AN EVALUATION OF PLANT LITTER ACCUMULATION AND ITS BENEFITS IN MANITOBA PASTURES

BY

SIMON JAMES REGEHR NEUFELD

A Thesis
Submitted to the Faculty of Graduate Studies
in Partial Fulfillment of the Requirements
for the Degree of

MASTER OF SCIENCE

Department of Plant Science
University of Manitoba
Winnipeg, Manitoba

ACKNOWLEDGEMENTS

While only one name may lie upon the title page as author of this work, the pages within bear the marks of many whose contributions have made its fruition possible. So it is with sincere gratitude that I thank my supervisor, Dr. Martin Entz, who provided me with guidance, support, and many rejuvenating conversations about my work and the big universe within which it fits; my committee members, Drs. Paul Bullock and Kim Ominski; those who provided guidance and assistance with field work, Keith Bamford, Matthew Wiens, Yuying Shen, and the many summer students; and my fellow graduate students, who were always ready with wit and encouragement to keep my spirits up.

It might be said that the life of a graduate student is lived in a precarious balance, at all times teetering between calamitous despair and self-destructing over-confidence. It is only through the generous and loving support of Judith Klassen, life partner and occasional field assistant, that this balance was achieved. In fact, I can say without reservation that her presence in my life has made this work a joy.

This work was supported financially by Greencover Canada and the Manitoba Graduate Scholarship. I also wish to acknowledge the generosity of the atmosphere, which received approximately 7.3 tonnes of CO_2 equivalents as a result of the driving required for my research.

> … for the land is mine; with me you are but aliens and tenants. Throughout the
> land that you hold, you shall provide for the redemption of the land.
> *Leviticus 25:23-24 (NRSV)*

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

Litter (dead plant material) is important in pasture for its role in conserving soil water. Litter traps winter precipitation, slows runoff, and reduces evaporative losses. Litter can also trap moisture above the soil surface making it unavailable to plants. Grazing impacts litter by reducing the amount of plant material returning to the soil as litter. It also increases the decomposition of litter through treading and trampling the surface, and the deposition of greater amounts of mineral nutrients in urine and feces. Optimum litter benchmarks for healthy pasture, ranging from 600 kg/ha – 1600 kg/ha, have been determined for grazing regions of Alberta. Similar data has not been published for Manitoba. Three studies were undertaken from 2006 to 2007 to examine litter in southwestern Manitoba pastures. In the first study the relationship between litter, soil microclimate and forage yield was tested across five pasture sites. Litter was applied to bare soil at rates from 0 kg/ha to 3000 kg/ha. The amount of litter biomass was not strongly related to soil moisture, though near-surface soil temperatures were reduced when litter was present. Further, the presence of litter did not influence yield. The objective of the second study was to measure the effect of different grazing strategies on the litter layer of six pastures in southwest Manitoba. Four grazing systems (continuous, time-controlled, twice-over, and stockpiled) were simulated using different frequencies of defoliation. It was found that after three years of simulated grazing, litter was present in largest quantities in the least-frequently grazed treatments. Litter ranged from 1000 kg/ha under the continuous grazing treatment to 3711 kg/ha in the ungrazed control. Litter amounts under time-controlled grazing averaged 1130 kg/ha, while twice-over averaged 1736 kg/ha. The third study involved a field survey assessing the quantity of litter present in native pastures in different ecoregions of Manitoba. Litter biomass was measured in grazing exclosures located in twelve pastures across the province that were lightly clipped twice per year. Litter in these cages was extremely variable, ranging from 825 kg/ha to 3750 kg/ha. Over two years of study, litter biomass averaged 1902 kg/ha. Through this research, the value of litter as an indicator of sustainable pasture management was confirmed, though it remains unclear whether litter is important to pastures from the perspective of soil microclimate.

FORWARD

The manuscripts contained in this thesis have been prepared following the journal format provided in *Rangeland Ecology and Management*.

1 INTRODUCTION

Pasture management research has been conducted for decades, always with the aim of maximizing the pasture's output while minimizing the impacts upon it. Over the years, ecological principles have been applied to pasture management in an effort to "take advantage" of natural processes instead of ignoring them. The concepts of nutrient and water cycling, plant community structure, animal-plant interactions, and others improve environmental sustainability while maintaining economic viability.

Litter – the dead plant material standing or lying on the soil surface – has been seen as a benefit to pasture health for many reasons. The biggest benefit attributed to litter in pastures is the effect litter has on soil water. Litter has been shown to increase snow deposition and slow overland flow of water (Naeth and Chanasyk 1995), reduce energy inputs to the soil surface (Bussiere and Cellier 1994; Horton et al. 1994) and thereby reduce evaporation (Weaver and Rowland 1952).

Other research has explored the potential costs of litter, such as its ability to intercept precipitation above the soil surface, allowing rainwater to evaporate without becoming available to plants (Naeth et al. 1991a). Further, climatic conditions impact the ability of litter to influence soil moisture. Litter cannot serve its function as a "tool" for moisture conservation when conditions are too dry or too wet. Under these conditions, there is either no moisture to conserve, or no need for conservation (Willms et al. 1993; Deutch and Bork 2008). Thus, litter does not have a consistent, predictable effect in all pastures or in all years.

The influence of grazing on the litter layer has also been a point of concern in previous studies. As long ago as 1948, Hedrick reported that heavy grazing reduced the amount of litter in a pasture environment. More recently, long-term grazing has been shown to lead to significant reductions in the litter layer (Dormaar and Willms 1998).

The growing interest to improve the management of pasture resources has led the Alberta government's Public Lands Division and Alberta Sustainable Resource Development (another government department) to publish a guide for pasture health assessment (Adams et al. 2003). In this guide, litter thresholds have been recommended for Alberta's principal grazing regions based on average litter accumulation expected under light grazing. These thresholds allow pasture managers to use the litter layer as an indicator for determining whether their land is being managed in a sustainable manner.

Litter research has not been published for Manitoba. Given the fact that the effect of litter on pasture varies based on location, climate, and grazing system, a comprehensive study of the role of litter in pastures within the context of Manitoba's climate and geography is important. Three studies were undertaken with this aim in mind.

The first study measured soil moisture, soil temperature, and forage production under a range of litter biomass in four tame and one native pasture in southwest Manitoba. The second study measured litter biomass in three tame and three native pastures in southwest Manitoba after three years of different grazing systems had been applied. A third study surveyed litter biomass quantities in 12 native pastures across Manitoba.

The objectives of these studies were to:

1. quantify the effect of litter on soil microclimate and yield,
2. measure the effect of different grazing systems on the litter layer, and
3. to develop litter benchmarks for four grazing regions of Manitoba.

2 LITERATURE REVIEW

2.1 Introduction

Research on the importance of plant residues, or *litter*, in pastures has been occurring for decades, predating the intensive focus on residue management that grew in cropping research through the 1970's. Despite the early recognition of litter's importance in pastures, however, little research has been conducted in Manitoba to describe its role within this province's climatic conditions.

Existing research has investigated litter from several perspectives. First, it has attempted to quantify the effects of litter in pasture, by investigating how litter affects soil moisture and temperature, provides habitat for decomposer communities, and improves site stability (as measured by soil erosion risk and species composition). Second, it has looked at grazing intensity and its effect on the accumulation of litter. Third, it has attempted to determine litter benchmarks that can act as targets for healthy pasture management.

My present research has attempted to place these three perspectives into a Manitoban context. The following is a review of the literature developed in other regions.

2.2 Definitions

Dead plant material remaining on the soil surface has been called by many names. Crop science calls it residue or mulch. Grassland science has used the terms mulch, duff, or thatch. In forestry, fallen leaves are known as litter. Pasture science, as a hybrid of several of these fields, has used many of these terms, though the predominant terms are *mulch* and *litter*. In this thesis, dead plant material will be called litter.

These terms have been further divided in the literature into sub-categories. *Standing litter* is that material still anchored to the plant or the ground, and remaining in a vertical orientation. *Fallen litter* is that litter that has fallen and can make up a layer of horizontally oriented litter. *Humic litter* or *humic mulch* is litter that is already partially decomposed – it has not become organic matter, but it is clearly not in its original state.

Unless specified, the use of *litter* in the present study refers to all dead plant material standing or lying on the soil surface.

2.3 Litter functions in pasture

Litter plays myriad roles in pasture; it captures, intercepts, and conserves moisture, reduces erosion, and provides a habitat for decomposers and other fauna.

2.3.1 Capturing moisture

Litter can contribute to moisture gains on a year-round basis. The presence of standing litter on the soil surface creates resistance to air movement, causing increased snow deposition (Naeth and Chanasyk 1995). Increased snow can potentially lead to increased spring recharge, which is further enhanced by litter through its effect on overland water flow – runoff is slowed allowing greater amounts of water to enter the soil (Naeth and Chanasyk 1995). Throughout the growing season litter helps slow runoff from rainfall events, thus increasing infiltration.

The benefit of litter as a moisture capture agent is conditional. Litter intercepts rain and holds it above the soil surface where it is unavailable to plants and quickly evaporates (Horton et al. 1994). The water holding capacity (WHC) of litter can be as high as twice its weight (Naeth et al. 1991a); WHC differs among plant species, litter architecture, and level of decomposition. The net effect of WHC on soil moisture depends on the nature of the precipitation events and the overall climate. Large precipitation events will not be as strongly affected by litter interception, but in areas with frequent small rainfall events, interception can represent a significant loss (Naeth et al. 1991a).

2.3.2 Modifying the microclimate: soil moisture and temperature

The conditions that govern the movement of water through the soil profile have been well defined; so well defined, in fact, that mathematical models, such as the SHAW model (Flerchinger 2000), have been developed to predict how water will move in given micrometeorological conditions. These mathematical models have been modified to incorporate and describe the effect of a litter layer on the soil surface (Flerchinger et al. 2003). The litter layer modifies the microclimate primarily by modifying the energy balance at the surface. Though most of the research quantifying these effects have taken place in cropping systems rather than pasture, the basic principles hold true in both contexts.

The surface energy balance. When sunlight strikes the surface of the earth, some energy is reflected back into space, some is absorbed and then re-radiated as longwave radiation, and the remaining energy is partitioned into sensible heat (air temperature), latent heat (evaporation), and ground heat (soil temperature).

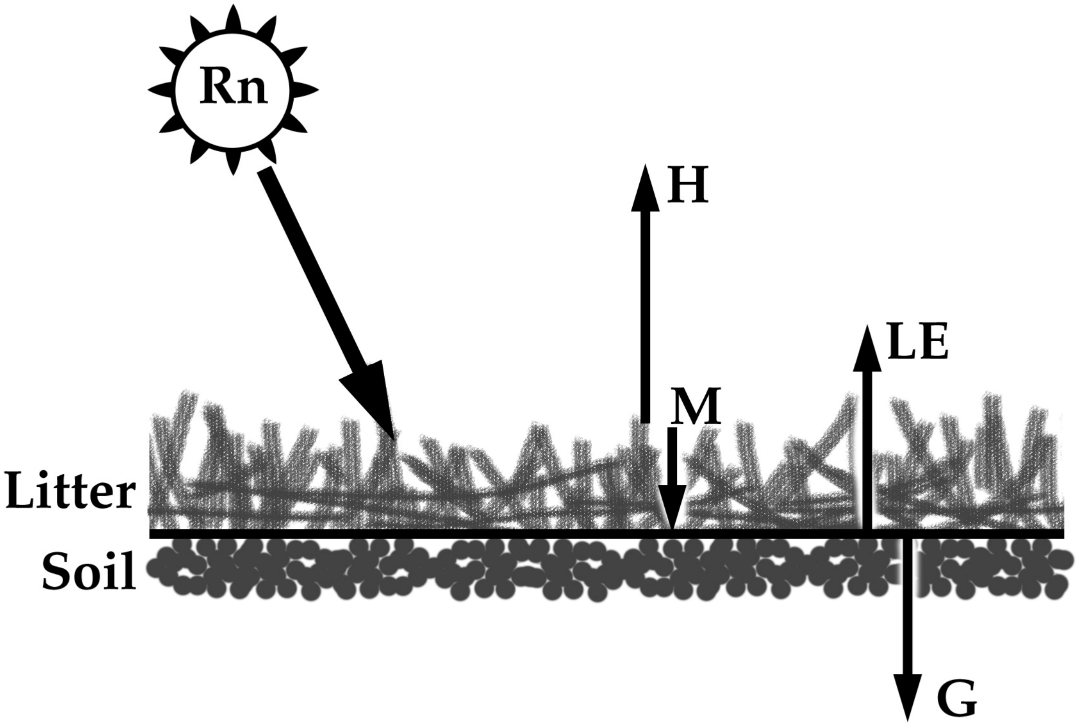

Figure 2-1: Surface energy partitioning when litter is present. Rn, net solar radiation; H, sensible heat flux; M, residue heat flux; LE, latent heat flux; G, ground heat flux. After Horton et al. (1994).

On a bare soil, all energy partitioning occurs at the soil surface. Litter adds complexity to the system – effectively separating energy transfer into two strata: litter surface and soil surface (Horton et al. 1994). Modeled in its simplest form, litter can be treated as a solid and opaque layer (Figure 2-1). In this simplified model, net radiation (Rn) is received at the top of the residue layer, where it is partitioned into sensible heat (H) and "residue heat flux" (M – the equivalent to ground heat flux). The heat that travels through the residue reaches the soil surface where it is partitioned into evaporation (LE) and ground heat flux (G).

Net Radiation. Litter reduces the amount of net radiation (Rn) in two ways. Residue is often light tan in colour and can be shinier than bare soil. Because of these characteristics, the albedo (reflectivity) of residue is usually higher than the albedo of bare soil. Straw mulches have an albedo in the order of 0.2 to 0.3 (Horton et al. 1996), while bare soil can range from as high as 0.4 when light-coloured and dry to as low as 0.05 when dark and wet (Oke 1987). Raising the albedo of the surface means reducing Rn.

The emission of longwave radiation from a surface depends on its temperature. The temperature of residue can climb much higher than the temperature of the air or the temperature of a bare soil (Novak et al. 2000), leading to higher emissions of longwave radiation (Bussiere and Cellier 1994). This also reduces the amount of Rn available to the system.

Bussiere and Cellier (1994) found that sugar-cane residues reduced the amount of incoming net radiation. Approximately half of the reduction was attributed to albedo effects, and the remainder was a result of increased longwave radiation from the surface. Weaver and Rowland (1952) took light measurements in a heavily mulched grassland, and found that light was completely excluded 2.54 cm below the surface of the litter.

Sensible Heat. The magnitude of sensible heat (H) depends largely on the difference in temperature between the surface and the atmosphere – a large difference will generate a larger H (Horton et al. 1994). As already stated, the temperature of the residue surface can be much higher than the air temperature (Novak et al. 2000). In moisture limited conditions, such as a quickly dried litter layer, this large temperature gradient can lead to an increase in H (Bussiere and Cellier 1994). The remaining energy that is not lost through H is transferred down through the residue to the soil surface via residue heat flux (M), where it is then available for evaporation and soil warming (Figure 2-1).

A study by Novak et al. (2000) found that the flux of sensible heat decreased as measurements were taken deeper into a residue layer, supporting the assertion that heat is generated primarily at the surface of the litter layer.

Bussiere and Cellier's tropical research (1994) reveals a strong relationship between heat loss and mulch. Between 12 and 2 PM, when solar energy inputs are the largest, sensible heat was up to four times higher over a mulched soil than over a bare soil.

Latent Heat. Since residue dries out quickly, soil is the primary source of water for evaporation (Horton et al. 1994). Thus, energy becomes latent heat (LE) at the bottom of the residue layer, only after being partitioned into H and M (Figure 2-1).

The rate of evaporation is primarily controlled by two factors: the magnitude of resistance caused by the layer of still air at the soil surface (known as the "skin friction layer"), and the vapour pressure gradient between the point of evaporation and the atmosphere. First, litter affects the skin friction layer directly. Any surface characteristic that reduces turbulence (such as a rough layer of litter) will increase the thickness of still air above the soil. Movement of vapour through this layer of still air by conduction is slower than that of the turbulent flow above; therefore the thickness of the skin friction layer has a direct effect on the rate of evaporation.

On a bare soil, air turbulence interacts directly with the soil surface, thereby keeping the thickness of the skin friction layer to a minimum. Residue slows down wind speeds, thus increasing the thickness of the boundary layer. This added thickness creates a great deal more resistance to vapour flow than the boundary layer above a bare soil.

Second, litter has an indirect effect on the vapour pressure gradient. Vapour moves from areas of high pressure to low pressure; for example, a moist soil on a warm dry day will produce a large pressure gradient – vapour pressure at the soil surface will be much higher than the vapour pressure in the atmosphere – and the latent energy flux will be correspondingly large. If the gradient is small or the resistance is high, the flow of vapour will be slow as will the rate of evaporation. The fact that residue keeps a soil moist longer than bare soil causes a larger vapour pressure gradient, which will in turn act to drive up evaporation.

The resulting evaporation rate is a result of the balance struck by these two opposing forces. As long as a vapour pressure gradient exists evaporation will continue – though its rate is slowed by the presence of litter at the surface.

This equilibrium can be measured by tracking the change in soil moisture after a precipitation event. Working in Australia, Bristow and Horton (1996) attempted to predict soil moisture and temperature under a residue cover using a mathematical model. Working in both sand and clay soils, soil moisture measurements were taken from the 0-5 cm depth either with or without a mulch layer. In the clay soil, moisture levels under mulch followed a steady downward drying trend and remained higher than the bare soil throughout the measurement period. Moisture in the bare soil dropped immediately over the first two days, after which the level remained fairly constant. In the sandy soil, the two treatments were basically similar throughout the measurement period.

Working in simulated grassland conditions, Weaver and Rowland (1952) found that evaporation during the first day after soil wetting was reduced up to 75% when a mulch was present. On the second day evaporation was 43% less under mulch. It took eight days for the mulched soil to become as dry as the bare soil became in three days.

Willms et al. (1993) measured soil moisture under differing amounts of litter in an experiment located in a mixed prairie site near Lethbridge, Alberta.

Litter treatments were 377, 787, and 1171 kg/ha. Soil moisture levels were statistically similar in all treatments on all measurement dates except one. On this date, the low, medium and high litter treatments averaged 22, 23, and 25% moisture respectively.

Deutsch and Bork (2008) found that litter played a significant role in determining soil moisture on the fourth and fifth days after precipitation. While soil moisture in the first three days after wetting was primarily a function of soil texture, the fourth and fifth days were determined primarily by litter cover, with the fourth day exhibiting the strongest positive relationship (R^2=0.25, p=0.005).

Ground heat flux. The flow of heat into the soil (G) is not directly altered by the presence of a residue layer. The fact that less energy reaches the soil surface when residue is present than when the soil is bare does mean that less heating will occur in the soil during the day. At night when the flow of energy reverses, residue slows the loss of heat to the atmosphere, and slows the rate of cooling.

Horton et al. (1996) studied the temperatures of bare and residue-covered soils, and found that mulch dampens diurnal temperature fluctuations. Under residue, fluctuations at the soil surface were smaller than those 5 cm below a bare soil surface. The mulch was effectively moving the soil surface "underground".

Weaver and Rowland (1952) measured soil temperature at 1.27 cm below the soil surface of a grassland, and found that a heavy mulch of big bluestem reduced soil temperatures from approximately 26° C to 14° C in early May, and from 32° C to 17° C in late May. By June, the growth of pasture grass had effectively "overshadowed" the litter effect, and temperature differences between the two treatments at the soil surface were no more than 4° C.

2.3.3 Other roles of litter in pasture

Erosion prevention and site stabilization. Erosion risk is highest in landscapes with little surface cover. By slowing wind and water movement at the surface, litter reduces erosion (Dormaar and Carefoot 1996). Another form of erosion, known as "splash erosion", is a problem when soil cover (including litter) is absent and raindrops hit the soil with their full force; the soil is compacted and redistributed by the drops, leading to increased bare ground, heightened erosion, and eventually grassland degradation (Bestelmeyer et al. 2006). In Texas, where the movement of sand dunes by wind erosion can cause significant damage to rangeland, residues are employed to stabilize dunes and prevent them from moving (Fulbright et al. 2006).

Litter also helps maintain stable plant communities by preventing establishment of weedy species that invade patches of bare soil (Zimmer and Corea 1993 in de Oliveira et al. 2004). In 1956, Heady examined species composition over several years under differing residue rates. His experiment revealed remarkable changes in the composition and growth habit of plant species over a period of four years. In plots where litter was removed every year, short-growing species of grass and broadleaves dominated and normally tall-growing plants grew shorter. Conversely, in plots where litter was allowed to accumulate, high amounts of litter every year, tall growing grasses such as *Bromus mollis* (soft brome) dominated and grew taller than in the litter removal treatment.

Habitat. Litter is an important habitat for soil decomposers. The quality of litter influences the composition of the decomposer community, which in turn affects the decomposition rate. In a study by Smith and Bradford (2003), quality of litter (i.e. nitrogen content) significantly affected decomposition rate, through its influence of decomposer species composition. Larger decomposers actively seek and consume higher quality materials, and can break down litter more quickly. This rapid break down in turn makes the litter more accessible to bacteria and fungi.

It has been said that litter is more important for maintenance of wildlife than the living forage (Holechek et al. 1982). For example, cotton rats have been found to be positively correlated with grass litter (Goertz 1964). According to a study conducted in Minnesota (Tester and Marshall 1961), savannah sparrows prefer heavy litter while bobolinks preferred moderate amounts of litter.

2.3.4 The Manitoba climate

Litter has its strongest effect on soil moisture in years when precipitation is moderate. In conditions that are too dry, there is no moisture to conserve. In conditions that are too wet, conservation is irrelevant. What can be said about climate conditions in Manitoba?

Manitoba is less moisture deficient than regions to the west. That is, the Manitoba climate is classified as "extreme continental", whereas Saskatchewan and Alberta are categorized as continental (Shaykewich et al. 1994). Mean annual temperature in the Red River Valley is 2.3°C, with the temperature of the warmest month averaging 19.7°C and that of the coldest month averaging –18.3°C. These temperatures as more extreme than regions of Saskatchewan and Alberta, which experience warmer winters and cooler summers than Manitoba. Agricultural regions of Manitoba receive a range of 1500 to 1750 growing degree days per year (Shaykewich et al. 1994).

Growing season precipitation across Mantioba ranges from 200 to 225 mm (Shaykewich et al. 1994), with annual totals between 400 and 550 mm (Weir 1968). In comparison, aveage annual precipitation is 373 mm in Regina, 345 mm in Swift Current, and 470 mm in Beaverlodge (De Jong and Steppuhn 1983).

Annual potential evapotranspiration exceeds annual precipitation across the prairies, with the largest deficits corresponding to the warmest months. However, these deficits tend to be smaller in Manitoba than regions further west (De Jong and Steppuhn 1983). Regina's annual moisture deficit is 310 mm, while in Swift Current a deficit of 387 mm is experienced. Beaverlodge strikes a balance between precipitation and potential evapotranspiration (De Jong and Steppuhn 1983). Average annual water deficiencies in agricultural regions of Manitoba range from 25 mm to 114 mm (Weir 1983).

While Manitoba is subject to a more favorable moisture regime than agricultural regions to the west, it remains in a moisture deficit during the peak period of the growing season (De Jong and Steppuhn 1983). Thus, the effect of litter in Manitoba pastures may not be as significant as elsewhere, but to date this impact has not been quantified.

2.4 Grazing effects on litter accumulation

The presence of cattle or other grazers in a pasture alters the litter layer in several ways. As grazers, cattle act as an intermediate step between living plants and the litter layer. Grazed plant biomass is prevented from senescing and becoming litter directly. The treading and trampling of the soil surface can alter the litter architecture, speeding decomposition and altering its water holding capacity. Digested plant material is returned to the soil surface via feces and urine, the nutrient balance of which alters the decomposition rates of litter on the surface.

2.4.1 Herbage removal

Over 50 years ago, researchers were already concerned with the role of grazing on litter accumulation. Hedrick (1948) reported that heavy grazing reduced the amount of *humic mulch*. Fire removed the surface vegetation but did not affect the humic litter, while heavy grazing removed both the surface vegetation and the humic mulch layer.

Dormaar and Willms (1998) reported that after forty-four years of very high grazing intensity (4.8 Animal Unit Months per hectare, AUM ha^{-1}, three times the recommended rate for range in good condition) the litter layer was completely absent, while under light grazing (1.2 AUM ha^{-1}) the layer was four to five centimeters deep. Accompanying the absence of litter in the heavily grazed treatments was a thinner topsoil (7.5 cm versus 22 cm) and significantly lower soil carbon (7.5% versus 11.4%) than seen in the lightly grazed treatment.

Baron et al. (2002) found that in tame meadow bromegrass pasture, heavy rotational grazing (5-6 times per season, beginning in late May) allowed only 16% of aboveground dry matter to become litter, while light rotational grazing (3 times per season, beginning in mid-June) allowed 34%. The same amount of plant matter was grazed under both treatments, measured as mass of forage removed from pasture over the course of the season. However, forage production under light grazing was significantly higher than that of the heavily grazed treatment, resulting in greater amounts of residual material returning to the litter layer.

Donkor et al. (2003) studied the effect of defoliation on forage productivity in smooth brome/Kentucky bluegrass pasture seeded in the 1950s The site was situated 48 km southeast of Edmonton, Alberta in an aspen boreal ecosystem. Their experiment examined the effects of start date, severity, and frequency of defoliation on forage production. Litter data from this research shows that defoliation start date, severity, and frequency all had significant effects on litter accumulation. Reducing the rest period between defoliation events from 6 weeks to 3 weeks caused a reduction of litter from 274 kg/ha to 128 kg/ha.

2.4.2 Other effects of grazing

Treading and trampling. Decomposition rates are highest at the point of soil-litter contact (McCalla 1943). Mixing the litter into the soil, or providing a better soil contact, as the presence of grazers will do, will thus speed the litter decomposition rate. This altered decomposition rate in turn leads to changes in the water holding capacity (WHC) of the litter layer (Naeth et al. 1991a). Standing and fallen litter were found to have higher WHC than medium, fine, or very fine organic matter. Thus in heavily grazed pastures with less coarse litter and more fine organic matter, less water can be trapped above the surface than in lightly grazed pastures.

Soil Nutrients. Heavy grazing leads to a reduction of carbon and phosphorous in the soil, and a corresponding increase in mineral nitrogen compared to light grazing (Dormaar and Willms 1998). These findings were supported by Baron et al. (2002), who examined the effect of grazing on litter deposition and found that grazing intensity had an indirect effect on the rates of nutrient cycling. Nutrient returns to the soil were measured in two pathways: as plant litter, and as animal waste. The proportion of total nitrogen deposition deposited via animal waste was higher under heavy grazing (83%) than under light grazing (72%). This shift towards a more mineralized nitrogen form would likely lead to increased rate of nitrogen cycling. Increasing the intensity of grazing also led to a shift towards more mineralized forms of carbon deposition.

Thus, under light grazing litter acts as a fertility sink, binding nutrients up in slowly decomposing materials rather than making them available in more mineral forms. The impact of grazing on the litter layer is an important consideration with respect to nitrogen loss through volatilization and carbon loss through respiration.

2.4.3 Grazing systems used in Manitoba

Several grazing strategies have been adopted in Manitoba with differing intensities of both management and grazing. In terms of the litter layer, the timing of grazing activities is important because the impact of grazing on litter accumulation varies throughout the growing season. Research in south and central Alberta found that grazing late in the season (August – October) did not have as great an effect on the litter layer as grazing earlier in the season (May – July) (Naeth et al. 1991b). On the other hand, research conducted southeast of Edmonton found that starting defoliation in May caused a litter accumulation of 338 kg/ha, while June and July start dates caused an accumulation of 238 kg/ha and 166 kg/ha respectively (Donkor et al. 2003, litter data unpublished). Thus grazing systems must be tailored to specific conditions to optimize litter accumulation.

Continuous grazing involves keeping cattle on a single pasture for the duration of the grazing season, without any rest or recovery period. The number of cattle the pasture can support (i.e. the carrying capacity) is calculated based on the expected level of forage production over the entire grazing season. Management is considered low-intensity, while the intensity of grazing in this system is a result of actual stocking rates, which may be above or below the carrying capacity. Selective grazing for preferred forage species and near water sources has been known to cause localized areas of over-grazing, and can lead to shifts in species composition (Holechek et al. 2001).

Time-controlled, or rotational, grazing is a management intensive method that requires moving cattle through a series of paddocks, timing each grazing period to coincide with maximum growth in each paddock; grazing intensity is a function of stocking density and length of rest between grazing periods. Rotational grazing has been seen as an improvement to continuous grazing in terms of pasture health and overall productivity. For example, a study conducted in the Flooding Pampa region of Argentina (2006) found that the use of rotational grazing affected species composition and litter accumulation. Bare soil was higher in continuously grazed treatments, while litter was higher in rotationally grazed paddocks in three out of four years.

Twice-over grazing is used in native pastures to give warm-season grasses a chance to develop; pastures are given only a light graze early in June to stimulate grazing tolerance mechanisms in the plants, and then cattle are put out for a longer duration after a designated rest period (Manske 2004). This method is seen as appropriate for pastures in which the desirable species have a high sensitivity to grazing, where long-term resting can be beneficial. In some situations, twice-over grazing could improve litter accumulation by delaying the introduction of grazing at the beginning of the season (Naeth et al. 1991b). Of course, in other situations, the introduction of an early defoliation treatment stimulated litter accumulation (Donkor et al. 2003, litter data unpublished).

Forage “stockpiling” is a practice used to extend the grazing season by allowing a pasture to reach optimal forage levels just prior to killing frost (Manitoba Agriculture, Food, and Rural Initiatives 2000). The pasture is usually grazed early in the season, and then allowed to rest for the remainder of the summer. This “stockpiled” forage is then grazed late in fall after other pastures have become dormant, or in early spring before new growth.

