unaffected, and inhibited. The limited phase is characterized by temperatures too low for optimul plant growth. The relatively unaffected phase occurs when temperatures are favourable, while the inhibited phase has excessive temperatures that retard plant growth (Sachs 1860 as cited by Stafelt 1960). An accumulation of litter would probably prolong the limited phase but shorten the relatively unaffected and inhibited phases. Range managers could manipulate the litter layer (by controlling defoliation intensity), and thereby manipulate the temperature induced growth phases. Early-season growth can be promoted by removal of the litter layer, if soil water is not limiting (Sharrow and Wright 1977).

Sneva (1977) reported a negative association between spring yields of crested wheatgrass and February and March air temperatures. Only April air temperatures had a positive relationship with spring yields. Sneva (1977) concluded that growth initiation in April was followed by favourable growing temperatures. Seasonally warm temperatures in late winter may have caused a reduction in spring production by stimulating growth initiation at a time when subsequent temperatures were not favourable for plant growth. He used air temperature, and did not study the effect of a litter layer, which may modify the temperature-growth relationship. In the event of warm, late-winter air temperatures, a litter layer might insulate against soil warming, inhibiting growth initiation, thus promoting spring growth. Conversely, if cool winter temperatures were followed by warm spring temperatures, a litter layer might reduce spring growth by retarding soil warming. Recently, growing degree days have been related to range plant development (Frank 1989). Once again, relationships have been developed using air temperature, which does not include a litter effect. Soil temperatures frequently have a more marked effect on growth than air temperatures (Evans, Wardlaw, and Williams 1964). This may be a result of the shoot apices and tiller buds lying close to the soil surface. The effect of grazing intensity on the litter layer and soil temperature of rangeland requires further investigation.

OBJECTIVES

The objectives of this study were:

1. To determine the effect of litter accumulation on:
   a. peak herbage production
   b. the herbage growth cycle
   c. total soil water

d. soil temperature

2. To determine if distance from stock water has an effect on the rate and degree of herbage disappearance under a short duration grazing system.

3. To provide baseline data for recommendations for:

   a. maximum distances to stock water

   b. optimum levels of litter accumulation.

LITERATURE CITED

Bailey, A.W., M.G. Willoughby, and B.D. Irving. 1987. Effect of grazing on forage and beef production from rough fescue rangeland in central Alberta. Alberta Farming For the Future Rep. 87-0099.

Branson, F.A. and J.R. Owen. 1970. Plant cover, runoff, and sediment yield relationships on Mancos shale in western Colorado. Water Resour. Res. 6:783-790.

Buwai, M. and M.J. Trlica. 1977. Multiple defoliation effects on herbage yield, vigor, and total non-structural carbohydrates of five range species. J. Range Manage. 30:164-171.

Cook, C.W. 1966. Factors affecting utilization of mountain slopes by cattle. J. Range Manage. 19:200-204

Evans, L.T., I.F. Wardlaw, and C.N. Williams. 1964. Environmental control of growth. pp. 102-125. IN: C. Barnard (ed). Grasses and Grasslands. MacMillan, London.

Frank, A.B. and L. Hoffman. 1989. Relationship among grazing management, growing degree days, and morphological development for native grasses on the Northern Great Plains. J. Range Manage. 42:199-202.

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

Gillen, R.L., W.C. Krueger, and R.F. Miller. 1984. Cattle distribution on mountain rangeland in north-eastern Oregon. J. Range Manage. 37:549-553.

Hanson, C.L., A.R. Kuhlman, C.J. Ericson, and J.K. Lewis. 1970. Grazing effects on runoff and vegetation on western South Dakota rangeland. J. Range Manage. 23:418-420.

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

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

Kirby, D.R., M.F. Pessin, and G.K. Clambey. 1986. Disappearance of forage under short duration and seasonlong grazing. J. Range Manage. 39:496-499.

Kothmann, M.M. 1980. Evaluation of livestock needs on designing grazing systems for rangeland. Chap. 6 Part B. IN: Digestive Physiology and Nutrition of Ruminants, D.C. Church (ed.), Vol 3. O&B Books, Inc. Corvallis, Or.

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

Liacos, L.G. 1962a. Soil moisture depletion in the annual grass type. J. Range Manage. 15:67-72.

Liacos, L.G. 1962b. Water yield as influenced by degree of grazing in the California winter grasslands. J. Range Manage. 15:24-42.

Lusby, G.C. 1970. Hydrologic and biotic effects of grazing vs. no grazing near Grand Junction, Colorado. J. Range Manage. 23:256-260.

Marston, R.B. 1952. Ground cover requirements for summer storm runoff control on aspen sites in northern Utah. J. For. 50:303-307.

Mueggler, W.F. 1965. Cattle distribution on steep slopes. J. Range Manage. 18:255-257.

Naeth, M.A., R.L. Rothwell, D.S. Chanasyk, and A.W. Bailey. 1990a. Grazing impacts on infiltration in Mixed Prairie and Fescue Grassland ecosystems of Alberta. Can. J. Soil Sci. 70:593-605.

Naeth, M.A., D.J. Pluth, D.S. Chanasyk, and A.W. Bailey. 1990b. Soil compacting impacts of grazing in Mixed Prairie and Fescue Grassland ecosystems of Alberta. Can. J. Soil Sci. 70:157-167.

Naeth, M.A., D.S. Chanasyk, R.L. Rothwell, and A.W. Bailey. 1991. Grazing impacts on soil water in Mixed Prairie and Fescue Grassland ecosystems of Alberta. Can. J. Soil Sci. 71:313-325.

Ogden, P.R. 1980. Meeting the physiological requirements of a plant with grazing systems. Proc. Graz. Manage. Systems Southwest Range. Symp., Albuquerque, N.M.

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

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

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

Roath, L.R. and W.C. Kruegger. 1982. Cattle grazing and behaviour on a forested range. J. Range Manage. 35:332-338.

Sachs, J. 1860. 'Physiologische Untersechengen uber die Abhangigkeit der Keimung von der Temperatur'. Fb. wiss. Bot. 2:338.

Sharrow, S.H. and H.A. Wright. 1977. Effects of fire, ash, and litter on soil nitrate, temperature, moisture, and Tobosograss production in the Rolling Hills. J. Range Manage. 30:266-270.

Sneva, F.A. 1977. Correlations of precipitation and temperature with spring, regrowth, and mature crested wheatgrass yields. J. Range Manage. 32:270-275.

Stafelt, M.G. 1960. Plant Ecology. English translation by M.S. Jarvis and P.G. Jarvis. William Clowes & Sons Limited, London.

Trlica, M.J., M. Buwai, and J.W. Menke. 1977. Effects of rest following defoliations on the recovery of several range species. J. Range Manage. 30:21-27.

Uresk, D.W., J.F. Cline, and W.H. Rickard. 1979. Growth rates of a cheatgrass community and some associated factors. J. Range Manage. 32:168-170.

Van Poolen, H.W. and J.R. Lacey. 1979. Herbage response to grazing systems and stocking intensities. J. Range Manage. 32:250-253.

Weltz, M. and M.K. Wood. 1986. Short duration grazing in central New Mexico: Effects on infiltration rates. J. Range Manage. 39:365-368.

II. SITE SELECTION AND CHARACTERIZATION

STUDY SITE

The study site was located in the Neutral Hills, north of Kirriemuir, Alberta $52^{0}15$"N $110^{0}15$"W (400 km southeast of Edmonton).

Climate

The climate of the study site is continental, characterized by long warm summer days and bright, cold winter weather (Wyatt and Newman 1938). Mean precipitation for Consort (about 30 km west of the study site) was 340 mm, 70% as rain during the growing season (May - September) and 30% as snow during the dormant season (October - April) (Environment Canada 1982b). Mean daily maximum and minimum temperatures were lowest in January (-13 and -24^{0}C, respectively) and highest in July (24 and 9^{0}C, respectively). Extreme maximum and minimum temperatures were 39 and -46^{0}C, respectively (Environment Canada 1982a). Potential evapotranspiration for the town of Coronation (100 km west of the study site) is 400 mm (Bothe and Abraham 1990). This yields a precipitation to potential evapotranspiration ratio of 0.85.

Geology

Bedrock geology of the study area consists of Upper Cretaceous rock of the Belly River series, the bedrock consisting of sandstones and shales of non-marine origin (Wyatt and Newton 1938). The subsurface geology has had little effect on surface soil formation as the area is covered with a thick layer of glacial till. The area was last glaciated by the Keewatin ice sheet about 10,000 years ago. Surficial deposits are glacial till that originated to the north-east of the study site, possibly as far away as Hudson's Bay. The Neutral Hills were formed at the western edge of the continental ice sheet currently known as the Viking Moraine. Melting ice sheets deposited glacial till in veneers up to several hundred feet thick. Kettles (depressions) were formed when ice blocks mixed with the morainal material melted. They often form small lakes or sloughs. The topography of the area is known as Knob and Kettle, with numerous short steep slopes and accompanying depressions.

Soils

Soils of the study site are moderately well drained loams and are classified as Orthic Dark Brown Chernozems. They are members of the Kirriemuir soil series (Kjearsgaard 1976). Soils of the Kirriemuir series occupy the mid and lower slope positions. These soils are characterized by a friable structure, caused by a low concentration of carbonates in the A and B horizons (Kjearsgaard 1976). The Kirriemuir soil series is associated with Rego Dark Brown Chernozems (Altario soil series) which are found on the tops of the slopes and on dry, exposed slopes, and Gleysols which are found in the depressions (Kjearsgaard 1976).

Vegetation

The Neutral Hills are located on the boundary between the Mixed Prairie and Aspen Parkland vegetation associations. Vegetation in the Neutral Hills consists of Festuca-Stipa grasslands (Looman 1981, Coupland 1961) on south facing slopes and flat areas interspersed with aspen groves on north facing slopes. Festuca-Stipa grasslands are dominated by Festuca hallii (Vasey) Piper (Pavlick and Looman 1984) (plains rough fescue) on ungrazed sites, with Stipa curtiseta(A.S. Hitchc.) Barkworth (western porcupine grass) being a codominant on grazed areas. Other common species include Carex obtusata Lilj. (dryland sedge), Agropyron albicans Scribn. & Smith (thickspike wheatgrass), Koeleria macrantha (Ledeb.) J.A. Schultes f. (junegrass), Anemone patens L. (prairie crocus), Cerastium arvense L. (chickweed), Thermopsis rhombifolia (Nutt.) Richards. (golden bean), and Artemisia frigida Willd. (pasture sage). Festuca-Stipa grasslands that are not grazed or otherwise disturbed for extended periods are heavily dominated by plains rough fescue, almost to the total exclusion of all other species.

Some exposed slopes are occupied by a Stipa-Agropyron range type (Coupland 1961). The dominant species of this range type are western porcupine grass and Agropyron dasystachyum (Hook.) Scribn. (northern wheatgrass). Stipa comata Trin. & Rupr. (speargrass) and Agropyron smithii Rydb. (western wheatgrass) are also quite common. Low lying areas are dominated by wetland vegetation. Lowland vegetation consists mainly of Carex spp. L. (sedges) with Glyceria grandis S. Wats. *ex* A. Gray (tall manna grass) and Calamagrostis spp. Adans. (reedgrasses) being locally abundant. The physiognamy of the area is about 70 percent grassland and 30 percent forest.

Soils-Vegetation Interaction

Vegetation and soils in the study area followed a predictable pattern. Festuca-Stipa grassland was associated with soils of the Kirriemuir soil series (Orthic Dark Brown Chernozems) and occupied most south facing slopes and flat areas that had not been invaded by aspen. Vegetation considered to represent the Stipa-Agropyron range type was not common, occurring only on a few dry, exposed slopes. Vegetation of the Stipa-Agropyron range type occurred in association with soils of the Altario soil series (Rego Dark Brown Chernozems). Wetland vegetation was associated with Gleysolic soils and was common only in depressions.

METHODS FOR SITE CHARACTERIZATION

Site Selection

The study site was located on a private ranch (Rutledge Cattle Company) that consisted of about 13,000 ha of deeded and lease land. The main livestock enterprise of the ranch was cow/calf, with periodic backgrounding of steers and heifers depending on market and forage production conditions. Continuous (season-long) grazing was the main grazing system employed on the ranch (for 40-50 years) prior to 1988. In 1988 grazing management on the ranch was intensified, and an extensive fencing and stock water development program (wells) was initiated. At the end of 1989, most of the ranch had been crossfenced into 130 ha paddocks, each with a supplied water source. The most common fencing pattern was to fence large areas into squares of 260 ha in size (equal to one section, 640 acres, by the dominion land survey) and then split those areas in half by a diagonal fence. This resulted in maximum distances to stock water of 2.2 km (1.4 mile). This fencing pattern (see Appendix A) allowed the maximum number of paddocks to be serviced from a single well. Livestock management consisted of sequentially moving a herd of about 1000 cow/calf pairs through a series of paddocks (five days stay in each paddock). Usually, paddocks were only grazed once per year.

An anomoly of management occurred in an isolated area of the ranch. A bank of hills (rising about 100 m above the rest of the ranch) occurred on the northern boundary of the ranch. Three shallow wells (30-m depth) were drilled in a natural saddle in the hills. The combined rate from the three shallow wells was sufficient to supply water to the herd of 1000 cow/calf pairs. Additional wells drilled throughout the hills were dry. Consequently, the cluster of wells in the saddle in the hills was the only source of stock water. To maintain field sizes similar to those of the rest of the ranch, the area serviced by the wells (1.6 x 3.2

km) was fenced into four paddocks. The dimensions of the paddocks were 0.4 x 3.2 km (130 ha). Paddocks not directly attached to the water source were accessed by the cattle via an alleyway. Historical water sources (dams and dugouts) were located in similar areas as the current water source (well) (Pat Rutledge 1989, 1990, 1991, personal communication). The historical water sources had sufficient water volume to service the smaller herds used under the old continuous grazing system (about 250 cow/calf pairs). However, surface water was not sufficient under the new grazing system because of a series of dry years and increased demands of the larger herd (1000 cow/calf pairs). The configuration of the current fields, combined with historical grazing distribution, resulted in litter accumulations that varied from light close to the water sources to heavy at the far end of the fields.

Data Collection

Intensive sampling sites were established in one of the fields, which was arbitrarily divided into three zones based on the amount of litter present. The zones of the field were visually classified as light (little or no litter cover), moderate (moderate amount of litter cover), and heavy (heavy litter cover). Visual classification was done by visually estimating the amount of litter present in each zone. This entailed determining the zones of light and heavy litter cover first and then locating the zone of moderate litter cover (intermediate between light and heavy). All sampling sites were restricted to Festuca-Stipa grassland, the dominant vegetation type of the area, and modal soils (Orthic Dark Brown Chernozems). To be considered appropriate for study, each site had to be uniform in litter accumulation, have relatively homogeneous vegetation, and be at least 10 x 20 m in size. Within each zone, four sample sites were selected, two on south facing slopes and two on flat areas. Randomness of sample sites was restricted by the small number of appropriate sites available for study.

Undecomposed litter was sampled from random quadrats in early May, while green growth was at a minimum. In each year of the study (2 years), five quadrats (50 x 50 cm) per site (four sites) in each zone (three) were randomly located and hand harvested. Litter was sorted to standing and fallen. Standing litter was defined as growth from previous years that was still attached to the base of the plant. Fallen litter was defined as that not attached to the plant and was relatively undecomposed (i.e. recognizable as plant material and/or plant parts). Fallen litter was manually separated from soil and decomposed plant material in the field based on particle size and recognition as plant material. Particles of recognizable plant material were picked by hand out of raked material from sample plots. Most decomposed plant material was separated from fallen litter by hand sifting the samples through outstretched fingers. A final visual inspection of sifted material was conducted and any recognizable plant material was picked out by hand. Litter samples were oven dried (70^{0}C, 48 hours) and weighed.

Plant species composition was estimated in early August 1991 through a combination of clipping and visual field estimation. In each litter accumulation zone, eight plots were mechanically clipped (1 cm stubble height) and hand sorted to plains rough fescue, other grass and grasslikes, palatable forbs, unpalatable forbs, and standing litter. The percentage of each species in each class was visually estimated in the field. Each bag was oven dried (70^{0}C, 48 hours) and weighed and the weight of each species calculated from the percentage estimates made in the field. This procedure yielded an estimate of actual weight of each species for each plot. Species composition was calculated from the weight estimates.

At each sample site, three neutron probe access tubes were installed to measure soil bulk density with a 501 Campbell Scientific moisture/density probe, calibrated for soils of the region. This gave a total sampling intensity of 12 access tubes per litter accumulation zone. Soil bulk density measurements were made from a depth of 15 cm and in 10-cm increments to a maximum depth of 65 cm.

Soil samples were taken at each site in August 1991. A single composite slice of soil (15 cm wide by 5 cm deep) from a depth of 5-15 cm was collected in the center of each site. Soil samples were analysed for sand, silt, and clay (hydrometer method) and for total organic carbon (Leco method) (McKeague 1978). Soil organic matter was calculated from total organic carbon (percent organic matter = percent total organic carbon x 1.8) (McKeague 1978).

A data logger, located at the study area, was installed to continuously record precipitation. The furthest distance between any sample site and the data logger was 3 km.

Data Analysis

Significant effects for litter accumulation were detected using analysis of variance techniques. Means for species composition, precipitation, and soil bulk density, particle size distribution, and organic matter were generated but not analysed using analyses of variance. These parameters were only collected for site characterization; sample sizes were not sufficient to warrant in depth analyses. All analyses followed convention as outlined in the SPSS-X User's Guide, 3rd Edition (SPSS Inc 1988).

RESULTS

In all three litter classes (standing, fallen and total) there was a significant year effect (Table II-1). A heavy defoliation by cattle during the 1991 growing season removed a substantial portion of the litter base. The litter gradient, from light to moderate to heavy accumulations, was also significant for all litter classes. Aspect had no significant effect on litter accumulations. Although all classes of litter were reduced by a heavy defoliation by cattle at all points along the litter gradient from 1990 to 1991, only standing and total litter under heavy litter accumulations were significantly reduced. The lack of significance between 1990 and 1991 under moderate and light litter accumulations was probably a result of low initial litter levels. A heavy defoliation by cattle (as occurred in 1991) would have a greater effect on heavy litter accumulations than on light and moderate litter accumulations. The Year x Accumulation interaction was not significant for fallen litter. The same trends of reduced litter along the litter gradient and reduced litter between 1990 and 1991 were apparent, but sampling was not sufficient to demonstrate a significant effect.

Plains rough fescue was the community dominant on all sites (Table II-2). However, the level of dominance was higher on sites with a large litter accumulation, with plains rough fescue contributing 75 % of the total production on those sites. Upland sedge, prairie crocus, and chickweed decreased in percent composition with increasing levels of litter. Thickspike wheatgrass had similar composition under all litter levels. The composition of other forbs was stable under light and moderate litter levels, but increased under light litter cover.

There were no significant differences in soil bulk density among the three litter accumulation levels (Table II-3). There was a general trend of higher bulk density at greater depths, a normal pattern for undisturbed native soils, but this was not tested statistically. There were no significant differences in bulk density among the three sites.

Neither organic matter nor sand, silt, and clay distribution varied significantly among litter accumulation levels (Table II-4). Soils in the study area were classified as loams and sandy loams, with high levels of organic matter accumulation.

