ENDOCRINE AND WINTER PERFORMANCE RESPONSES TO SUPPLEMENTAL LIGHT AND EVENING FEEDING IN HEIFERS

BY

TREVOR J. LAWSON

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

Master of Science

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THE UNIVERSITY OF MANITOBA

FACULTY OF GRADUATE STUDIES

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ABSTRACT

The manipulation of photoperiod is useful to improve dairy cattle milk production and may be useful to improve beef cattle production efficiency. Studies were conducted to investigate the threshold intensity of supplemental light for inhibition of melatonin secretion and to examine the efficacy of supplemental light and evening feeding for improvement of production efficiency of beef cattle housed outdoors in the winter. The threshold intensity of supplemental light for inhibition of melatonin secretion was investigated in dairy heifers using a 5 × 5 Latin Square design with repeated measures. Light treatments were exposure to 0, 50, 100, 200 and 400 lx for 8 h following an 8 h control period at 400 lx. Exposure to 50 lx significantly ($P < 0.05$) inhibited melatonin secretion for the initial 2 to 3 h of the 8 h exposure period. Exposure to 400 lx significantly ($P < 0.05$) inhibited melatonin secretion for the entire 8 h exposure period. Therefore, an intensity of 50 lx is sufficient to temporarily inhibit melatonin secretion, and research investigating the effect of repeated daily exposure to lower light intensities should be carried out. Two experiments (Exp. 1, 1998; Exp. 2, 1999) were conducted to investigate the effects of supplemental light and evening feeding on heifer growth and efficiency, carcass composition, plasma prolactin concentration, and hair shedding of outdoor housed beef heifers ($n = 48$) in winter. The experiments were conducted using a 2 × 2 Factorial Design and treatments were morning (09:00 - 10:00 h) or evening (20:00 h) feeding and natural or supplemental light (SL). Heifers were backgrounded (56 d) and finished (70 d) during Exp. 1 and backgrounded (162 d) during Exp. 2. Mean daily temperature during backgrounding (-13.7 °C) and finishing (0.5 °C) of Exp. 1, and backgrounding (-5.1 °C) of Exp. 2 were above the thirty-year normal (-18.3 °C). During

backgrounding of Exp. 1 ADG ($P = 0.05$) and G:F ($P = 0.08$) were improved by evening feed, and G:F was improved by SL ($P = 0.08$). There were no treatment effects on body composition in Exp. 1. Plasma prolactin was higher in SL heifers on day 42, but the increase was not sustained. There were no treatment main effects during finishing, however, feeding time × light treatment significantly ($P = 0.02$) improved G:F which was highest in morning fed heifers exposed to natural light. Hair shedding was studied only in Exp. 1 and was not effected by treatments. There were no effects of feeding time or light treatment on growth and efficiency during Exp. 2. However, by the end of the experiment the ultrasonic backfat thickness of SL heifers was lower than that of heifers exposed to natural photoperiod ($P = 0.05$). Because heifer growth and efficiency was improved only during backgrounding of Exp. 1 when ambient temperature was coldest it is concluded that evening feeding during periods of cold temperature is beneficial. Supplemental light treatment can improve feed efficiency in backgrounding heifers and can reduce carcass fat content when the backgrounding period is prolonged. The results suggest that extension of photoperiod using low intensity lighting has potential benefits for the beef industry.

ACKNOWLEDGMENTS

There are several people who deserve great appreciation for all their co-operation, patience, understanding and guidance throughout the past two years, you know who you are, I would like to sincerely thank all of you. In particular I would like to thank my supervisor, Dr. Alma Kennedy and Mr. Reynold Bergen, both have become good friends who have taught me a lot about research and life. Finally, I would like to thank my wife, Tammy, who has supported me the entire time, even if only by telephone. I couldn't have done it without you.

DEDICATION

This thesis and all the work and effort put into it is dedicated to my mother, Janice Lawson, without whom it would not have been possible. It is not possible to describe the importance of the role you have played over the past 23 years, truly leading and teaching by example. Thank you.

FOREWARD

This thesis is written in manuscript style. The first manuscript has been submitted to the Canadian Journal of Animal Science and the second will be submitted to the Canadian Journal of Animal Science.

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GENERAL INTRODUCTION

Provision of supplemental light to extend day length for cattle yields variable production responses, possibly related to the management system. Extending the day length improved milk yield (Peters et al. 1981, 1978, Dahl et al. 1997, Miller et al. 1999) and reproductive performance (Reksen et al. 1999) of dairy cattle. The effects of photoperiod on growth of cattle, however is not well understood. Forbes (1982), in a review of the literature, suggested that season or photoperiod has a direct effect on growth characteristics of cattle, but concluded that additional work was warranted regarding the use of supplemental light to enhance carcass growth and development under practical husbandry conditions. Although photoperiod is known to have beneficial effects on cattle production the mechanism by which photoperiod acts to control bodily function has yet to be elucidated. Reiter (1991) stated that the light/dark ratio influences, either directly or indirectly, almost every organ system in the body and hypothesized that melatonin played a significant role in the endocrine control of animal metabolism. Dahl et al. (1997) suggested that the increase in milk production observed in dairy cattle is due to the effect of light on melatonin and IGF-I secretion. However, the specific set of conditions required to affect animal growth and metabolism is not yet understood.

Cold environmental conditions cause significant losses in production efficiency in beef cattle. Metabolic responses are associated with an increased maintenance requirement in cold environments. Cattle increase maintenance requirements in cold environments for several reasons. One reason for increased maintenance energy requirements is metabolic acclimatization that involves elevated resting heat production (HP) in response to prolonged cold exposure (NRC 1981). Young (1981) concluded that

cold ambient temperatures can decrease production efficiency by as much as 70% in Canada, and that ADG may be reduced by as much as 27% as a result of low ambient temperatures. It is thought that cold acclimatization is a major contributing factor to the increased winter energy requirements of feedlot cattle (NRC 1996). Young (1975a) found that cattle acclimatized to -25 °C have a 30 – 40% increase in resting HP. Although this may prove useful for survival reasons, it is impractical in the case of feedlot cattle. The lower critical temperature (LCT), the ambient temperature below which cattle must shiver to produce heat in an attempt to maintain homeothermy, of feedlot cattle is -41 °C (Webster 1970), an ambient temperature that rarely occurs in Western Canada. If one were able to prevent acclimatization the benefits could be enormous and there would be no detrimental effects associated with doing so. The Canadian feedlot industry could potentially benefit, through improved growth and efficiency, if the acclimatization response of cattle could be reduced or eliminated altogether. Other than the provision of low porosity fences there are no practical management strategies that reduce the effects of cold winter conditions on cattle productivity. One strategy that has potential is to shift feeding time from traditional morning feeding to evening feeding. Due to the nature of ruminant digestive processes heat is produced during digestion (heat increment)(NRC 1996). As a result of this fact, it may be beneficial to feed cattle at night when the environment is the coldest. Research has indicated that time of feeding may affect ruminant growth and efficiency during both summer and winter. Knutsen et al. (1994) reported that yearling steers fed late in the day outperformed morning and twice daily fed steers in some instances and that late day feeding had no detrimental effects on steer performance. Thus, feeding in the evening

and provision of supplementary light may be a beneficial management practices for Canadian feedlot operators.

LITERATURE REVIEW

1. Light and Physiology

Historically, most research concerning the effects of season and photoperiodic climate on mammals has been performed with reproductive performance and/or function as the primary concern. The effects of changing day length on reproductive status have been studied on mammals of many species ranging from hamsters and rats to ourselves, humans. Photoperiod provides environmental time cues by which animals set their entire physiological function or biological clock (Turek 1985). The effects of photoperiod observed in animals are often highly variable and species specific (Arendt 1997). Both the intensity and duration of the light play a major role in the effects of photoperiod induced change in animal physiology (Arendt 1997). Entrainment to a particular photoperiod (or day length), which serves to synchronize biological functions of the animal to a circadian clock, has been suggested by Ebling et al. (1988) and Rollag and Niswender (1976). As a consequence of photoperiodic memory, an animal may require repeated exposure to a new photoperiod in order to develop a new photoperiodic memory. The mechanism by which photoperiodic memory occurs is not fully understood, however, when sheep are exposed to complete darkness the circadian rhythm of melatonin secretion persisted and coincided with a 12 h photoperiod (Rollag and Niswender 1976). Likewise, Soay rams exhibited a circadian rhythm of melatonin and locomotor activity corresponding with either a long day (16L:8D) or short day (8L:16D) photoperiod (Ebling et al. 1988). The observed circadian rhythm of activity persisted for two weeks when rams were transferred to a photoperiod of complete darkness.

Photoperiod control of the body occurs via the pineal hormone melatonin. Melatonin (N-acetyl-5-methoxytryptamine) is a small, highly lipophilic molecule that is thought to easily penetrate cell membranes (Kokkola and Laitinen 1998). Melatonin is synthesized from the essential amino acid tryptophan. Pineal melatonin synthesis is primarily controlled by the availability of N – Acetyltransferase and Acetyl-CoA to transform 5-Hydroxytryptamine (Seratonin) to N-Acetyl-5-hydroxytryptamine (N-Acetylserotonin) (Ganong 1999).

Reiter (1991) stated that the light/dark ratio influences, either directly or indirectly, almost every organ system in the body. However, the exact mechanism by which photoperiod works to control bodily function is not completely understood. Stress is another factor that may influence the melatonin secretion pattern of animals (Maestroni et al. 1989), and it is an indicator of stress and for some purposes has been defined as a stress hormone (Lynch and Deng 1986). Reiter (1991) hypothesized that melatonin played a significant role in the endocrine control of animal metabolism. The proposed pathway was that light (or lack of) influenced the eye, which in turn signaled the pineal gland to control release of melatonin. It has been suggested that the stimuli sensed by photoreceptors in the eye travels in the form of action potentials to the suprachiasmatic nuclei (SCN) of the hypothalamus via the retinohypothalamic tract (Pickard 1982). If the eye senses light, the neural activity of the SCN will be reduced, and will in turn reduce the pineal melatonin production. This phenomenon has been demonstrated in cattle as melatonin declines almost immediately in response to light (Stanisiewski et al. 1988). Melatonin then affects the body via the hypothalamic pulse generator through the hypothalamo-pituitary-gonadal axis, which is responsible for the secretion of virtually

every hormone affecting the body (Reiter 1991). Likewise, Hedlund et al. (1977) have indicated that melatonin has many neurotropic effects including regulation of several hormones including luteinizing hormone(LH), follicle stimulating hormone (FSH), and prolactin. Hedlund et al. (1977) have shown that melatonin is present in relatively high concentrations in the lateral brain ventricle cerebrospinal fluid (CSF) of calves, and that it peaks during darkness. This would indicate that melatonin has access to brain areas responsible for neuroendocrine control including the hypothalamus and midbrain (Kamberi 1973).

2. Light and Growth

It is known that manipulation of photoperiod can be a valuable management tool to improve efficiency of production of large ruminants. Extending the day length improves milk yield (Peters et al. 1981, 1978, Dahl et al. 1997, Miller et al. 1999) and reproductive performance (Reksen et al. 1999) of dairy cattle. The effects of photoperiod on growth of cattle, however is not well understood. Forbes (1982), in a review of the literature, suggested that season or photoperiod has a direct effect on growth characteristics of cattle, but concluded that additional work was warranted regarding the use of supplemental light to enhance carcass growth and development under practical husbandry conditions. Likewise, Tucker et al. (1984) reviewed the literature and suggested that long daily photoperiod induces a growth response in sheep and cattle, although this may not always be the case. Tucker et al. (1984) also concluded that the mechanism by which photoperiod acts to control bodily function has yet to be elucidated, and suggest that further research into the controlling mechanism is required. The

following is a summary of the research performed to date, where long daily photoperiod has been found to have a positive or no effect on growing ruminants.

Early work by Forbes (1979) found that lambs exposed to 16L:8D grew faster than lambs exposed to 8L:16D when fed a concentrate diet both ad libitum and restricted (70 g $(kg^{0.75BW})^{-1}$). Efficiency of growth was higher in the 16L:8D restricted fed lambs. In a second experiment, Forbes (1979) again found that restricted fed lambs grew faster when exposed to 16L:8D. In both experiments, gut fill was significantly greater in lambs exposed to 16L:8D, and in the second experiment carcass weight was not different between treatments due to the increase in gut fill caused by 16L:8D. These findings led Forbes (1979) to conclude that long daily photoperiod stimulated both growth and gut fill by some central mechanism, and not simply by encouraging more eating.

Further research performed with growing-finishing ram and wether lambs exposed to 8L:16D or 16L:8D photoperiod found that growth rate, feed efficiency and carcass weight were improved by the 16L:8D photoperiod treatment (Schanbacher and Crouse 1980). Lambs were fed a pelleted diet ad libitum from 10 to 22 weeks of age, and were exposed to fluorescent light intensity between 800 and 900 lx. Both ram and wether lambs exposed to 16L:8D outperformed their 8L:16D counterparts. Ram lambs grew faster and more efficiently than wethers. Photoperiod treatment did not affect carcass quality or yield, and no sex by photoperiod interaction was observed. In an attempt to understand the growth promoting effect of 16L:8D, Schanbacher and Crouse (1980) measured testosterone and prolactin. Serum testosterone concentrations were elevated in ram lambs at 22 weeks of age and undetectable in wethers at the same age, regardless of photoperiod treatment. Short day exposed rams had higher serum testosterone

concentrations after 16 weeks of age than long day exposed counterparts. Serum prolactin concentration was elevated five fold in lambs exposed to 16L:8D photoperiod, and was not affected by sex of lambs. These findings led Schanbacher and Crouse (1980) to conclude that both, testosterone and prolactin, independently affect growth and performance of growing-finishing lambs and that that photoperiod induced growth increases are not dependent on the gonads in sheep since testosterone was not increased in wethers but growth and efficiency was improved.

Using male red deer and Suffolk cross rams exposed to an artificial photoperiod (558 lx), such that two cycles of day length occurred during one calendar year, Simpson et al. (1984) reported that both species displayed two distinct cycles of intake and growth in response to manipulation of day length. This suggests that growth cycles occur in response to a circadian or biological clock controlled by day length, and further supports the theory of Reiter (1991) that animal growth is controlled by the pineal gland and a compliment of hormones, particularly melatonin. It should be noted that the red deer showed more distinct cycles. Such cycles in growth may have been selected against in improved species. This would seem reasonable since cycles of growth would coincide with higher natural availability of food during long days of spring and summer.

Various research groups have reported that provision of long photoperiod (16L:8D), as opposed to a natural or short (8L:16D) photoperiod, improved cattle growth (Peters et al. 1978, 1980; Petitclerc et al. 1983; Zinn et al. 1986b; Mossberg and Jönsson 1996) and efficiency (Peters et al. 1980; Petitclerc et al. 1983).

Peters et al. (1978) found that peripubertal Holstein heifers exposed to 16L:8D (114 – 207 lx) had higher weight gains, despite consuming the same amount of feed, than

heifers raised under natural photoperiod conditions (9 – 12 h daily light, 39 – 93 lx). Also, Peters et al. (1980), compared growth of ad libitum fed peripubertal Holstein heifers exposed indoors to natural, 16L:8D or 24L:0D photoperiod (112, 104, and 116 lx, respectively). Heifers exposed to the 16L:8D treatment grew significantly faster (11 and 17%) than heifers exposed to 24L:0D or natural photoperiod, respectively. As well, feed intake of 16L:8D heifers was 6.9 and 8.3% greater than that of the 24L:0D or natural photoperiods, respectively. Nonetheless, heifers exposed to 16L:8D had better feed conversion efficiency than either 24L:0D or natural photoperiod exposed heifers. Similarly, Ingvartsen et al. (1992) found that long daily photoperiod increases voluntary dry matter intake (VDMI) in growing bulls, steers and heifers. VDMI increased at a rate of 0.32% per hour increase in day length (Ingvartsen et al. 1992). This research confirms earlier reports of photoperiod induced increases in VDMI by Forbes (1982) and Tucker et al. (1984). Kay (1988) reported that voluntary food intake of adult red deer stags and Soay rams decreases abruptly at the onset of the rut (in fall) and remained low throughout winter, despite the fact that the animals were individually fed and offered feed ad libitum. Kay (1988) also reported that feed intake began to increase in late February and reached a plateau in summer.