2.5 Litter benchmarks and surveys

In addition to knowing how litter functions in pasture, and how pasture management affects litter accumulation, it is important to understand how the inherent qualities of a pasture affect litter accumulation. To this end, studies have been conducted over the years to identify how much litter accumulates in different locations, soil conditions, plant communities, and so on. These surveys are a first step towards the development of benchmarks that can be used in pasture health assessment. Identification of these benchmarks has not only been the subject of ongoing research efforts, but has also been used to assess pasture health by pasture managers in Alberta.

Benchmark research has not been published for Manitoba, though it has been conducted in dryer climates such as western Canada and the American mid-west.

2.5.1 Native and tame pasture

Most litter research takes place in native pasture, most likely due to the fact that native pasture is not subject to the same level of management inputs as tame pasture, and is not typically renovated. However, inputs and renovation are expensive, and there is growing interest in improving the lifespan of tame pasture. Tame pasture is primarily dominated by species that are not native to Manitoba, and as such they may be more sensitive to low moisture conditions than those species found in native pasture (Page and Bork 2004).

Native pasture. Approximately 80% of Manitoba's grazing land is unimproved pasture, making up 1.58 million ha in 2002 (Manitoba Agriculture, Food, and Rural Initiatives 2003). This unimproved grazing land is managed as a natural system, with grazing and fire as the principal management tools.

Much of this unimproved pasture has never been converted from its original state as native grassland. Human management and the resulting shifts in animal and plant ecology have led to changes in the botanical composition of these grasslands, and so it is difficult to say that these grasslands are still "native". Native species such as blue grama grass have been replaced with introduced species like Kentucky bluegrass. However, the original "native" state is still understood to be the goal of sustainable pasture management. Thus the term “native pasture” refers more to the ideal of pasture management than to the presence of native species in the pasture.

Native pastures generally yield less than tame pastures, primarily due to the fact that they are operated as a low-input systems, dominated by mixtures of species that have not been bred for high productivity. Yields from a selection of studies are summarized in Table 2-1. The low yields seen in the Alberta mixed prairie, as compared to the rough fescue, are likely a result of the much lower precipitation received in that study.

Tame pasture. There are approximately 383 thousand hectares of tame pasture in Manitoba (Statistics Canada 2002). Tame pasture has the potential to yield higher than native pasture, through the selection of highly productive forage species, the use of inputs such as fertilizers, and intensive management.

In a study of litter and forage yields in tame pasture, Page and Bork (2004) analyzed tame pasture yields in three regions of northern Alberta. Their findings are summarized in Table 2-2.

Table 2-1: Forage yields garnered from research conducted on native pasture.

Author	**Year**	**Location**	**Site characteristics**	**Forage production**
				----- *kg ha^{-1}* -----
Ovington et al.	1963	Central Minnesota	Ungrazed native prairie	920
			Ungrazed savanna	1886
R. L. Dix	1960	Western North Dakota	Lightly grazed grassland	1700 – 1995
Willms et al.	1993	Lethbridge, Alberta	Ungrazed mixed prairie	959
Willms et al.	1996	Lethbridge, Alberta	Ungrazed rough fescue grassland	3160 – 4470

Table 2-2: Annual yields and litter production in tame pastures in three northern regions of Alberta. (Page and Bork 2004)

Region	Site	Year	Total production	Litter production
			-------- *kg ha^{-1}* --------	
Northwest	North Goodwin	1998	2,583	828
		1999	2,939	745
		2000	2,584	333
	Windsor Creek	2001	2,540	342
		2002	3,706	338
	Brochu	2001	3,204	607
	Goodfare	2001	3,200	451
North Central	Fawcett	2000	2,775	198
		2001	2,434	420
		2002	1,153	446
	Westlock	2002	2,412	953
Northeast	Clearhills	1998	1,522	170
		2001	2,138	298
	Rannach	2000	3,731	370
	Minburn	2000	3,512	352

2.5.2 Litter surveys

A literature review prepared by Tomanek in 1969 included dozens of articles dating from the 1930's through the 1960's, identifying the rate of litter present in pasture. Since that time, research has continued to measure the amount of litter in grasslands across the United States.

Historical studies. Ovington et al. (1963) studied four distinct ecosystems in a central Minnesota Natural History Area, including an undisturbed prairie. Due to physical limitations, the prairie had never been fully converted to agricultural production. Within the prairie system, vegetation was tall-grass prairie type with needle grass, Kentucky bluegrass, and big bluestem dominating. Vegetation was fairly open, without close cover. While deer were seen in the area, evidence of grazing was not.

Aboveground biomass in the prairie site averaged 930 kg/ha, ranging from 24 kg/ha in April to 944 kg/ha in August. Measurements of litter ranged from 2,044 – 3,805 kg/ha at different times throughout the year, and averaged 2,788 kg/ha. Litter was highest in November, and lowest in May, showing that weathering over winter has a significant effect on litter decomposition.

Ralph L. Dix (1960) studied the mulch structure following fire in three grassland sites in a western North Dakota national park. The sites were within a "badlands" area cut through by a river, and received approximately 400 mm of precipitation per year. The plant community was characterized by needle-and-thread grass, blue grama grass, and sedge species.

The first site was located on loamy fine sands and was historically subjected to only light grazing. No grazing had occurred in the two years prior to data collection, and fire had burned a section of this site four years prior to data collection. Four years after fire, forage production and litter levels were the same in both the unburned and burned areas. Production in the burned and unburned locations averaged 1,599 kg/ha and 1,995 kg/ha respectively, while litter averaged 1,214 kg/ha and 1,185 kg/ha in the unburned and burned sites respectively.

The second site was located on a creek flat, with clay loam soils. This site was subjected to light to moderate grazing, and fire had burned a section of this site three years prior to data collection. At the time of collection, forage yield was similar between burned and unburned treatments, at 1,700 kg/ha. However, litter differed significantly: in the unburned area, litter levels were 1,647 kg/ha, while the litter layer in the burned area was 756 kg/ha. Thus, in the three years following burning the litter layer had not yet "caught up" to that of the unburned treatment.

The final site in the study was located on a fine sandy loam, and a fire had burned a section of this area less than one year prior to data collection. The site was subjected to very light grazing. The unburned section of this site contained litter at a rate of 1,829 kg/ha, while the burned area was completely bare. Forage production in this site was greatly reduced by fire, from 1,712 to 906 kg/ha. As an interesting side-note, the humic mulch layer was not completely destroyed – roughly 579 kg/ha of this layer remained after the fire to provide at least some protection from site deterioration.

Recent studies. Since the 1990's, researchers in Alberta have been concerned with moisture conservation in rangeland. Studies undertaken in that province have examined the role of litter in pastures and the role pasture management plays in litter accumulation.

Willms et al. (1993) conducted a four-year litter study in the dark-brown soil zone near Lethbridge, AB. This mixed prairie site was located on a loamy soil, and historically receives an average of 404 mm of precipitation annually. Forage production averaged across all simulated grazing treatments (no clipping, clipping once per year to 7-cm height, or clipping once per year to 3-cm height) ranged from 200 – 1,406 kg/ha over the four-year period, and the average yield in the ungrazed treatment was 959 kg/ha over the period. Yearly average litter rates under all grazing treatments ranged from 555 – 912 kg/ha over those same years, with the ungrazed treatment averaging 1171 kg/ha.

In another study by Willms et al. (1996), a rough fescue grassland was found to contain litter amounts ranging from 9,840 – 10,310 kg/ha in the ungrazed treatment, 1,000 kg/ha in moderately grazed grasslands, and 600 – 1,120 kg/ha in heavily grazed pastures.

In a study of tame pasture in Alberta (Page and Bork 2004), litter rates ranged from 333 kg/ha in a Northwestern region up to 953 kg/ha in a North Central site. Litter did not exceed 1000 kg/ha in the study (Table 2-2).

2.5.3 Litter benchmarks

In addition to determining the amount of litter present in pastures, researchers have attempted to identify targets, or benchmarks, that can be used to determine pasture health status.

The desire to set optimal litter biomass targets is not new. In the very first issue of the Journal of Range Management (1948), D. W. Hedrick identifies an optimal litter rate range of between 448 and 1121 kg/ha based on “considerable work [that] has already been done.” It has since been shown that the amount of litter appropriate in specific pastures will vary based on a host of factors. Thus the development of benchmarks that are at least regionally relevant has become necessary as a starting point for formulating site-specific targets.

The *Alberta Rangeland Health Guide*. The development of regional benchmarks reached practical application in Alberta, with the publication of the *Rangeland Health Assessment for Grassland, Forest, and Tame Pasture* (Adams et al. 2003). This guide provides a comprehensive framework for assessing the condition of native and tame pasture, and includes categories such as integrity and ecological status (i.e. presence of desirable species), plant community structure (i.e. the physical architecture of the species mix), hydrologic function and nutrient cycling (i.e. amount of litter present), site stability (i.e. evidence of erosion), and noxious weeds.

Litter amount is used as an indicator within the hydrologic function category, based on research indicating that in the Alberta climate litter acts as a net benefit to soil moisture status.

Native pasture benchmarks. According the guide (Adams et al. 2003), the quality of the litter layer in native pasture may be scored by comparing the layer to established litter benchmarks for that region (Table 2-3). Benchmark values (located in the "Average" column of Table 2-3) were developed by long-term monitoring of healthy sites under light to moderate grazing pressure. The benchmarks range from 168 kg/ha to 1681 kg/ha, and vary based on region and site characteristics (e.g. elevation, soil quality).

Pastures are placed into one of three categories – healthy (greater than 65% of benchmark), healthy but with problems (between 35% and 65% of benchmark), or unhealthy (less than 35% of benchmark). Under this structure, two pastures with the same amount of litter could be given opposite ratings depending on their region and site characteristics.

Table 2-3: Regional and site-specific litter benchmarks in the *Alberta Rangeland Health Guide*. (Adams et al. 2003)

Natural Subregion (Soil Zone)	Range Sites	Healthy		Healthy but with Problems	Not healthy
		Average	*>65%*	*65% – 35%*	*<35%*
			----------- *kg ha^{-1}* -----------		
Aspen Parkland (Black)	Loamy	1681	>1093	1093 - 588	<588
	Sandy	1233	>801	801 - 432	<432
	Sands	897	>583	583 - 314	<314
	Choppy sandhills	448	>291	291 - 157	<157
Foothills Fescue, Foothills Parkland, and Montaine (Black)	Thick Black Loamy	1569	>1020	1020 - 549	<549
	Orthic Black Loamy	1345	>874	874 - 471	<471
	Shallow-to Gravel and Limy	1121	>729	729 - 392	<392
	Thin Breaks	560	>364	364 - 196	<196
Mixed Grass (Dark Brown)	Loamy (>1100 m)[1]	1009	>656	656 - 353	<353
	Loamy (<1100 m)[1] + Limited	673	>437	437 - 236	<236
	Thin Breaks	336	>218	218 - 118	<118
Dry Mixed Grass	Loamy	448	>291	291 - 157	<157
	Blowout	280	>182	182 - 98	<98
	Thin Breaks	168	>109	109 - 59	<59

[1] Elevation

Tame pasture benchmarks. The Rangeland Health Guide does not specify benchmarks for tame pasture, due primarily to a lack of litter research performed in tame pasture. Instead, the guide recommends three proposed thresholds for assigning a pasture health rating, with healthiest pasture exhibiting greater than

504 kg/ha litter (Table 2-4). From Table 2-4 it can be seen that the health score of a pasture declines with declining litter amounts, and is given a 0 rating when litter biomass is below 140 kg/ha.

Table 2-4: Tame pasture litter thresholds in the *Alberta Rangeland Health Guide*. (Adams et al. 2003)

Health Score	Description	Proposed Threshold (kg/ha)
15	A distinct litter layer is visible. Litter has a uniform distribution across the pasture with less than 5% of the pasture lacking an adequate thickness. Hand raked litter is estimated at 504 kg/ha or more.	>504
10	A distinct litter layer is visible, but litter thickness is reduced and is no longer uniform. Litter is reduced on about 5 – 25% of the pasture with some areas having little or no litter. Hand raked litter is estimated at about 280 – 504 kg/ha.	280 – 504
5	No litter layer is visible. Ground litter is mostly from this year's growth with previous years' litter significantly reduced. About 25 – 67% of the pasture area has sparse to no litter cover. Hand raked litter is between 140 – 280 kg/ha.	140 – 280
0	Litter is sparse or absent from the majority of the site (greater than 67% of the area). Human-caused bare soil is present. Hand raking produces less than 140 kg/ha.	<140

Zero-till benchmarks. A great deal of research has been performed on tillage-based agricultural systems to quantify how residue acts within these systems and to arrive at optimal targets or benchmarks. Though residue management may be practiced in cropping systems for different reasons than those in pasture, the basic premise – that residue improves the moisture status of the soil – holds in both situations.

Conservation tillage is defined as a tillage technique that leaves at least 30% of the plant residue on the soil surface, or roughly 1100 kg/ha (Kurkalova et al. 2006). Reduced tillage systems are considered "high residue management" if they preserve 60% of the residue on the soil surface. In the Northern Great Plains, this constitutes approximately 1600kg/ha of small grain residue (Black and Tanaka 1997).

In studies of residue effects on soil moisture, no upper limit has been identified where residue ceases to benefit soil moisture. In a straw mulch study at Bushland, Texas, residue rates up to 12,000 kg/ha continued to increase the amount of soil moisture available (Unger 1994).

Cropping systems are characterized by long periods where the soil is not under an actively growing plant cover. During these "rest" periods, erosion and evaporation can take their toll on the soil and the moisture contained within it. In this context, residue cover is crucial for maintaining moisture status and preventing erosion.

As a perennial system, pasture does not have a bare-soil period like that of annual cropping systems. Thus, evaporation and erosion may not be as large a concern in pasture. However, evaporation is a significant pathway for moisture moving from soil to atmosphere after killing frosts and during spring thaw (when transpiration is not occurring). During these periods, residue cover can play an important part in conserving soil water in pasture.

3 LITTER AFFECTS SOIL MOISTURE AND SOIL TEMPERATURE IN SOUTHWEST MANITOBA PASTURES

3.1 Abstract

Litter (dead plant material) is seen as important in pastures in part for its role in improving soil water conservation. A study was undertaken on one native and four tame pasture sites in southwest Manitoba to determine the relationship between the amount of litter biomass and soil moisture and soil temperature. Litter was applied to the soil surface at seven rates ranging from 0 kg/ha to 3000 kg/ha. Soil moisture was measured at surface, 20 cm, and 35 cm soil depths regularily over two growing seasons. Daily soil temperature characteristics were measured near the surface in the 0 and 3000 kg/ha treatments. Forage was harvested twice per year. No strong relationship between litter and soil moisture was found. A significant relationship between litter and soil moisture ($P<0.05$) was observed on only 12 of a total of 189 measurement dates. When significant, the relationship was generally positive but weak (R^2 from 0.137 – 0.280). Average daily temperature under litter was between 0.11 and 0.64 °C lower over the growing season compared to the bare soil treatment. Litter did not affect forage yield.

3.2 Introduction

Litter, defined as the dead plant material standing or lying on the soil surface, is considered beneficial in pastures primarily for its ability to conserve water (Adams et al. 2003). Litter improves water capture by trapping more snow than bare soil and slowing runoff throughout the year (Naeth and Chanasyk 1995). Litter reduces the amount of energy available for evaporation in several ways. The higher albedo of plant residues means more solar radiation reflected away from the soil surface (Bussiere and Cellier 1994). Litter presents a barrier between energy inputs at the litter surface and the moisture in the soil (Horton et al. 1994). Much of the received radiation is converted by litter into heat and lost to the atmosphere (Bussiere and Cellier 1994; Novak et al. 2000). The remainder is conducted through the litter layer where it becomes available to soil moisture for evaporation. The litter layer presents an additional barrier to the movement of water vapour from the soil to the atmosphere (Novak et al. 2000).

The benefit of litter to the moisture status of a soil is to some extent contingent on the water holding capacity of litter. For example, litter is capable of intercepting rainwater and holding it above the soil surface where it is unavailable to plants and quickly evaporates (Horton et al. 1994). The water holding capacity (WHC) of litter can be as high as twice its weight (Naeth et al. 1991a); WHC differs among plant species, litter architecture, and level of decomposition. The net effect of WHC on soil moisture depends on the nature of the precipitation events and the overall climate. Large precipitation events will be less affected by litter interception, but in areas with frequent small rainfall events, interception can represent a significant loss of moisture to the plant (Naeth et al. 1991a).

The balance struck between litter's ability to increase infiltration, reduce evaporation, and intercept precipitation determines the net effect of litter on soil moisture. In drier conditions, litter is considered a net benefit to soil moisture (Dormaar et al. 1997). In other situations, adequate precipitation makes litter insignificant (Page and Bork 2004).

Historically, pasture litter research was undertaken in the north-central United States; for example, Ovington et al. (1963) in central Minnesota, Dix (1960) in North Dakota, and Weaver and Rowland (1952) in Nebraska. This research tended to focus on litter's effects on yield, species composition, and other rangeland health indicators.

In recent decades, extensive litter research has been undertaken in Alberta, where litter is seen as a benefit to pasture primarily as a soil water conservation tool. For example, Willms et al. (1986), researching in the mixed prairie of Alberta, concluded that a 43% reduction in yield induced by removing the existing 570 kg/ha litter layer was the result of moisture deficit.

Litter research has reached practical application in Alberta, with the publication of the *Rangeland Health Assessment for Grassland, Forest, and Tame Pasture* (Adams et al. 2003). In this guide, litter is used as an indicator of hydrological status, with higher amounts of litter associated with improved pasture conditions. Recommended litter rates for native mixed grass pasture range from 168 kg/ha in dry, less productive locations up to 1009 kg/ha in moister, more fertile pastures. Litter amounts in tame pasture are considered adequate when they exceed 504 kg/ha (Adams et al. 2003).

Litter research has not been conducted in Manitoba, though conditions in the southwest region of the province can be as moisture-limited as those found further west.

Agricultural regions of Manitoba receive between 400 mm and 550 mm precipitation annually (Weir 1968), with at least half falling during the growing season (Shaykewich et al. 1994). In comparison, annual precipitation in Regina, SK, averages 373 mm, Swift Current, SK, averages 345 mm, and Beaverlodge, AB, averages 470 mm (De Jong and Steppuhn 1983). The largest moisture deficits occur during the warmest months, though these deficits tend to be smaller in Manitoba than regions further west (De Jong and Steppuhn 1983).

The objective of the present study was to determine how litter alters the soil microclimate in southwestern Manitoba pastures, and to identify whether litter has an effect on forage production in this region. It is hypothesized that increased litter amounts will be associated with higher soil water content and lower near-surface soil temperatures, leading to higher forage yields.

3.3 Materials and Methods

3.3.1 Research sites

Five research sites were established in southwest Manitoba in May 2006 (Figure 3-1). This region receives an average of 475 mm of precipitation per year

(De Jong and Steppuhn 1983), with 347 mm falling between April and September (Environment Canada 2004b). Temperatures average 18.9ºC in July and –17.9ºC in January (Environment Canada 2004b). One of the five sites (Shilo) was located on native pasture (having never been tilled or seeded to introduced forages). Unfortunately, an assessment of species present at this site was not conducted. Three others (Pipestone, Goodlands, and Souris) were located on tame pastures (seeded to monoculture or a limited mix of introduced forage species in the recent past). The Carman site was located in a regularly mowed grassed area, considered for the purposes of this study to be a tame pasture site. Site characteristics are outlined in Table 3-1.

Table 3-1: Characteristics of Litter Rate Study sites.

Site name	*Latitude (N)*	*Longitude (W)*	*Pasture type (principal species)*	*Soil Association (texture)*
Pipestone	49° 33′	100° 45′	Tame (Meadow bromegrass)	Souris sands (sand – loamy sand)
Goodlands	49° 6′	100° 33′	Tame (Bromegrass/Alfalfa)	Waskada/Melita series (fine sandy loam – loam)
Souris	49° 37′	100° 14′	Tame (Kentucky bluegrass)	Carroll clay loam (silty clay loam – clay loam)
Shilo	49° 41′	99° 36′	Native prairie	Wheatland series (sandy)
Carman	49° 30′	97° 59′	Tame (Timothy/Creeping red fescue[1])	Hochfeld series (fine sandy loam)

[1] Some thistle was distributed randomly through the study area. Thistles and alfalfa plants were spot-sprayed with herbicide at the beginning of the trial; no further weed control was undertaken during the experiment.

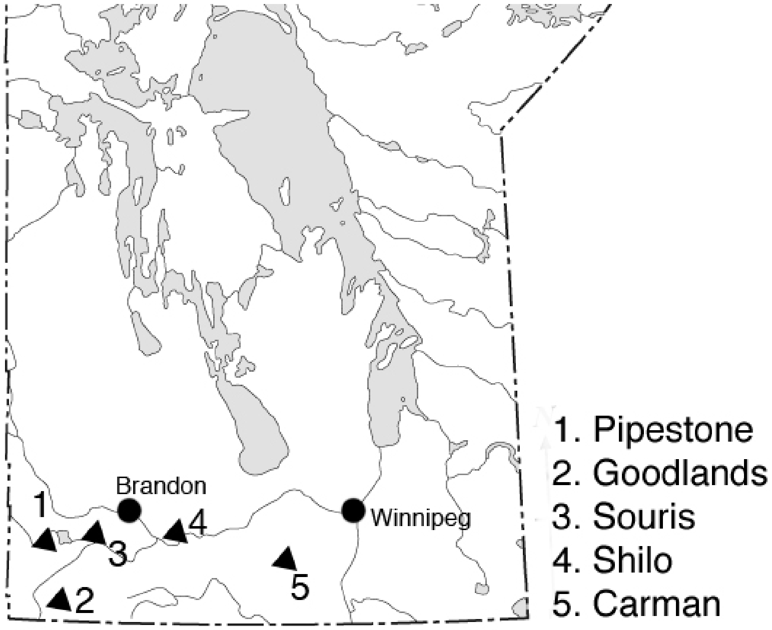

Figure 3-1: Location of Litter Rate Study sites in southwest Manitoba.

Weather data collected by Manitoba Agriculture Food and Rural Initiatives at stations nearest the five research sites are presented in Table 3-2 (Manitoba Agriculture, Food, and Rural Initiatives 2008). The year 2006 tended to be hot and dry compared to normals, with growing season precipitation (March 1 – September 30) ranging from 55% - 73% of normal in the southwest region of Manitoba, and growing degree days ranging from 110% - 123% of normal. Conditions were more typical in 2007, though precipitation was still below normal in some areas. Growing degree days ranged from 87% - 114% of normal, while precipitation fell at 77% - 109% of normal. Table 3-2 presents estimated growing season conditions for each site.

Table 3-2: Environmental conditions for pasture experiments, conducted March – September, 2006 and 2007 (Manitoba Agriculture, Food, and Rural Initiatives 2008).

Research Site	**Weather Station** (distance from site, km)	**Precipitation**			**Heat**		
		Normal[1]	*2006*	*2007*	*Normal*	*2006*	*2007*
		-------- *mm* --------			--- *Growing Degree Days* ---		
Carman	Carman (0)	411	226	376	1662	1872	1785
Goodlands	Melita (33)	391	236	341	1649	1852	1632
Pipestone	Virden (35)	372	249	354	1610	1858	1636
Shilo	Carberry (27)	364	269	398	1537	1770	1668
Souris	Souris (0)	364	267	369	1537	1889	1751

[1] 30-year normals.

3.3.2 Experimental design

In spring 2006, the experimental area at each site was fenced off from the surrounding pasture. Forage within the plot area was clipped to 2.5 cm with a sickle-bar mower, and the clippings collected and bagged. Clippings from each site were kept separate, oven dried at 65°C for 48 hours, and then weighed into seven litter rates (Table 3-3). At the time of initial clipping, litter samples were also taken from each site to determine *in situ* litter biomass rates. These samples were oven-dried as described above. Rates of *in situ* litter biomass for each site are identified in Table 3-3.

The eight litter treatments were arranged in a randomized complete block design with four replicates. Plots were 1 x 2 m, with a 1 m buffer surrounding each plot. The *in situ* treatment plots were left undisturbed to act as a control treatment. The *in situ* treatment was included to allow a comparison to determine whether the applied litter rates differed from “natural” litter layers. For the other treatments, plots were raked down to bare soil, and removed litter was discarded. Once the area was bare, the dried and weighed clippings were placed on the soil surface by hand, care being taken to ensure the litter was distributed evenly over the designated area. After litter application, each plot was covered with chicken wire to prevent litter loss due to wind. After grass had grown through the applied litter layer, the chicken wire was removed from the plots.

Table 3-3: Litter amounts applied to each treatment at the time of establishment, May 2006.

Treatment	*Litter Rate*
	kg ha^{-1}
1	0
2	300
3	600
4	900
5	1200
6	1500
7	3000
8	*in situ*[1]

[1] *in situ litter biomass:* Carman – 1820 kg/ha; Goodlands – 3238 kg/ha; Pipestone – 4772 kg/ha; Shilo – 2754 kg/ha; Souris – 5120 kg/ha.

3.3.3 Data collection

Soil moisture. Soil moisture was measured at three depths. Surface soil moisture (0-10 cm) was measured using a Time-Domain Reflectometer (TDR) and gravimetric soil samples. Due to instrument malfunctions, TDR was not used in 2006, and only used for a portion of 2007. Using a Troxler Neutron Moisture Meter (NMM), soil moisture was measured centered at 20 cm and 35 cm. To accommodate the NMM measurements, 5 cm diameter holes were augered in the centre of each plot to a depth of 50 cm. A 65 cm length of 5 cm diameter aluminum tube was inserted in each hole, leaving approximately 15 cm of tube length above the soil surface.

Gravimetric soil moisture determination. Gravimetric soil samples were taken from the top 10 cm of the soil using a 2.54 cm diameter soil punch. Two samples were collected and bulked from each plot more than 25 cm from plot boundaries, and more than 20 cm from NMM access tube and previous sampling holes. Samples were double-bagged in plastic, and refrigerated until weighed wet. Soil was oven dried at 65°C for at least 48 h and then reweighed. Gravimetric moisture was calculated as

$$\text{gravimetric moisture} = (\text{wet weight} - \text{dry weight})/(\text{dry weight})$$

and volumetric moisture was calculated as

$$\text{volumetric moisture} = (\text{gravimetric moisture}) * (\text{bulk density}).$$

Bulk density samples were taken from every plot prior to installation of NMM access tubes in 2006 using a 5 cm diameter ring. These bulk densities were used to convert gravimetric moisture into volumetric moisture. Appendix 8-1 contains the bulk densities calculated in each plot.

TDR soil moisture determination. The TDR works by sending a 100 MHz electrical signal along four steel posts inserted in the soil. The electrical impedance of the posts changes based on the impedance of the soil into which it is inserted, and moisture content is the principle factor affecting the impedance of the soil. The impedance combines with the electrical signal to create a standing voltage wave in the posts that is measured by the TDR (Delta-T Devices

Ltd. 1999). The voltage output is converted to volumetric moisture using a calibration curve. Two measurements were taken no less than 0.25 m from the plot edge, one from each of the front and back halves of the plot. To protect the TDR posts from damage during insertion into the soil, a dummy probe was used to pre-punch holes in the soil for the TDR posts.

Despite the use of the dummy probe, the TDR malfunctioned before a soil-specific calibration could be performed. While a soil-specific calibration would ensure more accurate calculations of soil moisture content, it was deemed unnecessary for calculating relative moisture differences between treatments. Thus, the manufacturer's default curve for mineral soils was used to convert all readings:

$$\text{volumetric moisture} = 100*[0.484211(\text{voltage output}) - 0.02421].$$

NMM soil moisture determination. The Neutron Moisture Meter works by emitting fast neutrons into the soil. Fast moving neutrons are slowed by hydrogen in water molecules, and these slower neutrons form a cloud around the probe. The probe then selectively counts only the slow neutrons, giving a measurement that is directly related to the amount of water in the soil (Troxler Electronic Laboratories, Inc. 2006).

Before collecting measurements from a site, a standard count was performed to generate a "baseline" reading for the conditions at that site at that time. All counts measured from the plots were then expressed as a ratio with the standard count. The standard count was measured at every site on every measurement date.

Counts measured by the NMM were converted to volumetric moisture using a calibration curve. Gravimetric soil moisture samples were taken from 20 cm and 35 cm depths during installation of the NMM access tubes, and converted to volumetric moisture using estimates of bulk density derived from soil texture information following the method of Saxon et al. (1986). NMM readings were taken at both depths on the same day that access tubes were installed. The ratio of measured counts versus the standard count were regressed against the converted volumetric measurements to generate a polynomial calibration curve:

$$\text{volumetric moisture} = 36.765(\text{NMM ratio})^2+13.717(\text{NMM ratio})+0.6012\ (R^2=0.97).$$

A second NMM probe was used for some sampling dates. The second probe was cross-calibrated with the principal probe to ensure consistent moisture values:

$$\text{volumetric moisture} = 21.726(\text{NMM ratio})^2+33.687(\text{NMM ratio}) - 4.0436\ (R^2=0.78).$$

Table 3-4: Soil moisture sampling schedule for research sites in 2006 and 2007.

Site	**Treatment schedule**	
	2006	*2007*
Carman	Monthly	Monthly
Goodlands	Monthly	Monthly
Pipestone	Monthly	Bi-weekly
Shilo	Monthly	Bi-weekly
Souris	Monthly	n.a.*

* Fence was breached by cattle in 2007. Data was discarded from this site.

Sampling schedule. In 2006, sampling occurred three times, once in July, once in August, and once in September. In 2007 sampling began earlier, and schedules differed at each site (Table 3-4). Some sampling dates were missed at some sites due to inappropriate weather conditions. Appendix 8-2 contains a detailed sampling schedule for the experiment.

Soil temperature. Soil temperature dataloggers (Onset StowAway TidbiT Temp Logger) were installed in the spring of 2007. Three treatments – 0, 900, and 3000 kg/ha – were instrumented in all four replicates at each site. Dataloggers were placed 2 cm below the soil surface at maximum distances from plot edges and neutron access tubes. Temperature readings were taken hourly. Temperature dataloggers were collected from the field in fall and data offloaded to computer spreadsheets.

Three dataloggers lost power while deployed, and all data from those loggers was lost.