Precipitation during the growing seasons of the study years is shown in Table II-5. Precipitation in May 1990 was not measured because of a malfunction in the data logger. However, very little rainfall occurred in May 1990 in the study area. A late spring snow storm occurred in late April 1991, just prior to installation of the data logger. Approximately 30 cm of snow occurred during the storm, roughly equivalent to between 30 and 50 mm of additional water (assuming a ratio of 10:1, snow:water and adjusting on the high side because it was a wet spring snow). Precipitation considered effective for plant growth (April-July) was higher in 1991 (180 mm) than in 1990 (144 mm).

DISCUSSION

The establishment of a signficant litter gradient was crucial to the completion of the study, as all subsequent data collection and analyses depended on the existence of this gradient. Season-long grazing had been applied to the study site for over 50 years before the SDG system was implemented (Pat Rutledge 1990, personal communication). Coincidentaly, the current and historical stock water sources were in similar locations. This resulted in grazing patterns under the old continuous grazing system and the current intensive system being quite similar. The observed litter gradient existed because of livestock selectivity for areas close to water and a reduction in grazing pressure as distances from water increased.

Of the parameters sampled the only one that showed differences between litter accumulation zones was species composition. The response of <u>Festuca</u>-

Stipa grassland to grazing has been documented (Bailey, Willoughby, and Irving 1988). High levels of herbage removal and growing season grazing tend to cause a decrease in the dominance of plains rough fescue (Bailey, Willoughby, and Irving 1988). Along the litter gradient examined in this study, the dominance of plains rough fescue declined as litter accumulation declined (indicating a heavier level of past grazing).

CONCLUSIONS

1. A significant litter gradient existed in the study area.
2. Plant species composition varied with litter accumulation. Heavy litter accumulation was associated with dominance of plains rough fescue.
3. Measured soil parameters (bulk density, organic matter, and sand, silt, and clay distribution) did not differ significantly among study sites.

Table II-1. Litter accumulation (kg/ha).

		Litter Type		
Effect		Standing	Fallen	Total
Year				
	S.E.	30	48	59
	Significance	0.000	0.000	0.000
	1990	370 a	640 a	1000 a
	1991	130 b	390 b	520 b
Accumulation				
	S.E.	37	59	72
	Significance	0.000	0.000	0.000
	Light	10 c	130 c	140 c
	Moderate	170 b	490 b	660 b
	Heavy	570 a	920 a	1490 a
Year x Accumulation				
	S.E.	53	84	102
	Significance	0.000	0.067	0.000
1990	Light	0 c	160	160 c
	Moderate	210 b	600	810 b
	Heavy	890 a*	1170	2060 a*
1991	Light	10 b	100	120 c
	Moderate	130 ab	390	510 b
	Heavy	250 a	680	930 a

1. Means within columns and effects followed by the same letter are not significantly different according to an SNK multiple range test (0.05 level).
2. An * indicates a significant difference between year means in the Year x Accumulation interaction.

Table II-2. Percent plant species composition (by weight).

Scientific Name	Common Name	Litter Accumulation Light	Moderate	Heavy
Grasses				
Festuca hallii	Plains rough fescue	36	44	75
Agropyron albicans	Thick spike wheatgrass	11	13	9
Carex obtusata	Upland sedge	22	18	6
Koeleria macrantha	Junegrass	7	1	0
Stipa curtiseta	Western porcupine grass	0	6	2
Poaceae spp.	Other grasses	1	2	1
Forbs				
Anemone patens	Prairie crocus	3	4	1
Cerastium arvense	Chickweed	4	1	0
Thermopsis rhombifolia	Buffalo bean	3	7	2
Artemisia frigida	Pasture sage	2	1	0
	Other forbs	11	3	4

Table II-3. Soil bulk density (Mg/m^3).

Litter Accumulation	Depth (cm) 15	25	35	45	55	65
Light	1.03	1.18	1.35	1.37	1.43	1.50
Moderate	1.20	1.25	1.35	1.30	1.37	1.50
Heavy	1.17	1.22	1.37	1.41	1.38	1.42
Mean	1.13	1.22	1.36	1.36	1.39	1.47

n=12 access tubes per litter accumulation.
Means are site averaged.

Table II-4. Particle size distribution (%) and soil organic matter (%) for the upper 15 cm.

	Litter Accumulation			
Soil Parameter	Light	Moderate	Heavy	S.E.
Sand	51	55	51	3
Silt	32	31	31	1
Clay	17	14	18	2
Organic Matter	5.4	5.1	5.4	0.2

Table II-5. Precipitation (mm) for the 1990 and 1991 growing seasons.

	Year		1951-1980
Month	1990	1991	Average
May	NA	30	36
June	85	98	68
July	59	52	61
August	4	37	47
September	NA	2	28
Total	148	219	240

NA Not available.
1990 and 1991 precipitation collected on site.
1951-1980 average precipitation from Consort, 30 km west of study site.

LITERATURE CITED

Bothe, R.A. and C. Abraham. 1990. Evaporation and evapotranspiration in Alberta, 1986 to 1988, Addendum. Alberta Environment, Edmonton, Alberta.

Environment Canada. 1982. Canadian Climate Normals Volume 2: Temperature 1951-1980. Ottawa, Ontario.

Environement Canada. 1982. Canadian Climate Normals Volume 3: Precipitation 1951-1980. Ottawa, Ontario.

Kjearsgaard, A.A. 1976. Soil survey of the Oyen map sheet (72M). Alta. Soil Survey Rep. 36. Agriculture Canada, Edmonton, Alberta.

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

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

SPSS Inc. 1988. SPSS-X User's Guide, 3rd Edition. SPSS Inc, Chicago.

Wyatt, F.A. and J.D. Newton. 1938. Soil survey of Sullivan Lake sheet. University of Alberta, College of Agr. Bull. 31.

III. THE EFFECT OF LITTER ON HERBAGE GROWTH AND SOIL WATER, AND THEIR INTERACTIONS.

INTRODUCTION

Characteristics of plant growth have fascinated researchers since the very beginnings of science. The growth of rangeland plants, and the factors that control that growth, is still a developing area of research. Historically, research of rangeland growth has concentrated on peak productivity, and the various factors that affect it. Grazing intensity has often been the factor of most interest. Lacey and Van Poollen (1981) conducted an extensive literature review on the effects of moderate grazing on herbage production. They concluded that moderate grazing resulted in a decline in herbage production compared to protected areas on most western rangelands. Moderate grazing resulted in an increase in herbage production only when litter accumulations reached levels that impeded growth and plant development. This occurred only on highly productive sites, which had the capability of accumulating large levels of litter (Weaver and Rowland 1952, Kelting 1954). Litter accumulations did not impede herbage growth, and grazing resulted in a reduction in growth in the Fescue Grasslands of central Alberta (Bailey, Willoughby, and Irving 1987). Moderate grazing (40% herbage removal), in both the growing and dormant season resulted in only a slight decrease in growth (about a 10% reduction in herbage production compared to an ungrazed exclosure). Heavy grazing (70% herbage removal), in any season, resulted in a 40% reduction in herbage production. Litter levels were reduced in all heavily grazed treatments to near zero, while on moderately grazed treatments litter levels were about 500 and 1500 kg/ha for growing and dormant season grazing, respectively (Bailey, Willoughby, and Irving 1987). Willms, Smoliak, and Bailey (1986) tested the hypothesis that litter removal from ungrazed Alberta rangeland would result in a decrease in herbage production. They found that dormant season removal of litter resulted in a decrease in herbage production in the Mixed Prairie (a decline of 43%), but had no effect in the Fescue Prairie. Litter removal from Festuca hallii (Vasey) Piper (Pavlick and Looman 1984) (plains rough fescue) plants resulted in shorter plants with greater numbers of tillers than plants that did not have the litter removed (Willms, Smoliak, and Bailey 1986, Sinton 1980). An increase in tillering compensated for shorter blade lengths and production remained about the same. The effect of litter on herbage production may be related to soil water. Litter is important in preserving soil water in arid regions, but is of less importance (and may even retard growth) in more moist areas (Willms, Smoliak, and Bailey 1986). In areas of high productivity, litter may accumulate to such levels that it actually impedes growth (Weaver 1952). The insulating effect of litter against evaporation is of less importance in areas where moisture is not a limiting factor in plant growth.

Soil water is affected by litter in complex interactions, many of which are not fully understood. It is logical to assume that higher grazing intensities lead to lower levels of litter accumulation. Therefore, litter accumulation is directly influenced by grazing intensity. Soil water is determined by the input processes of precipitation and infiltration, the redistribution process of percolation, and the output processes of transpiration and evaporation. Grazing has varying effects on soil water, depending on local conditions. Houston (1967), working near Miles City, Montana, found no grazing effects on soil water on sandy soils but noted some significant effects on loam soils. Water accumulation in loam soils was less at depths greater than 70 cm on heavily grazed areas than on moderately grazed areas. This reduction was attributed to a combination of a reduction in infiltration (caused by compaction and sealing by livestock), reduced percolation (caused by fewer root channels, a result of more shallow rooted plants), and less litter cover.

In contrast to this, Buckhouse and Coltharp (1976), working on crested wheatgrass and alfalfa in Utah, found that plots totally denuded of vegetation had higher levels of soil water than control plots. Plots with intermediate levels of vegetation removal had intermediate levels of soil water. This was a clipping study and had no effect of livestock (compaction); it was also short term, so there were no changes in species composition. Consequently, it could be concluded that the observed differences in soil water were caused by a reduction in evapotranspiration on the denuded plots. It would appear that in the absence of grazing animals, a lower level of herbaceous production will result in higher soil water. However, lower levels of herbaceous production associated with grazing (Lacey and Van Poollen 1981) are often accompanied by lower levels of soil water (Johnston 1961, Houston 1967, Johnston et al. 1971, Smoliak et al. 1972, Naeth et al. 1991b). Two conclusions can be drawn from the literature. Livestock grazing usually results in a depression in herbaceous growth. Livestock grazing usually results in a reduction in soil water, even though the transpiring capability of the plant community is also reduced.

Numerous studies have related production to climatic data (Smoliak 1956, Rauzi 1964, Shiflet and Dietz 1974, Smoliak 1986), providing estimates of production based on growing season precipitation. Relating production to growing season precipitation is of little use to range managers if the estimates of production cannot be obtained early enough in the season to allow for stocking rate adjustments (Shiflet and Dietz 1974). Regression equations utilizing May and June precipitation to predict production may be of use in some areas and for some types of grazing enterprises, but not for others. The earlier the predictions can be made in the year, the more value they have for range management decisions. Rogler and Haas (1947) found previous fall soil water and also fall soil water plus growing season precipitation were related to annual production. In this study, correlations between fall soil water and production were improved from 0.74 to 0.84 by including spring precipitation as an independent variable. It is debatable whether the extra 10% in explained variation is worth a delay in the information provided. Global models, developed using past year yield and incorporating an estimate of current soil moisture, have produced accurate regression equations, predicting yield to within 18 to 19% of actual yield over large geographic areas (Wisiol 1984).

Water has been recognized as the limiting factor determining rangeland productivity. The relatively large number of studies utilizing precipitation data to predict production is probably a result of the widespread availability of climate data. Conversely, there have been few studies using soil water to predict production, probably because of the historic difficulties in measuring soil water and, consequently, fewer sources of long term soil water data. Soil water should be more closely correlated to production than precipitaiton. Numerous factors affect the movement of precipitation through the hydrologic cycle until it eventually becomes soil water available for plant growth. Precipitation timing, intensity, duration, and type as well as site factors such as soil texture, surface crusting, surface cover, and current soil water are just a few of the factors affecting the interception, infiltration, and percolation of precipitation. Rapid and accurate estimates of soil water can now be obtained using neutron probes. This will likely lead to less dependence on precipitation data and more use of soil water data to develop prediction equations for annual production and growth on a specific site basis.

OBJECTIVES

1. To compare the herbage growth cycle under a range of litter accumulations along a grazing gradient.

2. To compare seasonal soil water over a range of litter accumulations along a grazing gradient.
3. To develop regression equations to predict herbage growth and standing crop from variables measured early in the growing season.

STUDY SITE

The study site was located in the Neutral Hills, north of Kirriemuir, Alberta 52°15"N 110°15"W (400 km southeast of Edmonton).

Climate

The climate of the study site is continental, characterized by long warm summer days and bright, cold winter weather (Wyatt and Newman 1938). Mean precipitation for Consort (about 30 km west of the study site) was 340 mm, 70% as rain during the growing season (May - September) and 30% as snow during the dormant season (October - April) (Environment Canada 1982b). Mean daily maximum and minimum temperatures were lowest in January (-13 and -24°C, respectively) and highest in July (24 and 9°C, respectively). Extreme maximum and minimum temperatures were 39 and -46°C, respectively (Environment Canada 1982a). Potential evapotranspiration for the town of Coronation (100 km west of the study site) is 400 mm (Bothe and Abraham 1990). This yields a precipitation to potential evapotranspiration ratio of 0.85.

Geology

Bedrock geology of the study area consists of Upper Cretaceous rock of the Belly River series, the bedrock consisting of sandstones and shales of non-marine origin (Wyatt and Newton 1938). The subsurface geology has had little effect on surface soil formation as the area is covered with a thick layer of glacial till. The area was last glaciated by the Keewatin ice sheet about 10,000 years ago. Surficial deposits are glacial till that originated to the north-east of the study site, possibly as far away as Hudson's Bay. The Neutral Hills were formed at the western edge of the continental ice sheet currently known as the Viking Moraine. Melting ice sheets deposited glacial till in veneers up to several hundred feet thick. Kettles (depressions) were formed when ice blocks mixed with the morainal material melted. They often form small lakes or sloughs. The topography of the area is known as Knob and Kettle, with numerous short steep slopes and accompanying depressions.

Soils

Soils of the study site are moderately well drained loams and are classified as Orthic Dark Brown Chernozems. They are members of the Kirriemuir soil series (Kjearsgaard 1976). Soils of the Kirriemuir series occupy the mid and lower slope positions. These soils are characterized by a friable structure, caused by a low concentration of carbonates in the A and B horizons (Kjearsgaard 1976). The Kirriemuir soil series is associated with Rego Dark Brown Chernozems (Altario soil series) which are found on the tops of the slopes and on dry, exposed slopes, and Gleysols which are found in the depressions (Kjearsgaard 1976).

Vegetation

The Neutral Hills are located on the boundary between the Mixed Prairie and Aspen Parkland vegetation associations. Vegetation in the Neutral Hills consists of Festuca-Stipa grasslands (Looman 1981, Coupland 1961) on south facing slopes and flat areas interspersed with aspen groves on north facing slopes. Festuca-Stipa grasslands are dominated by Festuca hallii (Vasey) Piper

(Pavlick and Looman 1984) (plains rough fescue) on ungrazed sites, with Stipa curtiseta(A.S. Hitchc.) Barkworth (western porcupine grass) being a codominant on grazed areas. Other common species include Carex obtusata Lilj. (dryland sedge), Agropyron albicans Scribn. & Smith (thickspike wheatgrass), Koeleria macrantha (Ledeb.) J.A. Schultes f. (junegrass), Anemone patens L. (prairie crocus), Cerastium arvense L. (chickweed), Thermopsis rhombifolia (Nutt.) Richards. (golden bean), and Artemisia frigida Willd. (pasture sage). Festuca-Stipa grasslands that are not grazed or otherwise disturbed for extended periods are heavily dominated by plains rough fescue, almost to the total exclusion of all other species.

Some exposed slopes are occupied by a Stipa-Agropyron range type (Coupland 1961). The dominant species of this range type are western porcupine grass and Agropyron dasystachyum (Hook.) Scribn. (northern wheatgrass). Stipa comata Trin. & Rupr. (speargrass) and Agropyron smithii Rydb. (western wheatgrass) are also quite common. Low lying areas are dominated by wetland vegetation. Lowland vegetation consists mainly of Carex spp. L. (sedges) with Glyceria grandis S. Wats. *ex* A. Gray (tall manna grass) and Calamagrostis spp. Adans. (reedgrasses) being locally abundant. The physiognamy of the area is about 70 percent grassland and 30 percent forest.

Soils-Vegetation Interaction

Vegetation and soils in the study area followed a predictable pattern. Festuca-Stipa grassland was associated with soils of the Kirriemuir soil series (Orthic Dark Brown Chernozems) and occupied most south facing slopes and flat areas that had not been invaded by aspen. Vegetation considered to represent the Stipa-Agropyron range type was not common, occurring only on a few dry, exposed slopes. Vegetation of the Stipa-Agropyron range type occurred in association with soils of the Altario soil series (Rego Dark Brown Chernozems). Wetland vegetation was associated with Gleysolic soils and was common only in depressions.

METHODS

Site Selection

The study site was located on a private ranch (Rutledge Cattle Company) that consisted of about 13,000 ha of deeded and lease land. The main livestock enterprise of the ranch was cow/calf, with periodic backgrounding of steers and heifers depending on market and forage production conditions. Continuous (season-long) grazing was the main grazing system employed on the ranch (for 40-50 years) prior to 1988. In 1988 grazing management on the ranch was intensified, and an extensive fencing and stock water development program (wells) was initiated. At the end of 1989, most of the ranch had been crossfenced into 130 ha paddocks, each with a supplied water source. The most common fencing pattern was to fence large areas into squares of 260 ha in size (equal to one section, 640 acres, by the dominion land survey) and then split those areas in half by a diagonal fence. This resulted in maximum distances to stock water of 2.2 km (1.4 mile). This fencing pattern (see Appendix A) allowed the maximum number of paddocks to be serviced from a single well. Livestock management consisted of sequentially moving a herd of about 1000 cow/calf pairs through a series of paddocks (five days stay in each paddock). Usually, paddocks were only grazed once per year (Pat Rutledge 1989, 1990, 1991, personal communication).

An anomoly of management occurred in an isolated area of the ranch. A bank of hills (rising about 100 m above the rest of the ranch) occurred on the northern boundary of the ranch. Three shallow wells (30-m depth) were drilled in a natural saddle in the hills. The combined rate from the three shallow wells was sufficient to supply water to the herd of 1000 cow/calf pairs. Additional wells drilled throughout the hills were dry. Consequently, the cluster of wells in the saddle in the hills was the only source of stock water. To maintain field sizes similar to those of the rest of the ranch the area serviced by the wells (1.6 x 3.2 km) was fenced into four paddocks. The dimensions of the paddocks were 0.4 x 3.2 km (130 ha). Paddocks not directly attached to the water source were accessed by the cattle via an alleyway. Historical water sources (dams and dugouts) were located in similar areas as the current water source (wells) (Pat Rutledge 1989, 1990, 1991, personal communication). The historical water sources had sufficient water volume to service the smaller herds used under the old continuous grazing system (about 250 cow/calf pairs). However, surface water was not sufficient under the new grazing system because of a series of dry years and increased demands of the larger herd (1000 cow/calf pairs). The configuration of the current fields, combined with historical grazing distribution, resulted in litter accumulations that varied from light close to the water sources to heavy at the far end of the fields.

Definitions

Terms defined here will follow conventions outlined by Cook and Stubbendieck (1986) and Milner and Hughes (1968).

Herbage - total aerial parts of herbs, individually and collectively, not necessarily palatable to any one herbivore. There may be some discrepancy in this definition between actual herbage and harvestable herbage. For the purposes of this discussion herbage and harvestable herbage are considered synonymous.