It should be kept in mind that the increase in VDMI associated with long days may be a consequence of photoperiod induced growth rather than cause of it. In other words, increased growth demands may partially be responsible for VDMI in ruminants. In support of this theory, Petitclerc and co-workers (1983) reported that growth and feed efficiency were improved in peripubertal heifers, regardless of feeding regime (i.e. limit

or ad libitum fed), when exposed to 16L:8D as opposed to 8L:16D as was also the case in sheep (Forbes 1979).

Research performed by Zinn et al. (1986b) agrees with earlier work, in that peripubertal heifers respond to long photoperiod (16L:8D) with improved body weight gain (6 – 8% increase) when compared to short photoperiod (8L:16D). More recent research carried out in Sweden (Mossberg and Jönsson 1996), using ad libitum fed Swedish Red and White bulls housed indoors found that feed intake peaked when day length was increasing (concentrate diet) or when day length had reached a plateau following an increase (silage diet). In the case of the silage diet, the authors suggest the peak in intake was more likely due to improved feed quality at this time of year, rather than photoperiod. In this study Mossberg and Jönsson (1996) also found that the daily live weight gain was positively associated with day length similarly in concentrate and silage fed bulls. Through calculation, Mossberg and Jönsson (1996) concluded that even with constant energy intake over the year the live weight gain, and thus efficiency were clearly associated with season. These findings are in accordance with earlier work by Forbes (1979) who reported that restricted fed lambs exposed to long days grew faster, and thus more efficiently than their short day counterparts.

Although the above studies demonstrate the positive effects of supplemental light or long days on growth and efficiency of growing cattle, not all studies are in agreement. For example, Bourne et al. (1984) suggest that exposing Hereford x Friesian heifer calves during the fall and winter to a 16L:8D photoperiod results in decreased growth rate in the first half of winter but appeared to improve growth during the second half of winter. The lack of growth response in the first half of winter in heifers exposed to supplemental light

may have been caused by supplemental light inhibiting winter coat growth in fall as hair samples taken in mid-January indicated that heifers exposed to 16L:8D had significantly ($P < 0.001$) lighter hair coats than heifers exposed to natural day length. Further research by Zinn et al. (1986c) appears to contradict previous research (Zinn et al. 1986b) in that extended photoperiod (16L:8D) had no effect on prepubertal Holstein heifers in terms of ADG, carcass weight or carcass composition. However, postpubertal Holstein heifers exposed to a short day photoperiod (8L:16D) had greater fat accretion and growth rate than their long day counterparts (Zinn et al. 1986c). These findings led Zinn et al. (1986c) to conclude that short day photoperiod resulted in increased body weight gain and fat accretion in postpubertal, but not prepubertal heifers. Similar effects of a short day photoperiod have been reported in more recent research carried out by Mossberg and Jönsson (1996) in which efficiency of growth was decreased under the influence of short day photoperiod; and may be explained by the fact that shorter days stimulate fat accretion (Zinn et al. 1986c). Abbott et al. (1984) reported that short day photoperiod stimulated body weight gain in white-tailed doe fawns, and that the increased body weight gain was primarily due to increased deposition of fat. Unlike peripubertal heifers (Peters et al. 1980, Petitclerc et al. 1983, Zinn et al. 1986b) and postpubertal heifers (Zinn et al. 1986c) prepubertal heifers appear not to respond to light (Zinn et al. 1986c). These facts led Zinn et al. (1986c) to speculate that mature gonads are required for a photoperiod induced improvement in body weight gain in cattle. This is not consistent with reports of photoperiod induced growth in sheep, where the response does not appear to be gonad dependent (Schanbacher and Crouse 1980).

Recently, Phillips et al. (1997) showed that steers and postpubertal heifers exposed to artificial long days (16L), as opposed to natural day length (mean 9.7L), did not increase ADG or improve feed efficiency. The fact that postpubertal heifers did not respond would appear to disagree with the suggestion of Zinn et al. (1986c) that mature gonads are responsible for improved growth under a long day photoperiod. However, the fact that steers did not show improved growth may serve to enforce the theory of Zinn et al. (1986c) since sex hormones would not be present as they would in postpubertal, intact bulls. Indeed, Tucker et al. (1984) has reported that peripubertal bulls grow faster under the influence of long day photoperiod. However, Phillips et al. (1997) reported that long day photoperiod (16L:8D) in winter in England resulted in leaner carcasses for both steers and peripubertal heifers; again indicating mature gonads may not be required to induce a photoperiod effect on growth, although only composition, not ADG, was impacted by light. Steers housed indoors under the influence of natural photoperiod (mean = 9.75 h) in winter produced fatter carcasses than those on long day treatment, and heifers deposited more fat between autumn and winter when under natural conditions and less fat between winter and spring when compared to heifers under long day photoperiod. Thus, in order to produce leaner carcasses when growing heifers, it may be beneficial to provide supplemental light between fall and winter only. The fact that steers appeared to respond to long photoperiod by depositing more lean tissue indicates that cattle may not be gonad dependent as previously suggested by Zinn et al. (1986c). Photoperiod induced changes in carcass composition have also been reported by Petitclerc et al. (1984) who found a 16L:8D photoperiod increased protein content of the 9-10-11th rib section,

compared with that of 8L:16D photoperiod, in prepubertal Holstein heifers when fed on a high plane of nutrition.

The effect of season on fattening pattern was studied by Laurenz et al. (1992) using mature, non-pregnant Simmental and Angus cows. Laurenz et al. (1992) found that both Simmental and Angus cows mobilized empty body protein in summer/fall while at the same time gaining empty body fat. The noted shift in body composition corresponds with a natural shift in day length, where the cattle mobilize protein and deposit fat during a period of decreasing day length. The opposite effect of day length was reported during the winter/spring when both breeds tended to gain protein and mobilize fat during a period of increasing day length. Currently, changes in body composition are not accounted for when predicting nutrient requirements of growing or maintaining cattle. However, Laurenz et al. (1991) suggests that season has a significant effect on maintenance energy requirements of mature, non-pregnant Simmental and Angus cows. Laurenz et al. (1991) reported the ME requirement for weight maintenance were highest in the summer/fall and lowest during winter/spring for both breeds. Laurenz et al. (1991) suggests the weight maintenance requirements are higher in the summer/fall as a consequence of increased fat deposition (high energy density) associated with summer/fall and the corresponding loss of body protein, whereas the opposite would apply in winter/spring. Therefore, effects of photoperiod on growth and composition of cattle should be considered when deriving nutrient requirements for mature beef cows. The research of Laurenz et al. (1991, 1992) supports research performed by Petitclerc et al. (1984) and Phillips et al. (1997) who reported long days resulted in increased protein accretion in growing heifers. Likewise, the research of Laurenz et al. (1991, 1992) also

serves to support findings of Mossberg and Jönsson (1996) where short days resulted in decreased efficiency due to increased fat accretion in growing bulls. In accordance with Laurenz et al. (1992), both Abbott et al. (1984) and Zinn et al. (1986c) reported increased fat deposition during short days in white-tailed doe fawns and Holstein heifers, respectively.

It appears likely that photoperiod or season affects growth and body composition of cattle. However, the specific set of conditions required to increase the rate of growth and improve production efficiency in the beef industry by manipulation of photoperiod is not clear from the literature.

3. Effect of Season on Metabolism of Wild Ruminants

Temperature extremes have the potential to cause a great deal of stress on animals housed in natural environments, however, animals have evolved specific mechanisms that help them to deal with both high and low temperature. It appears that wild ruminants try to conserve energy by reducing energy expenditure during winter (Moen 1978, Regelin et al. 1985). Moen (1978) found that white-tailed deer had their lowest HP in winter and highest during summer; and concluded that the metabolic rhythm displayed by white-tailed deer is an evolutionary adaptation to conserve energy when energy supply is typically limited by reduced range resources. Similarly, Regelin et al. (1985) found that adult moose had their lowest HP in winter and their highest HP in summer while kept in captivity and fed ad libitum. Feed intakes corresponded with HP, being lowest in winter and highest during summer, which suggests moose reduce activity in preparation for harsh winter conditions and reduced feed availability despite the fact that they were kept

in captivity and well fed. The findings of Regelin et al. (1985) suggest that metabolism of moose is independent of food availability and cold. This suggests that metabolism of moose and other wild cervids are controlled by photoperiod, as an evolutionary adaptation in anticipation of future food availability and environmental conditions. Research investigating the seasonal thermoregulatory responses of bison and Hereford cattle has reported that temperature influences metabolic rate of both species, however, season × temperature interactions were only significant for cattle (Christopherson et al. 1979). Cattle in the study had increased HP when exposed for 2 h to -30 °C at 7 – 10 months of age but lacked a HP response to the same temperature when 16 months of age (Christopherson et al. 1979). The lack of an increase in HP in older cattle may have been due to increased coat thickness (Christopherson et al. 1979). Bison responded in a different manner showing no change or a decrease in resting HP when exposed to -30 °C, and showed no difference between seasons (Christopherson et al. 1979). Christopherson et al. (1979) suggests that the lack of, or negative, metabolic response in bison, when exposed to -30 °C, was primarily a function of behavioral changes in which the animal became less active during the cold stress period. These findings agree with HP responses observed in white-tailed deer (Moen 1978) and moose (Regelin et al. 1985) during winter. Due to the natural habitat of bison, and the natural availability of food during winter, this response may be necessary in order to maintain survivability during harsh prairie winters. However, cattle have been domesticated for several generations and have been able to survive without this natural ability to reduce seasonal needs due to the fact that in a domesticated environment man has provided stored food during times of low natural availability.

4. Effect of Winter Conditions on Cattle Metabolism and Digestion

Domestic ruminants have been constantly selected for improved growth and production, and possibly as a result of this intense selection they react in a different manner than do wild ruminants when exposed to a cold, harsh winter climate. A cold environment has the ability to increase maintenance requirements of cattle in three ways. The first way is through metabolic acclimatization to cold temperature which involves elevated resting heat production (HP) in a thermoneutral environment as a result of prolonged cold exposure (Young 1975a). The second is due to an immediate increase in HP, through shivering, in order to maintain homeothermy when animals are exposed to acute cold stress (NRC 1996). The Canadian beef industry would benefit, through improved growth and efficiency, if the acclimatization response of cattle could be reduced or eliminated altogether. After all, bison and deer do not increase resting HP in response to cold winter conditions (Moen 1978, Regelin et al. 1985) and survive through cold winter conditions with much less feed resources than feedlot cattle, thus suggesting that the acclimatization response may not be necessary. The third way in which a cold environment can influence maintenance requirements is through decreased digestibility of feed (mainly forage)(Christopherson et al. 1993). Digestibility of forage decreases as a result of reduced ruminoreticulum retention time associated with low ambient temperature, which limits the time available for fermentation of slowly degraded components of the diet, such as fiber (Kennedy et al. 1986). As a result of the decrease in ruminoreticulum retention time and decreased digestion, cattle are less efficient during exposure to cold environmental conditions. A reduction in energy available for

productive purposes occur as a direct result of increased maintenance requirements in response to low ambient temperature.

5. Shivering Response and Non-shivering Thermogenesis

Rather than respond to cold ambient temperature by reducing energy expenditure like non-domesticated ruminants, domestic ruminants respond to an initial cold stress by shivering in order to increase metabolic heat production in an effort to maintain homeothermy (Sykes and Slee 1968). Sykes and Slee (1968) found that acclimation to cold temperatures resulted in less intense shivering during severe cold exposure and speculated shivering thermogenesis was replaced by non-shivering thermogenesis (NST). This conclusion was supported by results of Webster et al. (1969), who found that the resting HP of sheep exposed to constant cold increased over time, and that the increase in resting HP was additive to shivering HP as summit metabolism was increased after acclimation to cold. Sykes and Slee (1968) use the term acclimation to describe their experiment and results, however, the term acclimatization may also be used to describe the effects of cold exposure on animal HP, and the two have been used interchangeably. It should be noted that acclimation and acclimatization do not refer to the same circumstance. Acclimation, as defined by Hart (1957) and Eagan (1963)(in Bligh and Johnson 1973), describes "the adaptive changes which occur within the lifetime of an organism in response to experimentally induced changes in *particular climatic factors* such as ambient temperature in a controlled environment", and the term acclimatization describes "the adaptive changes which occur within the lifetime of an organism in response to changes in the natural climate". Because this thesis research was performed

in a natural winter environment, the term 'acclimatization' will be used to describe adaptive changes that occur in response to winter conditions in the context of this thesis.

Slee (1972) also reported that, despite their higher metabolic rate, cold acclimatized sheep shivered less than control (non-acclimatized) sheep. Webster (1970) reported similar evidence in feeder cattle where LCT decreased from -31°C in November to -41°C in February and this could not be entirely attributed to a change in insulation. This suggested that the feeder cattle became acclimatized to cold winter conditions with an increase in resting HP. As well, Webster (1970) found that the LCT of maintenance fed pregnant beef cows decreased from -11 °C in November to -23 °C in March.

Young (1975a), exposed maintenance fed, non-pregnant beef cows to warm (20 ± 3 °C) or cold conditions (-10 ± 2 °C or -25 ± 4 °C), for 8 weeks. Shivering occurred in animals exposed to both cold conditions, however, shivering rapidly subsided and could not be detected in the -10 ± 2 °C exposed group after 2 weeks of exposure. In the group exposed to -25 ± 4 °C shivering was more severe initially, however, severity diminished following the first week of exposure. Young (1975a) found that the resting HP of both cold exposed groups after 8 weeks was 30 to 40% greater than that of the 20 °C exposed animals. The elevated resting HP was considered an indicator of acclimatization to cold in large mammals. That shivering diminished or disappeared after a couple of weeks of cold exposure suggested that shivering thermogenesis was replaced by NST in order to maintain homeothermy (Young 1975a). Young (1975a) reported that resting HP values for both cold exposed treatments were similar, suggesting that a maximal degree of metabolic acclimatization had occurred in the -10 °C exposed group. As well, Young

(1975a) reported that the -25 ± 4 °C-exposed group shivered less with time, but shivering bursts still occurred.

In similar research, Young (1975b) investigated the acclimatization response of mature pregnant beef cows housed indoors and outdoors during winter and reported that outdoor housed animals had up to 37% higher resting HP than animals housed indoors, and that resting HP was independent of food intake since intake was constant.

In more recent work, Delfino and Mathison (1991) found that the resting HP of limit fed steers housed outdoors was 18% greater than that of indoor housed steers.

The acclimatization response of ruminants to cold conditions requires exposure for one or more weeks (Christopherson et al. 1993). NRC (1981) recommendations indicate that resting HP increases as temperature decreases below 20 °C. Although ruminants increase resting HP in response to cold, the underlying physiological mechanisms by which changes in resting metabolism occur are not fully understood. However, changes in resting HP may be the result of endocrine changes induced by the cold environment. Indeed, cold environments have been shown to increase secretion of thyroid hormones (Yousef and Johnson 1985), catecholamines (Thompson et al. 1978), and glucocorticoids (Graham et al. 1981) in ruminants. Young (1981) suggests that metabolic acclimatization may be the result of thyroid hormones and catecholamines acting synergistically to elevate resting HP.