3.3.4 Statistical analysis

Regression. Soil moisture and forage yield were analyzed using linear regression with litter rate as the independent variable (SAS Institute Inc. 2004). Due to differences in sampling schedule across sites and soil moisture variability between sampling dates, each combination of site, date, and depth was analyzed separately. Because the *in situ* treatment differed from the other treatments with respect to the type of litter layer present (“natural” as opposed to applied), as well as the level of disturbance (undisturbed as opposed to raked), it was deemed necessary that regression be performed on the data omitting the *in situ* treatment. Because all applied litter treatments were treated equally, the regression of soil moisture against litter rate remains a valuable indicator of the influence of litter amount on soil moisture dynamics.

Data collection differed between years with respect to frequency and duration of sampling. Thus, it was not possible to calculate the effect of year on the results.

Treatment means and contrasts. Soil moisture and forage yield least squares means were calculated for each litter rate using ANOVA (SAS Institute Inc. 2004). In addition, contrasts were performed to determine whether the *in situ* treatment was statistically different than the litter treatment with the most similar litter biomass rate. The *in situ* treatment differed from the nearest applied litter rate often enough to confirm the decision to exclude the *in situ* treatment from regression analysis.

Hourly temperature data was summarized to produce four variables: daily maximum, minimum, and average temperatures, as well as daily temperature amplitude. ANOVA was performed using Proc Mixed (SAS Institute Inc. 2004) on these variables over the season as a whole. To analyze the change over time, a repeated measures analysis on two-week periods over the course of the growing season was also conducted for these variables. To maximize treatment differences, only the 0 kg/ha and 3000 kg/ha litter treatments were contrasted. Means were separated using Fisher's Protected LSD.

3.4 Results

3.4.1 Soil moisture effects

Litter rate was significantly related to soil moisture in only a few instances (Table 3-5). At Pipestone, the location where the most readings were taken, moisture was significantly affected by litter rate only 8% of the time. At Souris, the location where the fewest measurements were taken, no instances of a significant litter rate effect were found at any depth. When the litter rate effect was significant, the relationships were weak, with R^2 values 0.28 or lower. Variability of moisture between sampling dates was much greater than the variability between plots on any given date.

Therefore, this study did not demonstrate a strong relationship between litter biomass and soil moisture content. Individual treatment means, and the results of the regression analyses for each site and date are presented in Appendices 8-3 to 8-7.

Table 3-5: Summary of soil moisture regression analyses at each site for 2006 and 2007, with litter rate as the independent variable. Regression model was considered significant when $P<0.05$.

Site	Number of measurements	Number of significant measurements	R^2 range (when significant)
Carman	33	3	0.131 – 0.196
Goodlands	33	1	0.145
Pipestone	51	4	0.140 – 0.242
Shilo	45	4	0.137 – 0.280
Souris	27	0	n.a.

Pipestone. Litter significantly affected soil moisture in only four cases. Three out of four significant cases occurred at the surface. Two of the three dates measured in 2006 had significance at some soil depth, while in 2007 significance was found on only two out of 14 dates.

The relationship between litter and soil moisture, when present, was positive (Figure 3-2). Therefore, on dates when it was significant, increased litter biomass led to increased soil moisture.

Shilo. Four sampling dates showed a significant relationship between litter and soil moisture (Figure 3-3). These significant instances were all in the surface layer. Two out of three dates in 2006 showed significance, while two out of 12 dates in 2007 were significant.

The relationship between litter and soil water was negative in three out of four cases, suggesting that litter was reducing soil moisture in some way. In the fourth case, the relationship was weakly positive (Figure 3-3).

Carman. Soil moisture was measured on three dates in 2006 and eight dates in 2007. Of these 11 dates, litter was only significantly related to soil moisture on two dates. In one instance, litter significantly affected soil moisture at both the surface and 20 cm soil depths. The relationship between litter and soil moisture, when present, was positive at Carman (Figure 3-4).

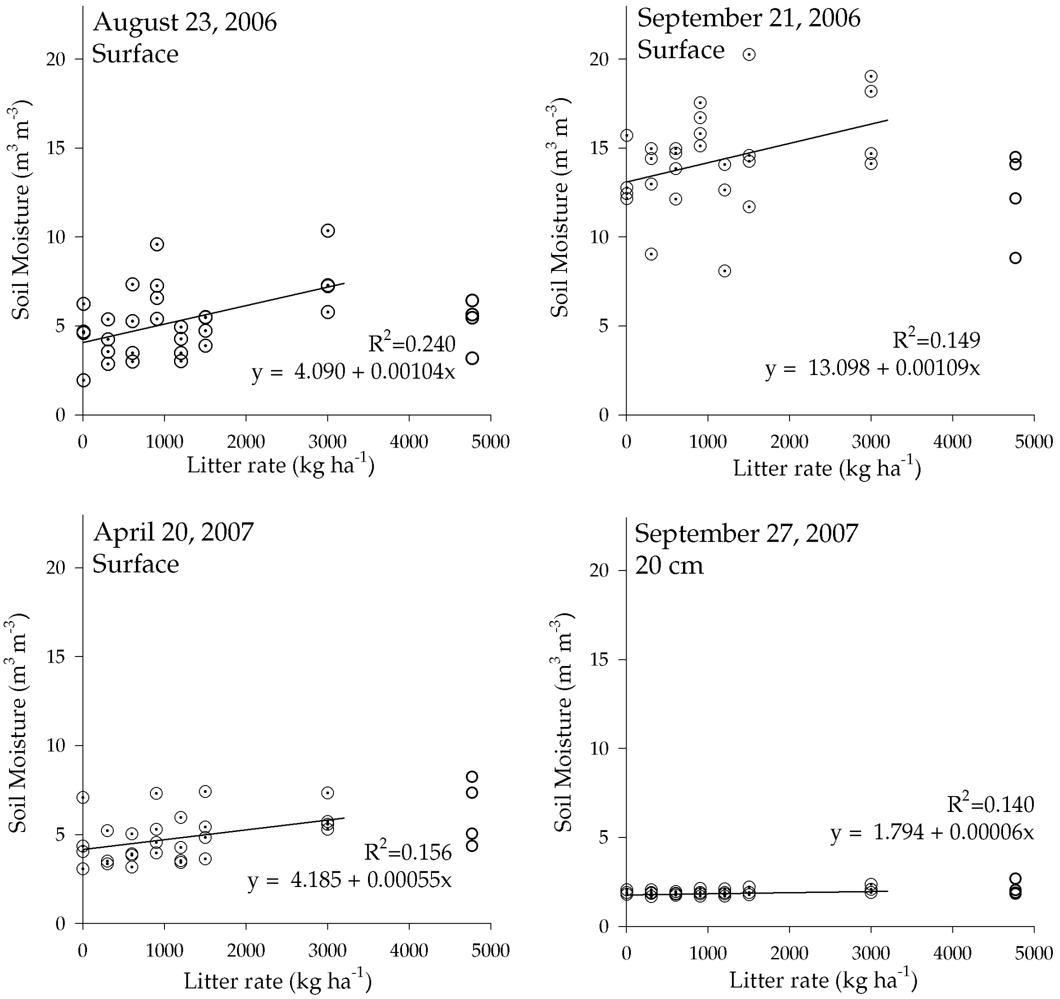

Figure 3-2: Relationship between litter rate and soil water content at the surface or at 10-30 cm soil depths at Pipestone, Manitoba. Only dates with significant R^2 values ($p<0.05$) are depicted. Lines represent regression equation calculated without *in situ* treatment (empty circles).

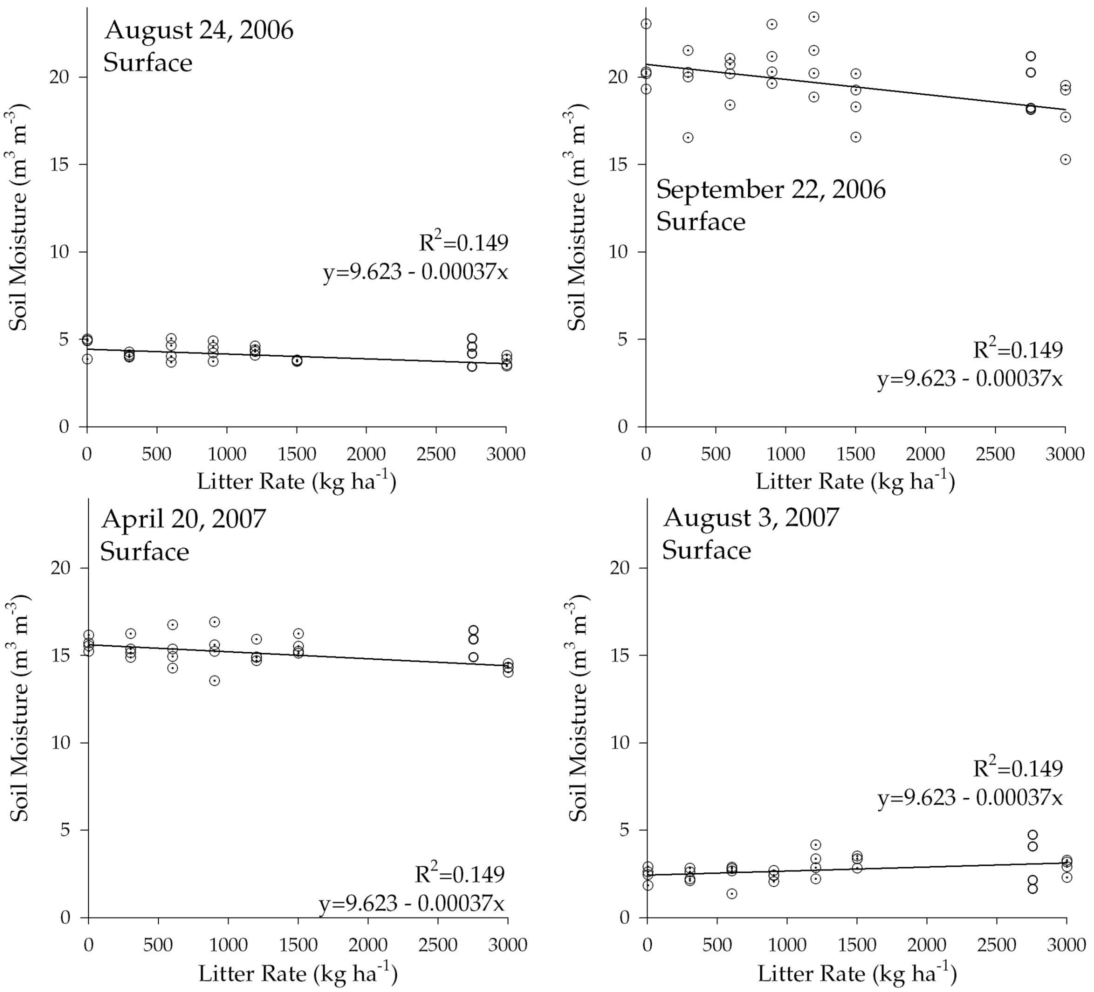

Figure 3-3: Relationship between litter rate and soil water content at the soil surface at Shilo, Manitoba. Only dates with significant R^2 values ($p<0.05$) are depicted. Lines represent regression equation calculated without *in situ* treatment (empty circles).

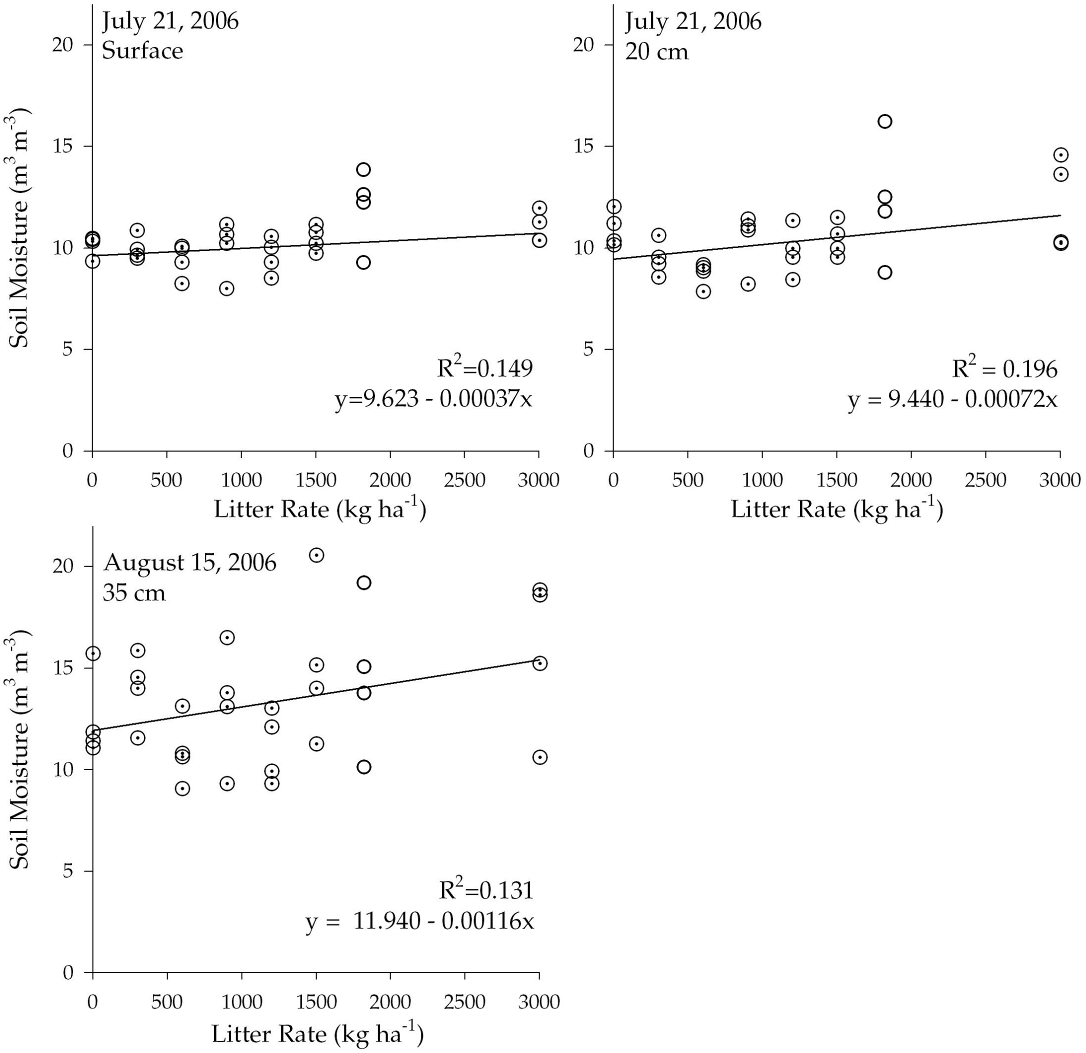

Figure 3-4: Relationship between litter rate and soil water content at Carman, Manitoba on July 21, 2006 at the surface and at 10-30 cm soil depths, and on August 15, 2006 at 25-45 cm depth. Only dates with significant R^2 values ($p<0.05$) are depicted. Lines represent regression equation calculated without *in situ* treatment (empty circles).

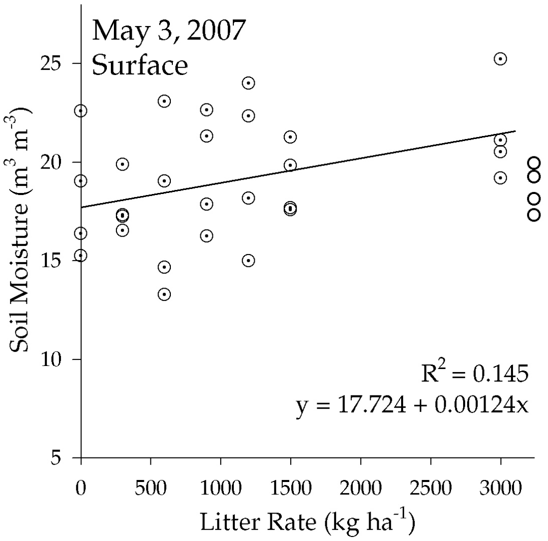

Figure 3-5: Relationship between litter rate and soil water content at the soil surface at Goodlands, Manitoba. The only date with a significant R^2 value ($p<0.05$) is depicted. Line represents regression equation calculated without *in situ* treatment (empty circles).

Goodlands. Soil moisture was measured on three dates in 2006 and eight dates in 2007. Litter was significantly related to soil moisture on only one of these dates. On May 3, 2007, litter significantly increased surface soil moisture content (Figure 3-5).

Souris. There were no instances of significance on any of the nine dates where measurements were taken at this site.

3.4.2 Soil temperature effects

Average growing season temperatures. At Carman, Pipestone, and Shilo, litter cover had a significant effect on growing season soil temperature. Maximum and average temperatures over the season were generally higher in the bare soil treatment compared to the high litter treatment, and temperature amplitude was larger in the bare soil treatment (Table 3-6). Minimum temperatures were generally lower in the bare soil treatment compared to the 3000 kg/ha litter treatment (Table 3-6).

Table 3-6: The average effect of litter on near-surface soil temperatures at five sites, April - September 2007. Treatments are considered significantly different when $P<0.05$.

Site	**Treatment**	**Temperature (SE)[1] – °C**			
		Maximum	*Minimum*	*Average*	*Amplitude*
Carman	Bare soil	24.04 (0.61)	13.79 (0.38)	18.09 (0.42)	10.24 (0.52)
	3000 kg/ha litter	23.76 (0.61)	13.57 (0.38)	17.86 (0.42)	10.19 (0.52)
	p-value	<0.0001	<0.0001	<0.0001	n.s.
Goodlands	Bare soil	29.22 (0.58)	12.55 (0.39)	19.16 (0.41)	16.68 (0.51)
	3000 kg/ha litter	25.79 (0.58)	13.65 (0.39)	18.52 (0.41)	12.14 (0.51)
	p-value	<0.0001	<0.0001	<0.0001	<0.0001
Pipestone	Bare soil	28.02 (0.56)	11.83 (0.45)	18.89 (0.42)	16.20 (0.56)
	3000 kg/ha litter	27.46 (0.56)	12.00 (0.45)	18.78 (0.42)	15.46 (0.56)
	p-value	<0.0001	<0.0001	0.0001	<0.0001
Shilo	Bare soil	25.32 (0.58)	12.77 (0.41)	18.31 (0.44)	12.56 (0.45)
	3000 kg/ha litter	24.59 (0.58)	13.12 (0.41)	18.18 (0.44)	11.48 (0.45)
	p-value	<0.0001	<0.0001	<0.0001	<0.0001
Souris	Bare soil	22.64 (0.55)	12.28 (0.38)	16.74 (0.37)	10.36 (0.56)
	3000 kg/ha litter	22.85 (0.55)	12.62 (0.38)	16.93 (0.37)	10.23 (0.56)
	p-value	0.0013	<0.0001	<0.0001	n.s.

[1] SE = standard error of the mean.

At the Souris site, higher maximum and average temperatures were observed in the litter covered soil compared to the bare soil. Therefore, the trend at Souris was opposite to that observed at the other sites. Full analysis of this site is unadvisable due to the failure of the fence and subsequent uncontrolled grazing by cattle for significant periods of time. However, the fact that this site – which was characterized by a more clayey soil type and different species composition than the other sites (see Table 3-1) – showed a different temperature response is worth noting. Detailed analysis for the Souris site are presented in Appendix 8-8.

Temperature effects over time. Generally, the litter effect appeared stronger in the first half of the growing season compared with the latter half of the season, as shown in scatterplots of temperature variables over time at Carman, Pipestone, and Shilo (Figures 3-6 to 3-8). In order to assess whether the soil temperature differences between bare and litter-covered soil changed over the course of the season, repeated measures ANOVA tests were conducted on two-week data collection periods throughout the season.

At Goodlands, the bare soil treatment reached temperatures beyond the capacity of the data-loggers (Figure 3-9). As such, all temperatures above 37°C were recorded as 37°C. Since the litter-covered soil did not get out of range as frequently as the bare soil, a strong litter effect is apparent. Analysis of this site, though not quantitatively accurate, is included to show the qualitative litter effect.

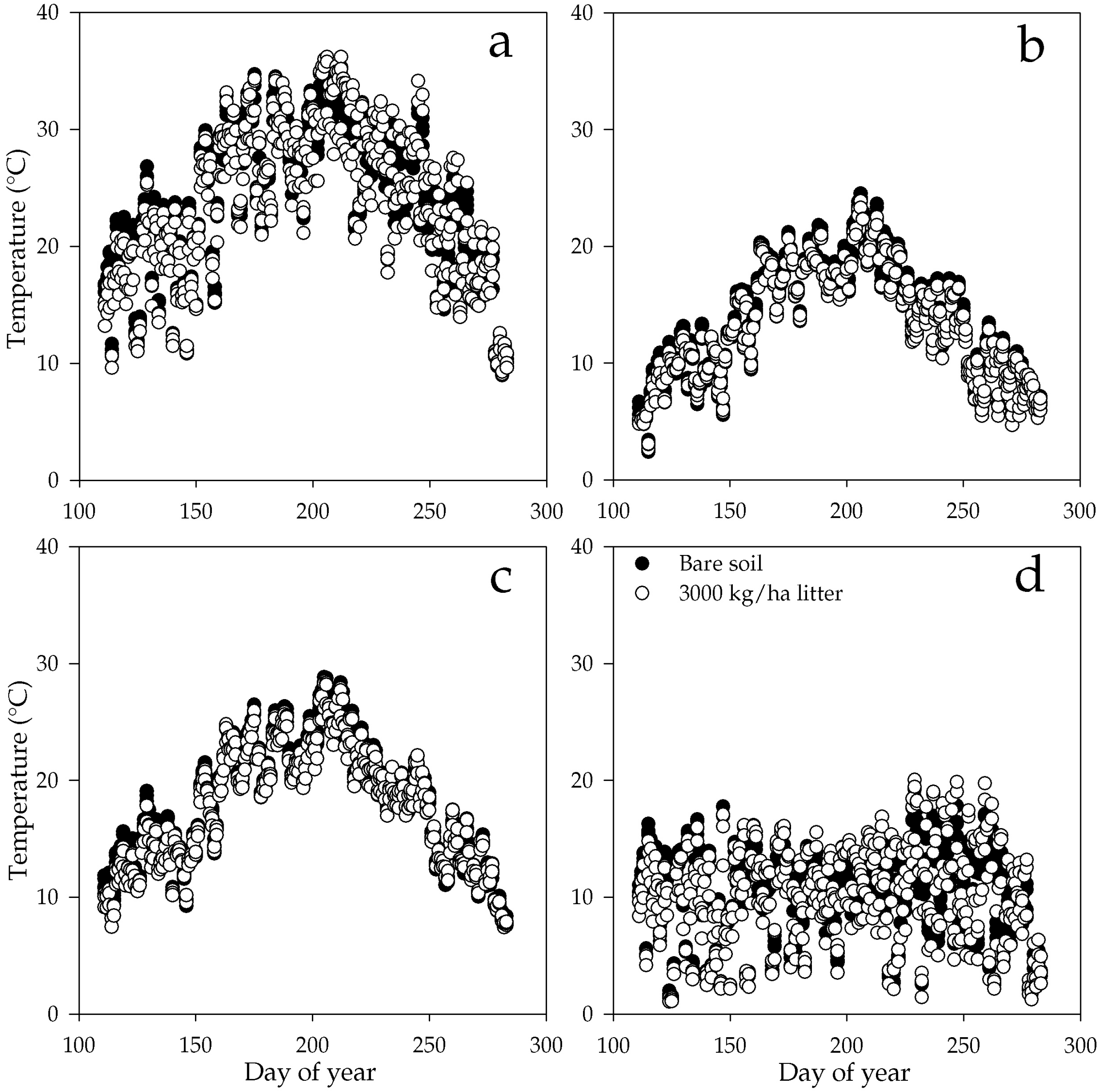

Figure 3-6: Daily near-surface soil temperatures as affected by litter cover at Carman, Manitoba; a) maximum temperature, b) minimum temperature, c) average temperature, and d) temperature amplitude.

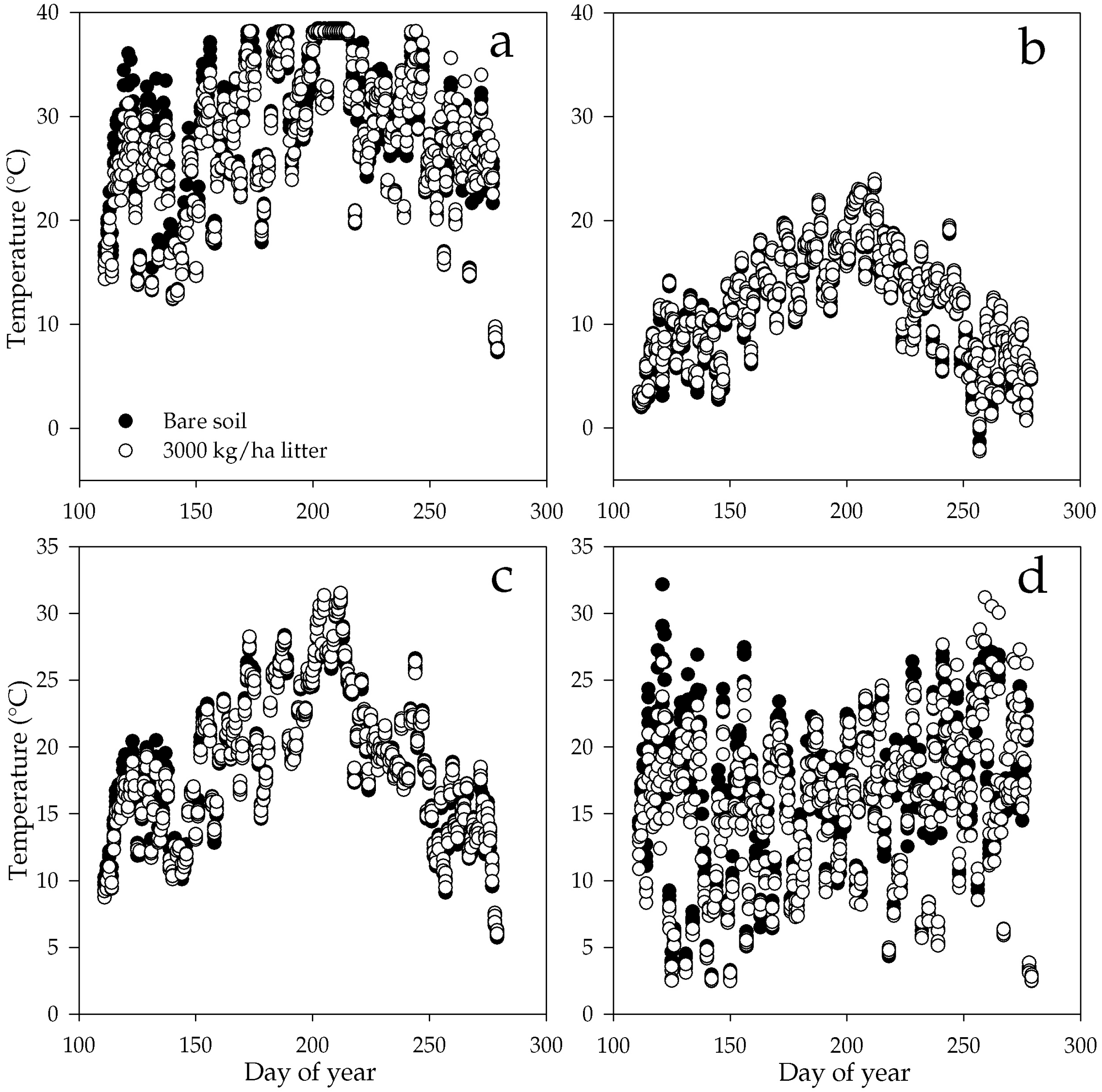

Figure 3-7: Daily near-surface soil temperatures as affected by litter cover at Pipestone, Manitoba; a) maximum temperature, b) minimum temperature, c) average temperature, and d) temperature amplitude.

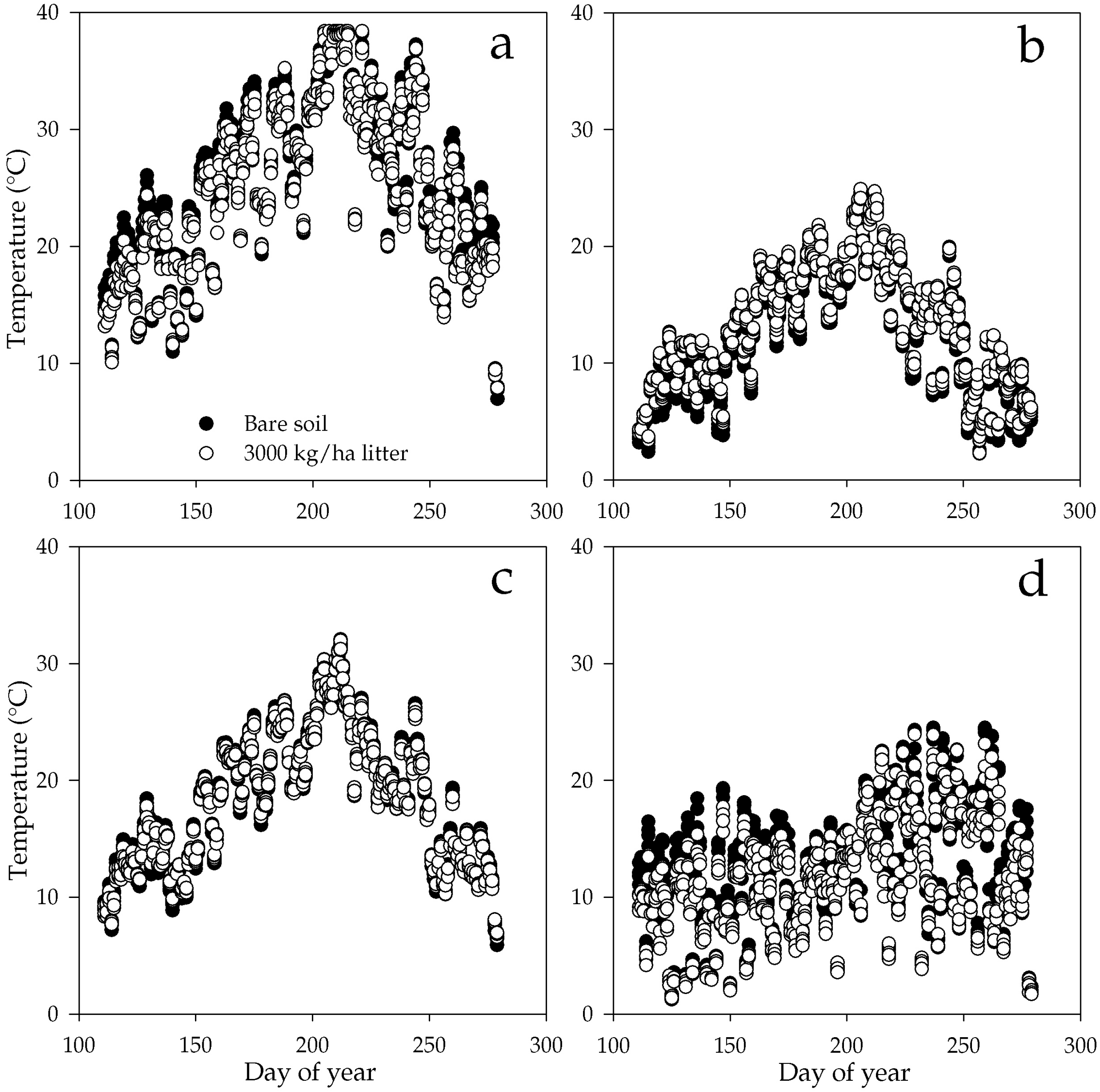

Figure 3-8: Daily near-surface soil temperatures as affected by litter cover at Shilo, Manitoba; a) maximum temperature, b) minimum temperature, c) average temperature, and d) temperature amplitude.