Production - weight of herbage (current year) on a per unit area basis. Peak herbage production occurs when herbage weight is at a maximum for the current year. The term production implies measurement of herbage in the absence of herbivores. Biomass and standing crop are also common terms to describe herbage weight. However, biomass and standing crop estimations can have removal of herbage by herbivores (prior to sampling), while production estimates cannot. For the purposes of this discussion herbage productivity and herbage production are not synonymous. Herbage production implies current years herbage weight, while herbage productivity implies long-term site productivity.

Growth - an irreversible increase in biomass. Growth deals with increases in weight and does not describe phenological or physiological development.

Senescence - wilting, mortality, and eventual shedding of plant parts. Senescence is associated with a decrease in biomass.

Data Collection

Intensive sampling sites were established in one of the fields, which was arbitrarily divided into three zones based on the amount of litter present. The zones of the field were classified as light (little or no litter cover), moderate (moderate amount of litter cover), and heavy (heavy litter cover). Litter was sampled in early May 1990 and 1991. The light accumulation zone had litter levels of 10, 130, and 140 kg/ha, the moderate accumulation zone had 170, 490, and 660 kg/ha, and the heavy accumulation zone had 570, 920, and 1490 kg/ha of standing (defined as litter that was still attached to the plant at the base), fallen (defined as litter that was not attached to the plant and was relatively undecomposed), and total litter, respectively. Within each zone, four sample sites were selected, two on south facing slopes and two on flat areas (twelve in total; three litter accumulations x two aspects x two sites). All sampling sites were restricted to Festuca-Stipa grassland, the dominant vegetation type of the area, and modal soils (Orthic Dark Brown Chernozems).

Herbage production was sampled at nine times throughout the growing season. At each site (twelve total), two macroplots (4.5 x 4.5 m) were established and were divided into nine microplots (1.5 x 1.5 m), one for each sampling date. Each microplot was randomly assigned a number from one to nine, corresponding to dates for herbage production sampling. Sampling herbage production began in early May and was repeated every 15 days until 1 August, and every 30 days thereafter until 1 October. On each sampling date, for each macroplot, vegetation from a 50 x 50 cm quadrat was harvested (1 cm stubble height) from the corresponding microplot and hand sorted to plains rough fescue, other graminoids, palatable forbs, unpalatable forbs, and standing litter. During the grazing period, production cages were used to exclude grazing from small areas so that herbage production sampling could be completed. All herbage production samples were oven dried for 48 hours (70^{o}C) and weighed.

Volumetric soil water was measured at the same sites and same dates as herbage production. Three neutron probe access tubes were installed at each site in early May 1990 to measure profile soil water with a Campbell Scientific 503 neutron probe. Measurements were taken at the surface (using a surface shield) (Chanasyk and Naeth 1988), 15-cm depth, and at 10-cm depth increments down to a maximum depth of 100 cm. Many sites had stones at shallow depths that restricted installation of the access tubes. At least one tube per sampling site was successfully installed to a depth of 75 cm.

Data Analysis

Significant effects for peak herbage production (1 August) and for volumetric soil water were detected using analysis of variance techniques. Year had no significant effect on herbage growth, so the data set was pooled across year for the herbage growth cycle and volumetric soil water analysis. Soil water was averaged into two broad depth intervals, 0-30 cm and 30-70 cm. Linear regression was used to develop prediction equations for the herbage growth cycle and production. Stepwise regressions (for the growth cycle and production) were developed using plains rough fescue, other grasses, forbs, total grass, and total herbage as dependent variables and volumetric soil water, litter, and time in the growing season (Julian day) as independent variables. The herbage growth cycle was characterized by calculating an increase (or decrease) in production between two sampling dates. All analysis followed convention as outlined in the SPSS-X User's Guide, 3rd Edition (SPSS Inc 1988).

RESULTS

A reduction in litter levels was associated with a reduction in peak production (1 August) of plains rough fescue, total grass, and total herbage (Table III-1). Litter accumulation had no significant effect on production of other grasses or forbs. As litter levels declined there was a decrease in total herbage. The principle cause was a decline in plains rough fescue production. Plains rough fescue accounted for 71, 50, and 36 % of total herbage production for heavy, moderate and light litter accumulations, respectively. Flat areas were more productive (plains rough fescue, total grass, and total herbage) than south facing aspects. Aspect did not affect the production of other grasses or forbs. The litter x aspect interaction was not a significant effect for other grasses, forbs, or total grass. Plains rough fescue production was lower on areas with lower levels of litter, the effect being significant for all three zones on flat areas, but only for heavy litter accumulations on south facing aspects. Plains rough fescue production was higher on flat areas as compared to south facing aspects on heavy and moderate but not on light litter accumulations. Total herbage production declined as litter was reduced on flat areas, but was not affected on south facing aspects, although similar trends were apparent. Total herbage production was higher under heavy litter accumulations on flat areas than south facing aspects.

Volumetric soil water was affected by litter accumulation (Table III-2). In the 0-30 cm depth interval there was no difference between light and moderate litter levels, while soil water was higher under heavy litter levels. In the 30-70 cm depth interval there was a difference in soil water between litter levels, with heavy litter sites having the highest soil water and light litter sites having the lowest. For both depths, flat areas had significantly higher soil water levels than south facing aspects.

During the two years of this study, soil water was characterized by spring recharge and summer and autumn drawdown with a recharge during the month of June (Table III-2, Figure III-1). In both years, soil water was highest in spring and declined as the season progressed. The decline in soil water was most rapid during the growth flush that occurred in May and early June. After recharge in June, soil water declined throughout the remainder of the season. Soil water levels decreased with depth, and fluctuated less. Recharge periods at greater depths lagged behind those of shallow depths by about two weeks. Soil water at both depths was generally highest under heavy litter and lowest under light litter.

Under heavy litter cover, plains rough fescue growth was rapid from 1 May to 1 June, with a period of senescence for the month of June, followed by another rapid growth phase during July, maintenance for the months of August and September, and gradual senescence in October (Figure III-1). Plains rough fescue growth under moderate and light litter cover had similar rapid growth early in the season, but no second growth flush. The growth of other grasses (and grasslikes) started slightly later than plains rough fescue. Production of other grasses was maximum at about 1 June and maintained itself thereafter. Forbs followed a similar growth pattern as other grasses. Under heavy litter, growth continued after 1 July, with a corresponding drawdown in soil water (0-30cm depth interval) while under moderate and light litter, growth did not occur after July 1, and there was still a drawdown in soil water.

Soil water depletion was calculated as the difference between soil water on 1 May and 1 October (Table III-3). None of the effects (litter accumulation and aspect) or interactions examined were significant, although trends were apparent. There was a trend towards higher soil water depletion under areas covered with heavy litter and on flat areas (compared to south facing aspects). In the litter x aspect interaction water depletion was similar on south aspects and flat areas for light and moderate litter levels. However, for heavy litter levels, water depletion was visibly higher on flat areas as compared to south aspects. Water depletion was less at greater depths, with water depletion for the 30-70 depth interval being about 40-60% that of the 0-30cm depth interval. Total water use in this area varied from 26 to 30 cm (adding soil water depletion to growing season rainfall).

Growth of plains rough fescue, other grasses, total grasses, and total herbage was positively correlated with volumetric soil water (0-30cm depth interval) measured at the beginning of the growth period (Table III-4). The forb growth cycle was negatively correlated with Julian day. All other variables did not significantly improve the regression equations.

Production of plains rough fescue, other grasses, total grasses, and total herbage was highly correlated with soil water, litter, and time (Table III-5). Production of forbs was only related to fallen litter with a relatively low correlation.

For all herbage classes except forbs, the regression equations were significantly improved by the inclusion of more than one independent variable.

DISCUSSION

There was a very strong positive relationship between litter accumulation and peak herbage production. Other researchers have found that productivity of Festuca-Stipa grassland decreases under any grazing during the growing season, and particularily under heavy grazing (Bailey, Willoughby, and Irving 1987, Trottier 1986). Peak productivity of Festuca-Stipa grassland may decrease because of the primary effect of physiological interference caused by grazing or the secondary effect of grazing removing plant material that would eventually become an accumulation of litter. Litter removal alone does not result in a decline in peak production of plains of rough fescue (Willms, Smoliak, and Bailey 1986). However, it should be noted that short term studies involving manual litter removal may not simulate the long term removal of herbage by cattle. Festuca-Stipa grasslands accumulate litter in layers of varying degrees of decomposition and particle size, and these accumulations vary with grazing (Naeth et al. 1991a). To separate the effects of grazing from the effects of litter accumulation, long term studies involving the annual removal of litter would be required. The present study made no attempt to separate the effects of grazing and litter accumulation. Grazing results in lower litter accumulations, and hence the two are intricately connected. In practical terms, litter cannot accumulate with heavy defoliation and there cannot be heavy defoliation with litter accumulation. Separating the two effects is more of academic interest than of practical significance. Festuca-Stipa grasslands are more productive when litter has been allowed to accumulate.

Total grass and total herbage peak production of Festuca-Stipa grasslands were closely tied to plains rough fescue peak production. This observation is important, as classical range management theory states that as one species declines with grazing pressure, others (which are more adapted to the conditions under grazing) will increase. In this study, there was only one major decreaser, plains rough fescue. If the production values were expressed on a percent basis instead of actual weight, then other grasses and forbs would increase in composition as litter accumulations decreased, but only because the actual weight of plains rough fescue declined. Unless exotic introductions occur, management for plains rough fescue is management for maximum herbage productivity.

Litter accumulations were associated with higher soil water levels (Naeth et al. 1991b). This is somewhat perplexing as higher levels of litter are also associated with significantly higher levels of production. Numerous studies have documented a reduction in soil water associated with heavy grazing (Johnston 1961, Houston 1967, Johnston et al. 1971, Smoliak et al. 1972, and Naeth et al. 1991b). This reduction was attributed to a combination of lower infiltration capacity (Naeth et al. 1990), lower percolation, and less ground cover to intercept rainfall. Percolation is enhanced by the presence of tall, deep rooted plant species. Bailey, Willoughby, and Irving (1987), found a significant reduction in plains rough fescue with heavy growing-season or heavy season-long grazing. A reduction in soil water (Naeth et al. 1991b) on heavily grazed areas could have been caused, in part, by reduced percolation caused by fewer deep roots of plains rough fescue on heavily grazed areas. In this study the dominance of plains rough fescue declined significantly as litter accumulation decreased, with an associated decline in volumetric soil water.

There was an association between areas of highest herbage production (and highest soil water depletion) with highest soil water content. Flat areas (especially with heavy litter cover) may trap and maintain more precipitation than south facing slopes or areas with lesser amounts of litter cover. Increased inputs of water could explain why flat areas with heavy litter cover have higher soil water depletion and higher volumetric soil water. Water input into the soil would be enhanced by increased catching of water (snow or rainfall), decreased removal of water (by wind and/or radiation), and by improved infiltration and percolation. It would appear that litter accumulation (and/or the corresponding effect on the plant community) improves the soil water regime by positively affecting the input processes (catching and infiltration). Litter may decrease evaporation through providing an insulating layer at the soil surface, but transpiration is increased because of increased production. Litter accumulations were associated with increased production and increased volumetric soil water.

The reason for the second flush of plains rough fescue growth on areas covered with heavy litter is unknown, but may be related to past selection pressures placed on the plant community. In a stressed plant community, plants that emphasized production would be eliminated, while those that emphasized survival would be maintained. It is well known that different species of plants have varying degrees of resistance to defoliation. Different individuals of plants within the same species also have varying resistance to defoliation. Grazing stress may not simply result in the elimination of a plant species, but may result in elimination of individuals within a species that cannot withstand the stress placed upon the community. A reduction in plains rough fescue production on moderate and light litter covered areas (as compared to heavy litter) may be a result of removal of individual plains rough fescue plants (high producing) and survival of others (low producing) that are capable of withstanding grazing. Whatever the reason, plains rough fescue produces more (mostly because of a second growth period) under heavy litter cover.

Predicting growth and herbage production is of great interest to land managers. Stocking rates and herd rotations are both determined by early season growth and peak production. Historic methods of predicting rangeland production relied heavily on weather data as independent variables. The major limitation of these models was that they relied on either growing season precipitation or May-June precipitation to predict current production. In the area examined in this study, peak production on sites of light and moderate litter cover occurred about the beginning of June. Therefore, production estimates based on May-June precipitation would be of little value for management decisions. Peak production on sites with heavy litter cover occurred about the beginning of August (after the second growth phase). May-June pecipitation could be used as an independent variable for predicting production on these sites but, again, the equations would be of little use. Heavy litter accumulations only occur under conditions of little or no grazing. Production predictions, of interest mainly for making stocking rate recommendations and revisions, are of little value if no grazing is occurring.

Growth and production predictions may also be of interest from a conservation viewpoint. Forage for migrating wildlife, cover for nesting waterfowl, and cover to impede soil erosion could be predicted. As in the previous discussion, estimates for light and moderate litter accumulations would likely be the most useful. Ungrazed native rangeland usually supplies ample forage and cover for current wildlife populations, and soil erosion is not a problem under heavy litter accumulations.

Soil water could be used to predict growth in increments of two weeks from 1 May to 1 August and one-month increments after 1 August. These equations may be of interest to managers who know their present production and can obtain an estimate of soil water. A model with a 14 day time step (soil water updated every 14 days) could be generated and used to plan stocking rates and field rotations. From this they could predict, with some level of accuracy, what production would be in two weeks time.

Spring soil water (0-30 and 30-70 cm depth intervals), Julian day, and litter cover (standing and fallen) can be used as independent variables to generate regressions with production as the dependent variable. Plains rough fescue, other grasses, total grasses and total herbage production were significantly correlated to combinations of the independent variables. From single measurements of soil water and litter made in the spring, managers could have relatively accurate predictions of production throughout the growing season. However, the equations require further field testing and more years of data before they could be considered reliable.

Measuring volumetric soil water and litter obviates the need for measuring the other variables that affect production. Litter levels are an indicator of past grazing intensity, and as discussed earlier, are related to plains rough fescue production. Sorting litter into fallen and standing classes further refines the inferences that can be drawn about past management. Standing litter levels may be reduced by one or two years of heavy defoliation, but fallen litter levels would respond only to long term defoliation regimes. By sorting litter into fallen and standing classes, inferences about past defoliation levels can be drawn for both the short and long term. Infiltration, evaporation, percolation, precipitation characteristics (kind, timing, intensity, duration), and site characteristics (soil texture, surface crusting, biomass cover, soil organic matter, etc.) affect soil water. Measuring soil water directly eliminates the need to evaluate these other factors independently.

CONCLUSIONS

1. Litter accumulation had a positive effect on production of plains rough fescue, total grasses, and total herbage production but had no significant effect on the production of forbs and other grasses.
2. Differences in total grass and total herbage production between heavy, moderate, and light litter accumulations were mainly due to differences in plains rough fescue production. This implies that management for plains rough fescue is management for maximum herbage production.
3. Accumulations of litter are associated with increased soil water.
4. Soil water was highest in the spring under all litter accumulations, declined as the season progressed, and was lowest in the fall. This indicates spring melt recharge of soil water is crucial for subsequent growth of herbage.
5. Herbage growth was significantly correlated with soil water.
6. Herbage production was significantly correlated with spring soil water, litter accumulation, and time.

Table III-1. Peak (1 August) herbage production (kg/ha) by herbage group.

Effect		Rough Fescue	Other Grass	Total Forbs	Total Grass	Total Herbage
Litter						
	S.E.	50	60	30	60	60
	Significance	0.001	NS	NS	0.006	0.003
	Light	260 c	300 a	160 a	560 b	720 c
	Moderate	460 b	300 a	160 a	760 b	920 b
	Heavy	850 a	180 a	180 a	1030 a	1200 a
Aspect						
	S.E.	40	50	30	50	50
	Significance	0.008	NS	NS	0.030	0.004
	South	410 b	260 a	130 a	680 b	810 b
	Flat	640 a	250 a	200 a	890 a	1090 a
Litter x Aspect						
	S.E.	70	90	50	90	80
	Significance	0.037	NS	NS	0.062	0.032
South	Light	290 b	290	130	590	720 a
	Moderate	290 b*	370	130	660	790 a
	Heavy	660 a*	120	130	780	910 a*
Flat	Light	230 c	300	200	530	730 c
	Moderate	640 b	220	200	860	1050 b
	Heavy	1040 a	230	220	1270	1490 a

1. Means within columns and cells followed by the same letter are not significantly different according to an SNK multiple range test (0.05 level).
2. An * indicates a significant difference between aspect means in the Litter x Aspect interaction.

Table III-2. Volumetric soil water (%) for two depth intervals.

Effect	0-30 cm depth interval Signif.	S.E.	Volumetric Water (%)	30-70 cm depth interval Signif.	S.E.	Volumetric Water (%)
Litter	0.000	0.29		0.000	0.37	
Light			14.9 b			11.8 c
Moderate			14.3 b			13.3 b
Heavy			16.9 a			16.3 a
Aspect	0.000	0.36		0.000	0.46	
South			14.0 b			12.6 b
Flat			16.7 a			15.0 a
Time	0.000	0.68		0.000	0.88	
April 15			21.0 b			12.0 bcd
May 1			26.7 a			16.4 a
May 15			21.7 b			17.0 a
June 1			12.3 e			15.5 a
June 15			17.1 c			14.2 abc
July 1			19.9 b			15.2 ab
July 15			15.1 d			17.5 a
August 1			10.7 e			14.2 abc
September 1			10.1 ef			11.1 cd
October 1			6.2 g			9.6 d
November 1			8.3 f			9.5 d

1. Means within columns and cells followed by the same letter are not significantly different according to an SNK multiple range test (0.05 level).

Figure III-1 Soil water (%) for two depth intervals and herbage production by month for three accumulations of litter.