6. Effect of Winter Conditions on Cattle Performance

Young (1981), in a review of cold stress as it affects animal production, reported that low ambient temperatures can decrease production efficiency by as much as 70% in

Canada, and that ADG may be reduced by as much as 27% as a result of low ambient temperatures. This is in agreement with Ames (1976) who studied annual steer performance of steers in Kansas. Ames (1976) reported that both heat stress and cold stress have a detrimental affect on steer (n = 40,000) finishing performance. Ames (1976) found that variation in intake was greatest when temperature was lowest and least when temperature was highest. Average daily gain was significantly ($P < 0.05$) affected by ambient temperature, as ADG was highest in spring and fall and lowest during summer and winter (Ames 1976). Feed efficiency was also lower in summer and winter (when animals are stressed) than in spring and fall when they are in a non-stressed state (Ames 1976). Young (1981) also indicated with ad libitum feeding the reduction in growth may be offset by increased feed consumption, however, the efficiency will decrease and there is an upper limit to ad libitum intake. Once a maximum intake is reached, ADG will continue to decrease.

Delfino and Mathison (1991) reported that environment had a major adverse effect on limit fed steer performance. Slow growing indoor (16.9 ± 2.7 °C) housed steers grew 49% faster than those kept outdoors (-7.6 ± 6.8 °C) and were 51% more feed efficient, relative to outdoor housed steers. The differences in performance were not attributed to a difference in intake as this was maintained equal in the two treatment groups. This agrees well with Young (1981) who reported that fast growing animals grew 27% slower when exposed to low ambient temperatures typical of a Canadian winter. Delfino and Mathison (1991) also found that the steers retained less energy as fat when housed outdoors compared to those housed indoors (78% and 86%, respectively),

indicating that the outdoor housed group had lower energy stores due to the higher maintenance energy requirement associated with a colder outdoor environment.

Research performed by Milligan and Christison (1974) showed that feedlot steer (n = 1,970) performance was severely reduced as a result of winter conditions. Average daily gain during winter (December, January and February), when the mean ambient temperature was -17 °C, was 70% of the average ADG for the remainder of the year. As well, feed required per unit of gain and metabolizable energy intake per unit of gain were, respectively, 149 and 140% of the mean requirements for the remainder of the year. Mean ambient temperatures were significantly correlated with average daily gain (r = 0.74) and feed per unit of gain (r = -0.85). Milligan and Christison (1974) also reported that cattle fed during the 90 coldest days required an extra 220 kg feed to reach market weight.

Young (1975a) found that cold exposure significantly affected water intake. During exposure to -25 °C water intake was completely inhibited during the first 24 h of exposure, following which it was significantly suppressed. Degen and Young (1980) found that wethers lost weight upon exposure to cold, 66% of which was due to loss of body water that came entirely from extracellular compartments. Reticulo-rumen contents decreased by 1.32 L, interstitial fluid by 0.39 L and plasma 0.13 L to account for the majority of weight loss as water. Cold associated reduction in body weight may largely be due to the observed reduction in water intake (Young 1975a, Degen and Young 1980). Caution should be taken when weighing cattle during winter feeding trials, and weigh days should be adjusted to try and avoid abnormalities in weight caused by water intake changes.

It would be beneficial to develop management strategies that result in improved winter productivity in beef production systems. However, use of housing to reduce cold stress is too costly although fences of low porosity do have some benefit. Another strategy may be to shift feeding time from traditional morning feeding to evening feeding. Due to the nature of ruminant digestive processes heat is produced during digestion (heat increment)(NRC 1996). As a result of this, it may be beneficial to feed cattle at night during periods of cold. Time of feeding can affect ruminant performance during both summer and winter. Knutsen et al. (1994) reported that yearling steers fed late in the day (16:00 h) had higher ADG and improved feed efficiency compared to morning (07:30 h) or twice daily (07:30 and 16:00 h) fed steers between the months of July and October (Exp. 1). No significant overall difference ($P > .10$) was found among treatments from January to May (Exp. 2), however, interim period performance suggested that 16:00 h feeding during the cold months was beneficial (Knutsen et al. 1994). Knutsen et al. (1994) concluded that there are no detrimental effects of 16:00 h feeding and suggested that further research was required to adequately determine if late in the day feeding was beneficial. Christopherson (1974) monitored heat production of limit fed mature ewes ($n = 2$) fed at 08:00 h and 16:00 h under controlled environmental conditions where room temperature was 4 °C during the day (07:00 – 15:00 h) and -10 °C at night. Sheep were fed just as temperature began to increase (08:00 h) or decrease (16:00 h). Heat production of the sheep increased during eating and the magnitude of the increase was the same when sheep were fed at 08:00 h or 16:00 h. Thus, the heat production in response to cold exposure and feeding were additive. Christopherson (1974) also monitored skin and rectal temperature of steers ($n = 2$) fed outdoors and

exposed -8 °C, and found that skin temperature of the extremities increased when animals were fed. As well, rectal temperature increased slightly when steers were fed which suggests the rate of heat production temporarily was higher than the rate of heat loss. Christopherson (1974) suggested that, in response to eating, body temperature will increase and the body will activate 'heat loss mechanisms' in order to avoid a large increase in body temperature, thus maintaining a constant internal environment. Christopherson (1974) concluded that the increase in heat production associated with eating results in increased heat loss, and may not substitute for cold-induced heat production. As a result, efficiency may well be reduced by feeding during the colder part of the day due to increased activity and thus increased heat loss that would result in poorer energetic efficiency. Although the research of Christopherson (1974) suggests that feeding during the colder part of the day might not be beneficial, the work was performed under controlled conditions and with few animals. Results obtained by Knutsen et al. (1994) under natural winter conditions suggest the opposite conclusion, that evening feeding may improve winter performance.

It is possible that the heat increment of feeding does not substitute for shivering thermogenesis during cold evenings, as previously suggested by Christopherson (1974) but that feeding in the evening would be beneficial for other reasons. Christopherson (1974) found feeding resulted in an increase in skin and rectal temperature. If fed during the coldest part of the day cattle may need to make less thermoregulatory effort such as changing posture or decreasing activity, vasoconstriction, piloerection, decreasing respiration, altering feed intake and rate of passage of feed to help cope with cold

conditions and may have a higher body temperature. In effect the animal might be less aware of the coldness of the environment and acclimatize less if fed in the evening.

INHIBITION OF NIGHT-TIME MELATONIN SECRETION IN CATTLE: THRESHOLD LIGHT INTENSITY FOR DAIRY HEIFERS

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ABSTRACT

The threshold intensity of supplemental light for inhibition of melatonin secretion was investigated using a 5 x 5 Latin Square design with pre-pubertal Holstein heifers. Heifers were exposed for 8 h to light intensities of 0, 50, 100, 200, and 400 lx after a normal 8 h exposure to 400 lx. Exposure to 50 lx significantly ($P < 0.05$) inhibited melatonin secretion for the initial few hours of the 8 h exposure period, after which time the plasma melatonin concentrations increased; possibly because of the animal's photoperiodic memory. Exposure to 400 lx significantly ($P < 0.05$) suppressed plasma melatonin for the entire 8 h exposure period and other intensities had intermediate effects. Although this study has demonstrated that 50 lx is sufficient to inhibit melatonin secretion for 2 to 3 h, it will be necessary to study lower intensities to establish the threshold. Because 50 lx was not adequate to inhibit melatonin secretion for the entire 8 h exposure period, further research is required to examine the cumulative effect of repeated exposure to low light intensity on plasma melatonin concentrations in cattle.

Key Words: threshold, supplemental, light, intensity, melatonin, heifer, cattle

INTRODUCTION

Seasonal changes in animal productivity are due to direct effects of changes in photoperiod on animal function as well as fluctuations in feed quality and availability, temperature, precipitation and wind (Tucker 1988). Long day photoperiod has been found to increase productivity in cattle when compared to natural short days of winter (Forbes 1982).

In dairy cattle, extending the photoperiod improves milk yields (Peters et al. 1981; Reksen et al. 1999) and reproductive performance as measured by decreased days open and calving interval (Reksen et al. 1999). Extending photoperiod has also been shown to increase rate of cattle growth (Petitclerc et al. 1983; Peters et al. 1978) and to alter composition of growth (Phillips et al. 1997; Mossberg and Jönsson 1996).

Reiter (1991) stated that the light/dark ratio influences, either directly or indirectly, almost every organ system in the body, however, the exact mechanism by which photoperiod works to control bodily function is not yet completely understood. Reiter (1991) hypothesized that melatonin played a significant role in the endocrine control of animal metabolism. The proposed pathway was that light (or lack of) influenced the eye, which in turn signaled the pineal gland to control release of melatonin. Melatonin then acted on the theoretical hypothalamic pulse generator to control the rest of the endocrine system. Stanisiewski et al. (1988) found that plasma concentrations of melatonin in cattle increased 1.6 to 5.1 fold in response to the onset of darkness. A plateau was reached within 2 h and melatonin remained high until the onset of light. Although not yet fully understood, recent work suggested that inhibition of melatonin secretion may be important in animal production because it has been linked to

elevated levels of IGF-I (Dahl et al. 1997). IGF-I has been implicated in photoperiod induced production responses in cattle (Dahl et al. 1997). Dahl et al. (1997) suggest that the increase in IGF-I is related to melatonin acting as a timing signal, providing endocrine control of growth, reproduction and lactation. Stanisiewski et al. (1988) found that serum prolactin increases in response to 16L:8D after four weeks of exposure, and that serum melatonin concentrations are high during the 8 h dark period and low during the 16 h light period, indicating that there is an inverse relationship between serum melatonin concentrations and serum prolactin concentrations.

It is currently recommended that 16 to 18 h of light at 200 lx be used to increase milk production in dairy cows (Dahl 1998). However, other than the knowledge that 200 lx is adequate, no scientific knowledge exists of the minimum light intensity necessary to have an impact on cattle productivity (Reksen et al. 1999). Stanisiewski et al. (1987) found light intensity as low as 11 to 16 lx was adequate to cause an increase in prolactin in prepubertal Holstein bulls. A survey by Reksen et al. (1999) suggested that dim illumination (Mean = 36 lx, Range = 4 to 160 lx) was adequate to increase milk production in Norwegian dairy cattle when supplementing a photoperiod >12 h.

Knowledge of the threshold light intensity for inhibition of melatonin secretion in cattle has the potential to cut industry costs, reducing both light fixture requirements and operational costs. The purpose of this study was to determine the light intensity threshold for inhibition of melatonin secretion following a normal 8 h period of exposure to light at 400 lx.

MATERIALS AND METHODS

Animals and Housing

A total of six (5 treatment, 1 companion) prepubertal Holstein heifers (140 ± 9 d of age, mean ± SE) weighing (mean ± SE) 260 kg ± 9 kg from the University of Manitoba Glenlea dairy herd were used. The trial consisted of a 21 d pre-experiment environmental conditioning period, followed by a 35 d experimental period. Heifers were transferred from the University of Manitoba dairy unit to the University of Manitoba Animal Science Research Unit and kept indoors for the duration of the pre-experimental and experimental periods. During the pre-experimental period and when not receiving light treatment during the experimental period, the heifers were group housed in pens (3.7 m x 3.1 m) bedded with wood shavings. Animals were maintained at a basic 8L:16D photoperiod of 400 lx intensity from 08:00 h to 16:00 h. Standard 2.4 m fluorescent lights situated evenly throughout the room at a ceiling height of 2.6 m were used. Room temperature was 21.0 ± 0.7 °C (mean ± SE) during the experiment. Heifers were fed 2 kg $hd^{-1}d^{-1}$ of 16% CP dairy grower ration and mixed legume-grass hay *ad libitum*. Water was available *ad libitum*.

Heifers were housed in a second room in raised metabolic crates to receive light treatment (Figure 1). The animal was moved at 08:00 h to the light treatment room for a 24 h period. The light treatment room had the basic photoperiod (8 h @400 lx) with an additional 8 h of light applied as described below. Light in the treatment room was provided using standard 2.4 m fluorescent fixtures situated evenly throughout the room at a ceiling height of 2.6 m. Lengths of solid plastic tubing (8 – 30 cm) were evenly installed over the fluorescent bulbs to block light in order to achieve the required light

treatment intensities. Installation of the tubing was achieved in less than 30 min commencing at 15:30 h. A sixth heifer served as a companion animal to the individual treatment heifer confined in the light treatment room. The companion animal, which remained in the metabolism crate for five consecutive days each week, was allowed exercise for 1 h d^{-1} in a pen with another animal. The treatment animal and companion animal were held in adjacent 1.9 m × 1.1 m metabolism crates within viewing distance while in the treatment room. Feed and water were available as described for the control room. Animals were maintained throughout the experiment in accordance with the guidelines of the Canadian Council on Animal Care (1993).

Experimental Procedure

The experimental design was a 5 × 5 Latin Square with repeated measures taken as blood samples throughout the treatment period. The five treatments were exposure to: 0, 50, 100, 200, and 400 lx for 8 h immediately following the basic 8 h photoperiod of 400 lx. Each animal received a different light treatment at 7 day intervals over a period of five weeks beginning May 10, 1999 and ending June 11, 1999. Light intensity during treatment was assessed daily at heifer eye height (1.2 m) at 16 locations around the animal using a dual range light meter (Control Company, USA).

Treatment animals were jugular catheterized (1.57 mm I. D. x 2.08 mm O. D., Becton Dickinson & Company, Spark, MD) on the day prior to light treatment and the catheters were removed after the last sample on the day of light treatment. The catheter was flushed with sterile heparinized (50 units ml^{-1}) saline in order to maintain patency. Heparinized (200 units ml^{-1}) blood samples of 8 ml volume were collected at 30 min

intervals from 14:00 h to 16:00 h and then at 20 min intervals from 16:00 h to 24:00 h on the day of light treatment. Blood samples were taken under low red light conditions (< 3 lx) during the 0 lx treatment period. Blood hematocrit was determined immediately for samples taken at 1 h intervals from 14:00 h to 16:00 h, and at 2 h intervals from 16:00 h to 24:00 h. After overnight storage at 4 °C, blood was centrifuged at 3000 × g for 20 min and plasma was collected and stored at -20 °C until required for radioimmunoassy. The melatonin radioimmunoassay was conducted using the Buhlmann kit (ALPCO, Windham, NH). Assay sensitivity was calculated to be 0.19 pg ml^{-1}. Mean intra-assay coefficient of variation was 14.3%, and the inter-assay coefficient of variation was 16.4%. Melatonin radioimmunoassay was performed on pre-treatment blood samples taken at 14:30, 15:00, 15:30, and 16:00 h and only on treatment blood samples taken at 40 min intervals commencing at 16:40 h due to the high cost associated with the radioimmunoassay kit. Whether the treatment animal was lying or standing was observed and recorded upon entering the room for blood collection.

Statistical Analysis

Observation of the raw data showed that the maximum effectiveness of all treatments persisted at least to 18:00 h and that plasma melatonin concentrations increased over time thereafter (Appendix I, Figure 1). Therefore, for the purpose of statistical analysis, melatonin values were assigned to four time periods that were designated as T0 (14:30 h - 16:00 h), T1 (16:40 h - 18:40 h), T2 (19:20 h - 21:20 h), and T3 (22:00 h - 24:00 h). Log transformation of plasma melatonin concentrations was used to create homogeneity of variance (Steele et al. 1997). An ANOVA (SAS Institute, Inc.

1996) was performed to determine significance of animal, treatment, time, and treatment x time. Interaction means were subjected to a Tukey's (Steele et al. 1997) comparison. Hematocrit values were subjected to an ANOVA at each time point, and behavioral observations were assigned to four time periods (T0, T1, T2, T3) as indicated above and subjected to an ANOVA (SAS Institute, Inc. 1996) to determine significance of animal, treatment, time, and treatment × time interaction. Behavioural observations were analyzed as a proportion of time spent standing within each of the four time periods.