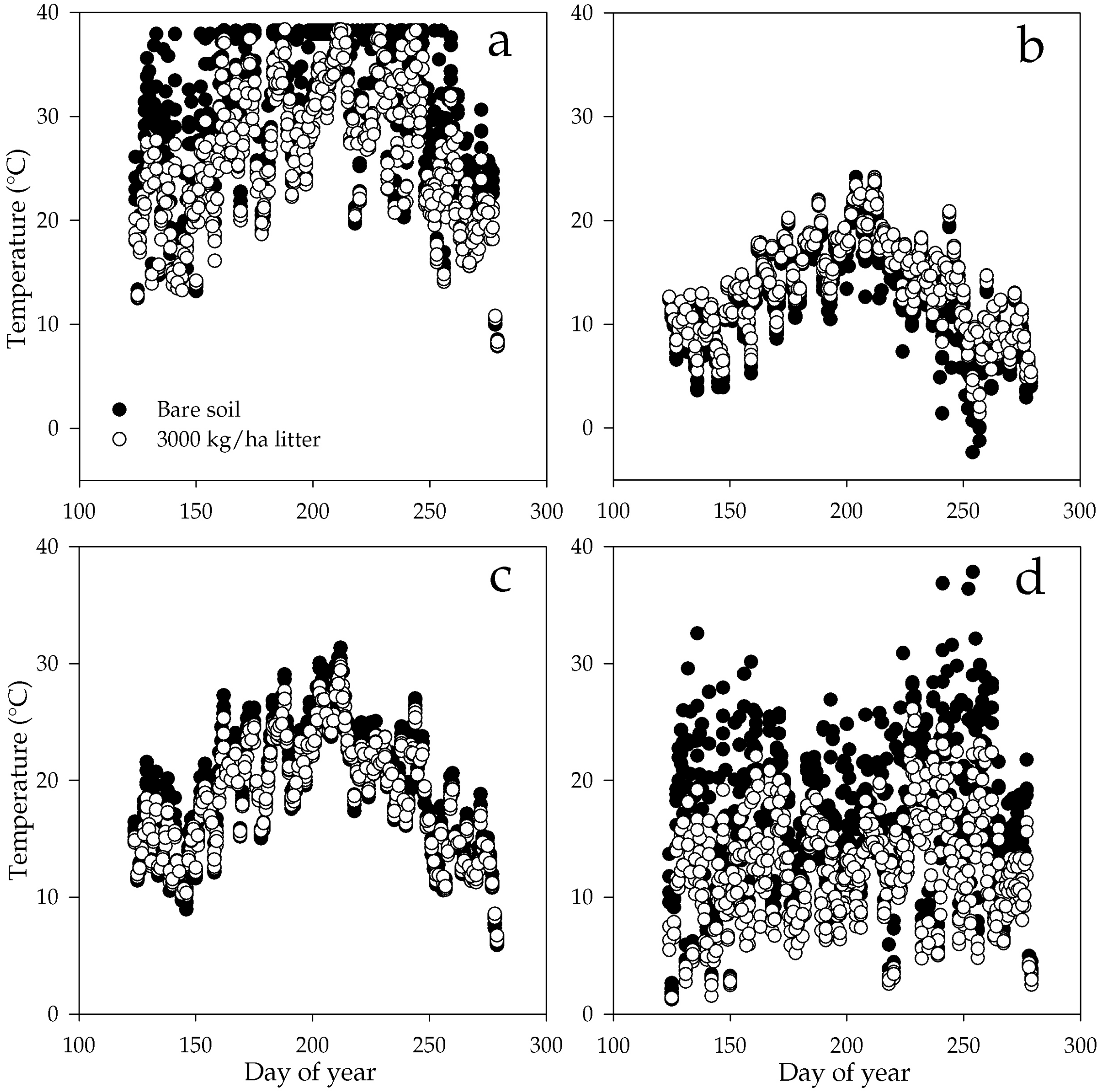

Figure 3-9: Daily near-surface soil temperatures as affected by litter cover at Goodlands, Manitoba; a) maximum temperature, b) minimum temperature, c) average temperature, and d) temperature amplitude.

When data was analyzed in two-week segments the seasonal pattern was confirmed: most variables at most sites show more instances of significant treatment differences in the first half of the season than the second half (Figures 3-10 to 3-13). At Shilo (Figure 3-12), significant differences in maximum, minimum and average temperatures were seen in the periods of June 2-15 and

August 11-24, and in come cases significant differences were not seen in adjacent periods. It was during these two periods that the biomass harvests were taken: forage was clipped to 4 cm above the soil surface and removed from the plots.

Several temperature variables show a brief reversing of the effect in the latter part of the season. For example, Carman's daily temperature average, maximum, and amplitude are higher in the bare soil than under litter for the first half of the season. However, in two instances later in the season, these three variables are higher under litter (Figure 3-10).

Short term temperature effects. Hourly temperature readings were plotted for a selected period of days at Shilo where soil temperatures were significantly different between treatments (Figure 3-14). Plotting temperature at this time scale appears to show that the treatment difference (i.e. the difference in temperatures between the bare soil and litter covered soil) fluctuated on a daily and even hourly basis.

On day 157, when precipitation fell, the two treatments did not appear to differ greatly. In the period following this, however, the two treatments separated and converged several times. The minimum temperatures were different on day 158 (the day after the rain), while maximum temperatures were similar. By day 159 (two days after the rain), both minimum and maximum temperatures were different between the two treatments. The two treatments converged again on day 161 (when it rained), and separated once again at the maximum temperature on day 162.

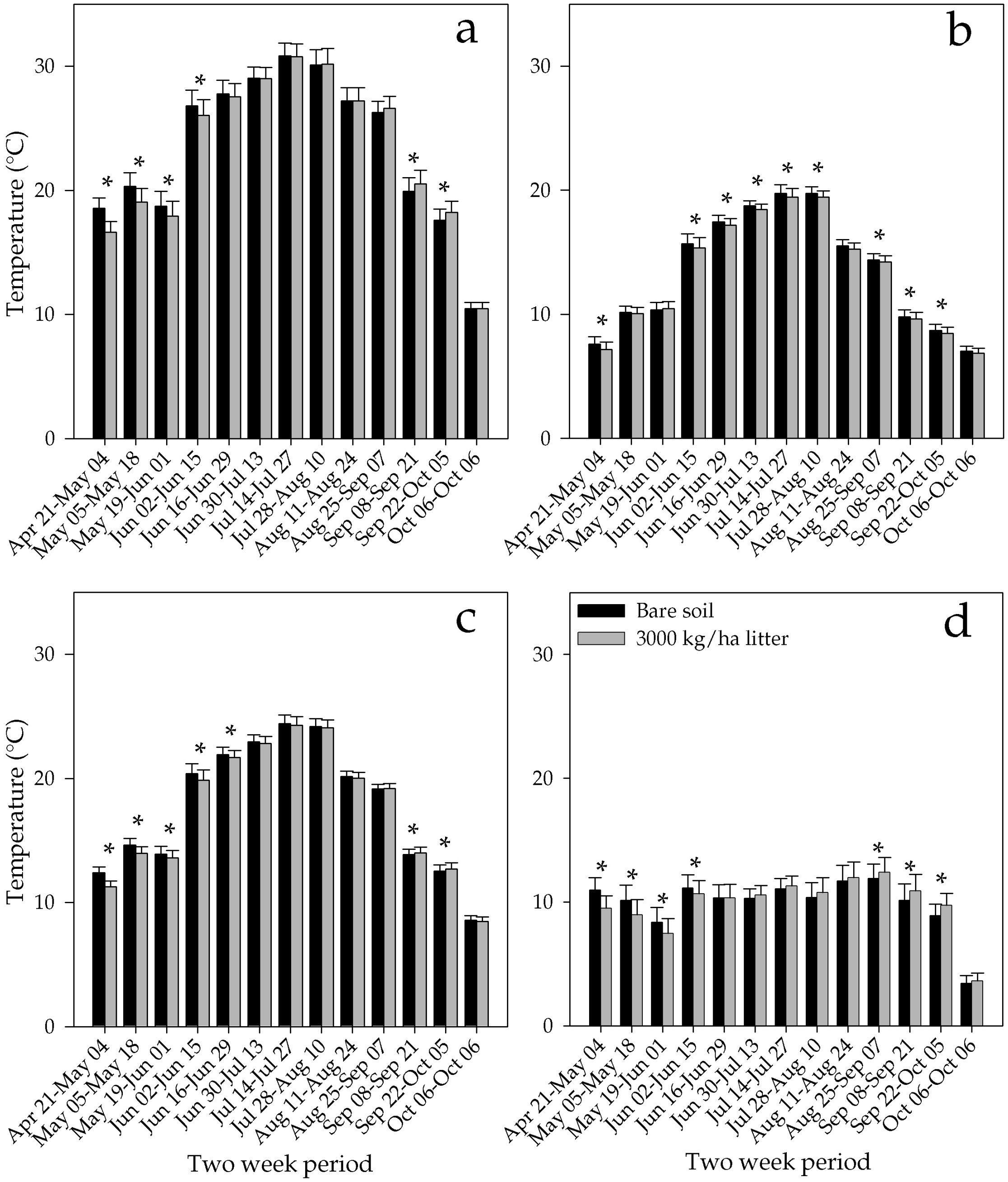

Figure 3-10: Daily near-surface soil temperatures as affected by litter cover at Carman, Manitoba, analyzed in two-week periods; a) maximum temperature, b) minimum temperature, c) average temperature, and d) temperature amplitude. Error bars are standard errors calculated on original untransformed data. Significant difference ($p<0.05$) between the bare soil treatment and the litter-covered treatment is indicated with (*).

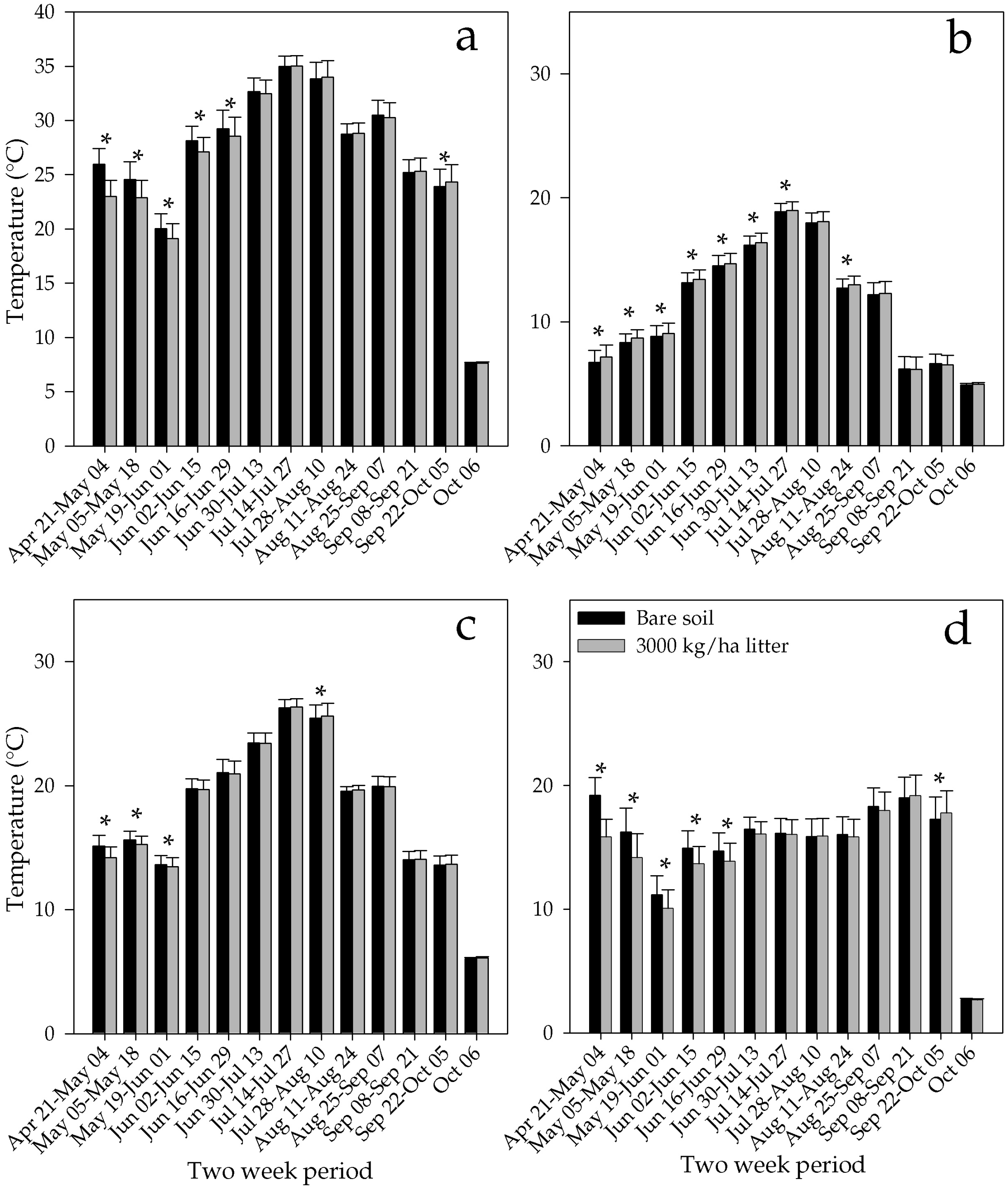

Figure 3-11: Daily near-surface soil temperatures as affected by litter cover at Pipestone, Manitoba, analyzed in two-week periods; a) maximum temperature, b) minimum temperature, c) average temperature, and d) temperature amplitude. Error bars are standard errors calculated on original untransformed data. Significant difference ($p<0.05$) between the bare soil treatment and the litter-covered treatment is indicated with (*).

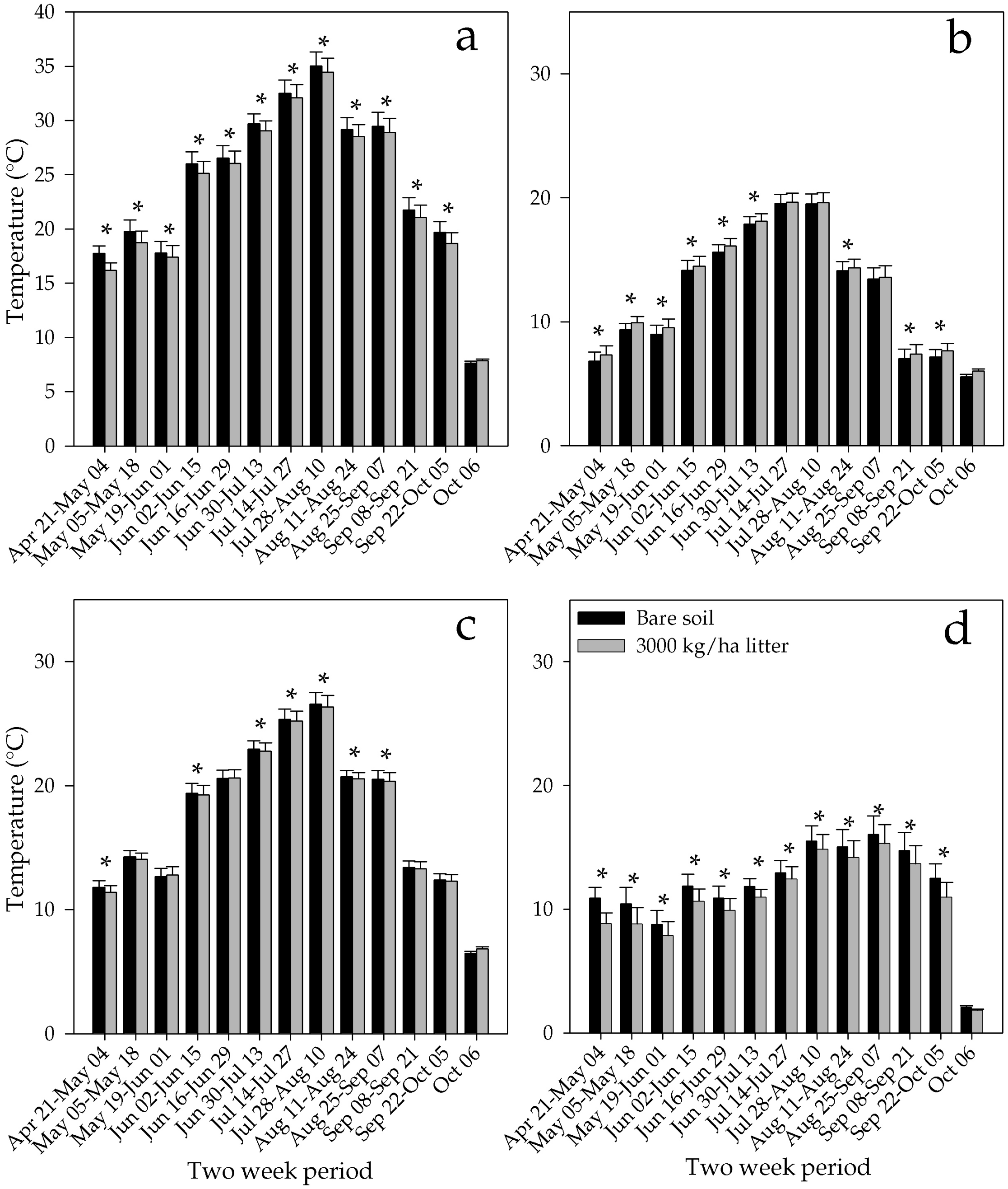

Figure 3-12: Daily near-surface soil temperatures as affected by litter cover at Shilo, Manitoba, analyzed in two-week periods; a) maximum temperature, b) minimum temperature, c) average temperature, and d) temperature amplitude. Error bars are standard errors calculated on original untransformed data. Significant difference ($p<0.05$) between the bare soil treatment and the litter-covered treatment is indicated with (*).

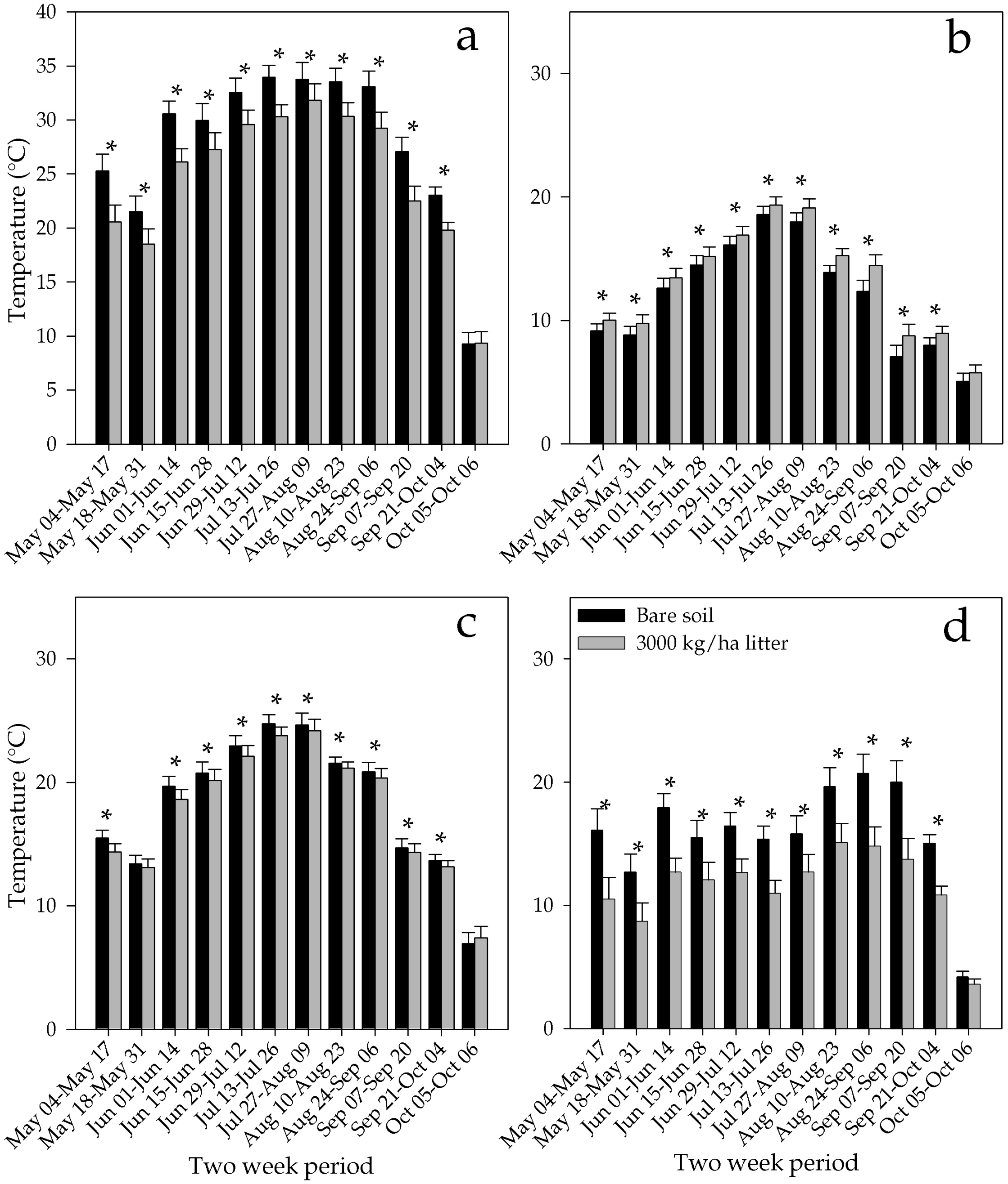

Figure 3-13: Daily near-surface soil temperatures as affected by litter cover at Goodlands, Manitoba, analyzed in two-week periods; a) maximum temperature, b) minimum temperature, c) average temperature, and d) temperature amplitude. Error bars are standard errors calculated on original untransformed data. Significant difference ($p<0.05$) between the bare soil treatment and the litter-covered treatment is indicated with (*).

Measurement of near-surface soil temperatures in pasture with and without litter cover has shown that litter does alter the soil microclimate at an hourly time scale as well as over the course of the growing season. Precipitation appears to lessen the effect of litter, though litter's effect can reappear within a day after a rainfall event.

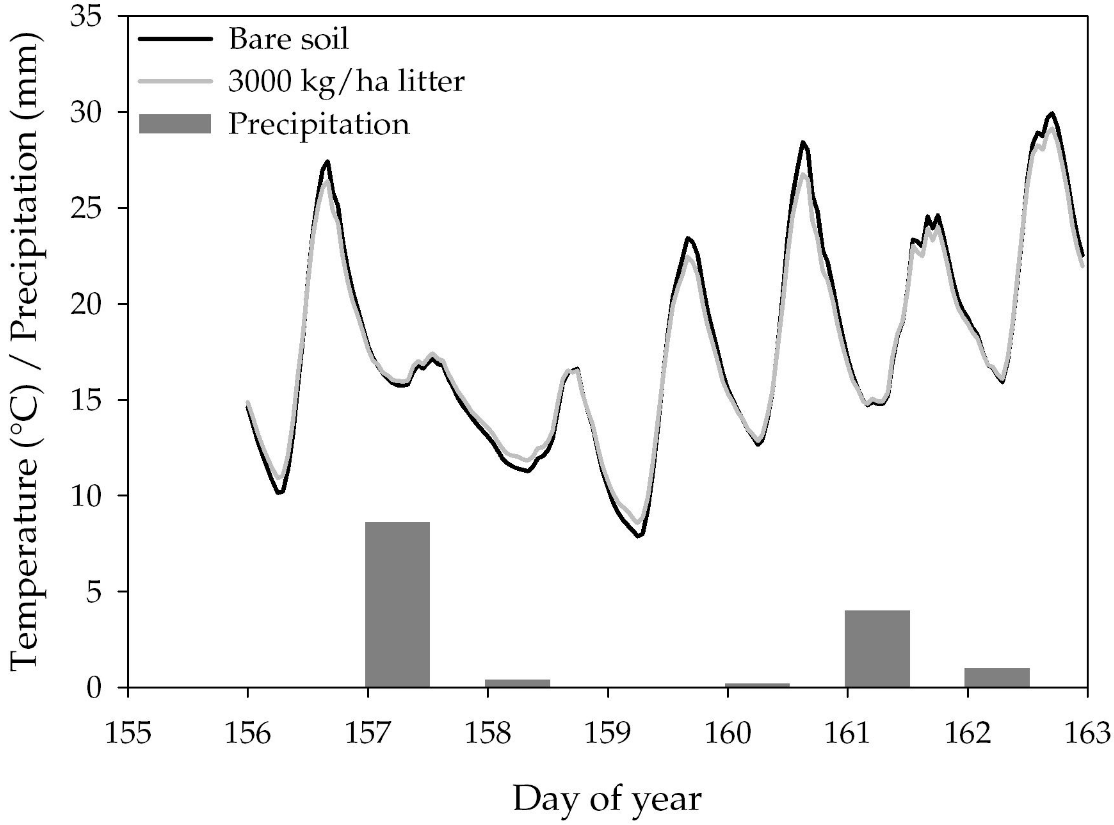

Figure 3-14: Hourly near-surface soil temperature fluctuations in bare soil and under a litter cover at Shilo, Manitoba, June 5 to 11, 2007. Precipitation data collected at Carberry, Manitoba (approximately 17 km away) by the Manitoba Ag-Weather Program (Manitoba Agriculture, Food, and Rural Initiatives 2008).

3.4.3 Forage production

Litter did not affect forage production. First cut, second cut, and total annual forage production were similar across years and sites (detailed treatment means for each site are located in Appendix 8-9). A notable exception was observed for the second cut at Souris in 2006, where litter was negatively related to forage production (Figure 3-15).

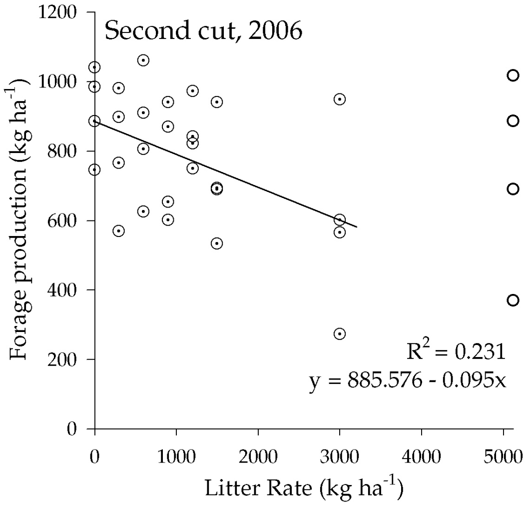

Figure 3-15: Relationship between litter rate and 2006 second-cut forage yield at Souris, MB. Line represents regression equation calculated without *in situ* treatment (empty circles).

3.5 Discussion

3.5.1 Soil moisture

A strong connection between litter and soil moisture was not found in this study. Significant relationships between litter biomass and soil moisture were observed only sporadically, and when present these relationships were extremely weak. With few exceptions, the significant correlations between litter and soil moisture were limited to the surface soil layer. Therefore, it appeared that when litter affected soil moisture, the effect was stronger at the surface than at greater soil depths.

At Pipestone, Carman, and Goodlands, the relationship between litter and soil water (when present) was positive, implying that at these sites litter was performing a small service to the moisture content of the soil. At Shilo, the opposite was observed, leading to a conclusion that at this site litter was inhibiting soil moisture in some way.

The negative relationship between litter and moisture observed at Shilo may have been due to higher water holding capacity of litter at that site, though this cannot be stated conclusively as an analysis of the physical characteristics of the litter layer at each site was beyond the scope of this study. However, Shilo was the only native pasture in the experiment, and as such the physical composition of the litter (architecture, nutrient composition, species composition) may have been different from that of the tame pasture sites. Physical characteristics are the principal factor determining water holding capacity (Naeth et al. 1991a). Alternatively, the negative relationship between litter and soil water at the Shilo site may have been a result of the type of precipitation received. Lighter rainfall events are known to be absorbed in greater amounts by the litter layer (Naeth et al. 1991a). This theory cannot be validated in the present study, however, since data respecting the nature of precipitation events was not collected.

The question yet remains why litter did not appear to be as important to soil moisture as reported in other studies (Naeth et al. 1991a; Dormaar and Willms 1998; Bradshaw et al. 2007). Several explanations can be advanced.