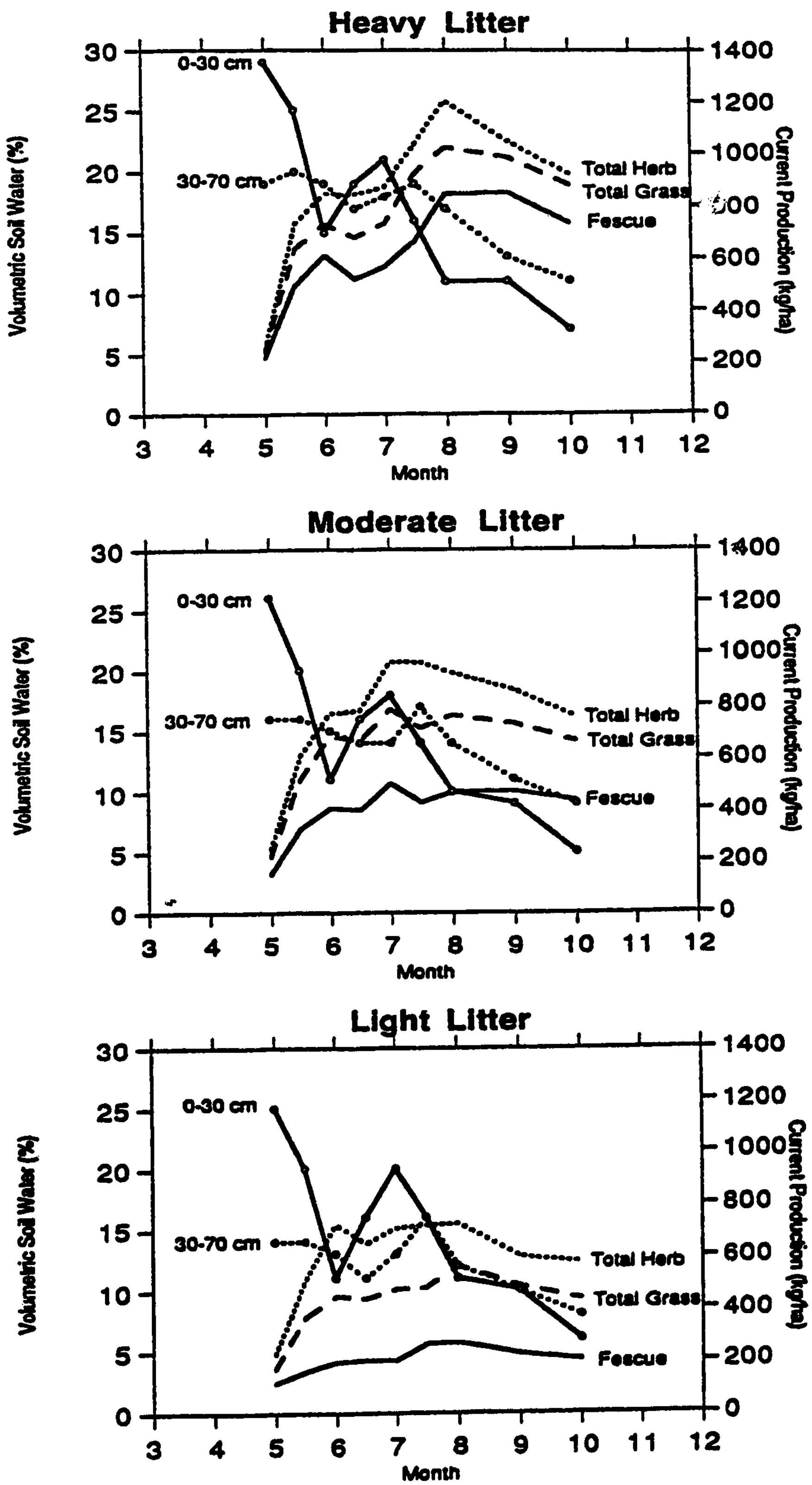


Table III-3. Depletion of soil water (cm) at selected depth intervals between May 1 and October 1, averaged over 1990 and 1991.

Effect		Depth	
	0-30	30-70	0-70
Grand Mean	6.1	2.7	8.9
Litter Accumulation			
Light	5.7	2.4	8.1
Moderate	6.2	2.7	8.9
Heavy	6.5	3.1	9.7
Aspect			
South	5.7	2.3	8.0
Flat	6.5	3.2	9.7
Litter x Aspect			
Light South	5.8	2.2	8.0
Flat	5.6	2.6	8.2
Moderate South	5.9	2.9	8.8
Flat	6.5	2.5	9.0
Heavy South	5.5	1.8	7.3
Flat	7.6	4.5	12.0

Note: There was an additional input of water (18.3 cm average summer rainfall over the two years of the study) that could be added to these numbers to get total water use.

Table III-4. Herbage growth as related to volumetric soil water and time.

Dependent Variable	Independent Variable	Multiplier	R^2
Rough Fescue	Water	10.97	0.44
	Constant	-145.89	
Other Grass	Water	6.57	0.31
	Constant	-90.16	
Forbs	Julian Day	-0.76	0.45
	Constant	155.88	
Total Grass	Water	17.55	0.62
	Constant	-236.05	
Total Herb	Water	22.97	0.61
	Constant	-318.87	

Note: Units for dependent variables are kg/ha.
Water is volumetric soil water (%) for the 0-30 cm depth interval. Predictions are based on two week intervals from 1 May to 1 August, and one month intervals after 1 August. To predict growth from 1 May to 15 May, volumetric soil water would be measured on 1 May.

Table III-5. Herbage production as related to soil water, time, and litter.

Dependent Variable	Independent Variable	Multiplier	R^2
Rough Fescue	Water 2	40.52	0.84
	Julian Day	11.71	
	Total Litter	0.16	
	(Julian Day)^2	-0.03	
	Constant	-1629.84	
Other Grass	Fallen Litter	-0.11	0.62
	Julian Day	24.39	
	(Julian Day)^2	-0.08	
	(Julian Day)^4	2.6E-07	
	Constant	-1668.16	
Forbs	Fallen Litter	-0.10	0.16
	Constant	185.48	
Total Grass	Water 2	32.78	0.79
	Julian Day	20.53	
	(Julian Day)^2	-0.05	
	Standing Litter	0.03	
	Constant	-2123.63	
Total Herb	Water 1	180.71	0.83
	Julian Day	64.37	
	(Julian Day)^2	-0.21	
	Fallen Litter	0.95	
	(Julian Day)^4	5.9E-07	
	Water 2	-166.75	
	Standing Litter	-0.88	
	Constant	-7704.06	

Note: Units for dependent variables and total, standing, and fallen litter are kg/ha. Water is volumetric soil water (%) measured on or near 1 May. Water 1 is soil water for the 0-30 cm depth interval while Water 2 is soil water for the 30-70 cm depth interval.

LITERATURE CITED

Bailey, A.W., M.G. Willoughby, and B.D. Irving. 1987. Effect of grazing on forage and beef production from rough fescue rangeland in central Alberta. Alberta Agriculture Farming For the Future Rep. 87-0099.

Bothe, R.A. and C. Abraham. 1990. Evaporation and evapotranspiration in Alberta, 1986 to 1988, Addendum. Alberta Environment, Edmonton, Alberta.

Buckhouse, J.C. and G.B. Coltharp. 1976. Soil moisture response to several levels of foliage removal on two Utah ranges. J. Range Manage. 29(4):313-315.

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

Cook, C.W. and J. Stubbendieck. 1986. Range Research: Basic Problems and Techniques. Society for Range Management, Denver, Colorado.

Coupland, R.T. 1961. A reconsideration of grassland in the Northern Great Plains of North America. J. Ecology 49:135-167.

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

Environment Canada. 1982. Canadian Climate Normals Volume 2: Temperature 1951-1980. Ottawa, Ontario.

Environment Canada. 1982. Canadian Climate Normals Volume 3: Precipitation 1951-1980. Ottawa, Ontario.

Houston, A.R. 1967. Soil moisture on native grazing lands in the semiarid northern plains of USA. Ann. Arid Zone 7:230-234.

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

Kjearsgaard, A.A. 1976. Soil survey of the Oyen map sheet (72M), Alta. Soil Survey Rep. 36. Agriculture Canada, Edmonton, Alberta.

Kelting, R.W. 1954. Effects of moderate grazing on the composition and plant production of a native tall-grass prairie in central Oklahoma. Ecology 35:200-207.

Lacey, J.R. and H.W. Van Poollen. 1981. Comparison of herbage production on moderately grazed and ungrazed western ranges. J. Range Manage. 34(3):210-212.

Looman, J. 1981. The vegetation of the Canadian Prairie Provinces II. The grasslands, Part 2 Mesic grasslands and meadows. Phytocoenologia 9:1-26.

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

Milner, C. and R.E. Hughes. 1968. Methods for the measurement of the primary production of grassland. IBP Handbook No. 6.

Naeth, M.A., A.W. Bailey, D.J. Pluth, D.S. Chansyk, and R.T. Hardin. 1991a. Grazing impacts on litter and soil organic matter in mixed prairie and fescue grassland ecosystems of Alberta. J. Range Manage. 44(1):7-12.

Naeth, M.A., D.S. Chanasyk, R.L. Rothwell, and A.W. Bailey. 1991b. Grazing impacts on soil water in Mixed Prairie and Fescue Grassland ecosystems of Alberta. Can. J. Soil Sci. 71:313-325.

Pavlick, L.E. and J. Looman. 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.

Rogler, G.A. and H.J. Haas. 1947. Range production as related to soil moisture and precipitation on the Northern Great Plains. J. Amer. Soc. Agron. 39:378-389.

Shiflet, T.N. and H. E. Dietz. 1974. Relationship between precipitation and annual rangeland herbage production in southeastern Kansas. J. Range Manage. 27:272-276.

Sinton, H.M.M. 1980. Effect of burning and mowing on Festuca hallii (Vasey) Piper, Festuca scabrella Torr. M.Sc. Thesis, Univ. of Alberta, Edmonton.

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

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

Smoliak, S. 1986. Influence of climatic conditions on production of Stipa-Bouteloua prairie over a 50-year period. J. Range Manage. 39:100-103.

SPSS Inc. 1988. SPSS-X User's Guide, 3rd Edition. SPSS Inc, Chicago.

Trottier, G.C. 1986. Disruption of rough fescue, Fesctuca hallii, grassland by livestock grazing in Riding Mountain National Park, Manitoba. Ca. Field Nat. 100:488-495.

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

Willms, W.D., S. Smoliak, and A.W. Bailey. 1986. Herbage production following litter removal on Alberta native grasslands. J. Range Manage. 39(6):536-540.

Wisiol, K. 1984. Estimating grazingland yield from commonly available date. J. Range Manage. 37:471-475.

Wyatt, F.A. and J.D. Newton. 1938. Soil survey of Sullivan Lake sheet. University of Alberta, College of Agr. Bull. 31.

IV. THE EFFECTS OF LITTER ON SOIL TEMPERATURE

INTRODUCTION

Air temperature is a major factor affecting the growth and development of plants. Plants are poikilothermic organisms; their temperature tending to approach the temperature of their surroundings (Larcher 1980). The effect of external temperature on plants has been divided into three wide classes. Uresk, Cline, and Rickard (1979) classified cheatgrass growth response into three temperature phases; limited, relatively unaffected, and inhibited. The limited phase is characterized by temperatures too low for optimal plant growth. The relatively unaffected phase occurs when temperatures are favourable for plant growth, while the inhibited phase has excessive temperatures that retard plant growth (Sachs 1860 as cited by Stafelt 1960). Lehenbauer (1914) found that maize seedling growth increased with increasing temperature in the 11 to 30^{0}C range, was unaffected in the 30 to 32^{0}C range and was inhibited in the 32 to 44^{0}C range. Maize is a warm season plant, so extrapolations of Lehenbauer's findings to cool season grasses would be inappropriate. Temperate perennial grasses are likely to have much lower cardinal temperature points than maize. Litter (mulch) generally reduces soil temperatures, resulting in seasonally cooler soils (Hogg and Lieffers 1991, Kohnke and Werkhoven 1963, Gupta, Radke, and Larson 1981, Van Wijk, Larson, and Burrows 1959, Burrows and Larson 1962) and less diurnal variation in surface soil temperatures (Hogg and Lieffers 1991, Burrows and Larson 1962). It follows that litter could have the effect of inhibiting plant growth by creating cooler soils (Hogg and Lieffers 1991, Van Wijk, Larson, and Burrows 1959, Burrows and Larson 1962) or have no effect on soils because of the moderate temperature regime (Van Wijk, Larson, and Burrows 1959). In areas with warm soil climates, litter may promote growth by dampening extreme soil temperatures, although this does not appear to have been documented in the literature.

The purpose of this study was to compare the soil temperature regimes under two litter accumulation levels of Festuca-Stipa Grassland (Looman 1981, Coupland 1961) and to postulate if differences in growth can be attributed to differences in soil temperature. The main hypothesis is that litter accumulation will result in a cooler soil climate, which will be conducive to higher levels of production during the hot part of the growing season and to lower levels of production during the cool part of the growing season.

STUDY SITE

The study site was located in the Neutral Hills, north of Kirriemuir, Alberta 52^{0}15"N 110^{0}15"W (400 km southeast of Edmonton).

Climate

The climate of the study site is continental, characterized by long warm summer days and bright, cold winter weather (Wyatt and Newman 1938). Mean precipitation for Consort (about 30 km west of the study site) was 340 mm, 70% as rain during the growing season (May - September) and 30% as snow during the dormant season (October - April) (Environment Canada 1982b). Mean daily maximum and minimum temperatures were lowest in January (-13 and -24^{0}C, respectively) and highest in July (24 and 9^{0}C, respectively). Extreme maximum and minimum temperatures were 39 and -46^{0}C, respectively (Environment Canada 1982a). Potential evapotranspiration for the town of Coronation (100 km west of the study site) is 400 mm (Bothe and Abraham 1990). This yields a precipitation to potential evapotranspiration ratio of 0.85.

Geology

Bedrock geology of the study area consists of Upper Cretaceous rock of the Belly River series, the bedrock consisting of sandstones and shales of non-marine origin (Wyatt and Newton 1938). The subsurface geology has had little effect on surface soil formation as the area is covered with a thick layer of glacial till. The area was last glaciated by the Keewatin ice sheet about 10,000 years ago. Surficial deposits are glacial till that originated to the north-east of the study site, possibly as far away as Hudson's Bay. The Neutral Hills were formed at the western edge of the continental ice sheet currently known as the Viking Moraine. Melting ice sheets deposited glacial till in veneers up to several hundred feet thick. Kettles (depressions) were formed when ice blocks mixed with the morainal material melted. They often form small lakes or sloughs. The topography of the area is known as Knob and Kettle, with numerous short steep slopes and accompanying depressions.

Soils

Soils of the study site are moderately well drained loams and are classified as Orthic Dark Brown Chernozems. They are members of the Kirriemuir soil series (Kjearsgaard 1976). Soils of the Kirriemuir series occupy the mid and lower slope positions. These soils are characterized by a friable structure, caused by a low concentration of carbonates in the A and B horizons (Kjearsgaard 1976). The Kirriemuir soil series is associated with Rego Dark Brown Chernozems (Altario soil series) which are found on the tops of the slopes and on dry, exposed slopes, and Gleysols which are found in the depressions (Kjearsgaard 1976).

Vegetation

The Neutral Hills are located on the boundary between the Mixed Prairie and Aspen Parkland vegetation associations. Vegetation in the Neutral Hills consists of Festuca-Stipa grasslands (Looman 1981, Coupland 1961) on south facing slopes and flat areas interspersed with aspen groves on north facing slopes. Festuca-Stipa grasslands are dominated by Festuca hallii (Vasey) Piper (Pavlick and Looman 1984) (plains rough fescue) on ungrazed sites, with Stipa curtiseta(A.S. Hitchc.) Barkworth (western porcupine grass) being a codominant on grazed areas. Other common species include Carex obtusata Lilj. (dryland sedge), Agropyron albicans Scribn. & Smith (thickspike wheatgrass), Koeleria macrantha (Ledeb.) J.A. Schultes f. (junegrass), Anemone patens L. (prairie crocus), Cerastium arvense L. (chickweed), Thermopsis rhombifolia (Nutt.) Richards. (golden bean), and Artemisia frigida Willd. (pasture sage). Festuca-Stipa grasslands that are not grazed or otherwise disturbed for extended periods are heavily dominated by plains rough fescue, almost to the total exclusion of all other species.

Some exposed slopes are occupied by a Stipa-Agropyron range type (Coupland 1961). The dominant species of this range type are western porcupine grass and Agropyron dasystachyum (Hook.) Scribn. (northern wheatgrass). Stipa comata Trin. & Rupr. (speargrass) and Agropyron smithii Rydb. (western wheatgrass) are also quite common. Low lying areas are dominated by wetland vegetation. Lowland vegetation consists mainly of Carex spp. L. (sedges) with Glyceria grandis S. Wats. *ex* A. Gray (tall manna grass) and Calamagrostis spp. Adans. (reedgrasses) being locally abundant. The physiognamy of the area is about 70 percent grassland and 30 percent forest.

Soils-Vegetation Interaction

Vegetation and soils in the study area followed a predictable pattern. Festuca-Stipa grassland was associated with soils of the Kirriemuir soil series (Orthic Dark Brown Chernozems) and occupied most south facing slopes and flat areas that had not been invaded by aspen. Vegetation considered to represent the Stipa-Agropyron range type was not common, occurring only on a few dry, exposed slopes. Vegetation of the Stipa-Agropyron range type occurred in association with soils of the Altario soil series (Rego Dark Brown Chernozems). Wetland vegetation was associated with Gleysolic soils and was common only in depressions.

METHODS

Data Collection

A data logger with attendant sensors was installed to continuously monitor air temperature (1 m above the ground), soil temperature, and precipitation. The data logger was located along a fenceline, one side of which had a heavy cover of litter while the other side had a moderate litter cover. The data logger was located in open Festuca-Stipa grassland, the dominant vegetation type of the area, on a modal soil (Orthic Dark Brown Chernozem). Thermistors were installed at two depths (5 and 15 cm) on both sides of the fence. The data logger was installed in early May 1990 but programming problems resulted in data collection not beginning until 1 June. Thermistors were left in the soil over winter and readings in 1991 commenced on 6 May. Temperature readings were taken every 0.5 hour, averaged over 2.0 hours, yielding 12 composite temperature readings per day, and stored in memory.

In 1991 three neutron probe access tubes were installed in the heavy and moderate litter accumulation sites. Subsurface stones limited access tube installation to a maximum depth of 40 cm. Soil water readings were taken at the surface (using a surface shield) (Chanasyk and Naeth 1988), at 15-cm depth, and at 10-cm depth increments using a Campbell Scientific 503 neutron probe (McKeague 1978). Soil water readings were taken in early May and every two weeks until 1 August, then monthly until 1 November.

Three herbage clips (0.5 x 0.5 m) were taken in each litter accumulation level in conjunction with sampling for soil water. Herbage was hand clipped using mechanical shears to a height of about 1 cm and sorted to grass, forbs, and standing litter (defined as dead plant material that was still attached to the base of the plant). Herbage samples were oven dried (70 ^{0}C, 48 hours) and weighed.

In early May, three quadrats (0.5 x 0.5 m) were hand harvested and sorted to standing and fallen litter (defined as litter that was separated from the plant but not decomposed, i.e. recognizable as plant material and/or plant parts). Fallen litter was manually separated from soil and decomposed plant material in the field based on particle size and recognition as plant material. Particles of recognizable plant material were picked by hand out of raked material from sample plots. Most decomposed plant material was separated from fallen litter by hand sifting the samples through outstretched fingers. A final visual inspection of sifted material was conducted and any recognizable plant material was picked out by hand. Litter samples were oven dried (70 ^{0}C, 48 hours) and weighed.

Data Analysis

Data for herbage production and soil water were summarized and means calculated by date of sampling. Means for volumetric soil water were calculated for the surface and subsurface (15-45 cm depth) soil zones. Running three-day temperature means were generated to illustrate seasonal trends. Mean daily temperatures were calculated by averaging 12 daily temperature readings. Mean diurnal temperatures were calculated for three parts of the growing season: 10 May to 15 June, 16 June to 15 August, and 16 August to 15 September. Days with maximum air temperatures exceeding 30^{0}C were selected and diurnal temperature means were calculated. All data were plotted for visual comparisons.

RESULTS

Fallen litter was almost equal for both heavy and moderate litter levels, 720 and 700 kg/ha, respectively. However, there was a large difference in standing litter between the two sites. Under heavy litter accumulation there was 820 kg/ha of standing litter while under moderate litter accumulation there was only 80 kg/ha. Total litter on the two sites was 1540 and 780 kg/ha for heavy and moderate litter accumulations, respectively.