RESULTS

The mean light intensities for the five light treatments were (mean ± SE) 1, 46 ± 0.5, 92 ± 0.9, 186 ± 1.9, and 352 ± 4.9 lx, while the light intensity in the group housing room was 399 ± 3.5 lx. Treatment, time, and treatment × time interaction had no effect on hematocrit or behavior. Considerable variability in plasma melatonin concentrations existed between heifers as one heifer had substantially higher and one heifer had substantially lower plasma melatonin concentrations when exposed to the 0 lx treatment following 8 h of control lighting (Appendix I, Figure 2). The effects of animal, treatment, time, and treatment × time on plasma melatonin concentrations were significant ($P < 0.05$). Mean plasma melatonin concentration was low and did not differ ($P > 0.05$) among treatments in T0 (Figure 2) when all heifers were exposed to the final hours of the basic 8 h photoperiod (400 lx). Plasma melatonin was similar for all treatments above 0 lx during T1 and was significantly ($P < 0.05$) less than that found with 0 lx. By T2, there was no difference ($P > 0.05$) in plasma melatonin between the 0 and 50 lx treatments, however, 100, 200 and 400 lx lowered ($P < 0.05$) plasma melatonin, compared to 0 lx. Also in T2, there was no difference ($P > 0.05$) among the 50, 100 and 200 lx treatments, but plasma melatonin with 400 lx was lower ($P < 0.05$) than with 50 lx. In T3, there was no significant difference ($P > 0.05$) among 0, 50, 100, and 200 lx treatments, and no significant difference ($P > 0.05$) among 50, 100, 200, and 400 lx treatments. However, the 400 lx lowered ($P < 0.05$) plasma melatonin concentration compared to 0 lx.

Lying and standing behaviour and blood hematocrit were studied in order to determine if anything other than plasma melatonin concentration was affected by light

treatment. There was a significant (0.0001) effect of time on standing behaviour during the treatment period, however, there were no effects of animal, treatment or treatment × time on behaviour. Heifers spent less time standing as the treatment period progressed from T0 to T3 (Appendix I, Figure 3). There were no effects of animal, treatment, time, or treatment × time on blood hematocrit.

DISCUSSION

Reksen et al. (1999) stated that the threshold light intensity that affects melatonin secretion and cattle productivity is unknown. Yet, current dairy industry recommendations provide a value of 200 lx to increase milk production (Dahl 1998). This recommendation appears based on earlier research by Peters et al. (1978, 1981) where supplemental light elicited a milk yield response. The threshold light intensity for inhibition of melatonin secretion varies considerably between species, e.g. humans (2500 lx)(Lewy et al. 1980) and hamsters (0.25 lx) (Brainard et al. 1983). In small ruminants the threshold also appears to be quite low. Deveson et al. (1990) found that 2.3 ± 0.3 lx inhibited melatonin secretion in the goat and Arendt and Ravault (1988) found that 0.15 lx was adequate to manipulate melatonin plasma melatonin concentrations in sheep. Stanisiewski et al. (1988) found that 525 lx abolished the melatonin surge that occurs at the onset of darkness in cattle, however, no lower intensities were examined. Stanisiewski et al. (1987) suggested that cattle may be responsive to very dim light (11 – 16 lx), based on a plasma prolactin response.

There was considerable variation in plasma melatonin concentrations among heifers exposed to the 0 lx treatment in the present study. This finding agrees with earlier work by Coon et al. (1999) who found high variability of plasma melatonin in sheep and attributed this variability to differences in pineal weight caused by genetic variation. Our results indicate that all light intensities ≥ 50 lx were adequate to abolish the normal melatonin surge that occurs within the early hours (T1) of exposure to darkness. After this initial period, light intensities greater than 50 lx appeared to at least partially maintain their effectiveness, but the 50 lx treatment was no longer effective in preventing

the increase in melatonin concentration associated with darkness. The higher light intensities had the ability to partially inhibit the nocturnal increase in melatonin during the latter hours of exposure (T2), and in the case of 400 lx, for the entire treatment period.

The rise in melatonin, despite the presence of light, was likely a manifestation of photoperiodic memory or past entrainment of the animal (Ebling et al. 1988, Rollag and Niswender 1976), although melatonin may also have increased in response to stress (Lynch and Deng 1986). However, heifers in the present experiment appeared very calm and relaxed throughout the experiment and increased lying time throughout the light exposure period. Thus, it is unlikely that heifers were stressed during the treatment period. As a consequence of photoperiodic memory, it may be necessary for an animal to be repeatedly exposed to a new photoperiod before the pattern of melatonin secretion can be completely changed. The phenomenon of photoperiodic memory has been suggested previously by Linzell (1973) as it related to seasonal milk production in the goat. Linzell (1973) stated that the seasonal variations in milk production, which are most likely due to seasonal photoperiod variations, persisted even when goats were deprived of cues as to the time of year. A production response is slow to develop in response to photoperiod manipulation in dairy cattle (Miller et al. 1999). One should note that in the current study each new photoperiod (of variable intensity) was applied only once. It is possible that repeated daily exposure to light intensities of < 400 lx may also generate a prolonged (8 h) suppression of melatonin as was seen with the 400 lx treatment in the present trial. Our 100 to 200 lx treatments could not totally suppress plasma melatonin concentrations during the 8 h treatment period, but repeated daily photoperiod extension using 114 to 231 lx has been shown to alter cattle productivity (Peters et al. 1978, 1981). Thus, with

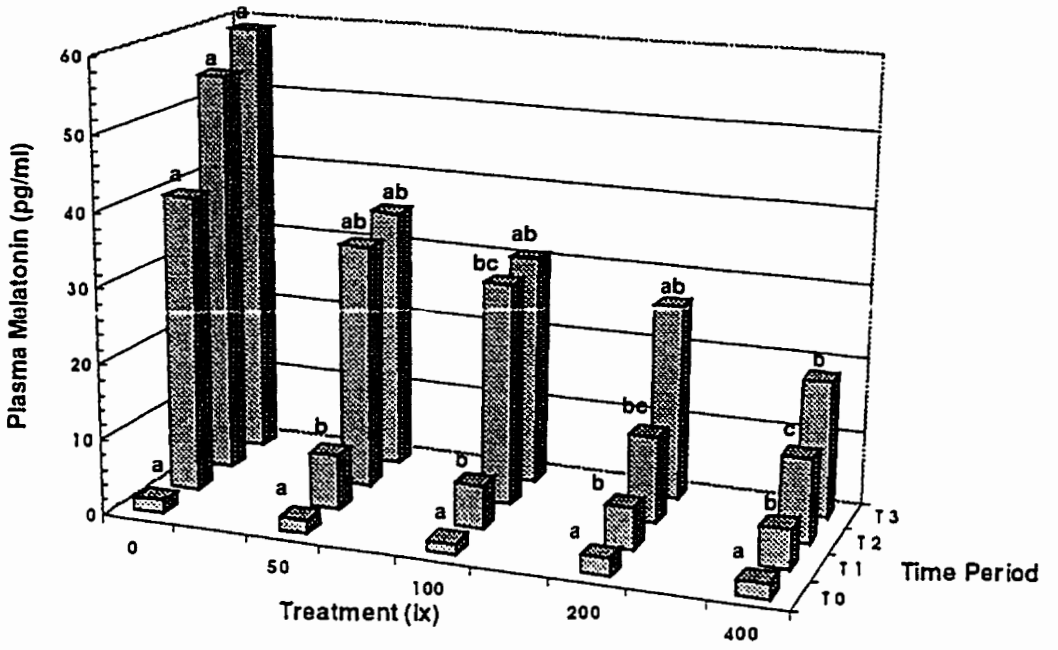
repeated exposure, this range of light intensity is likely capable of completely suppressing melatonin.

Although we have shown that 50 lx is adequate to inhibit the initial nocturnal rise in plasma melatonin, it is possible that the threshold light intensity for cattle is lower than the 50 lx treatment of this study. A recent epidemiological report by Reksen et al. (1999) suggested that dim illumination (mean = 36 lx, range = 4 – 160 lx) caused a positive production response in cattle when it was preceded by high intensity illumination during the day. The results show that sustained inhibition of melatonin secretion on the first occasion of exposure to extended photoperiod requires light intensity of at least 400 lx. Further research is required to demonstrate that lower intensities can have the same sustained effect if there is repeated daily exposure.

This is the first study to show that light of low intensity inhibits melatonin secretion in cattle. The use of low light intensity has the potential to reduce both the electricity and fixture costs associated with the use of supplemental light in cattle production systems.

Figure 1: Light treatment room equipped with fluorescent overhead lighting partially covered with strips of solid plastic tubing.

Figure 2: Mean plasma melatonin concentration before (T0) and during (T1, T2, T3) exposure to various light intensities. Means with different letters within a time period were significantly different ($P < 0.05$)(SE = 5.8 pg ml^{-1}). Statistical differences were derived from logarithmic transformed data in order to ensure homogeneity of variance.


Plasma Melatonin (pg/ml)
60
50
40
30
20
10
0
Treatment (lx)
0
50
100
200
400
Time Period
T3
T2
T1
T0

EFFECT OF EVENING FEEDING AND SUPPLEMENTAL LIGHT ON GROWTH, EFFICIENCY, ULTRASONIC BACKFAT THICKNESS AND RIBEYE AREA, PLASMA PROLACTIN CONCENTRATION AND HAIR SHEDDING OF BEEF HEIFERS HOUSED OUTDOORS DURING MANITOBA WINTERS

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ABSTRACT

The effects of evening feeding and light treatment on winter feedlot performance, carcass composition, plasma prolactin concentration, and hair shedding in crossbred beef heifers (n = 48) were investigated in two consecutive winters (Exp. 1,1998; Exp. 2, 1999) using a 2 × 2 Factorial Design. Heifers were morning fed (10:00 h 1998, 09:00 h 1999) or evening fed (20:00 h) and exposed to supplemental light (SL) or natural photoperiod in outdoor three-sided shelters. Heifers (275 kg ± 3.6 kg, mean ± SE) in Exp. 1 were backgrounded (56 d) and finished (70 d), and heifers (228.8 kg ± 2.7 kg) in Exp. 2 were backgrounded (162 d). Mean ambient temperatures during backgrounding and finishing in Exp. 1 were -13.7 °C and 0.5 °C, respectively. In Exp. 1 evening feeding increased ($P = 0.05$) ADG and tended to improve ($P = 0.08$) G:F during backgrounding, however, there was no effect on FI. Light treatment tended to improve G:F ($P = 0.08$) during backgrounding, but there were no effects on ADG or FI. There were no treatment main effects during finishing on ADG, FI or G:F, however, feeding time × light treatment was significant ($P = 0.02$) with the best performance seen in morning fed heifers exposed to natural photoperiod. There were no effects of feeding time, light treatment or their interaction on ultrasonic backfat thickness or ribeye area during Exp. 1. Hair shedding was only studied in Exp. 1 and was not affected by treatments. Main effects and their interaction had no effect on plasma prolactin concentration, however, light treatment × day was significant ($P < 0.01$) in Exp. 1. Plasma prolactin concentrations were very low for most of Exp. 1 but were elevated by light treatment on day 42. Mean ambient temperature during Exp. 2 was -5.1 °C. There were no main or interaction effects on ADG, FI or G:F in Exp. 2. There was no effect of feeding time, light treatment or their

interaction on ultrasonic backfat thickness during Exp. 2, however, day × light treatment was significant ($P = 0.002$). Light treatment had no effect on backfat on day 71 but significantly ($P < 0.05$) reduced backfat on day 156. Because ADG and G:F was improved only during backgrounding of Exp. 1 when ambient temperature was coldest it is concluded that evening feeding during periods of cold temperature is beneficial. Supplemental light treatment can improve feed efficiency in backgrounding heifers and can reduce carcass fat content when the backgrounding period is prolonged.

Key Words: evening feeding, light treatment, prolactin, backfat, ribeye area

INTRODUCTION

Historically, most research concerning the effects of season and photoperiod on mammals has been performed with reproductive performance and/or function as the primary concern. The effects of changing day length on reproductive status have been studied on mammals of many species ranging from hamsters (Brainard et al. 1983) to humans (Lewy et al. 1980). Photoperiod provides environmental time cues by which animals set their entire physiological function or biological clock (Turek 1985). Photoperiod control of the body occurs via the pineal hormone melatonin (N-acetyl-5-methoxytryptamine). Reiter (1991) stated that the light/dark ratio influences almost every organ system in the body, and that melatonin plays a significant role in the endocrine control of animal metabolism.

It is known that manipulation of photoperiod can be a valuable management tool to improve efficiency of production of large ruminants. Extending the day length improves milk yield (Peters et al. 1981, 1978, Dahl et al. 1997, Miller et al. 1999) and reproductive performance (Reksen et al. 1999) of dairy cattle. However, the effect of photoperiod on cattle growth is not well understood. Forbes (1982) suggested that season or photoperiod has a direct effect on growth characteristics of cattle, but concluded that additional work was warranted regarding the use of supplemental light to enhance carcass growth and development under practical husbandry conditions. Likewise, Tucker et al. (1984) suggested that long daily photoperiod induces a growth response in sheep and cattle, although this may not always be the case. Tucker et al. (1984) also concluded that the mechanism by which photoperiod acts to control bodily function has yet to be elucidated.

The effect of season on fattening pattern was studied by Laurenz et al. (1992) using mature, non-pregnant Simmental and Angus cows. Laurenz et al. (1992) found that both Simmental and Angus cows mobilized empty body protein in summer/fall while at the same time gaining empty body fat. The noted shift in body composition corresponds with a natural shift in day length, where the cattle mobilize protein and deposit fat during a period of decreasing day length. The opposite effect of day length was reported during the winter/spring when both breeds tended to gain protein and mobilize fat during a period of increasing day length. The research of Laurenz et al. (1991, 1992) supports research performed by Petitclerc et al. (1984) and Phillips et al. (1997) who reported long days resulted in increased protein accretion in growing heifers. Likewise, the research of Laurenz et al. (1991, 1992) supported findings of Mossberg and Jönsson (1996) where short days resulted in decreased efficiency due to increased fat accretion in growing bulls. In accordance with Laurenz et al. (1992), both Abbott et al. (1984) and Zinn et al. (1986c) reported increased fat deposition during short days in White-tailed doe fawns and Holstein heifers, respectively.

The specific set of conditions required to increase the rate of growth and improve production efficiency in the beef industry by photoperiod manipulation is not clear from the literature. Therefore, it is desirable to determine if backgrounded and finished heifers under Canadian winter conditions will increase growth and efficiency if exposed to extended photoperiod using low intensity artificial light.

Although temperature extremes have the potential to cause a great deal of stress on animals housed in natural environments, animals have evolved specific mechanisms that help them to deal with both high and low temperature. Metabolic responses are

associated with an increased maintenance requirement in cold environments (NRC 1981). Cattle increase maintenance requirements in cold environments for several reasons. One reason for increased maintenance energy requirements is metabolic acclimatization which involves elevated resting heat production (HP) in response to chronic cold exposure and the second is due to an immediate increase in HP, through shivering, in order to maintain homeothermy when animals are exposed to acute cold stress (NRC 1981). Young (1981) reported that cold ambient temperatures can decrease production efficiency by as much as 70% in Canada, and that ADG may be reduced by as much as 27% as a result of low ambient temperatures. Research performed by Milligan and Christison (1974) showed that feedlot steer (n = 1,970) performance was severely reduced as a result of winter conditions. Average daily gain during winter (December, January, and February), when the mean ambient temperature was -17 °C, was 70% of the average ADG for the remainder of the year. As well, feed required per unit of gain and metabolizable energy intake per unit of gain were, respectively, 149 and 140% of the mean requirements for the remainder of the year. Mean ambient temperatures were significantly correlated with average daily gain (r = 0.74) and feed per unit of gain (r = -0.85). Milligan and Christison (1974) also reported that cattle fed during the 90 coldest days required an extra 220 kg feed to reach market weight.