One explanation for the absence of a strong treatment effect is that weather in southwest Manitoba in the two years of study did not present conditions that made litter “necessary”. Willms et al. (1993), in Lethbridge, Alberta, found that litter affected herbage yield most strongly in moderate precipitation conditions, concluding that it was litter’s effect on evaporation that was responsible. Litter was not important in years with either too little or adequate rainfall. In other words, when water was not available to conserve, or when it was so abundant as to make conservation irrelevant, litter was not important. The study by Willms et al. (1993) found that litter (which averaged 377, 787, and 1171 kg/ha in the heavily grazed, moderately grazed, and ungrazed treatments, respectively) was significantly related to herbage production in three out of four years of study, and was most important in the one year when precipitation was moderately below normal and fell as substantial events uniformly distributed throughout the season. In the present study, conditions in 2006 were extremely dry, with growing season precipitation at 50% to 75% of normal. Precipitation in 2007 ranged from slightly below normal to almost 10% above normal. These two years most likely represent years that are “too dry” and “too wet” to allow litter to make a difference.

A second explanation for the lack of an effect of litter on soil moisture is that the litter layer was not “natural”. To create a range of litter rates, the plot areas were stripped down to bare soil, and then measured amounts of dried forage were then reapplied to the soil surface. This “manufactured” litter layer differed from natural mulch in several significant ways. For example, while the applied litter was made up of the same species as the litter found naturally in each pasture, the quality of the litter was different. The litter applied to the soil surface was made of freshly cut, oven-dried plant matter harvested in early spring. On the other hand, litter generated naturally is a result of plant death and leaf senescence. The C:N ratio of these two litters would differ, thus affecting the rates of decomposition after the litter was applied in 2006.

Also, the applied litter treatments differed from natural litter in their architecture. Natural litter is made up of a mix of vertically and horizontally arranged particles, some of which may still be anchored in the ground. The applied litter, made up of grass clippings, was hand applied and was for the most part horizontally arranged on the surface. The architecture of the litter layer impacts the flow of air and water vapor between soil and atmosphere (Flerchinger et al. 2003), and the amount of contact between soil and litter greatly affects the rate of decomposition (McCalla 1943). Thus the litter applied to the surface in this study would not have behaved as a natural litter layer would.

A third explanation for failing to find a strong relationship between litter biomass and soil moisture is one of detection. In the present study, soil moisture was not measured in relation to precipitation events. Thus it is possible that litter was affecting soil moisture at times when measurements were not taken.

The findings of Willms et al. (1993) regarding the influence of season-long weather conditions on the importance of litter may also apply in the short term. Deutsch and Bork (2008) have found that immediately following a significant precipitation event soil water is primarily a function of soil texture. In other words, just after a precipitation event conservation is not an issue and therefore litter is not a benefit. Measurements in the present study taken too soon after a precipitation event may have failed to find treatment differences. Likewise, measurements taken too long after the soil has been drying may also fail to find treatment differences.

A theoretical model of soil drying can be proposed, which reflects how litter alters soil water following a precipitation event (Figure 3-16). Litter affects the *rate* of evaporation, and so its effect changes over time as the soil moisture status of the soil changes. The difference in soil moisture between a bare soil and a litter-covered soil grows in the initial drying period as litter becomes more important compared to soil texture. Over time, however, evaporation continues and the benefit of water conservation is lost in the absence of water to conserve. At this point, the difference between the two soils will decline. The best time for measuring the "litter effect" on soil moisture would be at the point where litter is providing the most benefit to soil water compared to a bare soil (indicated by (b) in Figure 3-16).

Therefore, in the present study the lack of litter treatment effects may have resulted from moisture measurements being taken when transpiration out-weighed evaporation, or at a time outside the window when litter has its greatest effect.

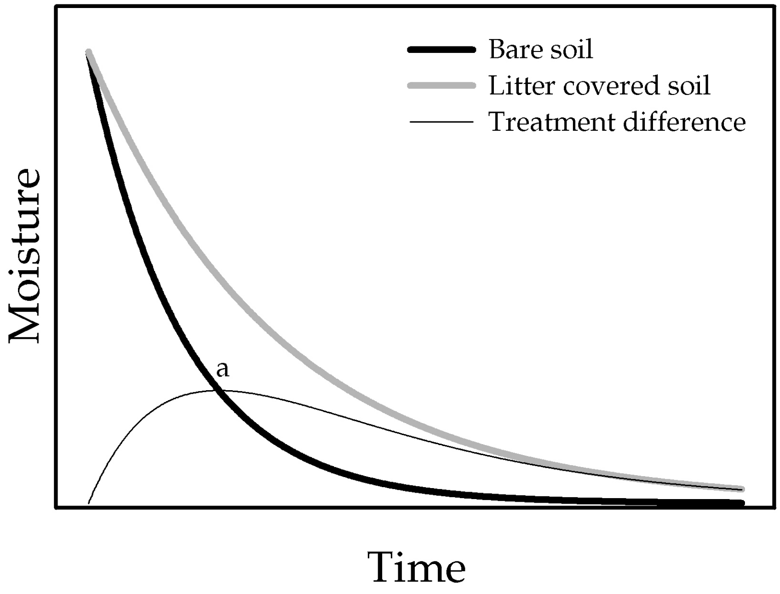

Figure 3-16: Theoretical drying curves for a bare soil and a litter covered soil (after Bussiere and Cellier 1994). The thin line depicts the difference between the two treatments; (a) indicates point during soil drying when litter is exerting maximum effect on soil moisture compared bare soil.

This third explanation assumes that a litter effect was present, but that the sampling methodology failed to detect it. While a more focused sampling technique may have detected this smaller litter effect, the fact remains that in the given locations and under the given environmental conditions in 2006 and 2007, the effect of litter biomass on soil moisture was weak enough to be undetectable using basic measurement practices.

3.5.2 Soil temperature

Results of the present study indicate that litter consistently affected near-surface soil temperature. The effect of litter was primarily to reduce maximum temperatures and increase minimum temperatures of soil, which resulted in narrower temperature amplitudes and lower average temperatures overall.

The effect of litter on near-surface soil temperature variables appeared to decay with time, and tended to be stronger in the first half of the season. Two-week repeated measures analysis showed that bare soil was consistently reaching higher maximum temperatures than the litter-covered soil until at least the end of June, after which time the effect was only seen periodically.

This might be explained by the growth of forage in the plots. Litter reduces soil temperatures in part by shading the soil from solar radiation (Horton et al. 1996). As forage grew over the course of the season, it may have shaded the plots which in turn may have caused reduced soil temperature differences between the bare and litter covered treatments in the latter half of the growing season. The significant differences in average temperatures between bare soil and litter-covered soil observed at Shilo during the period when the first biomass harvest was taken, and in minimum temperatures during the period when the second biomass harvest was taken appear to support this theory. In both cases temperatures the periods immediately preceding and following did not differ significantly, suggesting that the removal of forage caused the litter effect to appear once again.

Litter's effect on soil temperature is an underlying indicator of the changes to soil physical properties caused by the presence of residue at the surface, and as such gives us a foundation upon which to interpret our variable of interest: soil moisture. Soil temperatures can reflect two different moisture-related soil characteristics.

First, temperature reflects the amount of energy entering the system when soil is dry, with higher temperatures indicating more energy entering the soil. In the present study, the differences observed in soil temperatures between bare and litter-covered soils indicate that litter reduced the amount of energy entering the soil. This is consistent with the common understanding that litter intercepts solar radiation and reduces energy available at the soil surface (Bussiere and Cellier 1994; Horton et al. 1994; Novak et al. 2000). Willms et al. (1993) found that soil temperature was lower under litter, even when soil moisture measurements did not differ.

Second, soil temperature is influenced by soil moisture content. When soil is wet, incoming energy is used for evaporation rather than soil warming. Thus litter can reduce soil warming by slowing evaporation and improving the soil moisture status. In the present study, a difference in soil temperature between bare and litter covered soils emerged in the days following a precipitation event (see Figure 3-14). Though strongly significant litter effects were not observed in soil moisture measurements, litter’s more consistent effect on temperature indicates that litter may have played a role in slowing the rate of evaporation.

What does it mean that litter was primarily insignificant in soil moisture dynamics, when it was so clearly having an effect on soil temperature? Does the decay of the temperature effect help explain the lack of moisture effect in the latter portion of the season? How strong does the litter effect, as indicated by soil temperature, have to be to make a difference in soil moisture?

The connection between temperature and moisture was certainly weak. For example, soil temperature effects appeared strongest at Goodlands, with higher maximum temperatures in the bare soil treatment, but that site had the fewest instances where litter was significantly correlated with soil water. Likewise, Shilo showed significantly higher soil temperatures in the bare soil treatment throughout the 2007 growing season, but significant litter effects on moisture were only observed on two dates.

On the other hand, it is worth noting that all cases where soil moistures were significantly affected by litter occurred during two-week periods when soil temperatures were also significantly affected by litter. This could lead one to conclude that litter was cooling the soil and slowing evaporation, a conclusion supported by instances such as Pipestone on April 20, when litter both increased soil moisture and cooled soil temperatures.

However, contradictory examples were also observed. Litter significantly benefited soil moisture at Pipestone on September 27 (Figure 3-2), though the maximum temperatures during that time were significantly higher under litter than in the bare soil (Figure 3-11). Thus evidence of soil warming does not imply a dryer soil. At Shilo on April 20, litter was negatively affecting soil moisture (Figure 3-3), though the temperature data for that period shows that the litter covered soil was significantly cooler than the bare soil (Figure 3-12). Thus evidence of soil cooling does not imply a moister soil.

While the measurements of temperature prove that litter was altering the soil microclimate, the relationship between temperature and soil moisture was neither strong nor predictable. Identifying significant temperature effects is not enough to conclude that forage plants will have access to more favorable moisture conditions under litter.

3.5.3 Forage yield

Neither the weak effects of litter on soil moisture, nor the more consistent effects of litter on soil temperature were large enough to impact forage productivity. So, does litter matter? Though the results of the present study appear to suggest that litter plays a very limited role in pasture productivity, it must be noted that the long-term effect of litter accumulation or removal will not necessarily appear within the period of a two-year study.

There has been debate about the value of making conclusions about the effect of litter amounts on forage yield based on short-term observations. For example, Weaver and Rowland (1952) found that the removal of litter from pasture led to improved yields in the short term. They concluded that litter inhibited forage productivity. It was subsequently argued, however, that this type of study fails to account for the historically adequate litter levels prior to litter removal (Ellison 1960). When litter is removed from a pasture that has been under adequate litter, the resulting increase in soil temperatures can lead to greater biological activity in the soil, greater mineralization of organic matter, and therefore greater nutrient availability for forage plants. In the short term, yields will increase as a result of this increase in available nutrients. Over extended periods of time, such as decades, consistently removing litter from pasture will lead to reduced organic matter (Dormaar and Willms 1998), and thus reduced fertility of the soil and lower yields.

In the present study, the negative relationship between litter and yield seen in the 2006 second-cut at Souris may have been a result of this short-term effect where the reduction of litter cover led to improved forage re-growth after the first cut. However, the overall effects of litter on soil moisture and soil temperature across all sites and over the course of the growing season were not strong or consistent enough to have a meaningful impact on forage production.

3.6 Conclusions

Comparing near-surface soil temperatures with either 0 kg/ha or 3000 kg/ha litter cover, it was found that litter significantly affected the microclimate at the soil surface, reducing the amplitude of daily temperature fluctuations, and reducing the average daily temperature. This effect on pasture microclimate functioned at a daily and even hourly time-scale, with the difference between the two treatments waxing and waning as environmental conditions changed throughout the growing season. However, using applied litter rates between 0 and 3000 kg/ha, the present study failed to find a strong relationship between the amount of litter biomass on the soil surface and the amount of water present in the soil. Further, litter rates up to 3000 kg/ha were not found to have any significant short-term influence on forage production.

4 DEFOLIATION OF FORAGE PLANTS AFFECTS THE ACCUMULATION OF LITTER IN SOUTHWEST MANITOBA PASTURES

4.1 Abstract

Litter (dead plant material) is seen as important in pastures primarily for its role in improving soil water conservation. It is well established that grazing has a very significant impact on the accumulation of litter in pastures. A study was undertaken on three native (unimproved) and three tame (renovated) pasture sites in southwest Manitoba to determine the effect of grazing systems on the litter layer. Four grazing systems (continuous, time-controlled, twice-over, and stockpiled) were simulated using defoliation treatments and compared with an ungrazed control. Litter biomass was measured after three years of treatment. It was found that litter biomass was highest in the ungrazed control (3711 kg/ha). Litter was reduced in all grazing systems, with the amount of litter decreasing with increasing frequency of defoliation. Twice-over and stockpiled grazing had 1736 and 1690 kg/ha of litter respectively, time-controlled grazing had 1130 kg/ha of litter, and continuous grazing had 1007 kg/ha. When considering both the litter layer and forage yield in each of these systems, twice-over grazing appeared to be the most sustainable grazing system studied.

4.2 Introduction

Litter, defined as all dead plant material standing or fallen on the soil surface, is recognized as an important part of pasture functionality (Adams et al.

2003), especially when moisture is limiting (Naeth et al. 1991a; Willms et al. 1993). Grazing has been long recognized as having a significant influence on litter accumulation. Over 50 years ago, Hedrick (1948) reported that heavy grazing reduced the amount of *humic mulch* (partially decomposed litter). Specifically, grazing affects the addition of biomass to the litter layer, the function of litter as part of the nutrient cycle, and the nature of the litter layer itself.

Dormaar and Willms (1998) reported that after forty-four years of very heavy grazing in a native fescue grassland in southern Alberta the litter layer was completely absent, while the under light grazing the layer was four to five centimeters deep. Heavy grazing also caused significant deterioration of soil characteristics such as depth of Ah horizon and soil carbon, and the presence of bare ground increased. Baron et al. (2002) found that heavy grazing allowed only 16% of aboveground dry matter production to remain after grazing, while light grazing allowed 34% to remain. In that study, the same amount of dry matter was removed under both grazing intensities (approximately 4700 kg/ha), but light grazing treatments produced more forage than heavy grazing (7034 kg/ha versus 5826 kg/ha) resulting in greater amounts of residual material returning to the soil as litter.

Baron et al. (2002) also found that grazing intensity had an indirect effect on the rates of nutrient cycling. The deposition of carbon and nitrogen on the soil surface via plant litter was reduced under heavy grazing as compared to light grazing (by 13% and 14% respectively), though nutrients were returned to the soil via the feces and urine in greater amounts. Likewise, Dormaar and Willms (1998) found that the soil C:N ratio was lower under heavy grazing than under light grazing. Thus, under light grazing, litter acts as a fertility sink, binding nutrients up in slowly decomposing materials rather than adding them directly to the soil in mineral forms.

Plant decomposition rates are highest at the point of soil-litter contact (McCalla 1943). Treading and trampling by grazers speeds the decomposition of litter by mixing it into the soil or providing better litter-soil contact. This in turn leads to reduced rates of litter accumulation. Increased decomposition leads to functional changes as well. Litter in a more advanced stage of decomposition has a lower water holding capacity (Naeth et al. 1991a). Thus, in heavily grazed pastures with a greater proportion of fine litter, less water is trapped above the surface than in lightly grazed pastures.

Several grazing strategies have been adopted in Manitoba with differing intensities of both management and grazing. Continuous grazing involves keeping cattle on a single pasture for the entire grazing season without a rest period; intensity of grazing in this system is a result of pasture size, stocking rates, and selective grazing for desirable species or in desirable locations. Time-controlled, or rotational, grazing is a management intensive method that requires moving cattle through a series of paddocks, timing each grazing period to coincide with the maximum rate of growth in each paddock; grazing intensity is a function of stocking density and length of rest between grazing periods. Twice-over grazing is used in native pastures to give warm-season grasses a chance to develop; pastures are given only a light graze early in June to stimulate grazing tolerance mechanisms in the plants, and then cattle are put out for a longer duration after a designated rest period (Manske 2004). Forage "stockpiling" is a practice used to extend the grazing season by allowing a pasture to reach optimal forage levels just prior to killing frost (Manitoba Agriculture, Food, and Rural Initiatives 2000); grazing is stopped in July and forage is then allowed to rest (i.e. to "stockpile") until late in fall after other pastures have become dormant, or until early spring before new growth.

Little is known about how these grazing systems affect the accumulation of litter in Manitoba. The objective of this research was to simulate these grazing methods in southwest Manitoba and measure their effects on litter accumulation, and to characterize the relationship between litter quantity and forage production. It is hypothesized that systems with higher grazing frequencies will accumulate less litter than systems with lighter or less frequent grazing events, and that these lower litter levels will be associated with lower levels of forage production.

4.3 Materials and Methods

4.3.1 Research sites

Six sites were established in the spring of 2005 in the southwest region of Manitoba (Figure 4-1). Three sites were located on tame pasture (seeded to monoculture or a limited mix of introduced forage species in the recent past). Three sites were located on native pasture (having never been tilled or seeded to introduced forages). Unfortunately, an assessment of species present at this site was not conducted. Site characteristics are outlined in Table 4-1.

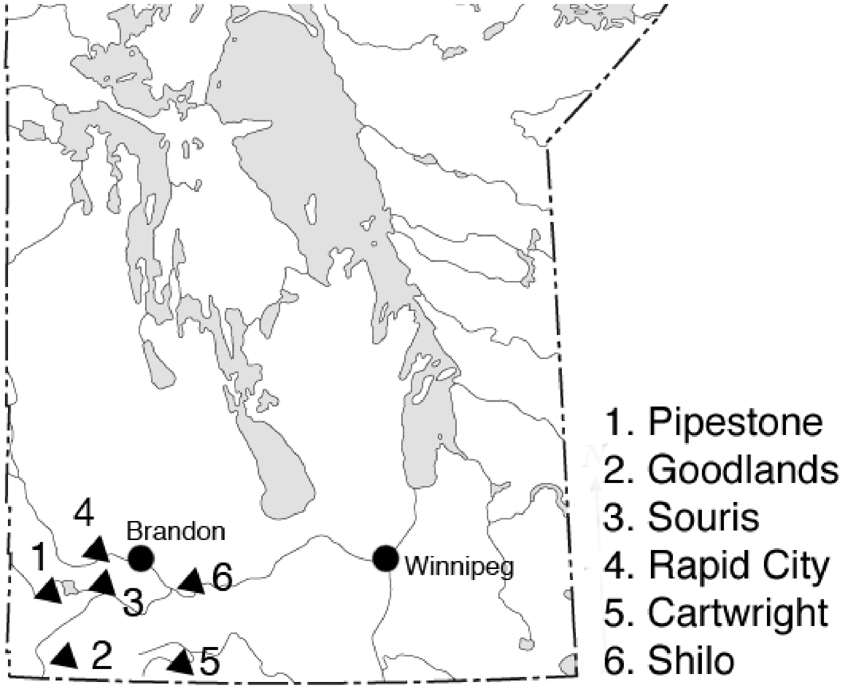

Figure 4-1: Location of Grazing Management Study sites in southwest Manitoba.

Southwest Manitoba receives an average of 475 mm of precipitation per year (De Jong and Steppuhn 1983), with 347 mm falling between April and

September (Environment Canada 2004b). Temperatures average 18.9ºC in July and –17.9ºC in January (Environment Canada 2004b).

Table 4-1: Characteristics of Grazing Management Study sites.

Site name	Latitude *(N)*	Longitude *(W)*	Pasture type *(principal species)*	Soil association *(soil texture)*	Initial litter levels *(kg/ha)*
Goodlands	49° 6′	100° 33′	Tame (bromegrass/alfalfa)	Waskada/Melita series (fine sandy loam – loam)	3238
Pipestone	49° 33′	100° 45′	Tame (meadow bromegrass)	Souris sands (sand – loamy sand)	4772
Souris	49° 37′	100° 14′	Tame (Kentucky bluegrass)	Carroll clay loam (silty clay loam – clay loam)	5120
Cartwright	49° 1′	99° 30′	Native prairie	Waskada (clay loam)	n.a.[1]
Rapid City	49° 53′	100° 27′	Native prairie	Marringhurst (coarse sandy loam)	n.a.
Shilo	49° 41′	99° 36′	Native prairie	Wheatland series (sandy)	2754

[1] Initial litter levels were not measured at these sites.

Table 4-2: Growing season conditions (March – September) near each site in 2006 and 2007 (Manitoba Agriculture, Food, and Rural Initiatives 2008).

Research Site	Weather station (distance from site, km)	Precipitation			Growing Degree Days		
		Normal[1]	*2006*	*2007*	*Normal*	*2006*	*2007*
		-------- *mm* --------			-------- *GDD* --------		
Goodlands	Melita (33)	391	236	341	1649	1852	1632
Pipestone	Virden (35)	372	249	354	1610	1858	1636
Souris	Souris (0)	364	267	369	1537	1889	1751
Cartwright	Killarney (25)	382	214	353	1635	1849	1765
Rapid City	Brandon (37)	364	328	347	1537	1766	1645
Shilo	Carberry (27)	364	269	398	1537	1770	1668

[1] Normals based on 30-year averages.

Above average precipitation fell in 2005. While precipitation was 125% of normal in that year, over half fell during June and July. Weather in 2006 tended to be hot and dry compared to normals, with growing season precipitation (March 1 – September 30) ranging from 52% to 74% of normal in the southwest region of Manitoba, and growing degree days ranging from 112% - 123% of normal (Manitoba Agriculture, Food, and Rural Initiatives 2008). Conditions were more typical in 2007, though precipitation was still below normal in some areas. Growing degree days ranged from 99% - 114% of normal, while precipitation fell at 88% - 109% of normal. Table 4-2 presents estimated growing season conditions near each site, based on data from the nearest weather station operated by the Manitoba Ag-Weather Program (Manitoba Agriculture, Food, and Rural Initiatives 2008). The distances between research sites and weather stations limit the interpretation of growing conditions at each research site to estimation.

4.3.2 Treatment set-up

Five grazing methods were simulated by timed defoliation in 4 m by 8 m plots arranged in a Randomized Complete Block design with four replicates. Clipping was performed using a sickle-bar mower set to a 3 cm height, with the clippings lightly raked off the plot, care being taken to prevent disturbing the surface soil and litter. In 2007, the mower was outfitted with a catch bag to collect clippings, though some light raking was still employed to ensure forage removal without soil or litter layer disturbance.

The five simulated grazing methods included continuous grazing (clipped every 14 – 21 days), time-controlled grazing (clipped every 25 – 40 days), twice-over grazing (clipped lightly in June, heavily at end of July), stockpiled grazing (clipped in June and late fall or early spring), and an ungrazed control (no clipping). The treatments were applied to each plot every year from 2005 to 2007, except the twice-over treatment, which was only clipped once in July 2007. The clipping frequencies for 2006 and 2007 are outlined in Table 4-3.

Table 4-3: Number of clippings performed under applied grazing treatments. Ungrazed treatment yields were taken July 2006 and April 2008. Data for 2005 was lost.

Site	Year	Number of clippings per year			
		Stockpiled	*Twice-over*	*Time-controlled*	*Continuous*
Goodlands	2006	2	2	4	7
	2007	2	1	3	6
Pipestone	2006	2	2	2	6
	2007	2	1	3	6
Souris	2006	2	2	3	7
	2007	-------------------- n.a.[1] --------------------			
Cartwright	2006	2	2	3	6
	2007	2	1	3	6
Rapid City	2006	2	2	3	6
	2007	2	1	3	6
Shilo	2006	2	2	2	4
	2007	2	1	3	6

[1] Fence was breached by cattle in 2007; data was not collected in 2007.

4.3.3 Data collection

Forage removal. Yield data was collected in 2005, 2006, and 2007, but the data from 2005 was lost by field assistants. To measure forage removal (yield), two above-ground biomass samples were harvested prior to each defoliation treatment. Live and standing dead plant material was cut 3 cm above the soil surface from a 0.25 m^2 quadrat and placed in paper bags. The two samples from each plot were bulked in a single paper bag and oven-dried at 65°C for at least 48 hours prior to measuring plant dry weight.

Litter accumulation. Litter samples were taken in September 2007, after three years of clipping treatments. Four litter samples were taken in each plot by hand-raking all dead plant material within 0.1 m^2 quadrats placed randomly within the plot at least 1 m from the plot edge. All samples from each plot were bulked in a single paper bag and oven-dried at 65°C for at least 48 hours before measuring litter dry weights.

4.3.4 Statistical analysis

The effects of grazing method, site, and their interaction on litter and forage yield were tested using Proc Mixed (SAS Institute Inc. 2004). Data were tested for normality of error variances, and litter rates and yields were subsequently cube-root transformed to achieve normality. Forage removal data from both years was summed with litter collected in 2007 to create a two-year accumulated above-ground biomass production variable. This variable was also analyzed using Proc Mixed; this data was square-root transformed to achieve normality.

Means and standard errors are presented in their original units (kg/ha), though ANOVAs and Fisher's Least Significant Difference comparisons were conducted on transformed values. Effects were considered significant when $P<0.05$.

4.4 Results and Discussion

4.4.1 Litter accumulation

Grazing method significantly affected litter accumulation (Table 4-4), and site was also a significant effect. There was a significant interaction between grazing method and site.

Grazing method effects. All grazing methods in this experiment reduced litter significantly from the ungrazed control (Table 4-5). This is similar to the results of Naeth et al. (1991b), who found that grazing increased the mass of standing and coarse litter. Under twice-over and stockpiled grazing, litter levels were reduced by 54% and 53%, respectively, compared to the control. Grazing treatments of higher frequency showed lower amounts of litter. Under continuous grazing, litter was reduced by 73% compared with the control treatment.

Table 4-4: ANOVA test results for the effects of site and grazing method on litter accumulation.

Effect	df	F-value	p-value
Treatment	4	112.23	<.0001[1]
Site	5	35.47	<.0001
Treatment*Site	20	4.05	<.0001

[1] Effects are considered significant when $P<0.05$.

The *Rangeland Health Assessment for Grassland, Forest, and Tame Pasture* (Adams et al. 2003) was produced in Alberta for the purpose of setting forth methods for determining the status of native and tame pasture. Litter is used by this guide as an indicator of hydrologic function and nutrient cycling. Litter levels are considered healthy when they are at least 65% of the regional average (developed in long-term benchmarking studies under light to moderate grazing). Litter is deemed unhealthy when present at less than 35% of the regional average. The findings of this study show that across all sites, time-controlled and continuous grazing reduced litter to unhealthy levels according to the *Rangeland Health Assessment Guide* (Adams et al. 2003).

Table 4-5: Litter accumulation in each grazing method in 2007, averaged across all research sites.

Grazing method	Litter biomass
	(kg ha^{-1})
Ungrazed control	3711 a[1]
Stockpiled	1690 b
Twice-over	1736 b
Time-controlled	1130 c
Continuous	1007 d
SE[2]	178

[1] Values in the same column followed by different letters are statistically different ($P<0.05$).

[2] SE = standard error of the mean.

The present study simulated grazing by applying varying frequencies of defoliation. Other effects of grazing on the litter layer, such as the increased surface contact and decomposition rates caused by treading and trampling of the surface (McCalla 1943; Naeth et al. 1991a), were not simulated. However, the results of this study indicate that defoliation alone has the potential to drastically alter the litter layer, by removing living forage before it has opportunity to senesce and become litter.

Site-to-site variation. There was site-to-site variation in litter amounts (Table 4-6). Tame pastures tended to accumulate similar, moderate, amounts of litter. Native pastures, on the other hand, varied tremendously in amounts of accumulated litter. Cartwright, a highly productive site with loamy soil, had a massive amount of litter compared to the less productive (and sandier) Rapid City and Shilo sites.

This appears to be in keeping with the common understanding that more productive sites accumulate more litter. The *Rangeland Health Assessment for Grassland, Forest, and Tame Pasture* (Adams et al.) has set different litter benchmarks based on the quality of the site. Within the Aspen Parkland subregion, for example, litter averages 1681 kg/ha in loamy sites, 1233 kg/ha in sandy sites, and 897 kg/ha in sands.

Table 4-6: Litter accumulation at each research site in 2007, averaged across all grazing methods.

Site	Litter biomass
	(kg ha^{-1})
Cartwright	3941 (281) a[1]
Goodlands	2049 (271) b
Souris	1967 (331) b
Pipestone	1881 (271) b
Rapid City	923 (271) c
Shilo	367 (271) d

[1] Values in parentheses are standard errors of the means. Means in the same column followed by different letters are statistically different (*P*<0.05).

Interaction between site and grazing method. The significant interaction between grazing method and site implies that sites also varied in the response of the litter layer to defoliation (Figure 4-2). Within tame sites a range of defoliation tolerance was seen. Pipestone's litter layer was very sensitive to grazing, with a 91% reduction in litter under continuous grazing, while Goodlands and Souris saw litter reduced by 69% and 79% respectively. In native pasture, sensitivity to grazing was not seen to the same extent. Cartwright, Shilo, and Rapid City saw litter reductions of 67%, 70%, and 73% respectively.

This variability among the sites is consistent with the findings of Naeth et al. (1991b) who found that the response of the litter layer to grazing differed between mixed grass, parkland fescue, and foothills fescue.

Can a blanket statement be made about how much litter is required to indicate proper pasture function? Alberta's *Rangeland Health Assessment Guide* (Adams et al. 2003) requires that litter be more abundant than a minimum percentage of average (based on data collected under light grazing in similar pasture and growing conditions). The present study appears to confirm this method, as the litter layers of different sites can withstand differing levels of grazing intensity. The litter layer becomes, therefore, a valuable indicator of grazing pressure: a pasture grazed too heavily will see a decline in litter, while litter will become excessive in underutilized pastures.

The question remains, however, whether a decline in litter levels is associated with a concurrent decline in forage yields.