The herbage growth cycle is shown in Figure IV-1. Herbage production was about the same (300 kg/ha) for the first harvest date (1 May). However, growth rates under heavy litter cover were higher after 1 May. On 15 June, the production of grass on the heavy litter site was about three times the moderate litter site, 1400 and 450 kg/ha, respectively. Total herbage production on the heavy litter site was almost four times that of the moderate litter site, 1800 and 500 kg/ha, respectively.

There was a general trend of declining soil water on both sites beginning in early May until the middle of June, at which time soil water was recharged by rainfall events (Figure IV-2). There was another recharge in surface soil water that occurred in September. Initially, surface soil water was much higher on the heavy litter site (27 % volumetric water) as compared to the moderate litter site (15 % volumetric water), while subsurface soil water was similar on both sites.

After 1 July, soil water trends on the two sites were quite similar, for both the surface and at depth.

Average daily air and soil temperatures (at two depths) followed a general trend of increasing gradually until 10 August, and then declining sharply throughout the remainder of August and into September (Figure IV-3). Soil temperatures under moderate litter cover were higher at all times than those under heavy litter. Soil temperatures at the 5 and 15-cm depths under heavy litter were similar with soil temperature at the 15-cm depth being slightly warmer than at the 5-cm depth. Under moderate litter, soil temperature at the 5-cm depth was always warmer than the 15-cm depth; the difference between the two depths increasing from about $2^{0}C$ in early May to $5^{0}C$ from 10 August to 15 August.

The mean diurnal temperature of the air and soil (two litter accumulations at two depths) followed a sine curve, with minimums occurring in the morning and maximums occuring in the late afternoon or early evening (Figure IV-4). The amplitude in temperature was larger under lower litter accumulations and closer to the surface. Air temperature had the largest amplitude (4.5-$5.5^{0}C$) at all times of the growing season. Soil temperature under moderate litter cover at the 5-cm depth had the second largest amplitude (about $3^{0}C$), with maximums equalling or exceeding those of the air temperature, but minimums being much higher than air temperature minimums. The amplitude for soil temperature under moderate litter cover at the 15-cm depth and heavy litter cover at 5 and 15-cm depth was quite similar (0.5-$1.0^{0}C$) for the whole growing season.

There was an evident time lag between maximum air temperatures and maximum soil temperatures (Figure IV-4). Within the soil, there was a time lag between maximum temperatures at the soil surface and at greater depths. Air temperatures were generally maximal at about 1600 h. Maximum soil temperatures at the 5-cm depth were attained at 1800-2000 h and at the 15-cm depth at 2000-2200 h. Minimum air temperatures occurred consistently at 0600 h while minimum soil temperatures occurred between 0800 and 1000 h. Trends in timing of maximum and minimum temperatures were consistent for air and soil (at two depths) throughout the growing season.

Maximum diurnal temperature amplitude occurred on days where the air temperature reached maximums greater than 30°C (Figure IV-5). The trends are the same as for the diurnal temperatures averaged in early, middle, and late growing season. Maximum soil temperature and amplitude were recorded under moderate litter at the 5-cm depth. The maximum temperature was 27.5°C and the amplitude was 4°C. Maximum soil temperatures and amplitudes for both moderate litter at 15-cm depth and heavy litter at 5 and 15-cm depth were 20-21°C and 1.0-1.5°C, respectively.

DISCUSSION

Growth was retarded on the sites with moderate litter accumulations as compared to areas of heavy litter accumulations. However, the cause of this decrease cannot be determined without further study. Soil temperatures near the surface were higher and more variable on the moderate litter accumulation site. Soil water (especially in the early part of the growing season) was also lower under moderate litter cover than heavy litter cover. A plant response to defoliation was also present. The moderate litter accumulation areas would have been subjected to a much higher level of defoliation than the heavy litter accumulation areas. The early season depression in surface soil water under moderate litter accumulation may have been caused by early warming of the soil and increased evaporation. Conversely, the early warming of the soil surface under moderate litter accumulation could have been caused by lower soil surface water, which would result in a lower thermal conductivity, and hence heat build up near the soil surface (Parikh, Havens, and Scott 1979). The heavy litter accumulation site may also have caught more snow, thus explaining higher spring surface soil water. The primary effects of grazing, soil water, and soil temperature do not act independently, and further research is required to separate them and document their interactions.

The present study should provide baseline data for growth studies in the future. Willms (1988) investigated the effect of temperature in a greenhouse study on foothills rough fescue growth, concluding air temperature was the least important environmental factor. However, he only investigated 20:10 and 15:5 (light:dark) temperature regimes. The temperatures investigated by Willms (1988) were probably too low to inhibit growth. Maximum soil temperatures exceeding 27°C were recorded in this study, with air temperatures exceeding 30°C required to produce them. It is possible that the temperatures investigated by Willms (1988) were in the unaffected temperature phase (Sachs 1860 as cited by Stafelt 1960). Much higher temperatures occur in the field.

It does not appear that the cooler soil under heavy litter resulted in depressed growth. Sites with moderate litter cover did warm faster, but this differential warming had no apparent beneficial effect. Areas under heavy litter cover may have remained in the unaffected temperature phase, while areas with no litter rapidly proceeded to the inhibitive temperature phase (too warm for optimal plant growth). Further research on temperature response of perennial grasses is required.

Temperature profiles measured in this study conform to models of heat flow proposed in various publications (Larcher 1980, Baver, Gardner, and Gardner 1972, Stafelt 1960). Temperature amplitude decreased with soil depth, there was a lag effect in maximum and minimum temperatures with depth, and litter had a moderating effect on soil temperature. Perhaps the only nonconformity with traditional models is that under heavy litter cover, the average daily temperature on a seasonal basis was higher at the 15-cm depth than at the 5-cm depth. This apparent anomoly can be explained by the nature of the local climate. The summer climate of the Northern Great Plains is continental and is characterized by warm days and cool nights. If the cooling portion of the night is longer than the warming portion of the day, average daily temperature of the surface of the soil should be cooler than at depth, simply because it is cooler for a longer period of time. Historical methods of determining average soil temperature calculate a mean of daily maximum and minimum temperatures. This produces an average daily temperature that ignores the length of time the soil temperatures were at those maximums and minimums. In areas with long cooling periods (nights), average daily soil temperatures can be lower at the surface than at depth.

CONCLUSIONS

1. In general soil temperature regimes followed expected patterns, except that under heavy litter, average temperatures were actually cooler near the soil surface than at a 15-cm depth.
2. Maximum soil temperatures ($27^{0}C$) under moderate litter cover exceeded temperatures commonly used for greenhouse growth studies ($20^{0}C$).
3. Plant growth was less under moderate litter cover than heavy litter. The cause of this depression cannot be determined from this study but may be caused by an interaction between soil temperature, soil water, and historic grazing effects.

Figure IV-1. Total grass and total herbage production from 1 May to 1 October, 1991, under two levels of litter accumulation.

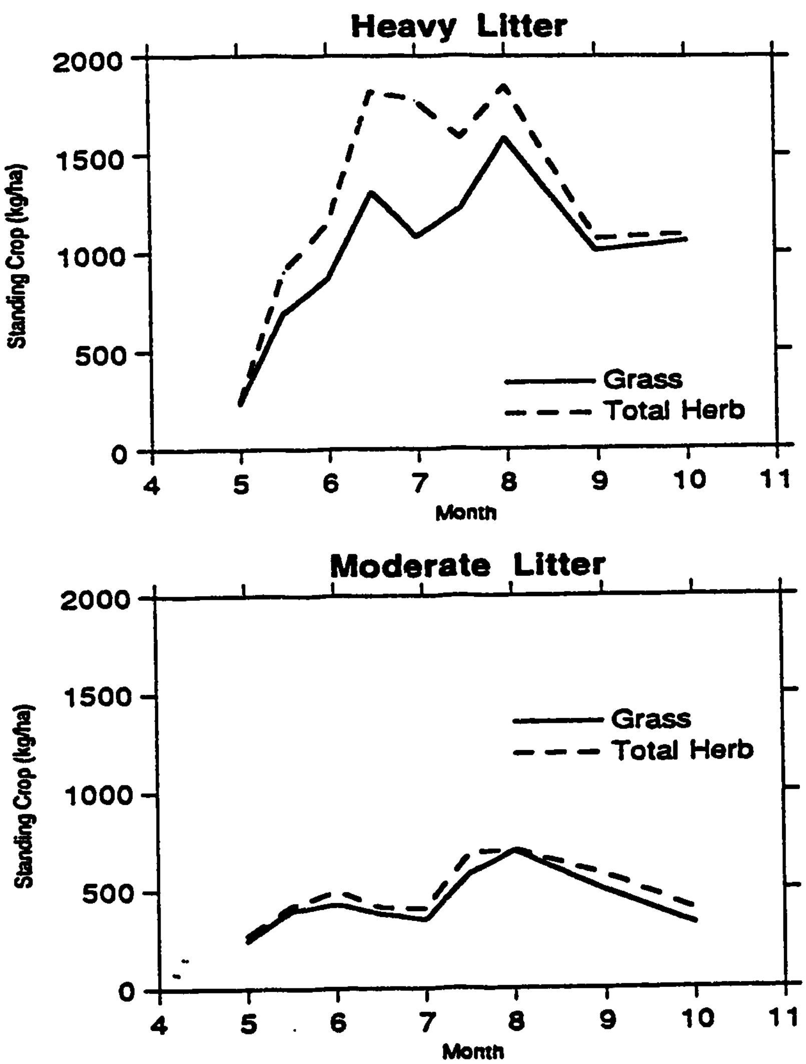


Figure IV-2. Soil water at the surface and 15-40 cm depth interval for two levels of litter accumulation (1991 only).

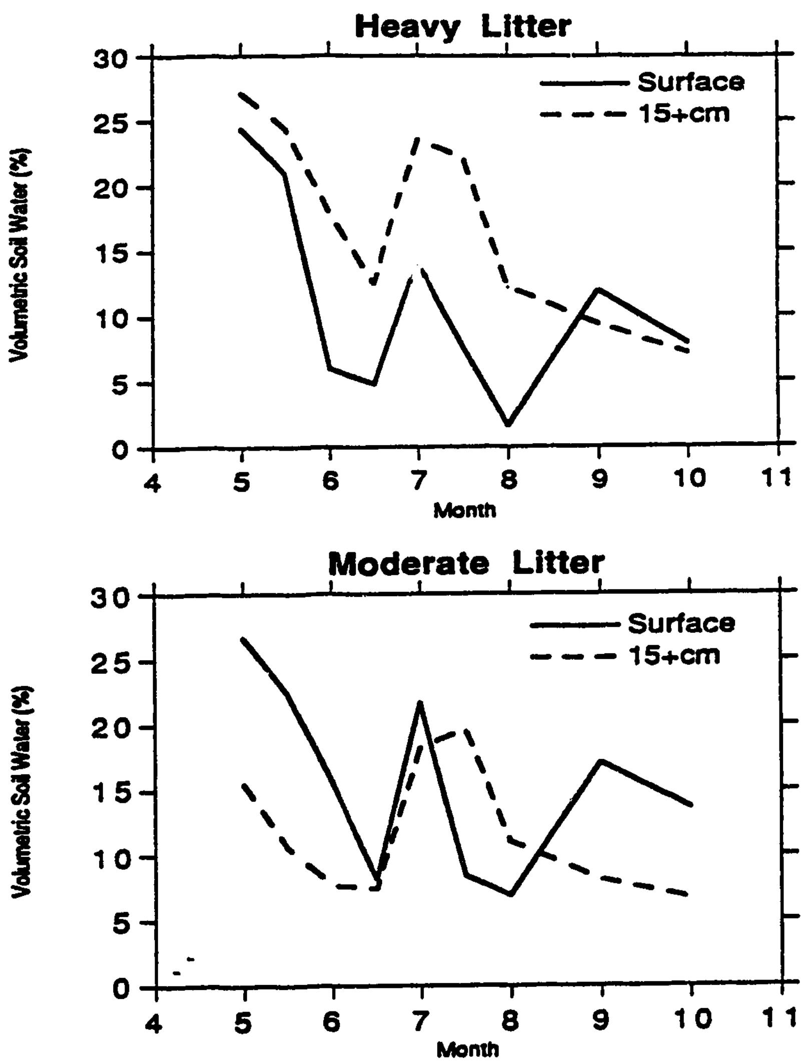


Figure IV-3. Running (three day) average daily mean temperature (C) for air and soil at two depths under two levels of litter accumulation (1990 and 1991 averaged).

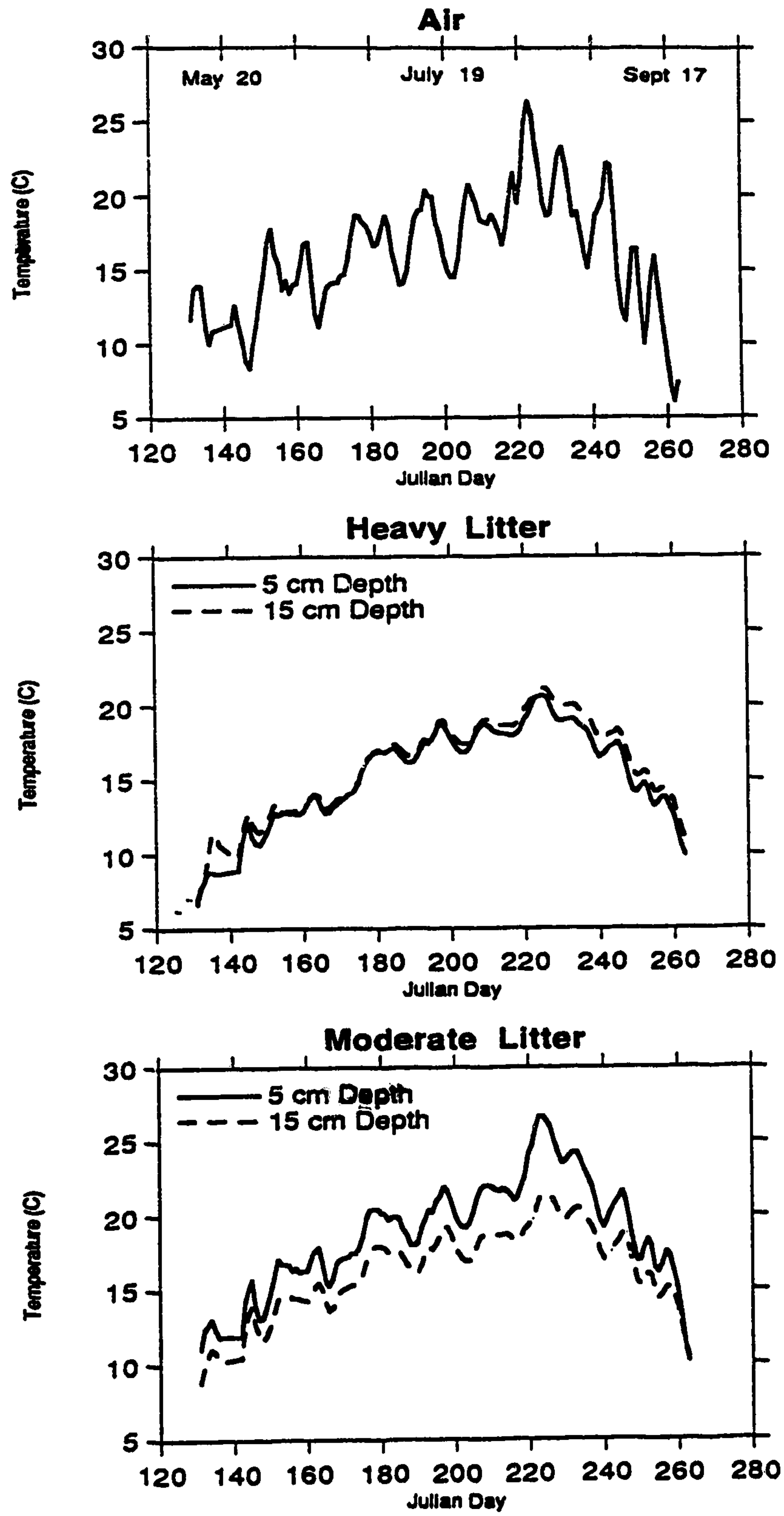


Figure IV-4. Diurnal air and soil temperatures (5 and 15-cm depth) for early, middle, and late growing season under moderate and heavy litter accumulations (1990 and 1991 averaged).

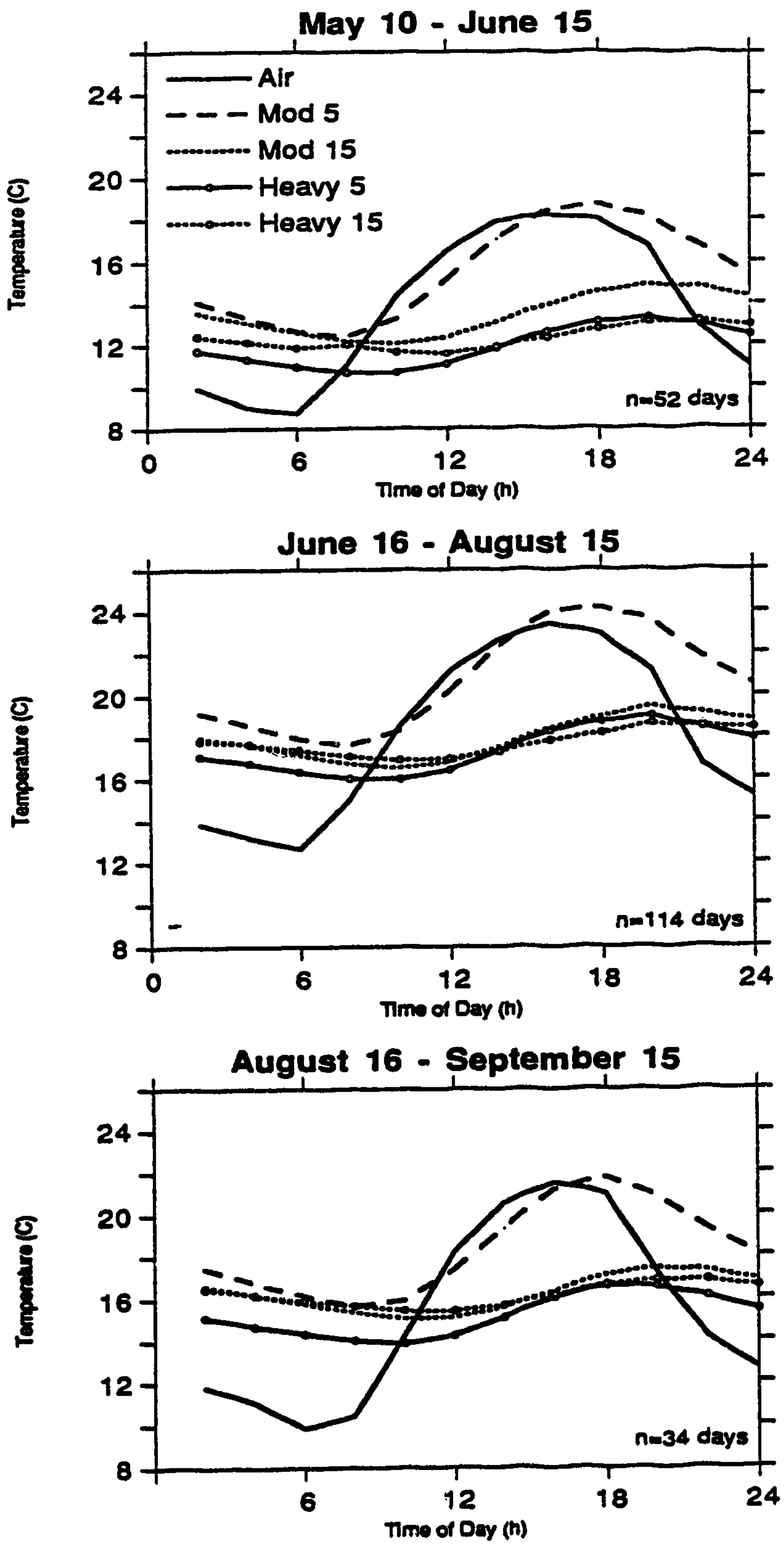
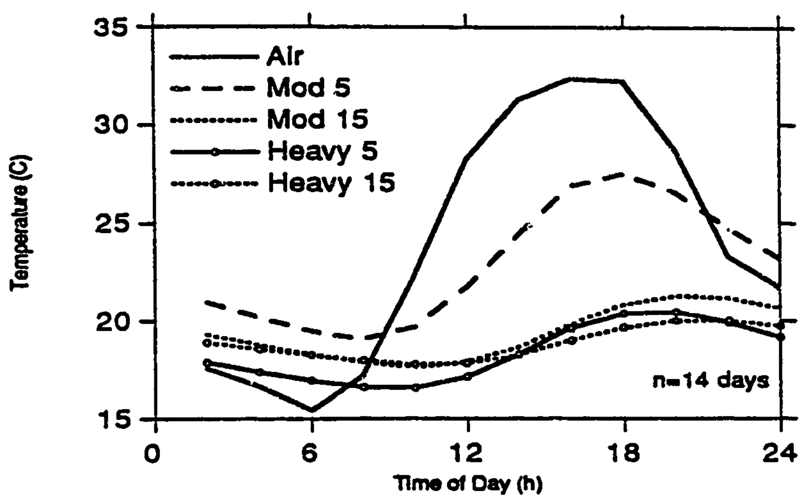


Figure IV-5. Diurnal air and soil temperatures (5 and 15-cm depth) for days with maximum daily temperatures exceeding 30°C under moderate and heavy litter accumulations.