It is thought that cold acclimatization is a major contributing factor to the increased winter energy requirements of feedlot cattle (NRC 1996). Young (1975a) found that cattle acclimatized to -25 °C have a 30 to 40% increase in resting HP. Webster (1970) found that the lower critical temperature (LCT), the ambient temperature below which cattle must shiver to produce heat in an attempt to maintain homeothermy,

of feedlot cattle is -41 °C, a condition that is rare in western Canada. Thus, acclimatization, rather than shivering is the response to cold which is most metabolically costly to feedlot cattle. One major benefit of acclimatization is the increased resting HP is additive to shivering (Christopherson 1974). Thus the summit metabolism of the animal is increased as a result of acclimatization. However, Western Canadian weather would never be severe enough that an ad libitum fed steer would require the improved summit metabolism caused by acclimatization. Feedlot cattle are rarely acutely cold stressed and the increased summit metabolism capacity developed through acclimatization is unnecessary under feedlot conditions where death due to hypothermia is never found. If one was able to prevent acclimatization the benefits could be enormous and there would be no detrimental effects associated with doing so. The Canadian feedlot industry would benefit, through improved growth and efficiency, if the acclimatization response of cattle could be reduced or eliminated altogether.

Use of housing to reduce cold stress is too costly although fences of low porosity do have some benefit (Mathison 1993). Another strategy to cope with cold may be to shift feeding time from traditional morning feeding to evening feeding. Due to the nature of ruminant digestive processes heat is produced during digestion (heat increment)(NRC 1996). As a result of this, it may be beneficial to feed cattle at night when the environment is the coldest. Research has indicated that time of feeding may affect ruminant performance during both summer and winter. Knutsen et al. (1994) reported that yearling steers fed late in the day (16:00 h) had higher ADG and improved feed efficiency than counterparts fed in the morning (07:30 h) or twice daily (07:30 and 16:00 h) between the months of July and October. No significant overall difference ($P > 0.10$)

was found among treatments from January to May, however, interim period performance suggested that 16:00 h feeding during the cold months was beneficial (Knutsen et al. 1994). Knutsen et al. (1994) concluded that there are no detrimental effects of 16:00 h feeding and suggested that further research was required to adequately determine if late in the day feeding was beneficial.

The purpose of this study was to determine if exposure to supplemental light and feeding during the evening in winter would result in improved growth and production efficiency in feeder heifers.

MATERIALS AND METHODS

Two experiments were conducted in consecutive winters (1998 and 1999) at the University of Manitoba Glenlea Research Station (49.8° Latitude and 100° Longitude). In 1998, freshly weaned crossbred commercial heifers were fed a backgrounding ration and then finished. In 1999, freshly weaned crossbred commercial heifers were backgrounded only. The primary objective of backgrounding is to provide controlled animal growth by limiting rate of growth and allowing development of the muscle and frame of the calf, while limiting fat deposition (McKinnon 1993). Backgrounding results in optimal growth of animals and reduces the incidence of light weight carcasses by giving the animal time to develop sufficient frame and muscle, such that they can be placed on finishing rations at the proper stage of growth (McKinnon 1993). Upon arrival in October, heifers were vaccinated (Cattlemaster 4 - Smithkline Beecham and Covexin 8 – Schering Plough, 1998; Pyramid MLV-4 – Ayerst and Tasvax - Schering Plough, 1999) and treated for parasites (Dectomax, Pfizer 1998, 1999). Heifers were also given vitamin injections (Poten A.D., Rogar/STB Inc.) upon arrival and again in mid-winter. Animals were maintained throughout both Exp. 1 and Exp. 2 in accordance with the guidelines of the Canadian Council on Animal Care (1993).

Experiment One (1998)

Animals and Housing

Forty-eight freshly weaned crossbred beef heifers (275 kg ± 3.6 kg, mean ± SE) (represented by Simmental, Charolais, Limousin, Angus, Gelbvieh, and Hereford in various proportions) from two different Manitoba locations, born in February and March

of 1998 were housed at the University of Manitoba Glenlea Research Station. Heifers were housed in three-sided shelters in pens (12 m L × 3 m W) of two (Figure 1). After arrival at the Glenlea Research Station heifers were fed grass-legume hay only (*ad libitum*) and allowed to adjust to the new location for 12 days. Heifers were then stepped up to the backgrounding ration (see below). High-pressure sodium (HPS) lights (Sentinel and Wide-beam Floodlights, 250W) were installed at a height of 3.2 m and 3.1m, respectively, in one of the three-sided shelters (Figure 1) to achieve a maximum intensity of 150 lx in the bedding area.

Experimental Procedure

Heifers were allocated by weight and source to a 2 × 2 factorial experiment with repeated measures as heifer weights, blood samples, ultrasonic backfat thickness and ribeye area measurements and hair samples were collected over the course of the experiment. The four treatments applied were feeding time (evening, 20:00 h vs. morning, 10:00 h) and supplemental light treatment (SL vs. natural photoperiod). Duration of light for the SL treatment was stepped up over 21 days by use of an automatic timer. The lights were turned on at 16:00 daily and initially remained on until 18:00 h (December 1, 1998). The photoperiod was then extended for two additional hours per week until reaching 24:00 h on December 21, 1998. Lights remained on from 16:00 h to 24:00 h until spring. Light intensity at several locations evenly distributed was measured inside each pen, with the light meter facing straight up (vertical), east and west (horizontal), at a height of 1.2 m using a dual range light meter (Control Company, USA). Mean (± SE) light intensity at the end of the experiment was 65 ± 9 lx (range 5 –

292) when measured with the meter vertical, and 44 ± 5 (range 5 – 162) when measured with the meter horizontal. The overall mean intensity was 54 ± 5 lx and ranged from 5 to 292 lx.

Heifers were stepped up to the backgrounding diet for 14 days and then were fed the diet for one week at 14:00 h prior to the start of the experiment (d 0). Heifers were limit fed to gain 0.68 kg d^{-1} for the 56 day backgrounding phase (November 24, 1998 to January 18, 1999). The backgrounding diet (13.3% CP) consisted of 60% chopped forage (mixed legume-grass hay) and 40% barley concentrate. Subsequently, heifers were then stepped up to the slick bunk *ad libitum* finishing diet over 28 days and finishing began February 15, 1999. Slick bunk *ad libitum* feeding is defined for the purpose of this thesis as feeding so that the feed bunk was empty or very close to being empty immediately prior to feeding. The finishing diet (14.2% CP) consisted of 25% forage and 75% barley concentrate and was fed for 70 days. Diet composition is shown in Table 1. Feed bunks were checked daily during the finishing phase prior to feeding and the amount fed was adjusted based on the previous day's consumption to achieve a slick bunk. Orts were removed and weighed on weigh days. Water was available *ad libitum* from heated water bowls for the entire experiment. Heifers were weighed at 08:00 h on days –1 and 0 of the experiment and were allocated to feeding treatments at 14:00 h on day 0. Morning and evening fed heifers were allocated to alternating pens in each barn. Heifers were weighed two hours prior to feeding (morning fed, 08:00 h; evening fed, 18:00 h) on days 14, 28, 42, 56, 70, 85, 98, 112, 146, 154 and 155. Blood and hair samples were collected on days 0, 14, 28, 42, 56, 70, 91, 107, 119, 133, and 147 at 09:00 h. Blood samples (10 ml) were obtained by jugular venipuncture into

heparinized tubes, refridgerated (4 °C) overnight and centrifuged for 20 minutes at 3000 rpm. Plasma was decanted and frozen for subsequent hormone analysis. Prolactin radioimmunoassay was performed by Prairie Diagnostic Services (Saskatoon, Canada). Assay sensitivity was calculated to be 0.5 ng ml^{-1}. Mean inter-assay coefficient of variation was 14.2%. Shedding of hair was assessed by use of a currycomb, stencil (16 cm H × 7 cm W) and collection tray (Figure 2). Hair samples were taken immediately posterior to the ileum of the heifers and samples were collected from alternate sides of the animal from one sampling day to the next. Hair was collected with one stroke of the currycomb to the described stencil area. Hair samples were stored in plastic bags prior to drying and weighing. Radiotransmitters (Redden et al. 1993) were put in three heifers per treatment for a companion study. Ultrasonic backfat measurements were taken between the 12 – 13^{th} rib section on days 10, 23, 75, 122, and 150; and ultrasonic ribeye area measurements were taken at the same location on days 75, 122, and 150. Animals were evaluated with an Aloka 500V diagnostic ultrasound unit equipped with a 17.2 cm, 3.5 MHz (Overseas Monitor Corporation Ltd., Richmond, B. C.) following the procedure of Perkins et al. (1992). Internal calipers of the ultrasound unit were used to measure backfat. Ultrasound images were recorded on VHS tapes, and ribeye area was determined using a commercial computer and software package (Animorph, Woods Hole Educational Associates, Woods Hole, MA.).

Statistical Analysis

Data was analyzed for each feeding period, i.e. backgrounding (d 0 – d 56) and finishing (d 85 – d 155). ADG was determined for individual animals using regression

analysis and significance of feeding time, light and feeding time × light on ADG were determined using ANOVA (SAS Institute, Inc. 1996) with a 2 × 2 factorial design. A 2 × 2 factorial ANOVA (SAS Institute, Inc. 1996) of pen data was performed to determine significance of feeding time, light and feeding time × light on G:F, and feed intake. G:F feeding time × light treatment interaction means were compared by a Tukey's test (Steele et al. 1997). ANOVA (SAS Institute, Inc. 1996) was used to test for significance of main effects (feeding time, light, and day) and interaction effects on ultrasonic backfat thickness, ribeye area and log transformed PRL values. Log transformation of plasma prolactin concentrations was used to create homogeneity of variance (Steele et al. 1997). Prolactin light × day interaction means were compared by a Tukey's test (Steele et al. 1997) within a day. Only end of trial hair data (d147) was analyzed by ANOVA (SAS Institute, Inc. 1996) to determine significance main effects (feeding time, light) and their interaction because most other samples were calculated to weigh zero or less than zero because of the low sample size and the variation in collection bag weight.

Experiment Two (1999)

Animals and Housing

Forty-eight freshly weaned crossbred beef heifers (228.8 kg ± 2.7 kg) (represented by Simmental, Angus, Hereford and possibly other breeds in various proportions) born in late winter of 1999 and purchased from an auction mart were housed at the University of Manitoba Glenlea Research Station. Housing and lighting were identical to that described for Exp. 1, however, heifers were housed in pens of three. Upon arrival at the Glenlea Research Station heifers were fed hay only (*ad libitum*) and

allowed to adjust to the new location for 12 days. Subsequently, heifers were stepped up to the backgrounding ration (see below).

Experimental Procedure

Heifers were allocated by weight to a 2 × 2 factorial experiment with repeated measures taken as heifer weights, blood samples, ultrasonic backfat thickness and ribeye area measurements collected over the course of the experiment. The four treatments applied were feeding time (evening, 20:00 h vs. morning, 09:00 h) and supplement light treatment (SL vs. natural day length). Lights for the SL treatment were stepped up over 13 days. The lights were turned on at 16:00 daily and initially remained on until 18:00 h (November 30, 1999). The photoperiod was then extended for two additional hours every four days until reaching 24:00 h on December 12, 1999. Lights remained on from 16:00 h to 24:00 h until spring. Light intensity was measured as in Exp. 1. Mean (± SE) light intensity at the end of the experiment was 51 ± 10 lx (range 4 – 280), and 31 ± 4 lx (range 5 – 123) for vertical and horizontal measurements, respectively. The overall mean intensity was 40 ± 5 lx, and ranged from 4 to 280 lx at the end of the experiment.

Heifers were stepped up to the backgrounding diet over seven days (October 29 to November 4, 1999) and were fed the backgrounding diet for 21 days at 14:00 h prior to the onset of the experiment. Heifers were limit fed to gain 0.78 kg d^{-1} for the 162 day backgrounding period (November 24, 1999 to April 26, 2000). The diet (16.2% CP) consisted of 60% chopped forage (mixed legume-grass hay) and 40% barley concentrate. Diet composition is shown in Table 2. Water was available *ad libitum* from heated water bowls for the entire experiment. Heifers were weighed at 12:00 h on days –1 and 0 of the

experiment and were allocated to feeding treatments at 14:00 h on day 0. Morning and evening fed heifers were allocated to alternating pens in each barn. Heifers were weighed two hours prior to feeding (morning fed, 07:00 h; evening fed, 18:00 h) on days 14, 27, 35, 50, 63, 77, 91, 105, 120, 133, 147, 161 and 162. To be consistent with the start of experiment weighing protocol (all animals weighed at 12:00 h) the heifers were fed for an additional six days at 14:00 h and then weighed on two consecutive days (d 169, d 170) at 12:00 h. Radiotransmitters (Redden et al. 1993) were put in three heifers per treatment for a companion study. Ultrasonic backfat thickness measurements, as described for Exp. 1, were taken between the 12 – 13th rib section on days 71 and 156. Blood samples were collected from all animals on days 2, 51, 79, 107, 135, and 163 at 11:00 h and 22:00 h. Blood samples (10 ml) were obtained by jugular venipuncture into heparinized tubes, refridgerated (4 °C) overnight and centrifuged for 20 minutes at 3000 rpm. Plasma was decanted and frozen. Results of melatonin, IGF-I, and prolactin analyses will be published elsewhere. In morning fed natural, morning fed SL, evening fed natural, and evening fed SL treatment groups there were 0, 1, 2, and 2 heifers, respectively, treated for coccidiosis with Amprol 9.6% solution (Merck Agvet) between day 0 to 17, and all appeared to be recovered within five days.

Statistical Analysis

ADG was determined for individual animals using regression analysis and significance of feeding time, light and feeding time × light were determined using ANOVA (SAS Institute, Inc. 1996) with a 2 × 2 factorial design. A 2 × 2 factorial ANOVA (SAS Institute, Inc. 1996) of pen data was performed to determine significance

of feeding time, light and feeding time × light for G:F, and feed intake. ANOVA (SAS Institute, Inc. 1996) was used to test for significance of main effects (feeding time, light, and day) and interaction effects on ultrasonic backfat thickness. Ultrasonic backfat light treatment × day interaction means were compared by a Tukey's test (Steele et al. 1997) within a day.

RESULTS

Experiment One (1998)

Mean daily, daily minimum and maximum temperatures during backgrounding (November 24, 1998 to January 18, 1999) were -13.7 °C, -17.9 °C and -9.7 °C, respectively (Figure 3). The winter was milder during finishing (February 17, 1999 to April 28, 1999) when temperature steadily increased with time. Mean daily, daily minimum and maximum temperatures during finishing were 0.5 °C, -4.5 °C, and 5.4 °C, respectively (Figure 3).

During backgrounding, ADG of evening fed heifers was 10.1% higher ($P = 0.05$) than morning fed heifers (Table 3). The ADG of light treated heifers was 6.2% higher than controls but the effect was nonsignificant ($P = 0.20$) and there was no interaction between feeding time and light treatment on ADG during backgrounding. The amount of feed offered to all treatment groups was similar and there was no feed refused during backgrounding. Thus, there were no effects of feeding time and light treatment on feed intake (FI). However, both feeding time ($P = 0.08$) and light treatment ($P = 0.08$) tended to improve G:F during backgrounding by 9.1% and 8.9%, respectively.