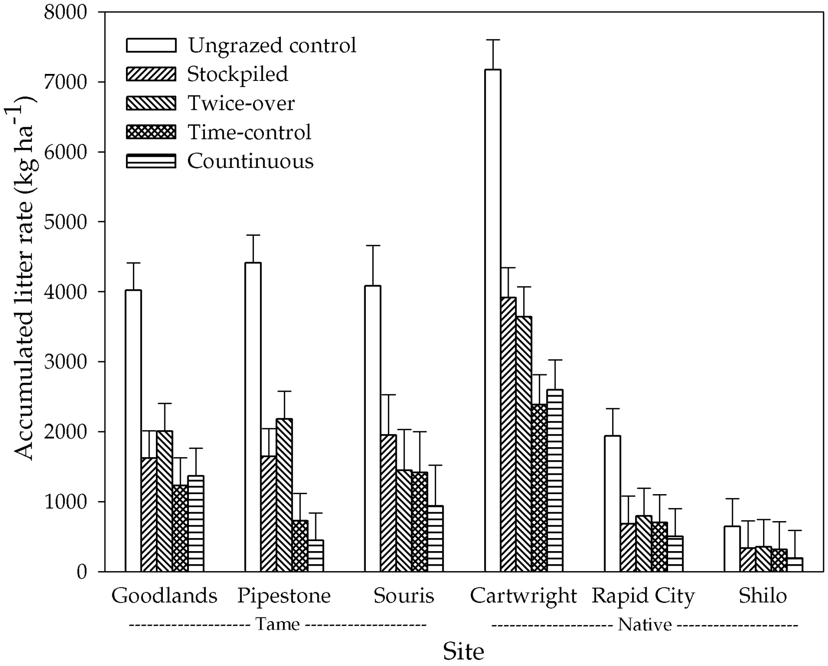

Figure 4-2: Litter accumulation at each site under different defoliation treatments. Error bars are standard errors calculated on original untransformed data.

4.4.2 Grazing impacts on forage yield

The effect of grazing systems on forage yield (i.e. biomass removal) was measured and analyzed for the 2006 and 2007 growing seasons. Data from 2005 was lost. In both 2006 and 2007, forage yield differed across both grazing methods and sites (Table 4-7). There was a significant interaction between grazing method and site in 2006 only.

Table 4-7: ANOVA test for the effects of site and grazing method on forage yield.

Effect	2006			2007		
	df	F-value	p-value	df	F-value	p-value
Grazing method	4	34.49	<0.0001[1]	3	16.86	<0.0001
Site	5	66.46	<0.0001	4	62.80	<0.0001
Site*Grazing method	20	6.98	<0.0001	12	0.97	0.4890

[1] Effects are considered significant when $P<0.05$.

Grazing method effects. The effect of grazing method on yields was different in 2006 and 2007 (Table 4-8). In 2006, highest yields were found in the twice-over grazing treatment. Treatments with higher grazing frequencies – continuous grazing and time-controlled grazing – showed lower annual yields. Thus, these pastures were unable to sustain production when grazed more than twice in 2006.

Table 4-8: Forage yield under each grazing method in 2006 and 2007, averaged across all research sites.

Grazing method	Forage removal	
	2006	2007
	-------- *(kg ha^{-1})*	--------
Ungrazed control	2869 b[1]	1367 c
Stockpiled	1936 c	2277 b
Twice-over	3332 a	2329 b
Time-controlled	2687 b	2413 b
Continuous	2891 b	3321 a
SE[2]	122	120

[1] Means in columns followed by different letters are statistically different ($P<0.05$).
[2] SE = standard error of the mean.

Treatments with fewer than two clippings – stockpiled and the ungrazed control – harvested less biomass than the twice-over grazing treatment (Table 4-8). This was most likely due to the fact that with decreased frequency of grazing, more forage was allowed to reach maturity, senesce, and become litter. Grazing these pastures fewer than two times per year failed to maximize forage yield.

In 2007, continuous grazing yielded the most forage (Table 4-8). Precipitation is a significant limiting factor for pasture production (Willms et al.

1993). Unlike conditions in 2006, which were hot and dry, growing season precipitation and temperatures were near normal in 2007. The continuously grazed treatment was clearly able to produce forage consistently enough throughout the growing season to allow for clipping every three weeks. In fact, a three-week clipping frequency is within the scope of some rotational grazing systems. Three weeks of rest may have been adequate to maintain the health of these pastures.

It is worth noting, however, that the twice-over grazing treatment only received one clipping in 2007. This treatment was clipped late in 2007, and so a second clipping was not possible due to lack of re-growth.

Site-to-site variation. Forage production differed across the research sites (Table 4-9). Cartwright yielded highest overall when both years were examined simultaneously. Souris was among the highest yielding sites in 2006, though it was not sampled in 2007. Shilo was the least productive in both years. Goodlands, Pipestone, and Rapid City all yielded moderately, with forage production at Goodlands tending to be higher yielding and Rapid City tending to be lower yielding.

Interaction between site and grazing method. An interaction was present in 2006 between site and grazing method (Table 4-10). At all sites but Pipestone and Goodlands, continuous grazing is amongst the highest yielding grazing strategies. At Pipestone, the most forage was removed from the twice-over and the ungrazed control, while at Goodlands the highest yields were taken from twice-over and time-controlled. In all cases but Souris, stockpiled grazing resulted in the lowest yields. At Souris, lowest yields were recorded in the time-controlled grazing system.

Table 4-9: Forage yield at each research site in 2006 and 2007, averaged across all grazing methods.

Research site	Forage removal	
	2006	2007
	------------- *kg ha*$^{-1}$ -------------	
Cartwright	3351 (124) a[1]	3565 (167) a
Goodlands	3370 (215) ab	2504 (127) b
Pipestone	2199 (103) c	2208 (75) c
Rapid City	2754 (73) b	2283 (138) bc
Shilo	1261 (77) d	1147 (53) d
Souris	3525 (160) a	n.a.[2]

[1] Values in parentheses indicate the standard error of the mean. Means in the same column followed by different letters are statistically different (*P*<0.05).

[2] Yield data was not collected from Souris in 2007 due to uncontrolled grazing in the experimental area after the fence was breached.

Table 4-10: Annual forage yield from five grazing methods at all six sites in 2006.

Grazing method	Site					
	Cartwright	Goodlands	Pipestone	Rapid City	Shilo	Souris
			------------------- *kg ha*$^{-1}$ -------------------			
Ungrazed control	3008 bc[1]	3371 ab	3159 a	3048 ab	1501 a	3130 bc
Stockpiled	2595 c	1417 c	1803 b	1801 c	303 c	3700 ab
Twice-over	4166 a	4464 a	2499 a	3109 a	1756 a	4001 a
Time-controlled	3319 abc	4485 a	1811 b	2578 b	1127 b	2804 c
Continuous	3669 ab	3114 b	1721 b	3237 a	1621 a	3988 a
SE[2]	276	480	226	159	168	355

[1] Means in the same column followed by different letters are significantly different (*P*<0.05).

[2] SE = standard error of the mean for each site.

Total biomass production. Measuring forage yield does not fully describe total biomass production: litter represents unharvested biomass that has not yet decomposed. By combining measurements of accumulated litter in the fall of 2007 with the measurements of total amount of biomass removed in 2006 and 2007, an approximation of total above-ground biomass produced over these two years was calculated.

This type of variable has not been widely used, and its limitations are acknowledged. First, the validity of clipping alone as a simulation of grazing has been questioned (Parsons et al. 1983). Second, a calculation of total biomass production would require data on root production, soil carbon changes, respiration, changes to the litter layer over time. Despite these concerns, there is still value in using this variable as a first approximation of above-ground biomass production. Thus, the results of this analysis are presented here as an exploratory exercise.

Above-ground biomass production varied significantly across grazing methods and sites, with a significant interaction between the two (Table 4-11).

Biomass was highest in the ungrazed control, mostly due to the high levels of litter biomass in that treatment (see Table 4-5). Of the four grazed treatments, biomass was highest in both the twice-over grazing and the continuous grazing treatments, though this effect was not present at all sites (Table 4-12). Time-controlled grazing produced moderate amounts of biomass, while stockpiled grazing produced the lowest amounts of biomass.

Table 4-11: ANOVA test results for the effects of site and grazing method on above-ground biomass production.

Effect	df	F-value	p-value
Treatment	4	112.23	<.0001[1]
Site	5	35.47	<.0001
Treatment*Site	20	4.05	<.0001

[1] Effects are considered significant when $P<0.05$.

Table 4-12: Two-year measured accumulated above-ground biomass production (kg/ha) from five grazing methods at all sites.[1]

Grazing method	Site					
	Cartwright	Goodlands	Pipestone	Rapid City	Shilo	Overall
			kg/ha			
Ungrazed control	14057 a[2]	11519 a	10202 a	7165 ab	2995 bc	9188 a
Stockpiled	10425 b	5708 c	5700 bc	4419 c	1500 d	5550 d
Twice-over	11310 b	8733 b	6718 b	6232 ab	3356 ab	7270 b
Time-controlled	9433 b	8143 b	4735 c	5730 bc	2704 c	6149 c
Continuous	10998 b	7575 b	5401 c	7347 a	3747 a	7013 b
SE[3]	705	448	380	507	315	219
Overall	11245 a[4] (315)	8335 b (200)	6551 c (170)	6178 c (227)	2860 d (141)	

[1] Data from Souris was not included due to uncontrolled cattle grazing in the plots.

[2] Means in the same column followed by different letters are significantly different (P<0.05), except for overall site averages.

[3] SE = standard error of the mean for each site.

[4] Overall site averages followed by different letters are significantly different (P<0.05). Values in parentheses are the standard error of the mean.

What does it mean that total biomass production was highest in both the continuous and twice-over grazing systems? Discussion must remain speculative due to the short duration of the study and the incomplete nature of the data, which does not include litter decomposition or changes to soil organic matter.

Climatic conditions favorable to forage production in 2007 made a three-week clipping frequency possible, such that the continuous grazing treatment appeared to yield as well as or better than the twice-over treatment. Clearly a three-week rest period between grazing events was adequate for maintenance of plant growth in that year.

In the long-term, however, grazing leads to increased mineralization of organic matter (Shariff et al. 1994). Increasing mineralization while at the same time reducing inputs to the litter layer must lead to an eventual decline in soil fertility. For example, Dormaar and Willms (1998) found that after 44 years of heavy grazing soil carbon was reduced by almost 4% compared to an ungrazed control. In the present study, the frequent removal of above-ground biomass under continuous grazing meant that little plant matter was allowed to become litter. Thus, if the continuous grazing treatment of the present study were applied for the long term, an eventual decline in forage productivity would likely be observed.

Twice-over grazing, on the other hand, struck a balance between biomass removal and biomass additions. More litter was added to the soil under twice-over grazing, while at the same time harvests were apparently timed to allow for significant levels of forage removal. Thus yields were able to exceed other grazing treatments, as in 2006, without the supposed sacrifice of long-term soil fertility. Long-term application of this grazing method would not be expected to cause a decline in pasture productivity or the amount of litter biomass.

Stockpiled grazing did not produce as much total biomass as the other grazing systems, most likely due to the timing of the harvests. Clipping very early or very late in the season meant harvesting forage at inefficient times with respect to forage growth patterns: allowing forage to reach maturity may have led to greater allocation of plant resources to below-ground and reproductive structures, and thus less biomass production.

4.5 Conclusions

The introduction of grazing caused a reduction of litter accumulation, with higher frequencies of defoliation leading to lower accumulations of litter. Grazing frequency also changed the amount of forage removed from pasture, though the continuously grazed treatment yielded the same as the twice-over grazing system.

Therefore, the choice of grazing method has the potential to drastically impact the litter layer, though the present study did not show a strong connection between litter accumulation and above-ground productivity.

In the short term, heavy grazing pressure appeared to benefit forage production by maximizing biomass removal and minimizing contributions to the litter layer. However, over time this grazing method is expected to cause significant reductions in soil fertility and an eventual decline in forage productivity. Based on both forage yield and litter layer dynamics, twice-over grazing appears to be the optimal and most sustainable grazing method for southwest Manitoba pastures.

5 A SURVEY OF LITTER ACCUMULATION IN MANITOBA PASTURES

5.1 Abstract

Litter (dead plant material) is understood as an important component in pasture health. Expected litter benchmarks for various regions and productivity conditions are an important tool in pasture health assessment, and have been developed for practical application in other provinces. A study was undertaken on native pastures across Manitoba to determine the mass of litter present under light grazing in four regions of the province and in three levels of pasture productivity. Litter was measured in 2006 and 2007 within grazing exclosures on upland sites that had been clipped twice per year since 2004. Paired measurements were also taken outside the grazing exclosures where cattle were free to graze. Within the grazing exclosures, litter biomass averaged 1902 kg/ha, ranging from 825 kg/ha to 3750 kg/ha. Litter outside the grazing exclosures was lower than inside, averaging 1236 kg/ha and ranging from 76 kg/ha to 4112 kg/ha. Litter tended to be present in greater quantities in higher quality sites.

5.2 Introduction

Litter, defined as the dead plant material standing or lying on the soil surface, is of interest in pastures primarily due to its perceived role in soil moisture conservation. Numerous studies have been conducted over the years to identify how litter accumulation is affected by location, soil characteristics, plant community, and environmental conditions. These surveys aid in the development of benchmarks that can be used in pasture health assessment.

Ovington et al. (1963) found that aboveground living biomass in an ungrazed prairie site in central Minnesota averaged 930 kg/ha, and litter averaged 2,788 kg/ha. In western North Dakota, Ralph L. Dix (1960) studied the mulch structure following fire in three grasslands. Litter averaged 1,185 kg/ha in a grassland site four years after burning. Another site burned three years prior contained only 756 kg/ha litter, while a corresponding unburned site contained 1647 kg/ha litter.

More recently, researchers in Alberta conducted a four year litter study in the Dark-Brown soil zone near Lethbridge, AB (Willms et al. 1993). Yearly average litter rates under three simulated grazing treatments (no clipping, clipping once per year to 7-cm height, or clipping once per year to 3-cm height) ranged from 555 – 912 kg/ha over four years of study, with the un-clipped treatment averaging 1171 kg/ha, the medium intensity clipping treatment averaging 812 kg/ha, and the heavily clipped treatment averaging 604 kg/ha. A second study by Willms et al. (1996) found litter amounts in a rough fescue grassland of 1,000 kg/ha under moderate grazing.

In a study of tame pasture (Page and Bork 2004), litter biomass ranged from 333 kg/ha in a northwestern Alberta pasture up to 953 kg/ha in a north-central site. Litter did not exceed 1000 kg/ha in the study.

The growing body of litter research in Alberta has provided practical guidelines, with the publication of the *Rangeland Health Assessment for Grassland, Forest, and Tame Pasture* (Adams et al. 2003). In this guide, litter is used as an indicator of pasture hydrological status, with higher amounts of litter associated with improved pasture conditions. Recommended litter rates for native mixed grass pasture range from 1009 kg/ha in loamy Mixed Prairie sites to as high as 1681 kg/ha for high quality pasture in the Aspen Parkland (see Table 2-3 for the complete range of litter thresholds contained in the guide**)**. Litter amounts in tame pasture are considered adequate when they exceed 504 kg/ha (see Table 2-4 for complete guidelines for litter in tame pasture).

Given the absence of Manitoba-specific information about existing litter quantities in native pastures, the present study sought to quantify litter accumulation under light defoliation pressure, as well as litter biomass accumulated under existing management practices in four regions of Manitoba. Research was carried out as part of a long-term benchmarking study coordinated by the Manitoba Forage Council, located on crown-owned native pastures leased to private managers. It was hypothesized that more litter would be found in pastures with higher quality soil, that more litter would be found inside grazing exclosures than in the pastures at large, and that higher accumulations of litter would be associated with higher forage yields.

5.3 Materials and Methods

5.3.1 Research Sites

Research sites were established in 2004 by the Manitoba Forage Council (MFC), Manitoba Agriculture, Food, and Rural Initiatives (MAFRI), and the Prairie Farm Rehabilitation Association (PFRA) in twelve pastures across `Manitoba for the purpose of collecting long-term benchmark forage yield data. These pastures were located in four regions: Northwest (NW), Southwest (SW), Central (CE), and East (EA) (Figure 5-1).

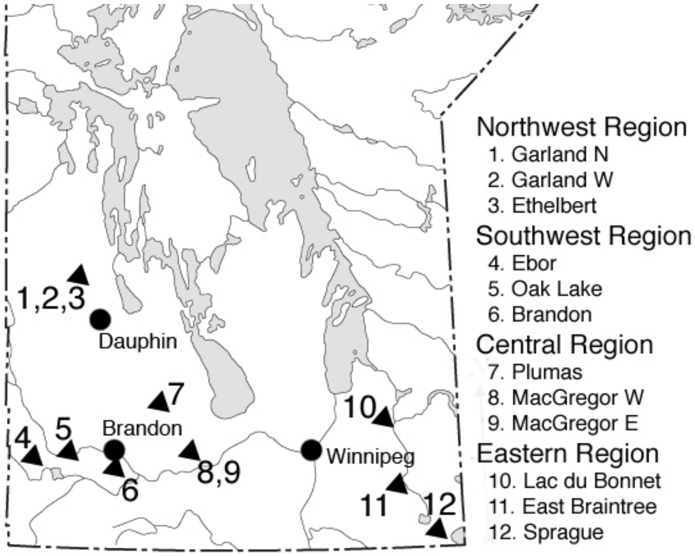

Figure 5-1: Approximate location of 12 sampling sites in the benchmark litter survey.

Within each region three pasture sites with different soil types were chosen to provide a range of pasture productivity. Pasture productivity was classified using a three-category system (Table 5-1). This system was based on a combination of MAFRI staff experience and the Canada Land Inventory Soil

Capability for Agriculture (SCA) classification (The Canada Land Inventory 1969). The same individuals classified each site.

Table 5-1: Soil associations and pasture productivity classification for each research site.

Region	Pasture productivity class		
	High (Group 1)	Medium (Group 2)	Low (Group 3)
	---------------------- research site ---------------------- *(soil association)*		
Northwest	Garland North *Meharry*	Garland West *Garson Complex*	Ethelbert *Selina Sands*
Southwest	Ebor *Oxbow*	Oak Lake *Tiger Hills-Hilton*	Brandon *Souris*
Central	Plumas *Isafold*	MacGregor West *Almassippi Loamy Sand*	MacGregor East *Almassippi Sand*
East	Lac du Bonnet *Peguis*	East Braintree *Wintergreen/Malonton*	Sprague *Wintergreen*

Table 5-2: Average growing season and annual precipitation and temperature for three regions of Manitoba in 2006 and 2007 (Environment Canada 2004a).

Period	Temperature			Precipitation		
	2006	2007	Normal[1]	2006	2007	Normal
	--------------- °C ---------------			--------------- *mm* ---------------		
Winnipeg[2]						
Mar-Sep	12.6 e[3]	11.5 e	11.0	230.5	384.1 e	399.7
Annual	5.8 e	4.4 e	2.6	325.5 e	470.6 e	513.8
Brandon						
Mar-Sep	11.6	10.7	10.3	361	347.8	375.4
Annual	3.7 e	3.9	2.0	462.2	462.8	472.1
Dauphin						
Mar-Sep	11.3 e	10.4 e	10.1	320.0	416.5 e	398.8
Annual	3.7 e	4.0 e	2.0	442.0	498.5 e	507.8

[1] Normals based on 30-year averages.
[2] See Figure 5-1 for proximity of weather stations to experimental sites.
[3] e indicates that value is based on estimated or incomplete data.

Weather conditions across the province in 2006 were in general drier and warmer than normal, with precipitation during the growing season (March – September) considerably lower than normal in the Dauphin and Winnipeg regions (Table 5-2). Conditions in the province in 2007 were more typical, with annual average temperature and total precipitation near 30-year normals. However, growing season conditions in 2007 were wet, especially in the spring and particularly in the Dauphin area (Table 5-2).

5.3.2 Grazing exclosures and treatment categories

At each site, grazing exclosures (Figure 5-2) were installed in five vegetative categories – upland, lowland, transitional, open woodland, and woodland. An additional class, field, was included in the northwest sites. The open-topped cages were 1 m x 1 m in dimension, and rose approximately 1.5 m above the soil surface. Each category was replicated four times randomly throughout the pasture for a total of 20 cages (24 cages in the northwest region) per pasture. Characteristics of the vegetation categories are described in Table 5-3.

Table 5-3: Characteristics of the six vegetation categories established for field sites in Manitoba.

Vegetation category	Characteristics
Upland	Grasses, shrubs, and forbs dominate.
Transitional	Transition between upland and lowland – moisture-loving grasses dominate.
Lowland	High moisture availability – sedges and reedgrasses dominate.
Open Woodland	Open canopy dominated by aspen or balsam poplar. Some growth of shrubs, forbs, and grasses.
Woodland	Closed canopy dominated by aspen or balsam poplar. Forbs and grasses are sparse.
Field	Vegetation has reverted from managed "tame" pasture to a "modified" plant community dominated by Kentucky bluegrass, clovers, and dandelion.

Figure 5-2: Two grazing exclosures located in the transitional vegetation category at the Ebor site, 2007.

5.3.3 Data collection

Forage biomass collection. Forage biomass was harvested, processed, and measured by staff of MFC, MAFRI, and PFRA. Biomass was harvested from each cage in late June and mid September between 2004 and 2007, inclusive. Living forage was clipped to 4 cm in the entire cage (1 m^2) and placed in mesh bags. Forage was oven-dried before weighing dry biomass.

Litter collection. In late June 2006, all sites but Plumas were visited for litter sampling. Paired litter samples were taken from inside and outside each exclosure in the upland, lowland, transitional, and field classes, as well as some cages in the open woodland class.

Samples were taken from inside the grazing cages immediately after the forage biomass had been harvested. All litter was hand-raked from inside a 400 cm^2 quadrat. Soil and green plant material were not taken in the sample. The small size of the quadrat was chosen to minimize effects of litter removal on subsequent biomass harvesting from the exclosure.

Samples taken from outside the cages followed the same procedure, using a 625 cm^2 quadrat. Living forage was removed as close to the soil surface as possible using a hand-sickle and discarded prior to litter collection. All samples were placed in paper bags, oven dried at 65°C for at least 48 hours prior to measuring litter dry weight.

In 2007, the same methodology was used. All 12 sites were visited between June 26 and July 5. Paired litter samples were collected from upland, transitional, lowland, and field classes. Due to high levels of spring precipitation across the province in 2007, many lowland cages were flooded making litter collection impossible. Lowland cages were only sampled at the Oak Lake pasture. In addition, lowland and transitional cages in the northwest were flooded, limiting litter collection to the upland and field cages only.

5.3.4 Statistical analysis

The only vegetation category sampled from all sites in both years was the upland category. For the purposes of this study, only data collected from upland cages was analyzed to maintain uniformity across sites.

The effects of region, productivity class, and their interaction were tested using Proc Mixed (SAS Institute Inc. 2004). The central region was left out of the 2006 ANOVA due to the absence of data from the Plumas site. All sites were included in analysis of 2007 data. Data were tested for normality; litter biomass and forage yield data were subsequently square-root transformed to achieve normality of residuals and homogeneity of variance.

Yields, litter rates, and standard errors are presented in their original units (kg/ha), though ANOVAs and Fisher's Least Significant Difference comparisons were conducted on transformed values. Effects were considered significant when $P<0.05$.

In order to test the hypothesis that grazing affects the amount of litter biomass, paired t-tests were conducted on litter inside and outside the grazing exclosures (SAS Institute Inc. 2004). These paired t-tests were conducted for all data across the study, and for each site individually. Years were analyzed separately. Regression analysis was performed on forage yield with litter as the independent variable, using Proc Reg (SAS Institute Inc. 2004). Data collected in 2006 and 2007 were analyzed separately and then combined and analyzed together.

5.4 Results and Discussion

5.4.1 Forage productivity

Yields in the upland vegetation category averaged 1880 kg/ha in 2006 and 1805 kg/ha in 2007. Region and productivity class did not significantly affect yield in 2006, though there was a significant interaction between them (Table 5-4). In 2007, productivity class significantly affected yield and significantly interacted with region (Table 5-4).

Table 5-4: ANOVA test results for the effects of region and productivity class on forage yield in 2006 and 2007.

Effect	2006			2007		
	df	F-value	p-value	df	F-value	p-value
Region	2	0.48	0.6254[1]	3	2.36	0.0894
Productivity Class	2	2.14	0.1388	2	8.23	0.0013
Region*Class	4	3.1	0.0334	6	2.57	0.0372

[1] Effects are considered significant when $P<0.05$.

Yields in 2006 ranged from 1023 kg/ha to 2345 kg/ha. Productivity classes appeared to rank differently at the different sites, though the overall effects were not significant (Table 5-5). For example, the high quality site yielded the most in the eastern region, while the low quality site yielded the most in the southwest.

In 2007, productivity class had a stronger effect on yield. Production was highest in the high quality sites, with medium and low quality sites yielding similarly (Table 5-5). This trend was consistent across regions, except in the northwest, where the medium quality site yielded the most forage.

Table 5-5: Upland forage yields collected from inside upland grazing exclosures in 2006 and 2007.

Productivity class			Region		
	Northwest	Southwest	Central	East	Overall
			----------- $kg\ ha^{-1}$ -----------		
2006					
High	2128 (314) a[1]	2080 (314) a	n.a.[2]	2345 (314) a	2184 (182)
Medium	2225 (314) a	1633 (314) a		1440 (445) a	1766 (210)
Low	1023 (314) b	2308 (314) a		1890 (314) a	1740 (182)
2006 Overall	1792 (182)	2007 (182)		1892 (210)	
2007					
High	1785 (277) ab[1]	2593 (277) a	1970 (277) a	2675 (277) a	2256 (139) a
Medium	2360 (277) a	1300 (320) b	1148 (277) b	1570 (392) b	1594 (160) b
Low	1225 (277) b	1505 (277) b	1220 (277) b	2065 (277) ab	1504 (139) b
2007 Overall	1790 (160)	1799 (169)	1446 (160)	2103 (185)	

[1] Values in parentheses are the standard errors of the mean. Means in the same column and year followed by different letters are significantly different ($P<0.05$), except for overall site averages.

[2] Data was not analyzed from the central region in 2006.

5.4.2 Litter inside grazing exclosures

Litter inside grazing exclosures was measured to identify quantity accumulated under light grazing pressure (i.e. two clippings per year). Accumulated litter inside upland grazing exclosures was extremely variable. In 2006, litter in the cages averaged 1514 kg/ha with a standard deviation of 909 kg/ha. In 2007, litter averaged 2289 kg/ha with a standard deviation of 1141 kg/ha.

Neither region nor productivity class significantly affected litter accumulation in 2006 (Table 5-6). However, litter present inside upland grazing cages varied significantly across regions in 2007. There was no interaction between region and class in either year (Table 5-6).

Table 5-6: ANOVA test results for the effects of region and productivity class on litter biomass inside grazing exclosures in 2006 and 2007.

Effect	2006			2007		
	df	F-value	p-value	df	F-value	p-value
Region	2	1.23	0.309	3	4.52	0.0094
Productivity Class	2	2.76	0.0826	2	2.85	0.0727
Region*Class	4	1.76	0.168	6	1.16	0.3539

[1] Effects are considered significant when $P<0.05$.

Table 5-7: Litter biomass collected from inside upland grazing exclosures in 2006 and 2007.

Productivity class	Region				
	Northwest	Southwest	Central	East	Overall
2006			----------- *kg ha^{-1}* -----------		
High	2769 (369)^1	1131 (369)	n.a.	1500 (369)	1800 (213)
Medium	1456 (369)	1394 (369)		825 (521)	1225 (246)
Low	874 (369)	1063 (369)		1281 (369)	1072 (213)
2006 Overall	1700 (213)	1196 (213)		1202 (246)	
2007					
High	2706 (488)^1	2563 (488)	2125 (488)	1438 (488)	2208 (244)
Medium	3381 (488)	1900 (564)	3750 (488)	1750 (691)	2695 (282)
Low	1644 (488)	1833 (564)	2650 (488)	1250 (488)	1844 (254)
2007 Overall	2577 (282) a^2	2099 (312) ab	2842 (282) a	1479 (326) b	

[1] Values in parentheses are the standard errors of the mean. Means in the same column and year followed by different letters are significantly different ($P<0.05$), except for overall site averages.
[2] Overall site averages for 2007 followed by different letters are significantly different ($P<0.05$).

In 2006, litter in upland cages averaged from a low of 825 kg/ha in the medium quality eastern site, to a high of 2769 kg/ha in the high quality northwest site (Table 5-7). Highest litter amounts were found in high quality sites, though this trend was not statistically significant ($P=0.083$). In 2007, litter amounts were greater than in 2006. In 2007, regional differences were significant, with the most litter present in the central and northwest regions. The least amount of litter was found in the eastern region, where litter ranged from 1250 kg/ha to 1750 kg/ha.

Though litter amounts were extremely variable across the province, this variation seems only weakly influenced by regional effects and site productivity. Under light grazing, as simulated by two light cuttings per year, litter accumulated in higher amounts than those identified for the Aspen Parkland in Alberta’s *Rangeland Health Assessment Guide* (Adams et al. 2003).

5.4.3 Litter outside grazing exclosures

While litter inside the cages gives an idea of each site’s potential to accumulate litter under conditions that simulate light grazing pressure, the litter outside the cages represents the status of litter accumulation in Manitoba pastures under grazing management. The grazing systems, stocking densities, and resulting grazing pressures at each pasture are unknown – this information is not in the public domain. Thus, the present analysis can only suggest how pasture management “in general” affects litter accumulation; it cannot lead to conclusions about the effect of any particular management strategy.

Litter outside the grazing cages was as variable as litter inside. In 2006, litter outside the upland cages averaged 1012 kg/ha, with a standard deviation of 845 kg/ha. Similar to results from inside the cages, more litter was present outside cages in 2007 compared with 2006. Litter present outside the cages in 2007 averaged 1460 kg/ha with a standard deviation of 1419 kg/ha.

In both 2006 and 2007, litter amounts outside the grazing cages varied significantly across regions and productivity classes, with a significant interaction between the two (Table 5-8).

Table 5-8: ANOVA test results for the effects of region and productivity class on litter biomass collected outside grazing exclosures in 2006 and 2007.

Effect	2006			2007		
	df	F-value	p-value	df	F-value	p-value
Region	2	11.09	0.0004[1]	3	11.93	<0.0001
Productivity Class	2	5.47	0.0107	2	12.31	0.0001
Region*Class	4	4.89	0.0047	6	14.84	<0.0001

[1] Effects are considered significant when $P<0.05$.