LITERATURE CITED

Baver, L.D., W.H. Gardner, and W.R. Gardner. 1972. Soil Physics. John Wiley & Sons, New York.

Bothe, R.A. and C. Abraham. 1990. Evaporation and evapotranspiration in Alberta, 1986 to 1988, Addendum. Alberta Environment, Edmonton, Alberta.

Burrows, W.C. and W.E. Larson. 1962. Effect of amount of mulch on soil temperature and early growth of corn. Agron. J. 54:19-23.

Chanasyk, D.S. and M.A. Naeth. 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 in the Northern Great Plains of North America. J. Ecology 49:135-167.

Environment Canada. 1982. Canadian Climate Normals Volume 2: Temperature 1951-1980. Ottawa, Ontario.

Environment Canada. 1982. Canadian Climate Normals Volume 3: Precipitation 1951-1980. Ottawa, Ontario.

Gupta, S.C., J.K. Radke, and W.E. Larson. 1981. Predicting temperatures of bare and residue covered soils with and without a corn crop. Soil Sci. Soc. J. 45:405-412.

Hogg, E.H. and V.J. Lieffers. 1991. The impact of Calamagrostis canadensis on soil thermal regimes after logging in northern Alberta. Can. J. For. Res. 21:387-394.

Kjearsgaard, A.A. 1976. Soil survey of the Oyen map sheet (72M). Alta. Soil Survey Rep. 36. Agriculture Canada, Edmonton, Alberta.

Kohnke, H. and C.H. Werkhoven. 1963. Soil temperature and soil freezing as affected by an organic mulch. Soil Sci. Soc. Am. Proc. 27:13-17.

Larcher, W. 1980. Physiological Plant Ecology. Springer-Verlag, New York.

Lehenauer, P.A. 1914. Growth of maize seedlings in relation to temperature. Physiol. Res. 1:247-288.

Looman, J. 1981. The vegetation of the Canadian Prairie Provinces II. The grasslands, Part 2 Mesic grasslands and meadows. Phytocoenologia 9:1-26.

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

Parikh, R.J., J.A. Havens, and H.D. Scott. 1979. Thermal diffusivity and conductivity of moist porous media. Soil Sci. Soc. Am. J. 43:1050-1052.

Pavlick, L.E. and J. Looman. 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.

Sachs, J. 1860. 'Physiologische Untersechengen uber die Abhangigkeit der Keimung von der Temperatur'. Fb. wiss. Bot. 2:338.

Stafelt, M.G. 1960. Plant Ecology. English translation by M.S. Jarvis and P.G. Jarvis. William Clowes & Sons Limited, London.

Uresk, D.W., J.F. Cline, and W.H. Rickard. 1979. Growth rates of a cheatgrass community and some associated factors. J. Range Manage. 32:168-170.

Van Wijk, W.R., W.E. Larson, and W.C. Burrows. 1959. Soil temperature and the early growth of corn from mulched and unmulched soil. Soil Sci. Soc. Am. Proc. 23:428-434.

Willms, W.D., A.W. Bailey, and A. McLean. 1980. Some effects of soil and air temperature on growth of Agropyron spicatum following clipping and burning. Can. J. Bot. 58:568-573.

Willms, W.D. 1988. Response of rough fescue (Festuca scabrella) to light, temperature, and litter removal, under controlled conditions. Can. J. Bot. 66:429-434.

Wyatt, F.A. and J.D. Newton. 1938. Soil survey of Sullivan Lake sheet. University of Alberta, College of Agr. Bull. 31.

V. GRASS UTILIZATION AND GRAZING DISTRIBUTION WITHIN INTENSIVELY MANAGED GRAZING PADDOCKS.

INTRODUCTION

Slope length and steepness, distance from water, and the presence of brush have been identified as factors affecting livestock distribution (Mueggler 1965, Cook 1966, Roath and Krueger 1982, Gillen, Krueger, and Miller 1984). It is difficult to separate the factors and evaluate them individually (Cook 1966). Gillen, Krueger, and Miller (1984) found that cattle preferred areas within 200 m of water and avoided areas farther than 600 m away from water. A change from continuous grazing to deferred-rotational grazing did not appreciably change the grazing pattern. Roath and Krueger (1982) speculated that when other factors influencing livestock distribution were not limiting, distance from water ultimately controlled the outer limits of vegetation utilization. They found that utilization approached zero at a distance of about 1900 m from water on relatively level rangeland. Recently, the use of short duration grazing (SDG) has become popular as a method to distribute grazing pressure evenly. Increased stock density has been associated, although not quantified, with more uniform utilization in intensively managed grazing systems (Kothmann 1980). Kirby, Pessin, and Clamby (1986) found that grazing uniformity in pastures containing five major plant communities did not differ significantly between SDG and repeated season long grazing treatments.

The purpose of this study was to determine if grazing distribution was uniform throughout intensively managed paddocks. Temporal grazing patterns in relation to distance from water were also examined. The central hypothesis was that grazing distribution would be uniform in intensively managed paddocks. A secondary hypothesis was that temporal patterns of grazing would exist, illustrating livestock selectivity.

STUDY SITE

The study site was located in the Neutral Hills, north of Kirriemuir, Alberta $52^{0}15"$N $110^{0}15"$W (400 km southeast of Edmonton).

Climate

The climate of the study site is continental, characterized by long warm summer days and bright, cold winter weather (Wyatt and Newman 1938). Mean precipitation for Consort (about 30 km west of the study site) was 340 mm, 70% as rain during the growing season (May - September) and 30% as snow during the dormant season (October - April) (Environment Canada 1982b). Mean daily maximum and minimum temperatures were lowest in January (-13 and -24^{0}C, respectively) and highest in July (24 and 9^{0}C, respectively). Extreme maximum and minimum temperatures were 39 and -46^{0}C, respectively (Environment Canada 1982a). Potential evapotranspiration for the town of Coronation (100 km west of the study site) is 400 mm (Bothe and Abraham 1990). This yields a precipitation to potential evapotranspiration ratio of 0.85.

Geology

Bedrock geology of the study area consists of Upper Cretaceous rock of the Belly River series, the bedrock consisting of sandstones and shales of non-marine origin (Wyatt and Newton 1938). The subsurface geology has had little effect on surface soil formation as the area is covered with a thick layer of glacial till. The area was last glaciated by the Keewatin ice sheet about 10,000 years ago. Surficial deposits are glacial till that originated to the north-east of the study site, possibly as far away as Hudson's Bay. The Neutral Hills were formed at the western edge of the continental ice sheet currently known as the Viking Moraine. Melting ice sheets deposited glacial till in veneers up to several hundred feet thick. Kettles (depressions) were formed when ice blocks mixed with the morainal material melted. They often form small lakes or sloughs. The topography of the area is known as Knob and Kettle, with numerous short steep slopes and accompanying depressions.

Soils

Soils of the study site are moderately well drained loams and are classified as Orthic Dark Brown Chernozems. They are members of the Kirriemuir soil series (Kjearsgaard 1976). Soils of the Kirriemuir series occupy the mid and lower slope positions. These soils are characterized by a friable structure, caused by a low concentration of carbonates in the A and B horizons (Kjearsgaard 1976). The Kirriemuir soil series is associated with Rego Dark Brown Chernozems (Altario soil series) which are found on the tops of the slopes and on dry, exposed slopes, and Gleysols which are found in the depressions (Kjearsgaard 1976).

Vegetation

The Neutral Hills are located on the boundary between the Mixed Prairie and Aspen Parkland vegetation associations. Vegetation in the Neutral Hills consists of Festuca-Stipa grasslands (Looman 1981, Coupland 1961) on south facing slopes and flat areas interspersed with aspen groves on north facing slopes. Festuca-Stipa grasslands are dominated by Festuca hallii (Vasey) Piper (Pavlick and Looman 1984) (plains rough fescue) on ungrazed sites, with Stipa curtiseta(A.S. Hitchc.) Barkworth (western porcupine grass) being a codominant on grazed areas. Other common species include Carex obtusata Lilj. (upland sedge), Agropyron albicans Scribn. & Smith (thickspike wheatgrass), Koeleria macrantha (Ledeb.) J.A. Schultes f. (junegrass), Anemone patens L. (prairie crocus), Cerastium arvense L. (chickweed), Thermopsis rhombifolia (Nutt.) Richards. (golden bean), and Artemisia frigida Willd. (pasture sage). Festuca-Stipa grasslands that are not grazed or otherwise disturbed for extended periods are heavily dominated by plains rough fescue, almost to the total exclusion of all other species.

Some exposed slopes are occupied by a Stipa-Agropyron range type (Coupland 1961). The dominant species of this range type are western porcupine grass and Agropyron dasystachyum (Hook.) Scribn. (northern wheatgrass). Stipa comata Trin. & Rupr. (speargrass) and Agropyron smithii Rydb. (western wheatgrass) are also quite common. Low lying areas are dominated by wetland vegetation. Lowland vegetation consists mainly of Carex spp. L. (sedges) with Glyceria grandis S. Wats. *ex* A. Gray (tall manna grass) and Calamagrostis spp. Adans. (reedgrasses) being locally abundant. The physiognamy of the area is about 70 percent grassland and 30 percent forest.

Soils-Vegetation Interaction

Vegetation and soils in the study area followed a predictable pattern. Festuca-Stipa grassland was associated with soils of the Kirriemuir soil series (Orthic Dark Brown Chernozems) and occupied most south facing slopes and flat areas that had not been invaded by aspen. Vegetation considered to represent the Stipa-Agropyron range type was not common, occurring only on a few dry, exposed slopes. Vegetation of the Stipa-Agropyron range type occurred in association with soils of the Altario soil series (Rego Dark Brown Chernozems).

Wetland vegetation was associated with Gleysolic soils and was common only in depressions.

METHODS

Site Selection

The study site was located on a private ranch (Rutledge Cattle Company) that consisted of about 13,000 ha of deeded and lease land. The main livestock enterprise of the ranch was cow/calf, with periodic backgrounding of steers and heifers depending on market and forage production conditions. Continuous (season-long) grazing was the main grazing system employed on the ranch (for 40-50 years) prior to 1988. In 1988 grazing management on the ranch was intensified, and an extensive fencing and stock water development program (wells) was initiated. At the end of 1989, most of the ranch had been crossfenced into 130 ha paddocks, each with a supplied water source. Livestock management consisted of sequentially moving a herd of about 1000 cow/calf pairs through a series of paddocks (five days stay in each paddock). This management yielded a stocking rate of 1.3 AUM/ha and a stocking density of 7.7 AU/ha. Usually, paddocks were only grazed once per year.

An anomoly of management occurred in an isolated area of the ranch. A bank of hills (rising about 100 m above the rest of the ranch) occurred on the northern boundary of the ranch. Three shallow wells (30-m depth) were drilled in a natural saddle in the hills. The combined rate from the three shallow wells was sufficient to supply water to the herd of 1000 cow/calf pairs. Additional wells drilled throughout the hills were dry. Consequently, the cluster of wells in the saddle in the hills was the only source of stock water. To maintain field sizes similar to those of the rest of the ranch the area serviced by the wells (1.6 x 3.2 km) was fenced into four paddocks. The dimensions of the paddocks were 0.4 x

3.2 km (130 ha). Paddocks not directly attached to the water source were accessed by the cattle via an alleyway. Historical water sources (dams and dugouts) were located in similar areas as the current water source (wells) (Pat Rutledge 1989, 1990, 1991, personal communication). The historical water sources had sufficient water volume to service the smaller herds used under the old continuous grazing system (about 250 cow/calf pairs). However, surface water was not sufficient under the new grazing system because of a series of dry years and increased demands of the larger herd (1000 cow/calf pairs).

Data Collection

Two paddocks were studied in 1990 while one paddock was studied in 1991. Vegetative dry matter disappearance was sampled at five locations within each paddock. Sampling locations were established at 0.1, 0.8, 1.6, 2.4, and 3.1 km from the water source. Prior to grazing, four randomly located quadrats (0.5 x 0.5 m) were hand harvested at each sample location to a height of about 1 cm and sorted to grass, palatable forbs, unpalatable forbs, and standing litter (defined as previous years growth still attached to the base of the plant). On each day of the grazing period, ocular estimates of forage removal were made at each sampling site. After grazing was completed, another quadrat was hand harvested at each sample location and final visual utilization estimates were made. All samples were oven dried for 48 hours (70^{o}C) and weighed. Utilization was calculated as the percent difference between before and after grazing standing crop.

RESULTS

Production prior to grazing and percent utilization after completion of grazing are shown in Table V-1. Production varied substantially between paddocks and within paddocks. Percent utilization was fairly uniform throughout all paddocks sampled to distances up to 2.4 km from water, ranging from 63 to 83% dry matter disappearance. There was a perceptable decline in utilization at 3.1 km from water in Field 1, 1990 (31%) and Field 1, 1991 (52%) but not in Field 2, 1990 (69%).

Temporal utilization patterns are shown in Figure V-1. Areas closer to water in all three paddocks were utilized earlier in the grazing period and more heavily by the end of the grazing period than areas farther away from water. Areas farther away from water (2.4 and 3.1 km) were not utilized until areas closer to water were approaching heavy utilization. Typically, areas farther than 1.6 km away from water were not grazed until 2-3 days into the grazing period. At that time, areas closer to water than 1.6 km were approaching 40-50% utilization.

There was a general trend for visual estimates to be less than clipped estimates (Table V-2). The difference ranged from 2-9% close to water (0.1 km) and 9-25% further away.

DISCUSSION

If the paddocks in this study were examined for utilization patterns after the grazing period was complete, the conclusion would be that utilization was relatively uniform, except perhaps in the extreme ends of the paddocks. However, if temporal grazing patterns are examined, the conclusion would be quite different. Temporal grazing patterns can best be described as a wave of defoliation. The wave started closest to water and proceeded outward from it. As areas closer to water became depleted of forage, livestock ranged farther into the paddock. The wave of defoliation proceeded through the paddock until such time as utilization was uniform, when the livestock were moved to the next paddock. High levels of utilization close to the water source had to exist before utilization was achieved farther from the water source. Selectivity for areas close to water was not removed by high stock densities, but was masked by the speed at which the defoliation wave progressed. The findings of Kirby, Pessin, and Clanby (1986) support the existence of temporal grazing patterns. They found no difference in cattle selection for vegetation communities between continuous and intensively managed grazing systems.

The peculiar shape (0.4 x 3.2 km) of the paddocks examined in this study was a result of limitations of economically available stock water. The finding of temporal grazing patterns is of interest from a research point of view. However, at the end of the five day grazing period (for this study) utilization was uniform, accomplishing a primary management goal. If final herbaceous utilization is relatively uniform and falls within the moderate range (40-60%), temporal utilization patterns are probably not of significance from a management point of view. Excessive travel during foraging may affect livestock performace. Horizontal distance travelled during foraging may increase maintenance requirements above that required for basal metabolism by 6-15% (Anderson and Kothman 1980). It should be noted that Anderson and Kothman (1980) examined cattle energy budgets in small scale studies (intensively managed paddocks, 4 ha in size, and continuously managed paddocks, 20 ha in size). Consequently, the energy expended by cattle during travel in this study may have been significantly higher than those examined by Anderson and Kothman (1980). Clearly, further research on distance to water in intensively managed systems is required. Cattle will utilize areas as far as 3.1 km from water (the maximum distance examined), but the effect of travel on livestock performance is not known.

Visual estimates are generally considered inferior to clipped estimates because of observer bias. However, clipped estimates may also contain a considerable level of potential bias. In the vegetation of this study, after grazing stubble heights were less than 2-3 cm. With short stubble, and frequently windy days, residual material can be shattered and lost during clipping. This causes underestimation of residual plant material and overestimation of utilization, using the before and after clipping method. Whether visual or clipped estimates were more accurate in this study cannot be determined as both contained potential biases.

How accurate do utilization estimates need to be? For management purposes, the ability to place utilization into broad classes is sufficient. Utilization can be classed as light (0-40% herbaceous removal), moderate (40-60%), and heavy (60-80%). Broad classes of utilization would also suffice for most research studies where utilization is evaluated. Even if more accurate estimates of utilization are required, researchers should critically examine before and after clipping techniques. Clipping estimates of utilization requires destructive sampling, which entails sampling one plot before grazing and a second plot (close to the first) after grazing. High variation in vegetation production occurs on rangeland in very short distances (less than 1 m). This causes variation in utilization estimates. Another problem is the separation of litter from the current years herbaceous material after grazing (which causes trampling). Litter and trampled herbaceous plant material are often quite similar in appearance, making separation difficult. The problems of high variability, confusion with litter, and sampling mechanics (discussed earlier) make before and after utilization estimates crude indicators of utilization. Even though significant digits can be generated by calculating utilization (using the before and after method) the true level of accuracy is probably broad classes; light, moderate, and heavy utilization.

CONCLUSIONS

1. Utilization after the grazing period was uniform, except at extreme distances (3.1 km) from water.
2. Temporal utilization patterns within the grazing period existed. Areas closer to water were defoliated sooner and more heavily than areas farther away from water.