During the finishing period, there were no main or interaction effects on ADG or FI (Table 3). Feeding time and light treatment did not affect G:F during finishing but feeding time × light treatment was significant ($P = 0.02$) for G:F (Figure 4); G:F of morning fed natural photoperiod exposed heifers appeared particularly high but interaction means did not differ ($P > 0.10$). Interaction means for ADG, FI and G:F during finishing are shown in Appendix II, Table 1. For the entire trial (data not shown) there were no effects of feeding time or light treatment on ADG, FI, or G:F but the

interaction of feeding time × light treatment (P = 0.13) reflected the interaction found in G:F during finishing. Weight of morning and evening fed and natural and SL heifers is shown in Appendix II, Figure 1 and 2, respectively.

Ultrasonic backfat and ribeye area results are shown in Table 4 and 5. There were no effects of feeding time, light treatment or feeding time × light treatment on ultrasonic backfat thickness or ribeye area (Table 4). However, day of experiment was significant (P = 0.0001) for both. Feeding time × day, light treatment × day, and their interaction were not significant for ultrasonic backfat thickness or ribeye area (Table 5).

Feeding time, light treatment and feeding time × light treatment had no effect on plasma prolactin concentrations, however, the light treatment × day interaction (P < 0.01) was significant. Plasma prolactin was lower (P < 0.05) in SL heifers at the start of the trial which was seven days before commencement of light treatment (Table 6). However, 36 days after the beginning of the light step up (d 42) the SL heifers had greater (P < 0.05) plasma prolactin concentrations than natural photoperiod heifers. There were no treatment effects on plasma prolactin concentrations after day 42 until the end of the trial (d 147) when SL heifers once again had lower (P < 0.05) plasma prolactin concentrations than natural photoperiod heifers.

Hair shedding was negligible from day 0 to 133 and the sparse samples could not be weighed accurately due to variation in bag weight. On day 147 (April 20, 1999) shedding was considerable (mean ± SE, 0.17g ± 0.02g) but there was no effect of feeding time, light treatment or feeding time × light treatment on hair shedding at this time (P ≥ 0.34) (Appendix II, Figure 3 and 4).

Experiment Two (1999)

Mean daily temperature was -5.1 °C, and the daily minimum and maximum temperatures were -10.9 °C and -0.4 °C, respectively (Figure 5). During the coldest month (January), days 46 to 76 of the experiment, the mean daily, minimum and maximum temperatures were -16.4 °C, -22 °C and -11.9 °C, respectively.

Statistical analysis of ADG was performed before and after deletion from the data set of results for the heifers that required coccidiosis treatment. Exclusion of sick animals had no effect on the results of statistical analysis so results for these animals were retained in the data set. There were no main or interaction effects on ADG or G:F (Table 7). Similarly, when ADG was calculated based on final minus initial weight or final weight at a common time minus initial weight there were no effects of treatment or their interaction on ADG or G:F. The amount of feed offered to all treatment groups was similar and there was no feed refused. Thus, there was no effect of treatment on FI during the experiment. Weight of morning and evening fed and natural and SL heifers is shown in Appendix III, Figure 1 and 2, respectively.

Ultrasonic backfat thickness increased from d 71 to d 156 and there were no effects of feeding time, light treatment, or feeding time × light treatment on ultrasonic backfat thickness (Table 4). However, effects of day ($P = 0.0001$) and light treatment × day ($P = 0.002$) were significant (Table 5). Comparison of light treatment × day means within day indicated that ultrasonic backfat thickness was not different on day 71, however, on day 156 the SL heifers had significantly less ultrasonic backfat than heifers exposed to natural photoperiod.

DISCUSSION

Both experiments one and two were performed in winters when the average temperature for the coldest month (January) was above the thirty year normal (mean -18.3 °C, mean minimum -23.6 °C, and mean maximum -13.2 °C). By western Canadian standards neither winter was cold for feedlot cattle which have a LCT in the vicinity of -41 °C or growing calves (210 kg) that have a LCT in the vicinity of -19 °C (Webster 1970). It is unlikely that the heifers would have needed to shiver during finishing of Exp. 1, which began February 15, 1998. Heifers may have needed to shiver if the effect of wind-chill were taken into account on a few occasions during backgrounding of Exp. 1 and the coldest month of Exp. 2. NRC (1981) predicts that the resting HP of feedlot cattle will have a linear inverse relationship with mean monthly temperature predicting a 54% increase at -40 °C. The NRC (1981) prediction for the conditions observed during backgrounding and finishing of Exp. 1 would be a 33% and 18% increase, respectively, in resting HP. Likewise, NRC (1981) would predict a resting HP increase of 23% for heifers during Exp. 2. Under the conditions of both experiments the increase in resting HP would have been considerably less than that found during a normal winter in Manitoba. One may expect full fed finishing heifers to benefit more from evening feeding than limit fed backgrounding heifers as a result of a higher heat increment (HI) associated with the higher intake of full fed animals. However, this may not be the case in the current study where the backgrounding diet had a higher forage content than the finishing diet. The high forage content of the backgrounding diet may result in a higher HI than the finishing diet as feed.

Evening feeding increased (P = 0.05) ADG and tended (P = 0.08) to increase G:F only during the backgrounding period of Exp. 1 when environmental conditions were the harshest encountered during the two winters studied. Knutsen et al. (1994) found that late day feeding (16:00 h vs. 07:30 h) significantly increased ADG and improved G:F in two of four 28 day periods from January 6 to May 10 during a winter in South Dakota where changes in weather conditions were described as "dramatic" but not published. Interestingly, Knutsen et al. (1994) also found a similar beneficial effect of late day feeding during summer months. As in our study, Knutsen et al. (1994) found that there was no overall effect of late day feeding on ADG and G:F in winter. Conditions during backgrounding of Exp. 1 are predicted (NRC 1981) to reduce G:F by 18.6% for heifers growing at the rate of 0.79 kg d^{-1}. Evening feeding improved ADG by 10.1% and G:F by 9.1% during backgrounding. Thus, it can be calculated that evening feeding prevented approximately 50% of the expected reduction in feed efficiency due to the increase in resting HP associated with acclimatization. The potential benefit of evening feeding would have been much less during finishing of Exp. 1 when the environmental conditions were milder and this may be the reason that no effect of evening feeding on ADG or G:F was found. Behavioural observations made during Exp. 2 (backgrounding) for a companion study revealed that feed was consumed 2 – 3 h after feeding, suggesting that differences caused by evening feeding during backgrounding of Exp. 1 were probably not caused by changes in feeding pattern. Although it is proposed that evening feeding inhibited cold-acclimatization, the improvement caused by evening feeding during backgrounding of Exp. 1 also may have been due to unknown metabolic shifts related to circadian rhythm at the time of feeding. The results during the finishing phase of Exp. 1

and during Exp. 2 do not agree with that of Knutsen et al. (1994) where late day feeding improved performance in late summer as well as during the winter although weather conditions cannot be compared between the two studies. Evening feeding did not increase FI during backgrounding of Exp. 1 or Exp. 2 because heifers were limit fed; or during finishing of Exp. 1 when heifers were fed *ad libitum*. The fact that FI was unaffected by evening feeding during finishing agrees with Knutsen et al. (1994) who found that FI was not different between morning fed and late day fed steers in winter-spring.

That light treatment did not significantly improve ADG in Exp. 1 and ADG or G:F in Exp. 2 agrees with Phillips et al. (1997) where artificial long days did not improve ADG or G:F of steers or postpubertal heifers, but disagrees with results of Peters et al. (1980), Petitclerc et al. (1983), Zinn et al. (1986b) and Mossberg and Jönsson (1996). Efficiency (G:F) during backgrounding of Exp. 1 tended ($P = 0.08$) to increase when heifers were exposed to light treatment, and agrees with earlier work performed by Peters et al. (1980), Petitclerc et al. (1983), and Mossberg and Jönsson (1996) who found efficiency of growth improved when animals were exposed to 16L:8D. The fact that the effect of light treatment on G:F only tended to be significant during backgrounding of Exp. 1 may have been due to the short duration of exposure in that full light treatment was only applied from days 27 to 56. Although step up of light treatment commenced December 1 (d 7) and reached the maximum by December 21 (d 27) it may be necessary to have >29 days of maximum exposure to light to achieve maximum effect on performance. In the present experiments the step up of light treatment did not commence until December 1 to ensure that a sufficient number of short days had been available to

induce growth of the winter hair coat (Bourne et al. 1984). Others have shown that extending photoperiod does not have an immediate production effect. Photoperiod must be extended for two to four weeks to induce a milk yield response in dairy cows (Dahl et al. 1997). Dahl et al. (1997) suggested that the increase in milk yield was due to an increase in IGF-I which also lagged two weeks behind the onset of light treatment. If IFG-I is a growth controlling endocrine factor with supplemental light, it is likely that a growth response will also have a lag time of at least two weeks. Performance responses to supplemental light may also be limited by the inability of supplemental light to increase prolactin when ambient temperature is below 0°C (Peters et al. 1980, Peters and Tucker 1978). In support of this, prolactin was only elevated by supplemental light on one sampling occasion, although this did occur when mean daily temperature was –21.2 °C. Finally, the intensity of light treatment in the current studies may not have been adequate to invoke a large increase in performance. Photoperiod induced improvements in performance have previously been found using mean light intensities greater than or equal to 104 lx (Peters et al. 1980, Zinn et al. 1986b). However, results of manuscript one suggest that light intensity of approximately 50 lx, as used in Exp. 1 and Exp. 2, was adequate to inhibit pineal release of melatonin in the short term. Light intensity during Exp. 1 was approximately 65 lx and 44 lx, when measured vertically and horizontally, respectively. Therefore, the intensity used in experiment one may have been adequate to induce a growth response, however, in Exp. 2 light intensity had decreased to approximately 51 lx and 31 lx for vertical and horizontal intensity, respectively. Thus, the light intensity of Exp. 2 may not have been adequate to induce a production response, although Stanisiewski et al. (1987) suggested 11 to 16 lx is adequate for day length

extension to increase prolactin. Although mean light intensity were as previously indicated, maximum intensities were found in the bedding area and heifers may have spent considerable time in the bedding area during the period of day light extension. Heifers studied in manuscript one were considerably younger than those studied in manuscript two and this may have resulted in different responses. However, Critser et al. (1988) studied ovariectomized heifers (approximately 8 months of age) and reported similar melatonin concentrations as found in manuscript one when heifers were exposed to control lighting. This indicates that age of heifers does not influence plasma melatonin concentrations and model used in manuscript one appears to be applicable to older heifers.

The reason that no improvement in ADG or G:F occurred in response to light during finishing of Exp. 1 may be that cattle have a physiological limit for protein accretion that is reached during periods of high growth (Byers 1980). Indeed, Byers (1980) found that, as ADG approaches 0.7 to 1.0 kg d^{-1}, protein accretion plateaus and no additional protein accretion was observed when ADG exceeded 1.0 kg d^{-1}. During the backgrounding period natural light and SL heifers grew 0.81 kg d^{-1} and 0.86 kg d^{-1}, respectively, thus their physiological limit for protein accretion would not have been reached. However, during the finishing period natural light and SL heifers grew 1.43 kg d^{-1} and 1.42 kg d^{-1}, respectively. The ability of the heifers to grow faster when exposed to SL may have been limited by a physiological limitation for protein accretion during finishing.

Light treatment had no effect on FI of heifers during either backgrounding of Exp. 1 or during Exp. 2 due to the fact that heifers were limit fed. The fact that FI was

unaffected by light treatment during finishing of Exp. 1 disagrees with earlier work by Peters et al. (1980), Ingvartsen et al. (1992) and Mossberg and Jönsson (1996). Possibly the natural increase in day length during finishing minimized any differences between the two light treatment groups. It may be important that light treatment and feeding of cattle be coordinated so cattle are treated with light when day length is decreasing through to the time of year when day length is shortest.

Although there only tended ($P = 0.08$) to be an effect of light treatment on G:F during backgrounding, the light × feed interaction was significant ($P = 0.02$) during finishing of Exp. 1, but interaction means did not differ ($P > 0.10$). The light × feed interaction suggests that light treatment decreases G:F in morning fed, but not evening fed heifers. This agrees with Phillips et al. (1997) who found peripubertal heifers exposed to supplemental light deposit more fat between January and March than heifers exposed to natural photoperiod. This suggests that heifers are unable to respond to the natural increase in daylight in the spring when the day is artificially extended. The results do not agree with earlier work by Peters et al. (1980), Petitclerc et al. (1983), and Mossberg and Jönsson (1996) who found efficiency improved in response to 16L:8D. Ultrasonic backfat thickness and ribeye area in Exp. 1 were not affected by treatment. Thus, the reason for the effect of supplemental light on G:F of morning fed heifers cannot be explained by differences in ultrasonic backfat thickness or ribeye area in the present study. It is possible that there were subtle carcass changes that could not be detected with ultrasonic backfat and ribeye measurements alone as ultrasonic backfat of supplemental light exposed heifers was numerically higher at the end of the experiment. Increased locomotor activity in response to extending day length (Phillips and Schofield 1989),

may have contributed to the lower G:F observed in the morning fed SL heifers, but Phillips et al. (1997) found that heifers spend more time lying down when exposed to 16L:8D. In a companion study performed during Exp. 2 light treatment had no effect on time spent standing or eating by heifers. Considering that other researchers (Peters et al. 1980, Petitclerc et al. 1983, Zinn et al. 1986b, and Mossberg and Jönsson 1996) have found a positive effect of supplemental light on ADG and G:F it may be that the results of the present study should be interpreted differently. In the finishing phase (Exp. 1) the light treatment may have had no positive effect on performance due to the time of year it was applied, when natural day length was increasing. Mossberg and Jönsson (1996) concluded that not only day length, but also changes in day length are significant factors influencing growth and efficiency. It is possible that the light treated heifers responded in terms of G:F to the artificially imposed increase in day length when days were naturally short (during backgrounding) and that, similarly, the control animal responded to the natural day length increase from approximately 10 h to 14 h daily light during the finishing period. If so, this could explain why G:F of the morning fed heifers exposed to natural photoperiod was very high during the finishing period. This would suggest that the morning fed heifers exposed to natural photoperiod were at a disadvantage during backgrounding and that increasing natural day length during finishing improved their G:F. Conversely, SL morning fed heifers would have already experienced a light induced response earlier in the experiment. The SL heifers (morning and evening fed) may not have responded to the increasing natural day length since they were already exposed to artificial long days. There was no evidence of a benefit of increasing natural day length on G:F in evening fed heifers which suggests a possible negative effect of

evening feeding during mild conditions. However, previous work on late day feeding in finishing cattle (Knutsen et al. 1994) found no detrimental effect although Christopherson (1974) working with two sheep suggested that afternoon feeding may result in reduced efficiency of growth due to increased activity and heat loss.

There were no effects of feeding time or light treatment on ultrasonic backfat thickness or ribeye area in Exp. 1. The fact that light treatment did not affect ultrasonic backfat thickness of heifers agrees with earlier research by Zinn et al. (1989) who reported that long days did not reduce fat deposition of steers. However, Zinn et al. (1986c) found that extending day length reduces fat content of the 9-10-11th rib section and Petitclerc et al. (1984) found that extending day length increases protein content of the 9-10-11th rib section of heifers. One reason for the lack of light treatment × day effect in Exp. 1 may have been that the sample size was not large enough (n = 48) for differences in ultrasonic backfat and ribeye area data to be detected. As previously discussed, the light treatment may have been applied too late, the light intensity may have been inadequate or light treatment may increase fattening in the winter and spring (Phillips et al. 1997). Although feeding time did not affect ultrasonic backfat thickness in Exp. 2, by the end of the study light treatment had caused a decrease in ultrasonic backfat thickness. This is in agreement with earlier work by Phillips et al. (1997) and Zinn et al. (1986c) where heifers deposited less fat in winter when exposed to supplemental light but disagrees with results of Exp. 1. It may be that in Exp. 2, where growth was less than 1 kg d^{-1}, the light treatment increased protein accretion and therefore decreased fat accretion. During finishing of Exp. 1 heifer growth was greater than 1 kg d^{-1}, thus, it is possible that no increase in protein accretion took place, and as a consequence there was

no decrease in fat deposition with supplemental light (Byers 1980). Unfortunately, due to technical difficulties, no data for ultrasonic ribeye area was available for Exp. 2. The fact that ultrasonic backfat was unaffected by light treatment in Exp. 1 and reduced in Exp. 2 may also be due to breed differences from Exp. 1 to Exp. 2 where in both years breed composition was unknown. Indeed, Laurenz et al. (1992) found that body composition changes due to season differ with breed, and cattle of different breed types differ in priorities for storage and retrieval of fat and protein in winter. Therefore, differences between Exp. 1 and Exp. 2 may have been due to different priorities for energy partitioning caused by breed type.