The pattern of litter accumulation outside the cages appears to have differed from that inside the cages. For example, the northwest region accumulated some of the highest amounts of litter when inside the cages (Table 5-7). However, in both years northwest litter amounts outside the cages were the lowest of all regions (Table 5-9).

The amounts of litter found outside the grazing exclosures averaged in some regions below those recommended in Alberta's *Rangeland Health Assessment Guide* (Adams et al. 2003). For example, the present study found litter averaged 76 kg/ha in the medium quality site of the northwest region, which was 5% of the average litter amount present inside the cages of that site. The *Rangeland Health Assessment Guide* recommends that healthy pasture contain litter at levels at least 65% of the amount expected under light grazing – for mixed grass native pasture for example, this minimum is 656 kg/ha of litter (Adams et al. 2003).

Table 5-9: Litter biomass collected from outside upland grazing exclosures in 2006 and 2007.

Productivity class	Region				
	Northwest	Southwest	Central	East	Overall
			----------- *kg ha^{-1}* -----------		
2006					
High	428 (277) ab[1]	1824 (277) a		2148 (277) a	1467 (160) a
Medium	76 (277) b	1064 (277) a	n.a.	992 (391) ab	711 (184) b
Low	996 (277) a	1252 (277) a		348 (277) b	865 (160) b
2006 Overall	500 (160) b[2]	1380 (160) a		1163 (184) a	
2007					
High	356 (355) b	4112 (355) a	2028 (355) b	1616 (355) a	2028 (177) a
Medium	128 (355) b	661 (410) b	3572 (355) a	1872 (502) a	1558 (205) a
Low	1360 (355) a	1120 (355) b	408 (355) c	288 (355) b	794 (177) b
2007 Overall	615 (205) c	1964 (216) ab	2003 (205) a	1259 (237) b	

[1] Values in parentheses are the standard errors of the mean. Means in the same column and year followed by different letters are significantly different (P<0.05), except for overall site averages.
[2] Overall site averages within the same year followed by different letters are significantly different (P<0.05).

5.4.4 Comparing litter inside and outside the cages

Paired t-tests of litter inside and outside the grazing exclosures were carried out to determine if litter was significantly different between the two. Across all sites, litter outside the grazing exclosures was significantly lower than litter inside cages: 20.2% lower in 2006 (*P*=0.002) and 24.8% lower in 2007 (*P*=0.0041). Again, the specific grazing strategies employed at each site is not known, and in fact pasture management across sites may have varied considerably, ranging from over-grazing to no grazing at all. A likely explanation for the reduced litter outside the cages was a higher grazing pressure outside the cages than was simulated inside the grazing exclosures.

Less litter was present outside cages versus inside cages in the northwest region, while the southwest appears to have accumulated more litter outside the cages than inside (Table 5-10). In both years, litter outside the grazing cages was significantly reduced compared to litter inside the cages in medium and low quality sites (Table 5-10). This suggests that litter in lower quality sites may be more sensitive to management than that of higher quality sites.

Table 5-10: Average ratio of litter biomass outside grazing exclosures to litter inside grazing exclosures.

Productivity class	Region				
	Northwest	Southwest	Central	East	Overall
2006	----------- *litter out (litter in)$^{-1}$* -----------				
High	0.15*[1]	1.61*	n.a.	1.43	1.22
Medium	0.05*	0.76		1.20	0.57*
Low	1.14	1.18		0.27	0.66*
Overall	0.23*	1.24*		1.15	
2007					
High	0.13	1.60	0.95	1.12	1.08
Medium	0.04*	0.35	0.95	1.07	0.61*
Low	0.83	0.61	0.15	0.23*	0.51*
Overall	0.39*	1.11	0.74	0.84	

[1] Value is calculated by averaging the ratio between litter found outside the cage and litter found inside the cage, for each pair of observations. A ratio followed by a (*) indicates that litter inside cages is significantly different from litter outside cages (P<0.05).

When sites were examined individually, the relationship was not as clear, further underscoring the impact sites can have on the accumulation of litter outside the grazing cages. Two of the nine sites analyzed in 2006 had significantly more litter inside the cages than outside, while one site had more litter outside the cages (Table 5-10). In 2007, two of the twelve sites showed more litter inside the cages than out, while the rest were similar (P>0.05).

The insides of the grazing cages were subject to two clippings per year, and so represent a light, twice-over type grazing system. At some sites, the employed grazing methods (or what might have been a complete absence of grazing) were clearly promoting litter at rates greater than a twice-over grazing system would. At other sites the grazing methods caused a greater reduction in litter biomass accumulation than the grazing pressure simulated inside the cages.

5.4.5 Yield as a function of litter

Litter and forage production data was collected from cages in eleven pastures in 2006 and twelve pastures in 2007. The relationship between litter and yield was explored through the use of regression analysis on data from upland cages only, with litter as the independent variable.

Litter was related to yield in 2006, and unrelated in 2007 (Table 5-11). When both years of data were combined, no significant relationship was found. The relationship between litter and yield in 2006 was positive, with a slope of 0.319. This positive relationship is similar to those found in the mixed prairie of Alberta, where slopes ranged from 0.114 to 0.802 over four years of study (Willms et al. 1993).

The strength of the relationship between litter and yield is dependent on the growing conditions (Willms et al. 1993). Litter can improve soil water by increasing snow capture and infiltration (Naeth and Chanasyk 1995), and slowing evaporation (Horton et al. 1994). For litter to benefit pasture, then, requires conditions that make moisture conservation possible and necessary.

Conditions that are too dry reduce the usefulness of litter because there is no moisture to conserve. Conditions that are too wet reduce the usefulness of litter because conservation of moisture is not necessary (Willms et al. 1993).

Table 5-11: Relationship between upland forage yields and litter biomass across all research sites for 2006 and 2007. Effects are considered significant when $P<0.05$.

Year	N	R^2	P<F	Intercept	Coefficient
2006	42	0.1548	0.01	1398	0.319
2007	44	0.0032	0.72	1889	-0.04
Combined	86	0.0122	0.31	1702	0.07

In the present study, the presence of a relationship between litter and yield in 2006 and its absence in 2007 can be explained at least in part by the differences in precipitation in those two years. Precipitation in 2006 was below normal, especially in the growing season, while 2007 was more typical. What cannot be concluded from this study is whether the relationship measured between litter and forage yield is a causal one, or merely a correlation.

5.5 Conclusions

Under simulated light grazing pressure, litter present in Manitoba native pastures averaged 1514 kg/ha and 2289 kg/ha in 2006 and 2007, respectively. These values are higher than those recommended by the *Rangeland Health Assessment Guide* (Adams et al. 2003). Regional variation was present in only one year, and productivity class did not appear to affect the amount of litter inside the grazing exclosures in a statistically significant way.

The most important factor governing the accumulation of litter in pasture was site. Grazing methods used by the managers of each site during the study are not known and were not controlled, making it impossible to draw conclusions about the effect of specific grazing methods on litter accumulation. However, the results confirm that existing pasture management practices employed in the pastures of this study had the potential to alter the amount of accumulated litter substantially.

The role of litter as an indicator of pasture productivity was confirmed by regression analysis – though this effect was not present in both years and appears to depend on growing conditions that make litter "useful" to the pasture. Also, it is difficult to say whether a causal relationship existed between litter accumulation and forage yield.

The results of this study indicate that there is potential for the use of litter measurements as part of an overall pasture health assessment program.

6 GENERAL DISCUSSION

6.1 Findings

Litter in native pastures across Manitoba averaged 1902 kg/ha over the two years of study. Grazing exerts a significant influence on litter accumulation, with increased defoliation associated with reduced litter levels. The present study did not indicate a strong relationship between litter and soil moisture conservation, though a small but consistent cooling effect on near-surface soil temperatures was observed. The amount of litter did not have an effect on forage production.

6.2 The use of grazing animals in litter research

Further research on the effect of grazing on litter accumulation will benefit from the use of grazing animals. Defoliation is clearly a significant component of the influence grazing exerts on litter. However, the impact of grazers on the litter layer extends beyond defoliation. Treading and trampling alters the architecture of the litter layer, thereby changing its rate of decomposition, its water holding capacity, and its characteristics as a soil insulator. The redistribution of nutrients via grazing is also an important function of animals on pasture. While defoliation represents the removal of nutrients contained in the plant matter, it does not simulate the return of a portion of those nutrients to the soil surface in the form of readily available nutrients in urine and feces. This shift in nutrient availability would impact litter decomposition, forage yield, and overall pasture fertility. Finally, animals will selectively graze preferred forage species. This selective grazing pressure would lead to shifts in species composition that a non-selective clipping treatment cannot simulate. The use of grazers would thus allow a more representative simulation of pasture dynamics.

6.3 The study of litter rates

A second consideration for further research is the method used to investigate the effects of varying amounts of litter. In the present study, litter was removed from all treatments and dried forage was laid on the surface at pre-determined rates. This method ensured that the effect of litter quantity was isolated from other variables. However, this method introduced a level of disturbance that would not be seen in a natural pasture. An alternative option might be the use of varying grazing intensities to induce changes in litter quantities. However, this practice introduces a confounding factor in terms of the difference in treatment of living biomass – transpiration, photosynthesis, and plant resource partitioning would be influenced by the grazing treatments. Thus any changes caused by the differing amounts of litter might be overshadowed by these other effects.

Isolating relationships between litter and individual components of pasture is difficult due to the interrelatedness of these components in the pasture system. Perhaps the effects of litter on individual pasture characteristics, such as soil moisture or soil temperature, are best understood within the larger context of pasture agroecosystems. The next step in litter research, I would suggest, might be the incorporation of litter data into comprehensive, landscape-level investigations of pasture functions and dynamics. By monitoring litter levels alongside soil moisture, soil temperature, forage production, animal production, species composition, and overall pasture health under varying grazing systems, in varying landscape positions, and over several years with varying climatic conditions, the interconnected relationships between litter and all other pasture characteristics and processes may be characterized. The long-term pasture benchmarking project managed by the Manitoba Forage Council, Manitoba Agriculture, Food and Rural Initiatives, and the Prairie Farm Rehabilitation Association, presents one such opportunity, though micrometeorological measurements such as soil moisture and soil temperature have not been collected to date.

6.4 Long-term effects of litter

Litter research in Manitoba will benefit from long-term studies. At longer time-scales, it becomes possible to measure gradual changes to the pasture system caused by changes to management practices. While the effects of grazing on the litter layer became apparent within two or three years of study, the implications of this change to the litter layer from a pasture health perspective may not become apparent in less than ten years. It is only through long-term study that the true impacts of different grazing methods can be measured.

7 LITERATURE CITED

Adams, B. W., Ehlert, G., Stone, C., Lawrence, D., Alexander, M., Willoughby, M., Hincz, C., Moisey, D., AND Bogen, A. 2003. Rangeland Health Assessment for Grassland, Forest, and Tame Pasture. Public Lands Division, Alberta Sustainable Resource Development.

Baron, V. S., Mapfumo, E., Dick, A. C., Naeth, M. A., Okine, E. K., and Chanasyk, D. S. 2002. Grazing intensity impacts on pasture carbon and nitrogen flow. *Journal of Range Management* 55:535-541.

Bestelmeyer, B. T., Ward, J. P., Herrick, J. E., and Tugel, A. J. 2006. Fragmentation effects on soil aggregate stability in a patchy arid grassland. *Rangeland Ecology & Management* 59:406-415.

Black, A. L. and Tanaka, D. L. 1997. A conservation tillage-cropping systems study in the Northern Great Plains of the United States. *In:* Paul, E. A., Paustian, K., Elliott, E. T., and Cole, C. V. [EDS.]. Soil Organic Matter in Temperate Agroecosystems: Long-Term Experiments in North America. Boca Raton: CRC Press, Inc.

Bradshaw, D. L., Chanasyk, D. S., Baron, V. S., and Naeth, M. A. 2007. Soil water regimes of annual and perennial forages during drought years in the Aspen Parkland ecoregion of Alberta. *Canadian Journal of Soil Science* 87:523-533.

Bristow, K. L. and Horton, R. 1996. Modeling the impact of partial surface mulch on soil heat and water flow. *Theoretical and Applied Climatology* 54:85-98.

Bussiere, F. and Cellier, P. 1994. Modification of the soil-temperature and water-content regimes by a crop residue mulch - experiment and modeling. *Agricultural and Forest Meteorology* 68:1-28.

De Jong, E. and Steppuhn, H. 1983. Water conservation: Canadian Prairies. *In:* Fuccillo, D. and Gates, K. E. [EDS.]. Dryland Agriculture. Madison: American Society of Agronomy, Inc. p. 89-106.

de Oliveira, O. C., de Oliveira, I. P., Alves, B. J. R., Urquiaga, S., and Boddey, R. M. 2004. Chemical and biological indicators of decline/degradation of Brachiaria pastures in the Brazilian Cerrado. *Agriculture Ecosystems & Environment* 103:289-300.

Delta-T Devices Ltd. 1999. ThetaProbe Soil Moisture Sensor Type ML2x User Manual. Cambridge, UK: Delta-T Devices Ltd.

Deutch, E. S. and Bork, E. 2008. Landscape influences on soil moisture within a rough fescue grassland of the Alberta Parkland [poster presentation]. In: Building Bridges: Grasslands to Rangelands. Joint Annual Meetings of the American Forage and Grassland Council and the Society for Range Management; 2008 Jan 26; Louisville, KY.

Dix, R. L. 1960. The Effects of Burning on the Mulch Structure and Species Composition of Grasslands in Western North Dakota. *Ecology* 41:49-56.

Donkor, N. T., Okello, M. M., Hudson, R. J., and Bork, E. W. 2003. Seasonal dynamics and defoliation impact on herbage yield in Aspen Boreal habitats of Alberta. *Canadian Field-Naturalist* 117:196-202.

Dormaar, J. F., Adams, B. W., and Willms, W. D. 1997. Impacts of rotational grazing on mixed prairie soils and vegetation. *Journal of Range Management* 50:647-651.

Dormaar, J. F. and Carefoot, J. M. 1996. Implications of crop residue management and conservation tillage on soil organic matter. *Canadian Journal of Plant Science* 76:627-634.

Dormaar, J. F. and Willms, W. D. 1998. Effect of forty-four years of grazing on fescue grassland soils. *Journal of Range Management* 51:122-126.

Ellison, L. 1960. Influence of grazing on plant succession of rangelands. *Botanical Review* 26:1-78.

Environment Canada. 2004a. Bulk Data (1941 - 2007). Environment Canada. *Available at:* http://www.climate.weatheroffice.ec.gc.ca/climateData/bulkdata_e.html?timeframe=3&Prov=XX&StationID=3471&format=csv&type=mly. *Accessed 12/3/2008a.*

Environment Canada. 2004b. Canadian Climate Normals 1971-2000. Environment Canada. *Available at:* http://www.climate.weatheroffice.ec.gc.ca/climate_normals/results_e.html?StnID=3471. *Accessed 12/3/2008b.*

Flerchinger, G. N. 2000. *The Simultaneous Heat and Water (SHAW) Model: Technical Documentation*. USDA Agricultural Research Service. 37 p.

Flerchinger, G. N., Sauer, T. J., and Aiken, R. A. 2003. Effects of crop residue cover and architecture on heat and water transfer at the soil surface. *Geoderma* 116:217-233.

Fulbright, T. E., Ortega-Santos, J. A., Lozano-Cavazos, A., and Ramirez-Yanez, L. E. 2006. Establishing vegetation on migrating inland sand dunes in Texas. *Rangeland Ecology & Management* 59:549-556.

Goertz, J. W. 1964. The Influence of Habitat Quality upon Density of Cotton Rat Populations. *Ecological Monographs* 34:359-381.

Heady, H. F. 1956. Changes in a California annual plant community induced by manipulation of natural mulch. *Ecology* 37:798-812.

Hedrick, D. W. 1948. The mulch layer of California annual ranges. *Journal of Range Management* 1:22-25.

Holechek, J., Pieper, R. D., and Herbel, C. H. 2001. Selection of grazing methods. *In:* Holechek, J., Pieper, R. D., and Herbel, C. H. [EDS.]. Range Management: Principles and Practices. 4 Edition. Upper Saddle River, N.J.: Prentice Hall. p. 247-290.

Holechek, J., Valdez, R., Schemnitz, S. D., Pieper, R. D., and Davis, C. A. 1982. Manipulation of grazing to improve or maintain wildlife habitat. *Wildlife Society Bulletin* 10:204-210.

Horton, R., Bristow, K. L., Kluitenberg, G. J., and Sauer, T. J. 1996. Crop residue effects on surface radiation and energy balance - Review. *Theoretical and Applied Climatology* 54:27-37.

Horton, R., Kluitenberg, G. J., and Bristow, K. L. 1994. Surface crop residue effects on the soil surface energy balance. *In:* Unger, P. W. [EDS.]. Managing Agricultural Residues. Boca Raton: Lewis Publishers. p. 143-162.

Jacobo, E. J., Rodriguez, A. M., Bartoloni, N., and Deregibus, V. A. 2006. Rotational grazing effects on rangeland vegetation at a farm scale. *Rangeland Ecology & Management* 59:249-257.

Kurkalova, L., Kling, C., and Zhao, J. H. 2006. Green subsidies in agriculture: Estimating the adoption costs of conservation tillage from observed behavior. *Canadian Journal of Agricultural Economics-Revue Canadienne D Agroeconomie* 54:247-267.

Manitoba Agriculture, Food, and Rural Initiatives. 2000. Pastures for profit: a guide to rotational grazing. *In:* Stewart, F., Joose, D., and Yaworski, K [EDS.]. Manitoba Grazing Reference Manual. Manitoba Agriculture, Food, and Rural Initiatives.

Manitoba Agriculture, Food, and Rural Initiatives. 2003. Manitoba Agricultural Review. *Available at:*

http://www.gov.mb.ca/agriculture/statistics/aac01s01.html#LAND%20RESOURCE. *Accessed 3/3/2008*.

Manitoba Agriculture, Food, and Rural Initiatives. 2008. Manitoba Ag-Weather Program: Growing Season Report. *Available at:* http://tgs.gov.mb.ca/climate/SeasonalReport.aspx. *Accessed 2/4/2008*.

Manske, L. 2004. Effects of grazing management treatments on rangeland vegetation. North Dakota State University. *Available at:* http://www.ag.ndsu.nodak.edu/dickinso/research/2003/PDF/range03c.pdf. *Accessed 9/5/2008*.

McCalla, T. M. 1943. Microbiological studies of the effect of straw used as mulch. *Transactions of the Kansas Academy of Science* 46:52-56.

Naeth, M. A., Bailey, A. W., Chanasyk, D. S., and Pluth, D. J. 1991a. Water holding capacity of litter and soil organic-matter in mixed prairie and fescue grassland ecosystems of Alberta. *Journal of Range Management* 44:13-17.

Naeth, M. A., Bailey, A. W., Pluth, D. J., Chanasyk, D. S., and Hardin, R. T. 1991b. Grazing impacts on litter and soil organic-matter in mixed prairie and fescue grassland ecosystems of Alberta. *Journal of Range Management* 44:7-12.

Naeth, M. A. and Chanasyk, D. S. 1995. Grazing effects on soil-water in Alberta foothills fescue grasslands. *Journal of Range Management* 48:528-534.

Novak, M. D., Chen, W. J., Orchansky, A. L., and Ketler, R. 2000. Turbulent exchange processes within and above a straw mulch. Part II: Thermal and moisture regimes. *Agricultural and Forest Meteorology* 102:155-171.

Oke, T. R. 1987. Boundary Layer Climates. Second Edition. London, UK: Routledge. 463 p.

Ovington, J. D., Heitkamp, D., and Lawrence, D. B. 1963. Plant Biomass and Productivity of Prairie, Savanna, Oakwood, and Maize Field Ecosystems in Central Minnesota. *Ecology* 44:52-63.

Page, H. and Bork, E. 2004. *Litter Biomass and Forage Production on Tame Pasture in Alberta: A Data Summary*. Alberta: Submitted to Sustainable Resource Development, Government of Alberta.

Parsons, A. J., Leafe, E. L., Collett, B., and Stiles, W. 1983. The Physiology of Grass Production Under Grazing .1. Characteristics of Leaf and Canopy Photosynthesis of Continuously-Grazed Swards. *Journal of Applied Ecology* 20:117-126.

SAS Institute Inc. 2004. SAS OnlineDoc® 9.1.3. Fourth Edition. Cary, NC: SAS Institute Inc.

Saxton, K. E., Rawls, W. J., Romberger, J. S., and Papendick, R. I. 1986. Estimating Generalized Soil-Water Characteristics from Texture. *Soil Science Society of America Journal* 50:1031-1036.

Shariff, A. R., Biondini, M. E., and Grygiel, C. E. 1994. Grazing intensity effects on litter decomposition and soil-nitrogen mineralization. *Journal of Range Management* 47:444-449.

Shaykewich, C. F., Holliday, N., Jeffrey, S., Kennedy, A., Mooney, S., and Woodbury, B. 1994. Weather and climate resources for Prairie agriculture. *In:* Morrison, I. and Kraft, D. [EDS.]. Sustainability of Canada's Agri-Food System. Winnipeg: International Institute for Sustainable Development. p. 31-48.

Smith, V. C. and Bradford, M. A. 2003. Litter quality impacts on grassland litter decomposition are differently dependent on soil fauna across time. *Applied Soil Ecology* 24:197-203.

Statistics Canada. 2002. Use of farm land, Canada and provinces, 1976-2001 (Table). Farm Data and Farm Operator Data (Full Release) for the 2001 Census of Agriculture Plus Selected Historical Data. Statistics Canada Catalogue no. 95F0302XIE. *Available at:* http://www.statcan.ca/english/freepub/95F0302XIE/2001001/tables/html/optab18.htm#46. *Accessed 3/3/2008*.

Tester, J. R. and Marshall, W. H. 1961. A Study of Certain Plant and Animal Interrelations on a Native Prairie in Northwestern Minnesota. Minneapolis: The University of Minnesota Press.

The Canada Land Inventory. 1969. Soil Capability Classification for Agriculture. Government of Canada - Department of Regional Economic Expansion. *Available at:* http://geogratis.cgdi.gc.ca/CLI/mapping/Cli-pdf/English/AgricultureMethodology.pdf. 2:16. *Accessed 13/6/2008*.

Tomanek, G. W. 1969. Dynamics of mulch layer in grassland ecosystems. *In:* Dix, R. L. and Beidleman, R. G. [EDS.]. The Grassland Ecosystem, A Preliminary Synthesis. Fort Collins, CO: Colorado State University, Fort Collins. p. 225-240.

Troxler Electronic Laboratories, Inc. 2006. Manual of Operation and Instruction, Model 4300 Depth Moisture Gauge. Research Triangle Park: Troxler Electronic Laboratories, Inc.

Unger, P. W. 1994. Residue management strategies - Great Plains. *In:* Hatfield, J. L. and Stewart, B. A. [EDS.]. Crops Residue Management. Boca Raton, FL: CRC Press, Inc. p. 37-61.

Weaver, J. E. and Rowland, N. W. 1952. Effects of Excessive Natural Mulch on Development, Yield, and Structure of Native Grassland. *Botanical Gazette* 114:1-19.

Weir, T. R. 1968. Geography of Manitoba. *In:* Buchanan, L. C., Feniak, E., Ferguson, A. C., Gallop, R. A., Hudson, J. P., Ridley, A. O., Robinson, A. G., Seale, M. E., and Campbell, D. [EDS.]. Principles and Practices of Commercial Farming. Second Edition. Winnipeg: Faculty of Agriculture and Home Economics. p. 3-20.

Weir, T. R. 1983. Atlas of Manitoba. Winnipeg: Surveys and Mapping Branch, Department of Natural Resources, Province of Manitoba.

Willms, W. D., Adams, B. W., and Johan, J. F. 1996. Seasonal changes of herbage biomass on the fescue prairie. *Journal of Range Management* 49:100-104.

Willms, W. D., McGinn, S. M., and Dormaar, J. F. 1993. Influence of litter on herbage production in the mixed prairie. *Journal of Range Management* 46:320-324.

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

8 APPENDICES

Appendix 8-1: Bulk densities for surface soil layer (0-10 cm) in each plot at Litter Rate Study sites.

Plot number	Site				
	Carman	Goodlands	Pipestone	Shilo	Souris
	---------------- *g mm*$^{-3}$ ----------------				
101	1.15	1.08	1.11	0.96	0.90
102	1.07	1.16	1.03	1.31	0.92
103	1.09	1.15	1.16	1.31	0.92
104	1.04	1.08	1.06	1.07	0.96
105	1.06	1.13	1.03	1.27	0.92
106	1.01	1.22	1.13	1.29	0.89
107	0.95	1.19	1.02	1.19	0.95
108	1.22	1.20	0.94	1.30	0.93
201	1.06	1.11	1.09	1.18	1.03
202	1.10	1.17	1.13	1.22	0.89
203	1.17	1.11	0.94	1.16	0.94
204	1.01	1.08	1.16	1.18	0.98
205	1.04	1.15	1.20	1.35	1.03
206	1.12	1.16	0.73	1.18	0.89
207	1.10	1.11	1.13	1.27	0.97
208	0.98	1.01	1.10	1.25	1.02
301	1.02	1.15	1.15	1.24	1.05
302	1.05	1.10	1.22	1.13	0.98
303	1.10	1.14	1.07	0.93	0.91
304	1.11	1.08	1.13	1.29	1.04
305	1.03	1.09	1.06	1.17	0.98
306	1.04	0.93	1.29	1.09	1.00
307	1.09	1.12	1.16	1.25	0.96
308	1.04	1.09	1.04	1.27	0.94
401	1.16	1.18	1.20	1.22	1.01
402	1.19	1.24	1.05	1.18	0.99
403	1.12	1.19	1.08	1.08	0.94
404	1.03	1.04	1.16	0.98	1.04
405	0.98	1.14	1.05	1.18	0.89
406	1.12	1.03	1.05	1.23	0.94
407	1.19	1.14	1.19	1.23	0.96
408	0.95	1.06	1.12	1.22	0.87

Appendix 8-2: Soil moisture measurement dates at Litter Rate Study sites in 2006 and 2007.

Carman	Goodlands	Pipestone	Shilo	Souris
2006				
July 21	August 1	August 2	July 25	July 26
August 15	August 23	August 23	August 24	August 24
September 25	September 21	September 21	September 22	September 21
2007				
April 20	April 21	April 20	April 20	April 21
May 3	May 3	May 2	May 2	May 2
May 7	May 8	May 8	May 8	May 8
		May 15	May 15	
		May 25	May 25	
June 8	June 5	June 5		
		June 20	June 20	
July 9	July 9	July 6	July 6	July 9
		July 30	August 3	
August 14	August 14	August 15	August 15	August 14
		August 30	August 30	
September 12	September 12	September 12	September 13	
		September 27	September 27	
October 11	October 7	October 7		

Appendix 8-3: Volumetric soil moisture treatment means for each measurement date and depth, the p-value comparing *in situ* means to the nearest applied litter rate mean, and regression R^2 values (excluding the *in situ* treatment) for Pipestone, MB.