Table V-1. Herbage production (kg/ha) at the beginning of the grazing period and utilization (percent disappearance measured by clipping at the end of the grazing period) by distance from water.

	Distance From Water (km)				
	0.1	0.8	1.6	2.4	3.1
Field 1, 1990					
Standing Crop (kg/ha)	650	840	1030	1140	790
S.E.	90	70	170	100	90
Utilization (%)	72	75	70	67	31
S.E.	5	4	7	7	5
Field 2, 1990					
Standing Crop (kg/ha)	490	740	700	710	700
S.E.	20	90	80	100	70
Utilization (%)	67	75	83	70	69
S.E.	8	10	4	8	7
Field 1, 1991					
Standing Crop (kg/ha)	660	1000	690	850	710
S.E.	140	210	130	70	140
Utilization (%)	63	80	81	79	52
S.E.	11	5	2	4	17

Figure V-1. Percent utilization (visually estimated) by distance from water and day of grazing in intensively managed paddocks.

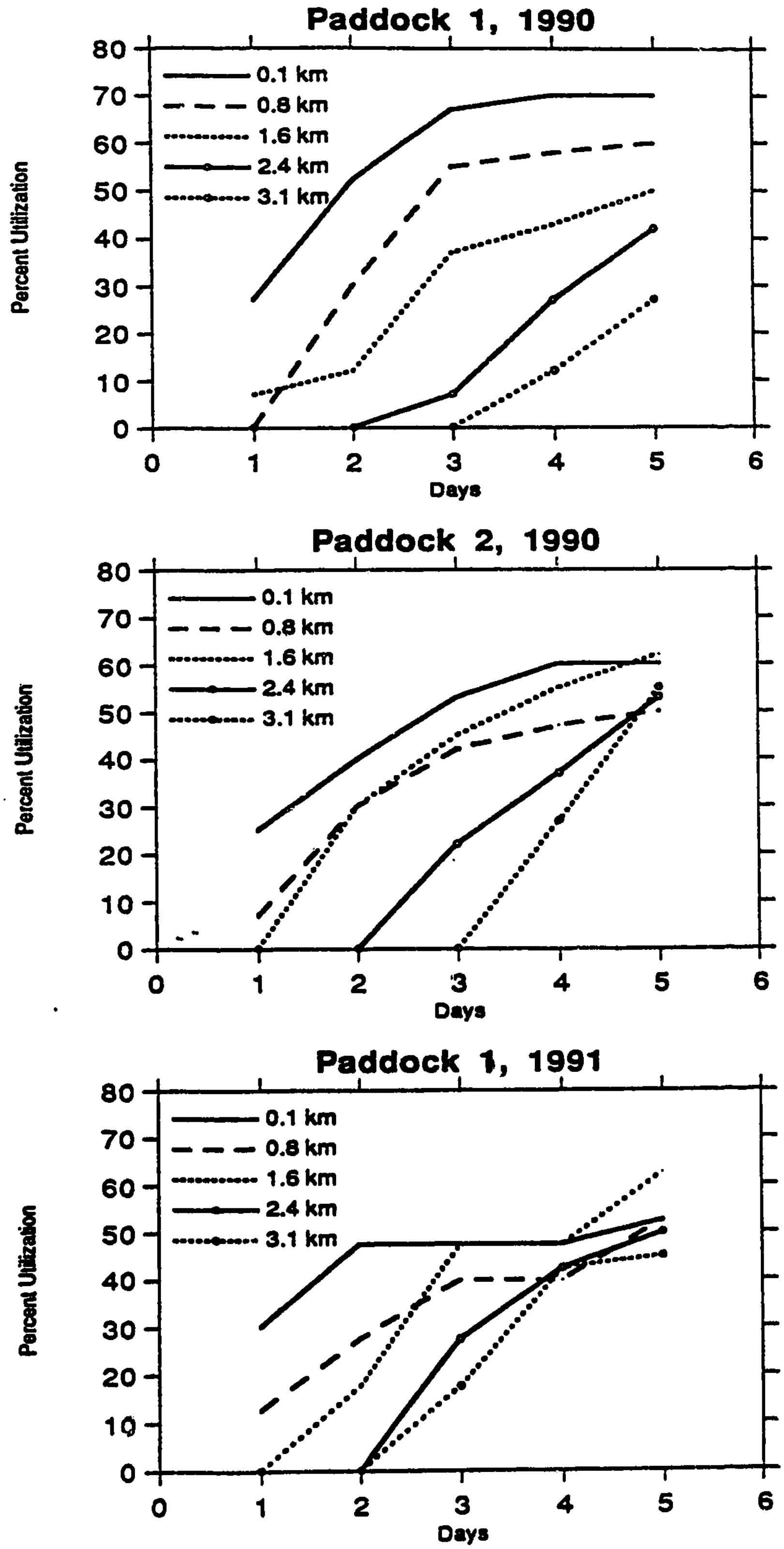


Table V-2. Comparison of clipped and visual estimates of grass utilization at the end of the grazing period.

	Distance From Water (km)				
	0.1	0.8	1.6	2.4	3.1
Field 1, 1990					
Clipped	72	75	70	67	31
Visual	70	60	50	42	27
Field 2, 1990					
Clipped	67	75	83	70	69
Visual	60	50	62	53	55
Field 1, 1991					
Clipped	63	80	81	79	52
Visual	52	52	62	50	45

LITERATURE CITED

Anderson, D.M. and M.M. Kothman. 1980. Relationship of distance traveled with diet and weather for hereford heifers. J. Range Manage. 33:217-220.

Bothe, R.A. and C. Abraham. 1990. Evaporation and evapotranspiration in Alberta, 1986 to 1988, Addendum. Alberta Environment, Edmonton, Alberta.

Cook, C.W. 1966. Factors affecting utilization of mountain slopes by cattle. J. Range Manage. 19:200-204

Coupland, R.T. 1961. A reconsideration of grassland in the Northern Great Plains of North America. J. Ecology 49:135-167.

Environment Canada. 1982. Canadian Climate Normals Volume 2: Temperature 1951-1980. Ottawa, Ontario.

Environment Canada. 1982. Canadian Climate Normals Volume 3: Precipitation 1951-1980. Ottawa, Ontario.

Gillen, R.L., W.C. Krueger, and R.F. Miller. 1984. Cattle distribution on mountain rangeland in north-eastern Oregon. J. Range Manage. 37:549-553.

Kirby, D.R., M.F. Pessin, and G.K. Clambey. 1986. Disappearance of forage under short duration and season long grazing. J. Range Manage. 39:496-499.

Kjearsgaard, A.A. 1976. Soil survey of the Oyen map sheet (72M). Alta. Soil Survey Rep. 36. Agriculture Canada, Edmonton, Alberta.

Kothmann, M.M. 1980. Evaluation of livestock needs on designing grazing systems for rangeland. Chap. 6 Part B. IN: Digestive Physiology and Nutrition of Ruminants, D.C. Church (ed.), Vol 3. O&B Books, Inc. Corvallis, Or.

Looman, J. 1981. The vegetation of the Canadian Prairie Provinces II. The grasslands, Part 2 Mesic grasslands and meadows. Phytocoenologia 9:1-26.

Mueggler, W.F. 1965. Cattle distribution on steep slopes. J. Range Manage. 18:255-257.

Ogden, P.R. 1980. Meeting the physiological requirements of a plant with grazing systems. Proc. Grazing Manage. Systems Southwest Range. Symp., Albuquerque, New Mexico. pp 37-48.

Pavlick, L.E. and J. Looman. 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.

Roath, L.R., and W.C. Kruegger. 1982. Cattle grazing and behaviour on a forested range. J. Range Manage. 35:332-338.

Wyatt, F.A. and J.D. Newton. 1938. Soil survey of Sullivan Lake sheet. University of Alberta, College of Agr. Bull. 31.

VI. GENERAL DISCUSSION

LITTER ACCUMULATIONS

The role litter plays in the productivity of Festuca-Stipa grasslands cannot be overemphasized. Three effects of litter accumulation need to be stressed:

1. Litter accumulation is an indication of the past defoliation regime.
2. Litter accumulation is associated with higher soil water, especially near the surface.
3. Litter accumulation results in a moderated soil temperature regime.

All of these result in litter accumulations on Festuca-Stipa grasslands being conducive to higher productivity.

Management Implications

Management of Festuca-Stipa grasslands for litter accumulation is management for highest productivity. However, in a commercial livestock operation, it is not that simple. Maximum herbage production occurred on areas with litter accumulations of about 1500 kg/ha. It is important to note that these levels of litter accumulations were only possible without grazing. It is of little value to manage for peak herbage production if grazing cannot be permitted in order to achieve it. The goal of livestock managers is not maximum herbage production, but maximum profit, which is related to beef production. Beef production is determined by forage production, forage quality, and efficiency of utilization. Forage quality will not be considered in this discussion as it was not examined in this study.

Livestock managers are faced with a dilemma. Forage quantity is increased by allowing litter to accumulate, but this requires low utilization rates, (low stocking rates). Higher stocking rates increase utilization rates, which result in lower litter accumulations and lower long term herbage productivity. Short term stocking rates can be maximized, but herbage productivity will be depressed in the long term, resulting in lower long term stocking rates. Moderate stocking rates, which allow a moderate accumulation of litter, will result in higher long term herbage productivity, and higher long term stocking rates. Stocking rates (short and long term) will be determined by the goals of the manager.

LIVESTOCK DISTRIBUTION

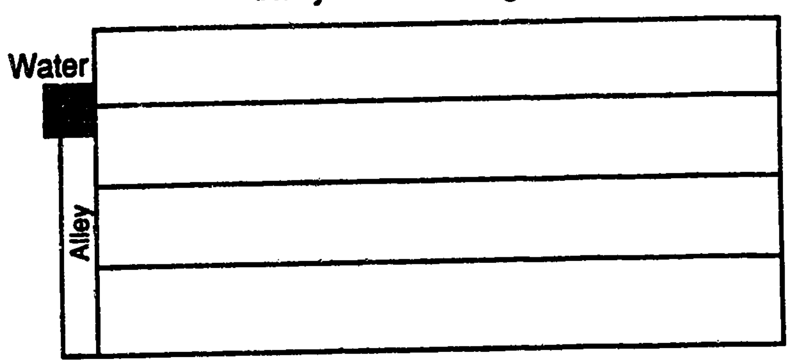
One of the goals of intensive livestock management is to remove livestock selectivity and thereby attain more even utilization of grazing paddocks. Stock water plays a major role in livestock distribution, and the effect of stock water placement cannot be overcome by high stock densities. Increasing stock density on paddocks with distances to water over 1.6 km will not eliminate livestock selectivity for areas closer to water. Even under the intensity of management of the paddocks examined in this study livestock still utilized areas closest to water first and most heavily compared to areas farther away.

Management Implications

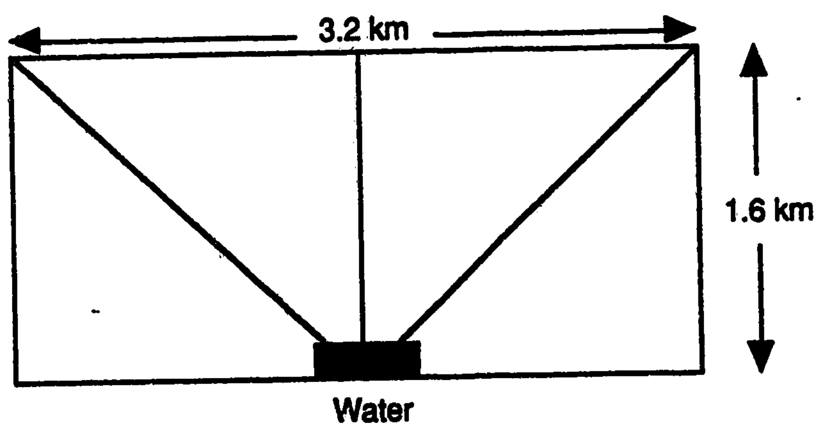
If distances to water are too far (greater than 1.6 km), the manager will be faced with heavily utilizing areas close to water in order to obtain satisfactory utilization of areas farther away or not utilizing areas farther away from water in order to assure moderate utilization of areas closer to water. Either choice will result in a suboptimum level of efficiency of forage harvest. Heavily utilizing areas close to water will result in a long term depression in herbage production while not utilizing areas farther away from water will result in lower than optimum beef production. Long term herbage productivity can be assured by well distributed stock water sources and moderate utilization levels.

APPENDIX A. SCHEMATIC MAPS OF THE STUDY AREA.

Study Area Fencing Pattern



Normal Fencing Pattern



APPENDIX B. DETAILED SOIL WATER DATA.

```
Criterion Variable   MOIST    Volumetric Soil Moisture
   Broken Down by    TIME
               by    DEPTH
  Controlling for    GRAZE    Litter Accumulation   Value:   1   Light
               by    ASPECT                         Value:   1   South Facing
               by    YEAR                           Value:   1   1990
```

TIME	Mean Count	Surface 1	15cm 2	25cm 3	35cm 4	45cm 5	55cm 6	65cm 7	Row Total
May 1	2	31.9300 2	22.2700 2	21.5600 2	18.9800 2	14.9450 2	11.2650 2	10.4900 2	18.7771 14
May 15	3	21.6050 2	18.7900 2	20.6750 2	18.5700 2	14.5700 2	11.4550 2	10.3300 2	16.5707 14
June 1	4	12.8450 2	7.8300 2	13.1850 2	14.9900 2	13.6400 2	11.2350 2	10.2450 2	11.9957 14
June 15	5	33.8600 2	18.3500 2	13.1850 2	12.4650 2	12.3300 2	10.9700 2	10.4250 2	15.9407 14
July 1	6	23.5900 2	8.0450 2	10.5950 2	12.3300 2	13.0250 2	11.5150 2	10.4750 2	12.7964 14
July 15	7	14.1850 2	6.4900 2	9.9350 2	11.6400 2	11.9400 2	11.0300 2	10.6400 2	10.8371 14
Aug 1	8	21.6150 2	6.0600 2	8.3800 2	9.0000 2	10.5300 2	10.1250 2	10.0050 2	10.8164 14
Sept 1	9	12.9150 2	3.1850 2	7.2250 2	8.8700 2	9.2800 2	9.0750 2	9.2450 2	8.5421 14
Oct 1	10	7.6700 2	1.4050 2	5.7200 2	7.4250 2	8.2250 2	8.3350 2	8.6300 2	6.7729 14
Nov 1	11	7.7250 2	1.6100 2	5.6550 2	7.2200 2	7.9300 2	8.1850 2	8.2850 2	6.6586 14
Column Total		18.7940 20	9.4035 20	11.6115 20	12.1490 20	11.6415 20	10.3190 20	9.8770 20	11.9708 140

```
Criterion Variable   MOIST     Volumetric Soil Moisture
  Broken Down by     TIME
              by     DEPTH
  Controlling for    GRAZE     Litter Accumulation    Value:   2   Moderate
              by     ASPECT                           Value:   1   South Facing
              by     YEAR                             Value:   1   1990
```

TIME	Mean Count	DEPTH Surface 1	15cm 2	25cm 3	35cm 4	45cm 5	55cm 6	65cm 7	Row Total
May 1	2	31.8950 2	20.9950 2	18.9700 2	16.1150 2	12.0400 2	8.3100 2	6.9900 2	16.4736 14
May 15	3	19.0300 2	17.4150 2	18.0500 2	15.8150 2	12.3950 2	8.5150 2	7.2700 2	14.0700 14
June 1	4	5.7950 2	7.2400 2	12.0750 2	12.7850 2	11.1450 2	8.4250 2	7.4900 2	9.2793 14
June 15	5	31.0900 2	18.0200 2	13.0550 2	10.6500 2	9.7150 2	7.7000 2	7.4450 2	13.9536 14
July 1	6	16.0650 2	5.8050 2	8.2550 2	8.8750 2	8.6150 2	7.3050 2	7.0100 2	8.8471 14
July 15	7	10.9650 2	7.3700 2	8.1800 2	8.1500 2	7.9950 2	7.5200 2	7.2650 2	8.2064 14
Aug 1	8	18.8400 2	3.2550 2	7.9233 3	6.4750 2	6.7000 2	6.8450 2	7.0700 2	8.1427 15
Sept 1	9	8.7850 2	1.2200 2	4.1000 2	4.6500 2	5.1400 2	5.4700 2	5.9950 2	5.0514 14
Oct 1	10	6.3150 2	-.6800 2	2.6300 2	3.6500 2	4.0600 2	4.3600 2	4.7850 2	3.5886 14
Nov 1	11	9.6250 2	-.4100 2	2.8800 2	3.6000 2	4.0750 2	4.4400 2	4.5550 2	4.1093 14
Column Total		15.8405 20	8.0230 20	9.5314 21	9.0765 20	8.1880 20	6.8890 20	6.5875 20	9.1649 141

Criterion Variable MOIST Volumetric Soil Moisture
Broken Down by TIME
by DEPTH
Controlling for GRAZE Litter Accumulation Value: 3 Heavy
by ASPECT Value: 1 South Facing
by YEAR Value: 1 1990

TIME	Mean Count	DEPTH Surface 1	15cm 2	25cm 3	35cm 4	45cm 5	55cm 6	65cm 7	Row Total
May 1	2	31.7000 2	25.9950 2	24.9650 2	23.8750 2	20.5650 2	15.6750 2	13.9000 2	22.3821 14
May 15	3	21.6550 2	22.4400 2	24.5350 2	24.2500 2	21.0300 2	16.2050 2	14.2000 2	20.6164 14
June 1	4	7.5150 2	14.5150 2	20.3050 2	22.2650 2	20.2450 2	16.2000 2	14.4700 2	16.5021 14
June 15	5	32.2500 2	24.5400 2	22.8900 2	21.1900 2	19.0800 2	16.5400 2	15.3950 2	21.6979 14
July 1	6	17.0250 2	15.2150 2	18.5800 2	19.2900 2	17.9800 2	16.2050 2	14.6150 2	16.9871 14
July 15	7	10.0400 2	13.4100 2	16.2050 2	18.0100 2	17.4600 2	15.5150 2	14.4300 2	15.0100 14
Aug 1	8	19.5100 2	7.0400 2	11.2200 1	14.9300 2	15.2550 2	14.5300 2	13.9050 2	13.9662 13
Sept 1	9	13.6700 2	3.5750 2	8.8200 2	11.1200 2	11.8100 2	11.9400 2	12.3150 2	10.4643 14
Oct 1	10	2.9850 2	.9900 2	6.8600 2	9.3150 2	9.8050 2	10.1150 2	10.7900 2	7.2657 14
Nov 1	11	11.0350 2	1.2750 2	6.9200 2	9.0800 2	9.2600 2	9.8400 2	10.4250 2	8.2621 14
Column Total		16.7385 20	12.8995 20	16.3884 19	17.3325 20	16.2490 20	14.2765 20	13.4445 20	15.3251 139

Criterion Variable MOIST Volumetric Soil Moisture
Broken Down by TIME
by DEPTH
Controlling for GRAZE Litter Accumulation Value: 1 Light
by ASPECT Value: 2 Flat
by YEAR Value: 1 1990