Earlier work by Petitclerc et al. (1983) and Stanisiewski et al. (1984) found that 16L:8D increased serum prolactin in Holstein heifers. However, others (Peters et al. 1980, Peters and Tucker 1978) have found that prolactin did not increase in response to long photoperiod and suggested that prolactin secretion was temperature dependant and that prolactin increased in response to extended photoperiod only when ambient temperature was above 0 °C. Overall mean ambient temperature in Exp. 1 was -6.6 °C and thus the inconsistent prolactin response to light treatment may have been related to the cold environment. Interestingly, Peters et al. (1980) found supplemental light improved heifer growth without a corresponding increase in prolactin concentrations when it was cold. A second possible reason for the inconsistent prolactin response may have been that the light intensity was too low to stimulate prolactin release. Stanisiewski et al. (1988) and Stanisiewski et al. (1987) reported an increase in serum prolactin when Holstein bull calves were exposed to 16L:8D using a mean light intensity greater than 400 lx. However, Stanisiewski et al. (1987) also found that continuous low intensity (11

to 16 lx) light supplemented with 16 or 8 h of high intensity (449 to 618 lx) light per day increased serum prolactin relative to bulls exposed only to 8 h of high intensity lighting per day. Stanisiewski et al. (1987) suggested that low intensity lighting was capable of increasing serum prolactin of cattle when used in combination with a minimum 8 h high intensity light. Also, in manuscript one it was found that 50 lx could eliminate the night-time release of melatonin for at least 3 h. In an epidemiological study Reksen et al. (1999) found a production response to low intensity (mean = 36 lx) lighting, and during the backgrounding of Exp. 1 G:F was improved ($P = 0.08$) 8.9% by the supplemental light without an associated change in plasma prolactin level which supports the findings of Peters et al. (1980). A third possible reason for the inconsistent prolactin response may have been related to barn differences other than the fact one barn was equipped with supplemental lighting and the other was not, although there were no obvious differences between barns. Previous research (Peters and Tucker 1978, Petitclerc et al. 1983, Stanisiewski et al. 1984, 1988) has found that serum prolactin concentrations typical of a long day are approximately 45 ng ml^{-1}, however, on day 147 of Exp. 1 plasma prolactin concentrations were substantially greater (approximately 225 ng ml^{-1}). The higher value may represent an intermittent peak in plasma prolactin concentration, or be a result of increasing natural photoperiod that may have a greater effect than supplemental light on prolactin concentrations.

Conclusions

1. Evening feeding improved ADG and G:F of backgrounded heifers during the coldest part of winter. Effects of evening feeding on finishing cattle in cold weather are unknown due the mild winter experienced in 1998.
2. Supplemental light had a beneficial effect on G:F during backgrounding of Exp. 1.
3. Supplemental light had no effect on heifers during finishing that began February 15. Possibly the increase in natural photoperiod during spring prevented any benefit from occurring with artificial photoperiod extension.
4. When supplemental light is applied in a Manitoba winter the prolactin response is inconsistent.

Implications

1. Feeding outdoor housed backgrounding cattle in the evening during periods of cold improves ADG and production efficiency.
2. Providing supplemental light to outdoor housed backgrounding cattle can improve production efficiency.

Table 1: Composition of diet for experiment one (1998).

Item	Background diet	Finishing diet
Ingredient (g kg^{-1} as fed)		
Alfalfa-Timothy hay	600	250
Concentrate mix	400[Z]	750[Y]
Composition (g kg^{-1} DM)	Alfalfa-Timothy hay	Concentrate mix
Dry Matter	853	892
CP	122	149
ADF	464	59
NDF	647	--
DE[X]	2.1	3.8

[Z]Containing (g kg^{-1}): barley grain (958); molasses (20); minerals (16.2); salt (6.5); Bovatec (0.06).

[Y]Containing (g kg^{-1}): barley grain (960); molasses (20); minerals (6.5); salt (2.6); Bovatec (0.05); limestone (11).

[X]Energy content expressed as DE (Mcal kg^{-1}).

Table 2: Composition of backgrounding diet for experiment two (1999).

Item		
Ingredient (g kg^{-1} as fed)		
Alfalfa-Timothy hay		600
Concentrate mix		400[Z]
Composition (g kg^{-1} DM)	Alfalfa-Timothy hay	Concentrate mix
Dry Matter	842	872
CP	179	136
ADF	342	52
NDF	460	--
DE[Y]	2.7	3.8

[Z]Containing (g kg^{-1}): barley grain (968); molasses (19.4); minerals (6.7); salt (5.4); Bovatec (0.72).

[Y]Energy content expressed as DE (Mcal kg^{-1}).

Table 3: Performance of heifers during experiment one (1998) during backgrounding (d 0 – 56) and finishing (d 85 – 155).

Time Period	Feeding Time			Light Treatment			Interaction	
	Morning	Evening	P value	Natural	SL	P value	P value	SE
Backgrounding								
Weight (kg)	319.5	321.8	0.73	320.7	320.6	0.99	0.68	4.6
ADG (kg d^{-1})[Z]	0.79	0.87	0.05	0.81	0.86	0.20	0.96	0.03
FI (kg $hd^{-1}d^{-1}$)[Y]	6.1	6.2	0.51	6.1	6.1	0.99	0.95	0.1
G:F (g kg^{-1})	122	133	0.08	122	133	0.08	0.65	4
Finishing								
Weight (kg)	434.5	444.3	0.34	442.9	435.8	0.49	0.55	7.2
ADG (kg d^{-1})[Z]	1.39	1.45	0.35	1.43	1.42	0.85	0.27	0.05
FI (kg $hd^{-1}d^{-1}$)[Y]	7.0	7.4	0.28	7.2	7.2	0.89	0.75	0.2
G:F (g kg^{-1})	196	194	0.71	198	192	0.40	0.02	4

Note: FI and G:F derived using pen as the experimental unit.

[Z] Values based on regression analysis of individual animal weights.

[Y] Dry matter basis.

Table 4: Effects of feeding time, light treatment, and feeding time × light treatment on overall mean ultrasonic backfat thickness and ribeye area of heifers in experiment one (1998) and overall mean ultrasonic backfat thickness of experiment two (1999).

	Feeding Time			Light Treatment			Interaction	
	Morning	Evening	P value	Natural	SL	P value	P value	SE
Experiment One								
Ultrasonic Backfat (mm)	3.3	3.1	0.48	3.1	3.3	0.51	0.28	0.3
Ultrasonic Ribeye Area (cm^2)	60.5	62.0	0.40	62.0	60.5	0.37	0.65	1.2
Experiment Two								
Ultrasonic Backfat (mm)	3.4	3.2	0.48	3.4	3.2	0.51	0.78	0.2

Table 5: Effects of feeding time × day, light treatment × day, and feeding time × light treatment × day on ultrasonic backfat thickness and ribeye area of heifers during experiment one (1998) and ultrasonic backfat thickness of heifers in experiment two (1999).

	Day	Feeding Time			Light Treatment				
		Morning	Evening	Feed × Day P value	Natural	SL	Light × Day P value	Feed × Light × Day P value	SE
Experiment One									
Backfat (mm)	10	1.7	1.4		1.5	1.5			
	23	1.9	1.5		1.7	1.8			
	75	2.3	2.0	0.95	2.2	2.1	0.39	0.91	0.2
	122	4.8	4.4		4.2	4.9			
	150	6.1	6.0		5.8	6.3			
Ribeye area (cm^2)	75	56.1	57.7		57.8	56.0			
	122	62.3	62.5	0.19	63.0	61.8	0.91	0.78	0.7
	150	63.1	65.8		65.4	63.6			
Experiment Two									
Backfat (mm)	71	2.4	2.3		2.3	2.5			
	156	4.4	4.0	0.31	4.6a	3.9b	0.002	0.47	0.1

Note: Different letters within row indicates a significant difference of means ($P < 0.05$).

Table 6: Effects of light treatment × day on plasma prolactin concentrations of heifers in experiment one (1998).

Date	Day of Trial	Treatment	Mean Prolactin (ng ml^{-1})
24 – November – 98	0	SL	21.38a
		Natural	37.47b
08 – December – 98	14	SL	18.57a
		Natural	25.40a
22 – December – 98	28	SL	28.39a
		Natural	34.42a
05 – January – 99	42	SL	110.59a
		Natural	52.48b
19 – January – 99	56	SL	22.45a
		Natural	18.47a
11 – February – 99	79	SL	5.49a
		Natural	8.33a
23 – February – 99	91	SL	6.97a
		Natural	5.40a
11 – March – 99	107	SL	6.40a
		Natural	5.84a
23 – March – 99	119	SL	9.10a
		Natural	12.85a
06 – April – 99	133	SL	50.10a
		Natural	37.15a
20 – April – 99	147	SL	215.35a
		Natural	248.45b

Table 7: Performance of heifers during experiment two (1999) when weighed two hours prior to feeding (d 162) and when weighed at a common time according to weighing protocol eight days after the end of the experiment (d 170).

	Feeding Time			Light Treatment			Interaction	
	Morning	Evening	P value	Natural	SL	P value	P value	SE
End of Test (d162)								
Weight (kg)	369.7	371.3	0.87	368.1	372.9	0.61	0.63	6.6
ADG [Z]	0.87	0.88	0.88	0.86	0.89	0.47	0.48	0.03
ADG (kg d^{-1}) [Y]	0.89	0.89	0.94	0.87	0.90	0.39	0.53	0.03
FI (kg d^{-1}) [X]	5.5	5.5	0.80	5.5	5.5	0.97	0.73	0 [W]
G:F (g kg^{-1})	159	160	0.80	157	162	0.39	0.43	4
Weighing Protocol (d170)								
Weight (kg)	372.5	368.7	0.68	370.0	371.3	0.89	0.70	6.6
ADG (kg d^{-1}) [Z]	0.85	0.82	0.47	0.83	0.84	0.86	0.55	0.02
FI (kg d^{-1}) [X]	5.5	5.5	0.79	5.5	5.5	0.99	0.73	0 [W]
G:F (g kg^{-1})	154	150	0.42	152	151	0.82	0.52	4

Note: FI and G:F derived using pen as the experimental unit.

[Z] Values based on day of trial weight minus start weight.

[Y] Values based on regression analysis.

[X] Dry matter basis.

[W] Indicates that the SE is very small and approaching zero due to fact that heifers were target fed based on body weight and little variation in FI levels occurred.

Figure 1: Three-sided beef shelter equipped with supplemental lighting. Overhanging Sentinel lights installed outside of the roof and Wide-beam floodlights installed under the roof.

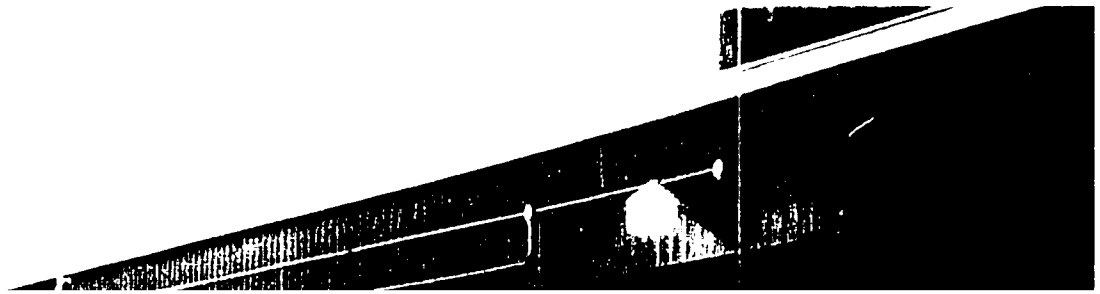


Figure 2: Hair sample collection equipment (tray, stencil, currycomb, bags and funnel).

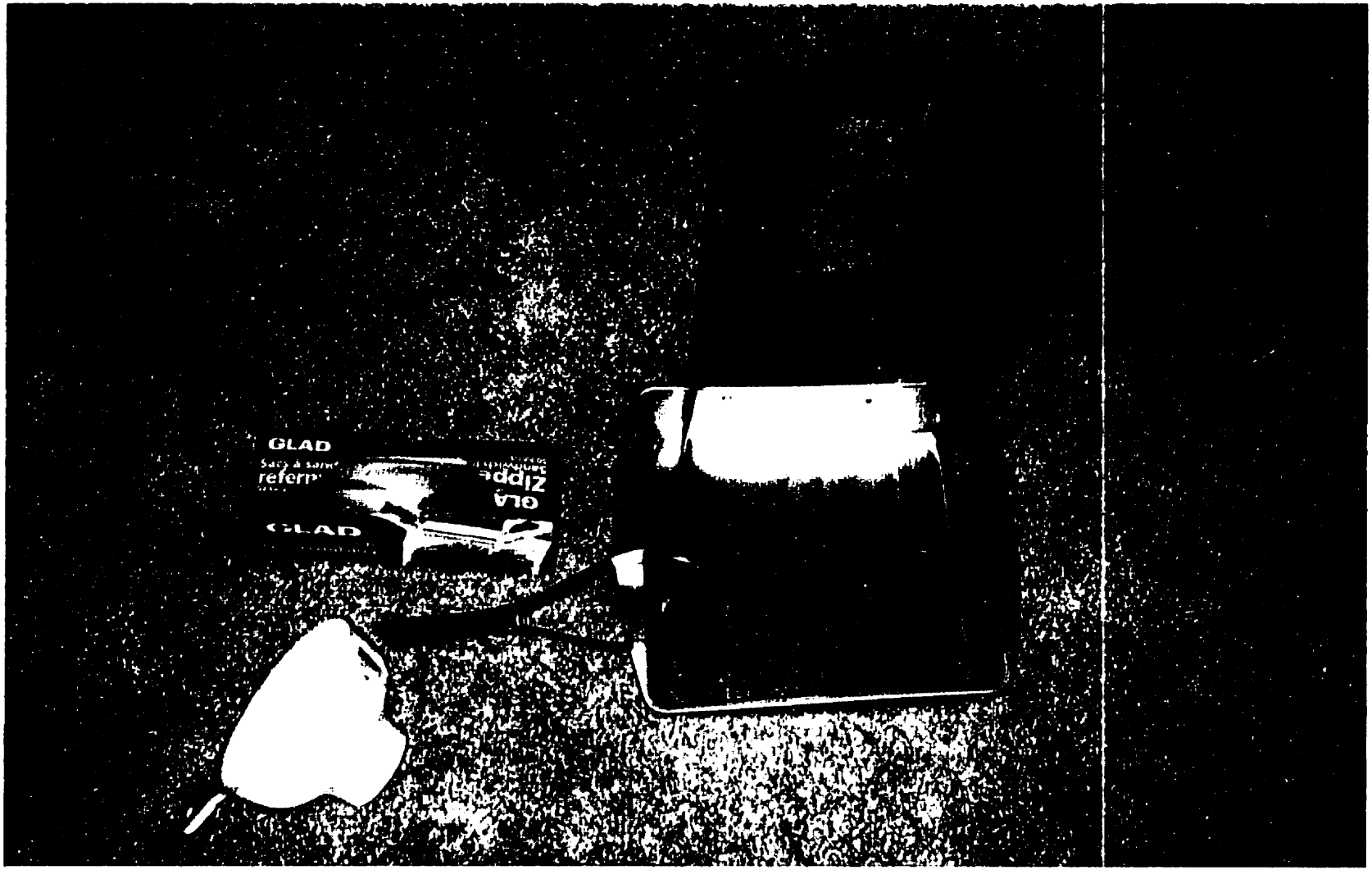

GLAD
GLAD

Figure 3: Daily mean, mean minimum and mean maximum ambient temperature during experiment one (1998) at Winnipeg International Airport (Environment Canada).