Date	Depth	Litter biomass (kg/ha)								*in situ* ≠ applied	Regression R^2
		0	300	600	900	1200	1500	3000	*in situ*		
		-------------------- % H_20 *volumetric* --------------------								*p value*[1]	
2006											
1	Surface	1.7	1.9	1.9	2.1	2.0	2.2	1.8	2.5	0.042	0
	20 cm	2.7	2.4	2.4	2.9	2.4	2.3	2.7	2.9	0.496	0.008
	35 cm	4.8	4.1	4.2	5.4	4.1	4.1	5.1	4.6	0.437	0.023
2	Surface	4.3	3.9	4.7	7.1	3.9	4.8	7.6	5.1	0.039	0.242*[2]
	20 cm	3.8	3.4	4.0	4.6	3.7	4.0	4.4	4.4	0.878	0.077
	35 cm	5.2	4.7	5.0	6.5	4.9	5.4	5.6	6.2	0.373	0.026
3	Surface	13.2	12.8	13.9	16.2	12.2	15.1	16.5	12.3	0.014	0.149*
	20 cm	7.0	6.3	6.7	7.4	6.7	6.4	7.0	7.2	0.797	0.007
	35 cm	7.5	6.6	7.1	8.4	6.7	6.4	7.5	8.1	0.527	0
2007											
1	Surface	4.6	4.3	3.9	5.2	4.2	5.3	5.9	6.2	0.745	0.156*
	20 cm	5.1	4.6	5.0	5.7	5.4	6.2	5.7	6.0	0.723	0.059
	35 cm	6.7	6.6	6.4	7.0	6.7	6.9	6.9	7.5	0.150	0.034
2	Surface	5.1	4.3	4.5	5.2	6.4	4.5	5.9	5.1	0.469	0.062
	20 cm	8.9	8.4	3.8	8.7	3.9	4.1	4.4	4.2	0.954	n.a.[3]
	35 cm	10.7	6.2	6.0	6.0	8.7	5.9	6.2	6.2	0.982	n.a.
3	Surface	14.9	14.0	15.3	15.1	13.6	16.1	16.6	17.5	0.576	0.073
	20 cm	6.6	6.7	6.4	6.6	6.3	7.1	7.5	6.3	0.141	0.045
	35 cm	7.9	8.0	8.4	8.4	8.4	7.7	8.2	9.0	0.249	0
4	Surface	15.8	16.8	14.5	16.7	15.8	16.2	16.5	17.4	0.481	0.006
	20 cm	5.5	5.5	5.5	5.8	5.4	6.0	6.4	5.6	0.269	0.056
	35 cm	6.3	6.7	6.3	6.2	6.0	5.7	6.4	6.8	0.370	0.008
5	Surface	20.5	19.0	18.6	20.8	18.7	19.9	19.6	20.2	0.624	0
	20 cm	10.3	9.7	9.3	9.7	9.0	10.6	9.7	8.9	0.409	0
	35 cm	10.1	10.7	10.5	10.3	10.6	10.7	10.3	10.3	0.985	0
6	Surface	5.4	5.1	5.6	6.6	6.0	6.5	6.3	7.3	0.172	0.113
	20 cm	1.4	2.0	1.8	2.4	1.7	2.9	2.5	3.0	0.579	0.06
	35 cm	4.8	5.0	5.2	4.7	4.9	4.9	5.2	5.7	0.282	0.005
7	Surface	12.0	10.6	11.1	13.2	11.0	12.0	13.6	14.1	0.654	0.124
	20 cm	5.9	6.3	5.1	5.8	5.7	6.7	6.3	6.1	0.764	0.023
	35 cm	7.3	7.2	7.5	6.7	7.2	7.4	7.2	7.6	0.204	0.005
8	Surface	17.0	16.0	18.5	18.9	17.8	16.4	16.3	17.7	0.272	0.013
	20 cm	3.2	3.5	3.3	3.5	3.4	4.1	3.5	4.0	0.197	0.046
	35 cm	5.3	5.9	5.5	5.5	5.6	6.1	5.7	6.2	0.372	0.03
9	Surface	1.8	1.9	1.2	1.6	2.2	1.6	1.7	1.3	0.413	0
	20 cm	1.9	1.9	1.9	1.9	2.0	2.1	2.0	2.5	0.014	0.037
	35 cm	3.1	3.2	3.2	3.0	3.0	3.3	3.2	4.1	0.007	0.002

… continues on next page

Date	Depth	Litter biomass (kg/ha)								*in situ* ≠ applied	Regression R^2
		0	300	600	900	1200	1500	3000	*in situ*		
		-------------------- *% H_20 volumetric* --------------------								*p value*[1]	
… continued from previous page											
10	Surface	7.3	8.2	7.7	7.8	9.3	8.9	8.8	8.9	0.947	0.065
	20 cm	2.4	2.4	2.5	2.5	2.3	2.6	2.6	3.3	0.005	0.064
	35 cm	3.1	3.1	2.9	2.8	2.8	3.1	2.9	4.1	0.000	0.019
11	Surface	1.8	1.9	2.1	1.4	2.6	2.7	2.1	1.3	0.360	0.016
	20 cm	2.0	2.0	2.0	2.0	1.9	2.2	2.1	2.6	0.030	0.012
	35 cm	2.9	2.7	2.8	2.7	2.7	2.8	2.7	3.8	0.001	0.011
12	Surface	3.5	2.8	3.1	3.2	3.6	4.0	3.3	3.4	0.853	0.009
	20 cm	2.0	2.0	1.9	2.0	1.9	2.1	2.0	2.3	0.167	0.019
	35 cm	2.7	2.8	2.8	2.6	2.5	2.7	2.7	3.6	0.001	0.003
13	Surface	2.4	2.4	2.0	2.8	3.1	2.8	2.8	2.3	0.405	0.054
	20 cm	1.9	1.8	1.8	1.8	1.8	1.9	2.0	2.1	0.603	0.14*
	35 cm	2.6	2.6	2.7	2.5	2.5	2.6	2.6	3.4	0.001	0.016
14	Surface	12.9	12.9	12.3	14.6	15.4	14.4	14.4	13.2	0.630	0.04
	20 cm	5.6	5.5	5.5	5.0	4.8	5.2	5.2	5.9	0.320	0.022
	35 cm	4.3	3.6	3.8	3.3	3.5	3.7	3.4	5.5	0.001	0.071

[1] *In situ* treatment is considered statistically different from the nearest applied litter rate when *P*<0.05.

[2] Regression model is considered significant when indicated with a (*), *P*<0.05.

[3] Data was not collected from the 20 cm and 35 cm soil depths on this date.

Appendix 8-4: Volumetric soil moisture treatment means for each measurement date and depth, the p-value comparing *in situ* means to the nearest applied litter rate mean, and regression R^2 values (excluding the *in situ* treatment) for Shilo, MB.

Date	Depth	Litter biomass (kg/ha)								*in situ* ≠ applied	Regression R^2
		0	300	600	900	1200	1500	3000	*In situ*		
2006		-------------------- % H_20 *volumetric* --------------------								*p value*[1]	
1	Surface	3.4	3.5	3.7	3.2	3.6	3.2	3.1	3.4	0.422	0.085
	20 cm	3.5	3.3	3.3	3.3	3.4	3.3	3.5	3.2	0.062	0.009
	35 cm	3.5	3.2	3.4	3.4	3.5	3.4	3.7	3.5	0.339	0.119
2	Surface	4.6	4.1	4.3	4.3	4.3	3.7	3.7	4.3	0.034	0.280*[2]
	20 cm	3.6	3.4	3.6	3.3	3.5	3.5	3.6	3.4	0.227	0
	35 cm	3.4	3.1	3.2	3.2	3.3	3.4	3.3	3.3	0.750	0.017
3	Surface	20.7	19.5	20.1	21.0	21.0	18.5	17.9	19.4	0.246	0.181*
	20 cm	5.7	4.5	5.0	4.4	4.8	4.6	4.8	4.2	0.160	0.03
	35 cm	2.9	2.7	2.5	2.5	2.7	2.5	2.5	2.3	0.359	0.111
2007											
1	Surface	15.6	15.4	15.3	15.3	15.1	15.5	14.3	15.8	0.008	0.216*
	20 cm	15.9	14.9	15.7	13.8	16.0	15.3	16.1	14.5	0.174	0.011
	35 cm	12.5	13.1	10.2	10.0	12.5	10.6	11.5	9.0	0.060	0.037
2	Surface	25.6	25.9	26.3	25.9	25.8	27.8	23.9	27.1	0.008	0.075
	20 cm	25.7	36.7	23.9	28.2	18.5	30.3	19.1	25.2	0.459	n.a.[3]
	35 cm	19.6	18.8	18.0	22.0	9.3	22.9	13.4	13.2	0.977	n.a.
3	Surface	26.9	26.7	27.8	27.8	27.1	28.1	26.3	28.7	0.014	0.024
	20 cm	16.8	15.9	14.4	14.4	15.6	15.2	16.6	15.6	0.366	0.008
	35 cm	10.7	9.5	8.2	8.1	10.0	8.7	9.6	8.1	0.264	0.002
4	Surface	24.7	24.8	26.7	25.1	26.2	26.6	25.2	26.4	0.342	0.006
	20 cm	14.5	14.1	14.2	13.0	14.1	13.4	14.4	13.4	0.490	0
	35 cm	9.4	8.6	8.9	7.3	9.2	7.8	8.0	7.5	0.673	0.03
5	Surface	31.8	31.3	33.7	32.0	30.7	32.6	30.7	32.9	0.119	0.041
	20 cm	20.1	21.0	20.5	19.7	21.4	20.1	21.8	21.2	0.714	0.022
	35 cm	14.3	13.0	11.7	12.1	17.3	11.8	13.3	11.7	0.489	0
6	Surface	24.5	23.1	22.5	23.3	24.1	25.1	22.2	25.8	0.002	0.041
	20 cm	13.4	12.5	11.9	11.7	12.9	12.5	12.8	12.3	0.542	0
	35 cm	9.5	8.8	8.0	8.1	9.3	8.3	8.6	7.9	0.434	0.014
7	Surface	5.8	6.5	6.2	6.0	6.2	5.8	6.4	6.1	0.682	0.004
	20 cm	10.3	9.4	8.8	9.1	10.3	9.4	9.6	9.8	0.711	0
	35 cm	8.8	7.8	7.5	7.4	8.3	7.5	7.6	7.4	0.869	0.037
8	Surface	2.4	2.4	2.4	2.4	3.1	3.2	2.9	3.1	0.644	0.137*
	20 cm	3.5	3.3	3.2	3.4	3.4	3.2	3.3	3.4	0.399	0.037
	35 cm	3.9	3.6	3.6	3.7	4.3	3.7	3.9	3.7	0.481	0.007
9	Surface	6.3	5.8	4.5	4.5	6.0	7.3	6.7	5.7	0.219	0.104
	20 cm	3.6	3.6	3.4	3.3	3.5	3.5	3.5	3.3	0.104	0.001
	35 cm	3.7	3.5	3.4	3.5	3.8	3.4	3.6	3.5	0.856	0

… continues on next page

Date	Depth	Litter biomass (kg/ha)								*in situ* ≠ applied	Regression R^2
		0	300	600	900	1200	1500	3000	*In situ*		
… continued from previous page											
10	Surface	1.1	1.4	1.7	1.4	1.0	1.8	1.5	1.2	0.269	0.036
	20 cm	3.1	3.2	2.9	2.8	3.1	3.1	3.0	2.9	0.417	0
	35 cm	3.6	3.4	3.3	3.2	3.5	3.3	3.4	3.3	0.587	0.011
11	Surface	3.2	3.5	3.7	3.8	3.7	4.2	3.5	4.4	0.238	0.01
	20 cm	3.2	3.1	3.0	2.9	3.1	3.2	3.0	3.0	0.854	0.022
	35 cm	3.3	3.3	3.2	3.4	3.4	3.1	3.3	3.1	0.334	0.007
12	Surface	6.8	7.6	6.7	6.3	6.8	6.1	8.4	8.8	0.762	0.047
	20 cm	3.7	3.5	3.6	3.3	3.6	3.6	3.6	3.4	0.270	0
	35 cm	3.4	3.3	3.4	3.3	3.5	3.3	3.4	3.2	0.430	0.006

[1] *In situ* treatment is considered statistically different from the nearest applied litter rate when $P<0.05$.

[2] Regression model is considered significant when indicated with a (*), $P<0.05$.

[3] Data was not collected from the 20 cm and 35 cm soil depths on this date.

Appendix 8-5: Volumetric soil moisture treatment means for each measurement date and depth, the p-value comparing *in situ* means to the nearest applied litter rate mean, and regression R^2 values (excluding the *in situ* treatment) for Carman, MB.

Date	Depth	Litter biomass (kg/ha)								*in situ* ≠ applied	Regression R^2
		0	300	600	900	1200	1500	3000	*In situ*		
2006		-------------------- % *H_20 volumetric* --------------------								*p value*[1]	
1	Surface	10.1	9.9	9.3	10.0	9.5	10.4	10.9	12.0	0.053	0.149*[2]
	20 cm	10.9	9.4	8.7	10.3	9.8	10.4	12.1	12.3	0.091	0.196*
	35 cm	13.0	11.2	9.3	12.1	11.0	12.3	13.6	14.7	0.127	0.08
2	Surface	20.1	17.9	16.7	19.0	18.1	18.6	18.8	21.1	0.157	0
	20 cm	17.4	15.9	13.0	17.2	12.6	17.4	17.8	18.2	0.733	0.023
	35 cm	12.4	13.9	10.8	13.1	11.0	15.2	15.8	14.5	0.724	0.131*
3	Surface	22.4	19.7	19.9	21.8	20.7	21.6	23.0	22.8	0.331	0.117
	20 cm	13.0	11.1	10.8	11.7	14.3	11.8	11.8	12.0	0.926	0
	35 cm	9.1	8.1	7.0	7.8	7.0	8.4	8.3	8.5	0.897	0
2007											
1	Surface	25.7	24.9	26.4	25.2	27.5	27.1	27.2	28.4	0.466	0.081
	20 cm	25.2	22.0	22.4	24.3	23.7	24.4	25.2	27.1	0.092	0.051
	35 cm	27.8	24.6	26.9	28.5	27.5	24.1	27.3	27.6	0.026	0
2	Surface	12.8	15.0	15.3	15.1	14.1	16.6	15.4	18.2	0.384	0.055
	20 cm	21.6	20.6	18.7	20.7	19.4	18.2	20.2	22.1	0.074	n.a.[3]
	35 cm	22.3	20.8	21.3	23.2	21.9	19.5	22.9	21.8	0.079	n.a.
3	Surface	30.7	31.0	30.6	30.5	30.3	30.4	30.8	31.8	0.216	0
	20 cm	28.3	26.1	25.4	27.3	27.3	26.1	27.9	29.2	0.128	0.006
	35 cm	26.8	23.6	24.5	26.2	25.2	24.2	26.7	26.3	0.166	0.027
4	Surface	20.2	24.2	21.3	21.9	23.1	22.3	21.8	24.4	0.338	0
	20 cm	33.4	31.5	31.7	33.4	32.2	30.9	33.8	34.2	0.087	0.012
	35 cm	32.2	28.3	27.8	28.8	28.7	26.9	29.7	29.9	0.080	0.017
5	Surface	10.2	12.8	11.9	11.6	13.5	11.7	11.5	12.9	0.395	0.002
	20 cm	21.1	17.2	15.2	18.4	18.2	17.7	17.0	19.2	0.326	0.044
	35 cm	22.8	20.6	19.8	21.4	21.0	20.3	21.4	21.2	0.503	0.003
6	Surface	9.6	10.2	9.4	9.5	10.6	10.3	10.0	10.4	0.882	0.013
	20 cm	9.6	8.2	8.0	8.3	8.8	8.5	8.5	8.7	0.778	0.007
	35 cm	12.3	10.6	8.8	10.2	9.9	10.0	10.9	10.7	0.480	0.005
7	Surface	8.5	8.7	7.9	8.8	9.4	8.6	8.4	9.4	0.399	0
	20 cm	8.5	7.2	6.7	7.6	8.1	7.2	8.1	7.8	0.405	0.004
	35 cm	9.6	8.9	7.9	8.4	8.5	8.8	9.4	9.3	0.521	0.01
8	Surface	20.3	20.5	20.9	21.0	21.8	17.7	20.5	21.8	0.013	0.005
	20 cm	19.8	17.8	17.4	19.9	17.0	18.0	16.7	20.1	0.368	0.042
	35 cm	13.6	14.8	12.6	11.9	11.3	14.6	11.6	12.3	0.341	0.036

[1] *In situ* treatment is considered statistically different from the nearest applied litter rate when *P*<0.05.

[2] Regression model is considered significant when indicated with a (*), *P*<0.05.

[3] Data was not collected from the 20 cm and 35 cm soil depths on this date.

Appendix 8-6: Volumetric soil moisture treatment means for each measurement date and depth, the p-value comparing *in situ* means to the nearest applied litter rate mean, and regression R^2 values (excluding the *in situ* treatment) for Goodlands, MB.

Date	Depth	Litter biomass (kg/ha)								*in situ* ≠ applied	Regression R^2
		0	300	600	900	1200	1500	3000	*in situ*		
2006		-------------------- *% H_20 volumetric* --------------------								*p value*[1]	
1	Surface	7.0	6.9	6.7	7.1	6.8	7.1	7.4	7.0	0.447	0.031
	20 cm	9.4	8.7	8.3	8.5	8.5	9.2	8.9	8.6	0.484	0
	35 cm	9.5	9.4	9.2	9.0	8.8	9.0	9.2	8.8	0.583	0.007
2	Surface	6.5	6.3	6.9	6.9	6.6	6.0	7.3	6.9	0.535	0.039
	20 cm	9.4	9.7	8.5	8.6	9.1	9.0	9.1	9.9	0.264	0.004
	35 cm	9.8	9.3	8.9	9.4	10.4	9.9	9.3	9.6	0.725	0
3	Surface	20.7	22.0	20.3	20.8	21.0	22.6	22.7	21.7	0.350	0.066
	20 cm	10.3	9.3	8.8	9.5	9.3	9.2	9.4	9.3	0.891	0.015
	35 cm	8.4	8.1	8.2	8.5	8.2	8.3	8.3	7.8	0.455	0
2007											
1	Surface	23.5	24.5	23.7	26.0	24.0	24.0	26.3	25.8	0.766	0.038
	20 cm	20.6	20.6	16.9	19.9	17.7	19.4	19.3	19.5	0.927	0.004
	35 cm	23.9	23.0	23.6	25.6	22.0	26.2	24.8	26.2	0.443	0.026
2	Surface	18.3	17.7	17.5	19.5	19.8	19.1	21.5	18.6	0.074	0.145*[2]
	20 cm	37.7	30.5	22.4	17.1	23.5	24.1	32.2	30.3	0.836	n.a.[3]
	35 cm	31.6	26.8	32.1	21.7	19.0	28.7	36.5	34.6	0.839	n.a.
3	Surface	21.9	22.5	24.2	23.2	21.1	24.0	25.1	22.6	0.224	0.059
	20 cm	26.2	24.1	20.8	25.3	22.1	25.3	25.2	25.0	0.905	0.006
	35 cm	23.6	22.0	23.9	24.5	21.9	25.0	26.7	23.3	0.083	0.085
4	Surface	13.1	11.1	10.9	12.9	10.7	10.8	12.8	11.1	0.229	0.002
	20 cm	18.8	18.1	17.7	21.4	18.0	20.1	20.4	18.1	0.274	0.025
	35 cm	20.8	20.0	20.4	22.9	20.0	23.5	24.4	20.6	0.096	0.096
5	Surface	6.7	6.0	6.9	7.6	6.3	6.1	7.2	8.6	0.342	0.009
	20 cm	12.4	11.9	12.8	13.3	12.0	12.9	13.5	12.6	0.490	0.027
	35 cm	15.6	15.3	15.4	17.5	14.3	17.0	17.7	15.5	0.245	0.038
6	Surface	7.0	6.8	7.9	7.6	7.6	7.5	7.3	7.7	0.555	0.003
	20 cm	8.2	7.9	7.2	7.9	7.3	7.8	7.7	7.2	0.382	0.011
	35 cm	9.4	9.3	8.8	9.8	8.8	9.3	9.3	8.4	0.223	0
7	Surface	5.9	5.6	5.9	6.3	6.4	5.3	6.2	6.2	0.996	0.007
	20 cm	7.1	6.6	6.5	6.8	6.8	6.7	6.7	6.7	0.990	0.001
	35 cm	8.8	8.6	8.4	8.7	8.1	8.8	8.6	8.1	0.406	0
8	Surface	10.0	10.2	10.4	11.0	10.7	11.7	10.7	11.3	0.502	0.027
	20 cm	8.7	8.1	7.7	8.4	7.6	8.1	8.2	8.5	0.613	0.004
	35 cm	8.8	8.4	8.1	8.9	8.1	8.5	8.3	8.2	0.827	0.003

[1] *In situ* treatment is considered statistically different from the nearest applied litter rate when *P*<0.05.

[2] Regression model is considered significant when indicated with a (*), *P*<0.05.

[3] Data was not collected from the 20 cm and 35 cm soil depths on this date.

Appendix 8-7: Volumetric soil moisture treatment means for each measurement date and depth, the p-value comparing *in situ* means to the nearest applied litter rate mean, and regression R^2 values (excluding the *in situ* treatment) for Souris, MB.

Date	Depth	Litter biomass (kg/ha)								*in situ* ≠ applied	Regression R^2
		0	300	600	900	1200	1500	3000	*in situ*		
2006		-------------------- % H_20 *volumetric* --------------------								*p value*	
1	Surface	14.4	14.0	11.9	14.0	13.7	14.1	13.4	14.3	0.473	0.003
	20 cm	20.5	21.6	22.2	19.7	20.7	17.9	20.4	21.5	0.713	0.013
	35 cm	20.3	23.1	23.1	21.4	21.5	17.7	22.9	20.7	0.417	0.000
2	Surface	12.2	13.1	12.1	12.6	12.9	12.1	13.7	13.5	0.889	0.043
	20 cm	18.5	19.5	20.6	19.0	18.5	16.2	19.3	19.6	0.939	0.002
	35 cm	17.8	21.6	20.5	19.3	18.8	16.6	21.5	19.6	0.444	0.010
3	Surface	28.0	27.6	28.7	27.8	28.1	27.5	29.1	26.8	0.139	0.025
	20 cm	22.7	23.0	23.0	21.0	27.8	20.7	21.3	21.5	0.962	0.006
	35 cm	16.8	20.4	18.6	22.9	23.4	15.0	18.8	15.7	0.536	0.000
2007											
1	Surface	33.8	34.4	33.5	34.1	33.6	34.1	33.6	31.9	0.129	0.011
	20 cm	29.1	27.5	38.3	32.0	33.6	37.5	27.8	40.6	0.122	0.001
	35 cm	35.8	39.3	41.0	37.2	38.4	40.2	31.8	49.8	0.118	0.016
2	Surface	27.8	28.2	25.5	28.2	27.5	26.6	27.2	27.5	0.899	0.004
	20 cm	53.3	49.6	51.1	54.4	40.9	44.0	46.5	44.3	0.854	n.a.[3]
	35 cm	43.5	50.6	51.9	55.7	41.4	41.7	45.8	51.3	0.633	n.a.
3	Surface	33.4	33.4	34.0	34.4	32.7	33.4	34.0	32.9	0.321	0.004
	20 cm	34.9	32.0	34.1	31.7	32.8	33.5	33.8	36.3	0.151	0.000
	35 cm	35.2	31.0	33.5	30.0	31.3	31.7	32.6	33.9	0.317	0.019
4	Surface	19.6	22.4	21.7	22.4	19.8	20.0	17.2	18.4	0.705	0.098
	20 cm	29.5	26.0	25.9	24.3	25.3	28.0	28.2	27.5	0.731	0.001
	35 cm	30.5	27.5	29.8	25.6	27.7	26.7	29.3	29.7	0.859	0.000
5	Surface	27.4	27.5	27.3	27.4	27.9	24.7	25.7	28.2	0.268	0.054
	20 cm	25.2	27.8	27.7	24.5	27.0	24.8	27.1	30.7	0.383	0.000
	35 cm	30.0	28.7	28.6	25.2	27.7	24.5	27.8	28.7	0.667	0.049
6	Surface	15.0	15.7	14.1	15.9	14.8	14.1	13.1	16.2	0.038	0.120
	20 cm	13.3	13.2	11.6	11.3	12.2	11.0	11.6	13.8	0.151	0.058
	35 cm	18.0	18.9	18.1	14.7	19.8	14.6	17.3	18.7	0.654	0.010

[1] *In situ* treatment is considered statistically different from the nearest applied litter rate when *P*<0.05.

[2] Regression model is considered significant when indicated with a (*), *P*<0.05.

[3] Data was not collected from the 20 cm and 35 cm soil depths on this date.

Appendix 8-8: Analysis of temperature data from Souris.

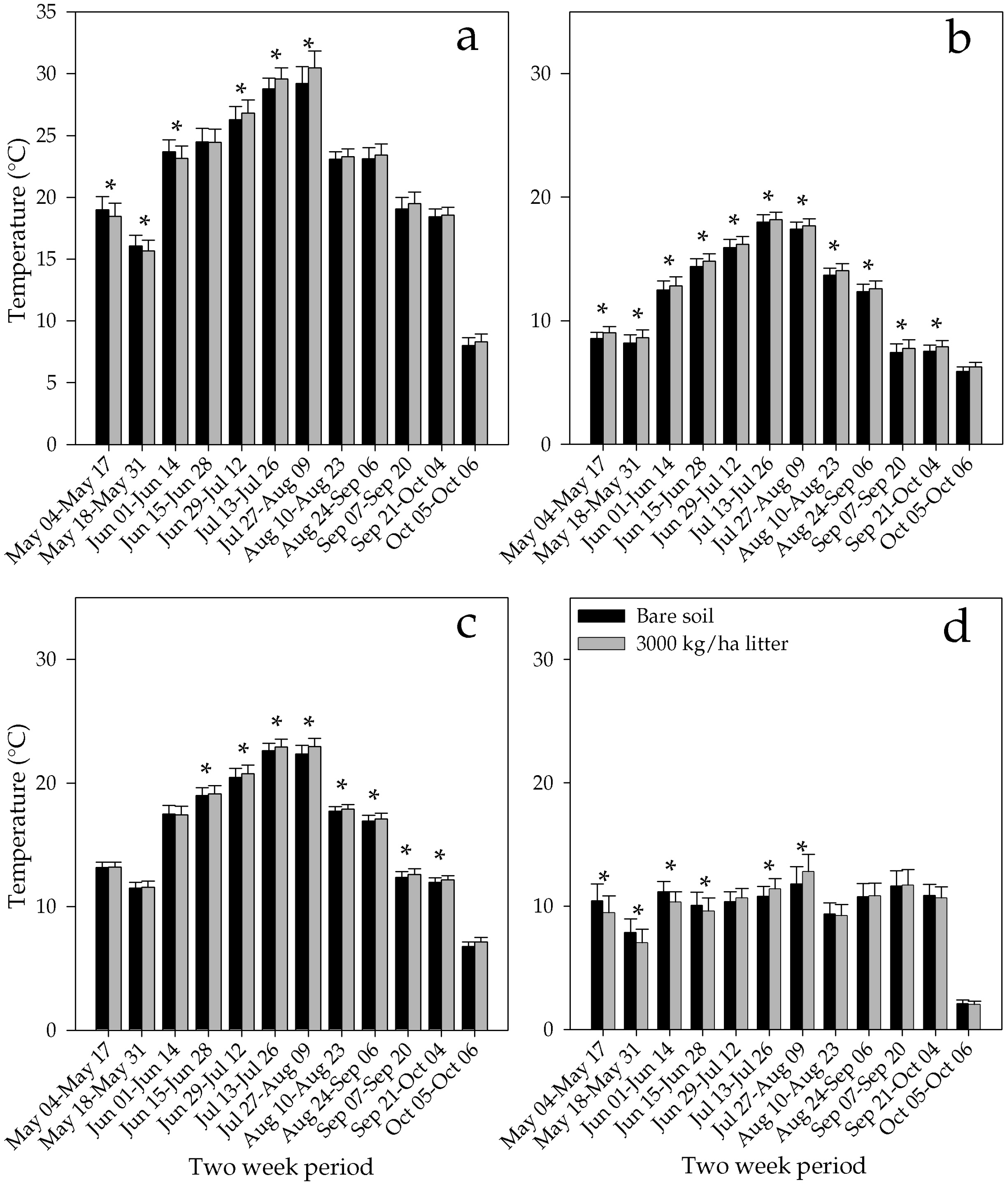

Figure 8-1: Daily near surface soil temperatures as affected by litter cover at Souris, Manitoba, analyzed in two-week periods; a) maximum temperature, b) minimum temperature, c) average temperature, and d) temperature amplitude.

Cattle breached the fence at Souris in early 2007, and the experimental site was subject to uncontrolled grazing for extended periods of time during the season. However, temperature data was collected throughout the growing season, and the results of the data analysis are presented here.

Early in the season, the bare soil and litter covered soils appeared to follow a similar trend to those seen at the other sites, with bare soil reaching higher maximum temperatures and lower minimum temperatures than the litter covered soil (Figure 8-1,a and b).

Minimum temperatures in the bare soil treatment remain lower than the litter covered treatment throughout the growing season (Figure 8-1, b). However, starting in the period of June 15-28, the maximum temperatures of the two treatments ceased to differ, and by the next two-week period (June 29-July 12) the bare soil treatment showed lower maximum temperatures than the litter covered soil (Figure 8-1, a). This trend remained statistically significant for six weeks, though the general trend was observed for the remainder of the season.

As a result of lower maximum and minimum temperatures in the bare soil compared to the litter covered soil, the average temperature and temperature amplitude in the bare soil treatment was significantly lower than the litter covered treatment for periods of time over the course of the growing season (Figure 8-1, c and d).

Appendix 8-9: Forage yield treatment means for each measurement date and depth, the p-value comparing *in situ* means to the nearest applied litter rate mean, and regression R^2 values (excluding the *in situ* treatment) for each site in 2006 and 2007.

Site	Cut	Litter rate (kg/ha)								*in situ* ≠ applied	Regression R^2
		0	300	600	900	1200	1500	3000	*in situ*		
		kg ha^{-1}								*p value*[1]	
2006											
Carman	Cut 1	837	768	728	1228	795	828	860	1587	0.009	0.002
	Cut 2	977	847	835	885	911	866	1020	1026	0.957	0.021
	Total	1814	1615	1563	2113	1706	1694	1880	2613	0.018	0.018
Goodlands	Cut 1	725	939	912	1017	703	634	645	1876	0.001	0.039
	Cut 2	345	1022	481	357	543	624	444	351	0.725	0.01
	Total	1070	1961	1393	1374	1246	1258	1089	2227	0.026	0.03
Pipestone	Cut 1	682	563	689	590	580	599	676	678	0.990	0.003
	Cut 2	393	282	458	226	341	277	327	314	0.885	0.011
	Total	1075	845	1147	816	921	876	1003	992	0.954	0.002
Shilo	Cut 1	417	379	388	313	486	317	341	450	0.265	0.018
	Cut 2	469	489	445	477	461	461	434	394	0.517	0.024
	Total	886	868	833	790	947	778	775	844	0.595	0.032
Souris	Cut 1	1102	1055	1027	1043	1131	1042	999	1399	0.036	0.011
	Cut 2	913	802	849	765	845	713	596	739	0.173	0.231*[2]
	Total	2015	1857	1876	1808	1976	1755	1595	2138	0.033	0.134
2007											
Carman	Cut 1	1656	1532	1548	1806	1737	1352	1888	1072	0.115	0.011
	Cut 2	2964	2728	3097	3221	2987	2735	3083	3087	0.989	0.007
	Total	4620	4260	4645	5027	4724	4087	4971	4159	0.264	0.012
Goodlands	Cut 1	1001	1646	1295	821	1107	998	827	1075	0.462	0.062*
	Cut 2	2051	2303	2343	2826	1930	2056	2297	2399	0.840	0
	Total	3052	3949	3638	3647	3037	3054	3124	3474	0.598	0.016
Pipestone	Cut 1	626	443	394	271	469	519	331	859	0.022	0.038*
	Cut 2	2028	2179	1904	2087	2240	2042	2214	1725	0.005	0.054
	Total	2654	2622	2298	2358	2709	2561	2545	2584	0.872	0
Shilo	Cut 1	192	369	453	230	283	461	328	410	0.322	0.013*
	Cut 2	1448	1333	1488	1439	1398	1402	1445	1454	0.892	0.005
	Total	1640	1702	1941	1669	1681	1863	1773	1864	0.403	0.016
Souris	Cut 1	n.a.[3]									
	Cut 2	1597	1898	1777	1895	1395	1701	1437	2089	0.110	0.037
	Total	n.a.									

[1] *In situ* treatment is considered statistically different from the nearest applied litter rate when $P<0.05$.

[2] Regression model was considered significant when indicated by a (*), $P<0.05$.

[3] Data unavailable due to breach of fence and un-controlled grazing.