TIME	Mean Count	DEPTH Surface 1	15cm 2	25cm 3	35cm 4	45cm 5	55cm 6	65cm 7	Row Total
May 1	2	27.6200 2	22.7100 2	21.9900 2	20.0800 2	16.8800 2	14.2300 2	16.0350 2	19.9350 14
May 15	3	22.7100 2	19.5300 2	20.9750 2	18.8950 2	16.2150 2	13.7650 2	15.2800 2	18.1957 14
June 1	4	8.6100 2	7.8350 2	13.1100 2	14.2800 2	14.0600 2	12.8850 2	14.3850 2	12.1664 14
June 15	5	31.1850 2	20.2500 2	13.9100 2	11.8250 2	11.7350 2	11.4700 2	12.7400 2	16.1593 14
July 1	6	21.3250 2	9.2550 2	10.4650 2	11.0200 2	11.0200 2	10.8800 2	11.8850 2	12.2643 14
July 15	7	16.3250 2	7.5700 2	10.0500 2	10.6500 2	10.6950 2	10.6750 2	11.0350 2	11.0000 14
Aug 1	8	21.1350 2	6.6700 2	8.9450 2	9.5150 2	9.7250 2	9.8300 2	9.8200 2	10.8057 14
Sept 1	9	11.9850 2	4.6200 2	7.6050 2	8.0900 2	8.5000 2	8.9350 2	8.7200 2	8.3507 14
Oct 1	10	9.2100 2	2.3950 2	6.1500 2	7.0200 2	7.4350 2	8.0000 2	8.2150 2	6.9179 14
Nov 1	11	7.5250 2	2.8250 2	6.2800 2	6.9400 2	7.2250 2	7.9500 2	7.9650 2	6.6729 14
Column Total		17.7630 20	10.3660 20	11.9480 20	11.8315 20	11.3490 20	10.8620 20	11.6080 20	12.2468 140

Criterion Variable	MOIST	Volumetric Soil Moisture		
Broken Down by	TIME			
by	DEPTH			
Controlling for	GRAZE	Litter Accumulation	Value: 2	Moderate
by	ASPECT		Value: 2	Flat
by	YEAR		Value: 1	1990

TIME	Mean Count	DEPTH Surface 1	15cm 2	25cm 3	35cm 4	45cm 5	55cm 6	65cm 7	Row Total
May 1	2	35.4400 2	27.0600 2	26.4150 2	23.1650 2	20.1050 2	19.1800 2	18.7650 2	24.3043 14
May 15	3	22.2400 2	24.0400 2	26.2100 2	23.5950 2	20.0750 2	19.2900 2	18.7400 2	22.0271 14
June 1	4	7.1750 2	13.9650 2	21.4150 2	21.7500 2	19.8750 2	19.4450 2	19.0700 2	17.5279 14
June 15	5	36.2900 2	21.5700 2	19.8800 2	19.6400 2	18.5950 2	18.6350 2	19.2250 2	21.9764 14
July 1	6	19.5200 2	9.5500 2	15.5950 2	17.5450 2	17.8200 2	18.3200 2	18.8900 2	16.7486 14
July 15	7	12.2700 2	9.8950 2	14.5350 2	16.1350 2	16.3900 2	15.9500 2	18.0750 2	14.7500 14
Aug 1	8	19.8000 2	6.8450 2	12.1350 2	13.9400 2	14.3450 2	15.7450 2	16.9450 2	14.2507 14
Sept 1	9	9.7100 2	6.2200 2	10.4400 2	11.8750 2	12.7650 2	14.1050 2	15.1600 2	11.4679 14
Oct 1	10	4.1250 2	3.0200 2	8.6150 2	9.9650 2	11.0400 2	12.4900 2	13.7650 2	9.0029 14
Nov 1	11	13.8700 2	3.1200 2	8.7050 2	9.9350 2	10.7950 2	12.4250 2	13.6600 2	10.3586 14
Column Total		18.0440 20	12.5285 20	16.3945 20	16.7545 20	16.1805 20	16.5585 20	17.2295 20	16.2414 140

Criterion Variable MOIST Volumetric Soil Moisture
Broken Down by TIME
by DEPTH
Controlling for GRAZE Litter Accumulation Value: 3 Heavy
by ASPECT Value: 2 Flat
by YEAR Value: 1 1990

TIME	Mean Count	Surface 1	15cm 2	25cm 3	35cm 4	45cm 5	55cm 6	65cm 7	Row Total
May 1	2	33.9950 2	31.4000 2	30.2250 2	26.3700 2	20.2750 2	13.7850 2	11.5500 2	23.9429 14
May 15	3	34.2600 2	28.0400 2	28.8850 2	26.7350 2	21.0150 2	14.3150 2	11.4150 2	23.5236 14
June 1	4	8.7750 2	18.5050 2	23.5450 2	22.5500 2	18.8150 2	14.1700 2	11.6500 2	16.8586 14
June 15	5	33.8600 2	25.0950 2	21.9750 2	20.2000 2	18.0850 2	13.8150 2	11.7050 2	20.6764 14
July 1	6	23.4200 2	12.2200 2	16.3550 2	17.4450 2	16.3800 2	13.5000 2	11.5750 2	15.8421 14
July 15	7	11.5700 2	10.6450 2	14.3900 2	15.3800 2	14.9500 2	12.7550 2	11.5400 2	13.0329 14
Aug 1	8	13.4950 2	5.9950 2	11.1500 2	12.2250 2	12.2250 2	11.5950 2	11.3150 2	11.1429 14
Sept 1	9	14.6650 2	5.2250 2	9.6150 2	10.5450 2	10.2050 2	9.7350 2	10.0150 2	10.0007 14
Oct 1	10	5.0900 2	2.6900 2	8.4000 2	9.7750 2	9.5250 2	9.1650 2	9.1200 2	7.6807 14
Nov 1	11	13.2100 2	3.2300 2	8.6750 2	9.6500 2	9.5000 2	8.9800 2	8.7350 2	8.8543 14
Column Total		19.2340 20	14.3045 20	17.3215 20	17.0875 20	15.0975 20	12.1815 20	10.8620 20	15.1555 140

Criterion Variable MOIST Volumetric Soil Moisture
Broken Down by TIME
by DEPTH
Controlling for GRAZE Litter Accumulation Value: 1 Light
by ASPECT Value: 1 South Facing
by YEAR Value: 2 1991

TIME	Mean Count / DEPTH	Surface 1	15cm 2	25cm 3	35cm 4	45cm 5	55cm 6	65cm 7	Row Total
Apr 13	1	28.8150 2	16.8200 2	15.3800 2	12.7700 2	10.9200 2	9.7800 2	10.0500 2	14.9336 14
May 1	2	31.0900 2	23.3400 2	21.6400 2	17.9600 2	14.5200 2	12.9300 2	13.6600 2	19.3057 14
May 15	3	19.7800 2	17.3950 2	19.4700 2	18.0850 2	15.5350 2	13.1350 2	13.4850 2	16.6979 14
June 1	4	12.9650 2	8.6050 2	13.1900 2	14.8900 2	14.2400 2	12.9000 2	12.6550 2	12.7779 14
June 15	5	12.1250 2	6.4650 2	10.5800 2	12.6850 2	13.0400 2	12.1050 2	12.3100 2	11.3300 14
July 1	6	28.1650 2	27.0350 2	25.1850 2	20.0400 2	15.2100 2	12.5250 2	12.0200 2	20.0257 14
July 15	7	17.8900 2	21.6850 2	24.9750 2	25.3700 2	23.4050 2	19.2150 2	15.2300 2	21.1100 14
Aug 1	8	9.0950 2	6.9650 2	12.5050 2	16.2200 2	17.1550 2	16.0100 2	14.5600 2	13.0729 14
Sept 1	9	19.7500 2	5.7750 2	8.9750 2	10.1600 2	11.0450 2	10.9650 2	11.0150 2	11.0979 14
Oct 1	10	10.8300 2	3.4000 2	7.3050 2	8.6100 2	9.5600 2	9.6950 2	9.6300 2	8.4329 14
Nov 1	11	15.6600 2	4.4000 2	7.4000 2	8.8750 2	9.3150 2	9.3150 2	8.7900 2	9.1079 14
Column Total		18.6514 22	12.8986 22	15.1459 22	15.0605 22	13.9950 22	12.5977 22	12.1277 22	14.3538 154

Criterion Variable	MOIST	Volumetric Soil Moisture	
Broken Down by	TIME		
by	DEPTH		
Controlling for	GRAZE	Litter Accumulation	Value: 2 Moderate
by	ASPECT		Value: 1 South Facing
by	YEAR		Value: 2 1991

TIME	Mean Count	DEPTH Surface 1	15cm 2	25cm 3	35cm 4	45cm 5	55cm 6	65cm 7	Row Total
Apr 13	1	24.7050 2	11.5950 2	10.1500 2	8.2800 2	7.4200 2	7.7200 2	6.8900 2	10.9657 14
May 1	2	29.5350 2	21.7000 2	19.1900 2	15.6600 2	14.9550 2	14.7500 2	13.5700 2	18.4800 14
May 15	3	13.5400 2	15.1450 2	15.3650 2	13.3600 2	13.1400 2	14.3200 2	14.0550 2	14.1321 14
June 1	4	9.8100 2	5.1900 2	9.8650 2	10.3950 2	11.2200 2	12.8850 2	12.9100 2	10.3250 14
June 15	5	7.3100 2	4.7750 2	7.6850 2	8.7900 2	9.6950 2	11.6900 2	12.3500 2	8.8993 14
July 1	6	20.9000 2	21.3350 2	20.7850 2	17.4650 2	14.1600 2	12.5500 2	11.8700 2	17.0093 14
July 15	7	8.6700 2	13.6050 2	18.9667 3	18.6750 2	19.8900 2	19.4750 2	18.2450 2	16.9347 15
Aug 1	8	7.2400 2	3.1450 2	7.3700 2	9.9600 2	12.9400 2	15.0150 2	15.3900 2	10.1514 14
Sept 1	9	21.9550 2	3.9000 2	5.6900 2	6.3600 2	8.0050 2	9.5900 2	10.3050 2	9.4007 14
Oct 1	10	10.4200 2	1.0100 2	4.1600 2	5.1650 2	6.3350 2	7.1300 2	8.0650 2	6.0493 14
Nov 1	11	15.5000 2	1.4050 2	4.3700 2	4.2950 2	5.0850 2	6.7900 2	6.7300 2	6.3107 14
Column Total		15.4168 22	9.3459 22	11.5722 23	10.7641 22	11.1677 22	11.9977 22	11.8527 22	11.7300 155

Criterion Variable MOIST Volumetric Soil Moisture
Broken Down by TIME
by DEPTH
Controlling for GRAZE Litter Accumulation Value: 3 Heavy
by ASPECT Value: 1 South Facing
by YEAR Value: 2 1991

TIME	Mean Count	DEPTH Surface 1	15cm 2	25cm 3	35cm 4	45cm 5	55cm 6	65cm 7	Row Total
Apr 13	1	23.8350 2	16.1000 2	14.7500 2	11.9550 2	10.5700 2	10.4250 2	10.8200 2	14.0650 14
May 1	2	21.4800 1	16.8200 1	13.1000 1	10.5400 1	9.6000 1	10.1700 1	11.5600 1	13.3243 7
May 15	3	18.9450 2	19.4050 2	20.1450 2	19.3250 2	18.9050 2	19.0800 2	20.1000 2	19.4150 14
June 1	4	12.9900 2	10.0950 2	15.8650 2	17.6150 2	17.4100 2	17.9550 2	19.2750 2	15.8864 14
June 15	5	11.5000 2	10.9700 2	14.4150 2	16.5600 2	16.8750 2	17.3600 2	18.6450 2	15.1893 14
July 1	6	20.5500 2	25.5450 2	26.0650 2	24.7000 2	21.3100 2	19.5800 2	19.6150 2	22.4807 14
July 15	7	10.9100 2	18.5100 2	24.5200 1	24.8250 2	24.6800 2	24.8750 2	25.5350 2	21.7838 13
Aug 1	8	5.8050 2	6.9900 2	14.5550 2	18.6400 2	20.3850 2	21.8400 2	23.1600 2	15.9107 14
Sept 1	9	18.4300 2	7.8350 2	11.2200 2	13.5750 2	14.8000 2	16.9550 2	18.7400 2	14.5079 14
Oct 1	10	15.4900 2	4.3800 2	9.5900 2	11.8700 2	12.7100 2	14.2300 2	16.3950 2	12.0950 14
Nov 1	11	15.5950 2	5.7900 2	10.8500 2	12.2650 2	12.9650 2	13.6650 2	16.0450 2	12.4536 14
Column Total		15.6943 21	12.7648 21	15.6265 20	16.8190 21	16.7057 21	17.2429 21	18.4867 21	16.1953 146

Criterion Variable MOIST Volumetric Soil Moisture
Broken Down by TIME
by DEPTH
Controlling for GRAZE Litter Accumulation Value: 1 Light
by ASPECT Value: 2 Flat
by YEAR Value: 2 1991

TIME	DEPTH Mean Count	Surface 1	15cm 2	25cm 3	35cm 4	45cm 5	55cm 6	65cm 7	Row Total
Apr 13	1	30.0500 2	21.3250 2	17.4300 2	10.7850 2	8.3100 2	8.1700 2	8.0250 2	14.8707 14
May 1	2	29.1800 2	27.2850 2	22.4850 2	16.7100 2	12.8900 2	10.3900 2	8.2050 2	18.1636 14
May 15	3	21.6600 2	21.5000 2	21.0000 2	16.7800 2	13.3150 2	11.6600 2	8.2750 2	16.3129 14
June 1	4	12.9750 2	9.7800 2	13.0700 2	12.8450 2	11.5800 2	10.8800 2	8.2050 2	11.3336 14
June 15	5	10.5700 2	6.9750 2	9.6550 2	9.6150 2	9.7100 2	9.6100 2	8.3400 2	9.2107 14
July 1	6	23.3300 2	29.1150 2	26.8750 2	21.8100 2	16.0800 2	11.6400 2	9.4250 2	19.7536 14
July 15	7	12.1450 2	21.8800 2	24.3350 2	23.9200 2	23.1800 2	20.1250 2	15.4200 2	20.1436 14
Aug 1	8	12.0650 2	6.9350 2	11.2450 2	12.6550 2	14.4550 2	14.7550 2	13.3900 2	12.2143 14
Sept 1	9	20.1500 2	6.1400 2	8.5550 2	8.8950 2	9.6100 2	9.8100 2	9.9250 2	10.4407 14
Oct 1	10	10.7100 2	3.5300 2	7.2400 2	7.8050 2	8.3650 2	9.0100 2	8.5050 2	7.8807 14
Nov 1	11	15.3950 2	5.3150 2	7.8150 2	7.8900 2	8.2800 2	9.4650 2	7.9700 2	8.8757 14
Column Total		18.0209 22	14.5255 22	15.4277 22	13.6100 22	12.3432 22	11.4105 22	9.6077 22	13.5636 154

Criterion Variable MOIST Volumetric Soil Moisture
Broken Down by TIME
by DEPTH
Controlling for GRAZE Litter Accumulation Value: 2 Moderate
by ASPECT Value: 2 Flat
by YEAR Value: 2 1991

TIME	DEPTH Mean Count	Surface 1	15cm 2	25cm 3	35cm 4	45cm 5	55cm 6	65cm 7	Row Total
Apr 13	1	25.8350 2	21.0250 2	20.1850 2	16.7600 2	14.9700 2	15.9100 2	14.6650 2	18.4786 14
May 1	2	29.8400 2	27.1200 2	24.6050 2	18.4900 2	15.5000 2	17.6600 2	18.6350 2	21.6929 14
May 15	3	23.6750 2	21.5650 2	24.5700 2	21.2150 2	18.7200 2	20.0750 2	19.0950 2	21.2736 14
June 1	4	9.5950 2	11.4050 2	18.0800 2	18.3750 2	17.3050 2	18.8900 2	18.3500 2	16.0000 14
June 15	5	12.5450 2	9.7150 2	14.8650 2	15.7300 2	15.4750 2	17.2750 2	17.6400 2	14.7493 14
July 1	6	24.9300 2	27.5600 2	25.6150 2	19.8900 2	15.9850 2	16.5950 2	17.0300 2	21.0864 14
July 15	7	13.2700 2	20.5850 2	25.7900 2	26.1400 2	24.6000 2	22.6250 2	20.9100 2	21.9886 14
Aug 1	8	9.7100 2	8.2250 2	15.1300 2	18.0200 2	19.6350 2	19.2850 2	19.1550 2	15.5943 14
Sept 1	9	19.8250 2	9.0550 2	12.3550 2	13.6950 2	14.6850 2	16.1500 2	16.8700 2	14.6621 14
Oct 1	10	9.9950 2	5.0100 2	10.4150 2	11.6450 2	13.0700 2	14.2100 2	15.2450 2	14.3700 14
Nov 1	11	15.1050 2	6.5600 2	11.3250 2	12.5650 2	14.3750 2	15.7900 2	16.1000 2	13.1171 14
Column Total		17.6659 22	15.2568 22	18.4486 22	17.5023 22	16.7564 22	17.6786 22	17.6086 22	17.2739 154

```
Criterion Variable    MOIST     Volumetric Soil Moisture
    Broken Down by    TIME
                by    DEPTH
  Controlling for     GRAZE     Litter Accumulation     Value:   3   Heavy
                by    ASPECT                            Value:   2   Flat
                by    YEAR                              Value:   2   1991
```

TIME	Mean Count	DEPTH Surface 1	15cm 2	25cm 3	35cm 4	45cm 5	55cm 6	65cm 7	Row Total
Apr 13	1	29.3350 2	25.6450 2	24.2500 2	20.3300 2	18.1950 2	16.8150 2	16.5550 2	21.5893 14
May 1	2	33.3000 2	32.6350 2	32.2900 2	30.6350 2	26.5500 2	23.3350 2	22.3600 2	28.7293 14
May 15	3	26.0250 2	24.8650 2	27.3950 2	27.6000 2	26.3500 2	23.0850 2	21.8650 2	25.3121 14
June 1	4	12.0100 2	12.4600 2	19.5000 2	22.3650 2	22.4600 2	21.0700 2	20.3700 2	18.6050 14
June 15	5	9.4850 2	10.3600 2	15.5150 2	17.2400 2	18.0600 2	18.7650 2	18.7800 2	15.4579 14
July 1	6	25.5600 2	28.6000 2	26.8950 2	21.4850 2	18.0450 2	17.7950 2	17.9650 2	22.3350 14
July 15	7	15.1750 2	21.9350 2	25.9900 2	26.6450 2	25.7750 2	23.4850 2	21.6250 2	22.9471 14
Aug 1	8	11.5900 2	9.0850 2	15.5400 2	17.6750 2	18.7750 2	19.3150 2	19.1100 2	15.8700 14
Sept 1	9	19.8250 2	8.5500 2	12.4900 2	13.4350 2	13.6550 2	14.0700 2	14.7600 2	13.8264 14
Oct 1	10	10.7350 2	5.3200 2	10.8100 2	11.8400 2	11.6600 2	11.6050 2	12.4100 2	10.6257 14
Nov 1	11	21.6250 2	8.5950 2	12.3400 2	12.0700 2	11.7600 2	11.0950 2	11.6250 2	12.7300 14
Column Total		19.5150 22	17.0955 22	20.2741 22	20.1200 22	19.2077 22	18.2214 22	17.9477 22	18.9116 154