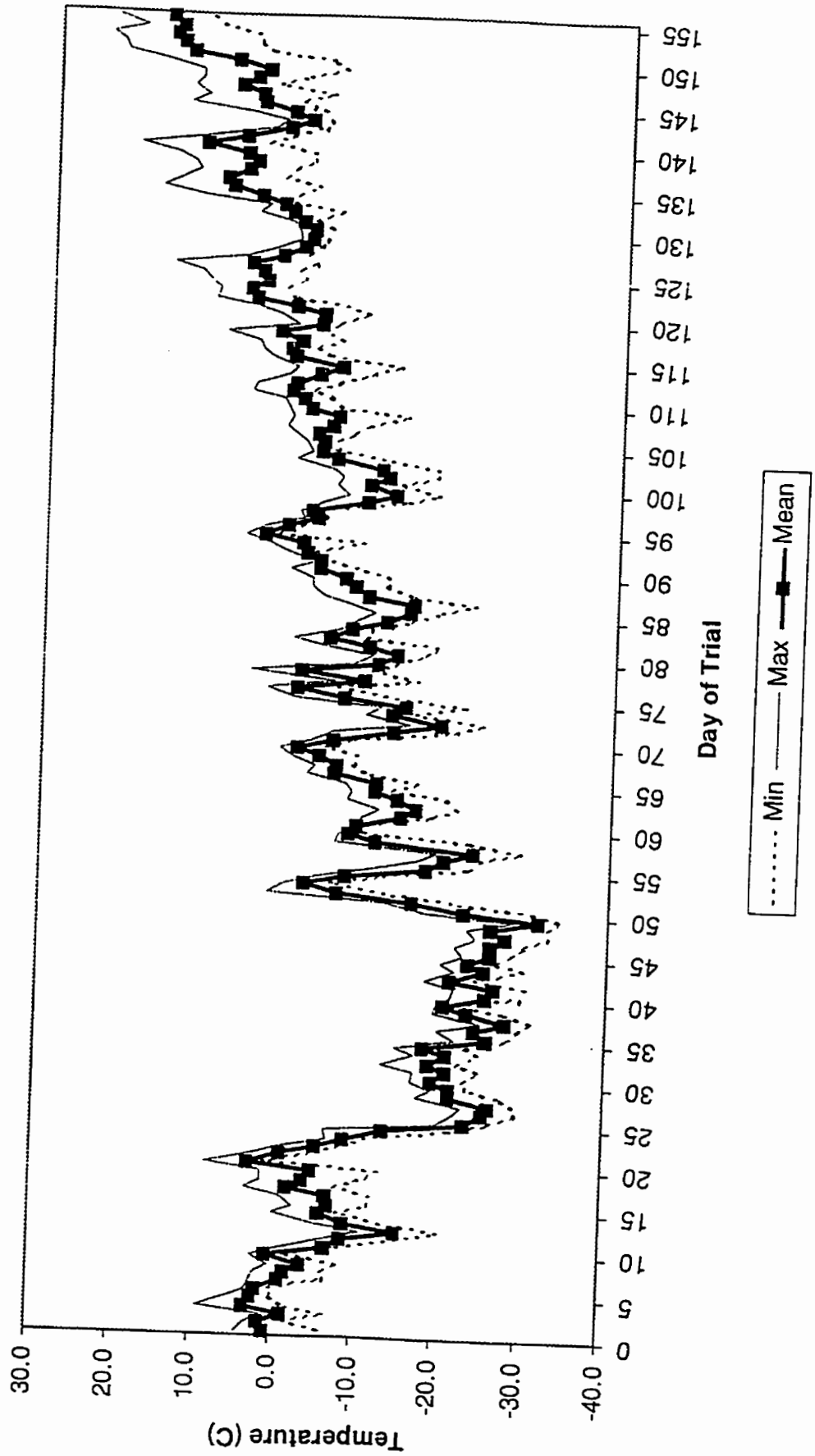

Temperature (C)
30.0
20.0
10.0
0.0
-10.0
-20.0
-30.0
-40.0
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
105
110
115
120
125
130
135
140
145
150
155
Day of Trial
Min
Max
Mean

Figure 4: Feed efficiency feeding time × light treatment interaction for finishing during experiment one (1998) (Mean ± SE).

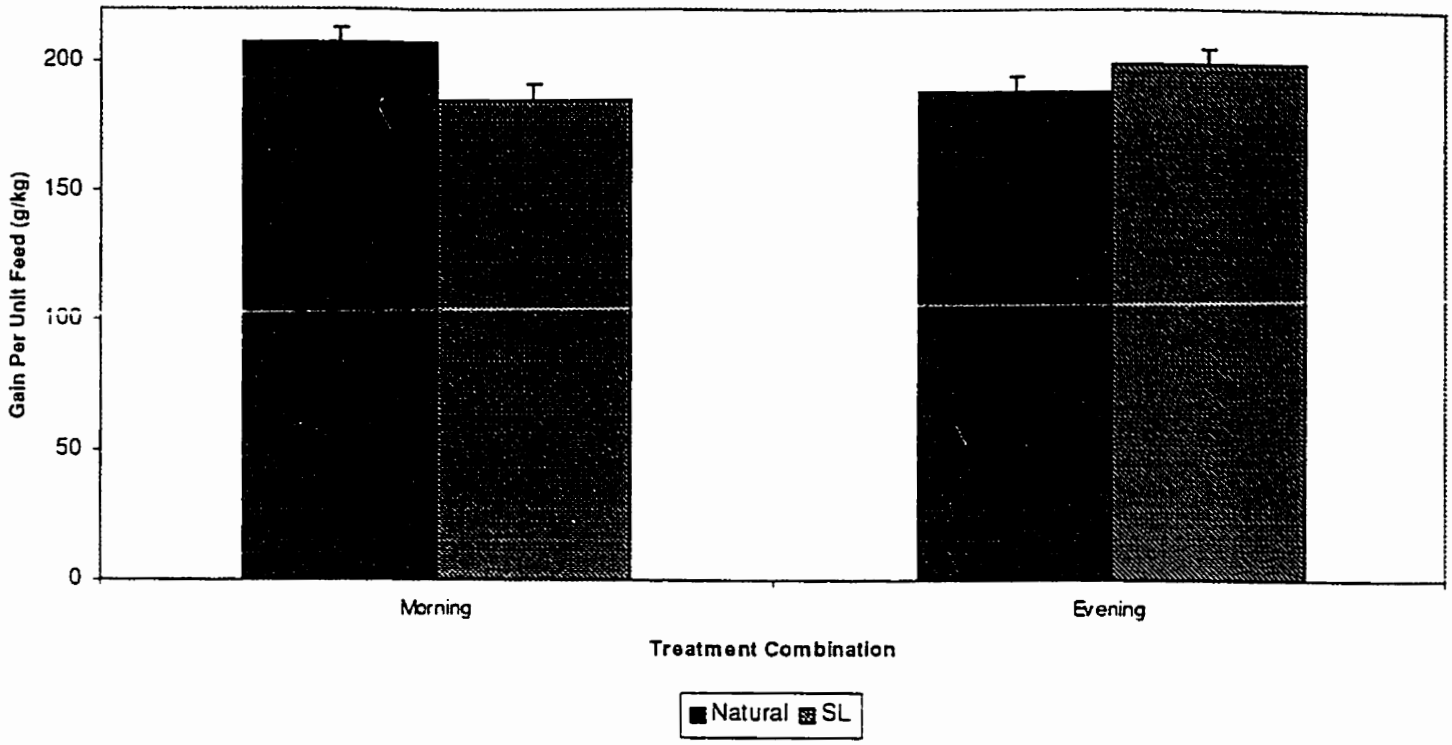
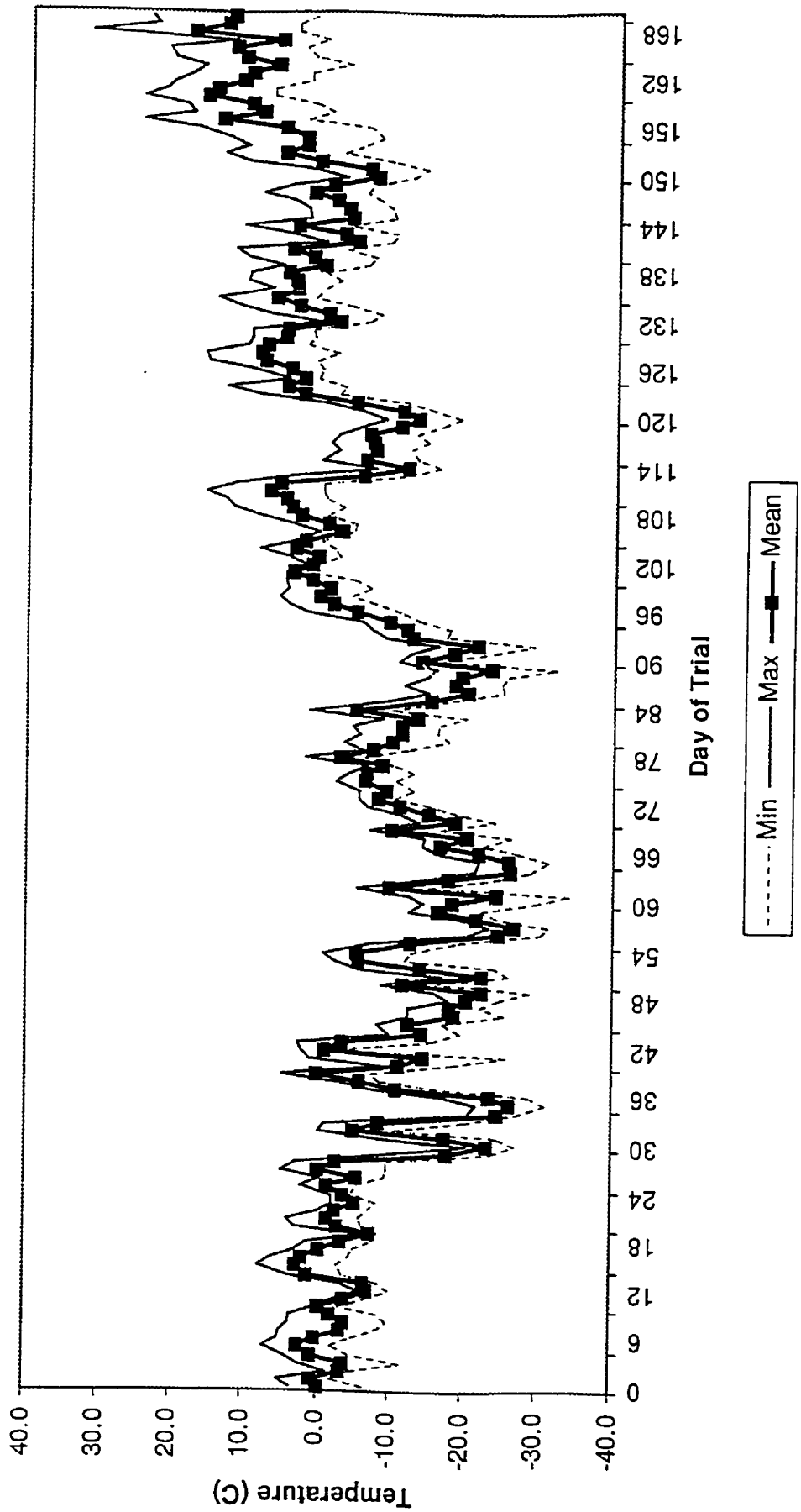

200
150
100
50
0
Gain Per Unit Feed (g/kg)
Morning
Evening
Treatment Combination
Natural
SL

Figure 5: Daily mean, minimum and maximum ambient temperature during experiment two (1999) at Winnipeg International Airport (Environment Canada).


Temperature (C)
40.0
30.0
20.0
10.0
0.0
-10.0
-20.0
-30.0
-40.0
0
6
12
18
24
30
36
42
48
54
60
66
72
78
84
90
96
102
108
114
120
126
132
138
144
150
156
162
168
Day of Trial
Min
Max
Mean

GENERAL DISCUSSION

Long day photoperiod has been found to increase productivity in cattle when compared to natural short days of winter (Forbes 1982). In dairy cattle, extending the photoperiod improves milk yields (Peters et al. 1981, Reksen et al. 1999) and reproductive performance as measured by decreased number of days open and calving interval (Reksen et al. 1999). Extending photoperiod has also been shown to increase rate of cattle growth (Petitclerc et al. 1983; Peters et al. 1978) and to alter composition of growth (Phillips et al. 1997; Mossberg and Jönsson 1996). Reiter (1991) suggests that melatonin plays a significant role in controlling almost every organ system in the body. Dahl et al. (1997) suggested that the increase in milk yield due to supplemental light is a result of reduced melatonin secretion that leads to increased IGF-I secretion. Although the specific mechanism by which photoperiod acts to improve animal growth is unknown, it is suspected that melatonin plays a role in control of growth through endocrine growth factors like IGF-I. Therefore, the ability to control or manipulate melatonin secretion may be beneficial. In manuscript one, exposure to 50 lx was adequate to inhibit the initial dark induced rise in melatonin, suggesting that light intensities much lower than those recommended by the dairy industry (200 lx) may in fact be capable of influencing milk production. However, manuscript one was only a brief experiment where Holstein heifers were exposed to controlled light conditions for one day at a time. Repeated daily exposure of Holstein heifers to low light intensity needs to be investigated. As well, effects of intensities lower than 50 lx are not known as 50 lx was the lowest treatment in manuscript one. Further information describing the threshold light intensity for inhibition of melatonin secretion in cattle is required.

Improved knowledge of melatonin secretion patterns of Holstein heifers under exposure to low light intensity may provide insight as to the actual intensity required to invoke milk yield responses in dairy cattle and may provide incentive to perform milk production trials under exposure to low light intensity in the future.

The fact that supplemental light tended to improve G:F of heifers in manuscript two suggests that it may provide some benefit when used with outdoor growing cattle as well as with dairy cattle. The intensity of light used in manuscript two was considerably less than previously used in the literature (Peters et al. 1980, Zinn et al. 1986b) for indoor housed animals, however, it was similar to the 50 lx used in manuscript one to reduce plasma melatonin concentration. Heifers studied in manuscript one were considerably younger than those studied in manuscript two, however, Critser et al. (1988) studied ovariectomized heifers (approximately 8 months of age) and reported similar melatonin concentrations as found in manuscript one when heifers were exposed to control lighting which indicates that age of heifers does not influence plasma melatonin concentrations. This suggests that low light intensities have the ability to influence beef cattle growth and efficiency. Light effects were only evident during backgrounding of Exp. 1 but effects during finishing may have been limited by several factors including rate of protein accretion and the time of year light was applied relative to natural day length. Application of supplemental light much earlier in the fall (October) may be one way of correcting for this in future research. Efficiency (G:F) differences in Exp. 1 of manuscript two could not be attributed to differences in carcass composition. However, the increase in G:F (8.9%) was not large and may not be noticeable in ultrasonic backfat thickness or ribeye area measured in the current experiments due to shifts in carcass

composition. A more accurate method of determining carcass composition would be through total carcass analysis and may be an option in the future.

Evening feeding in Exp. 1 of manuscript two improved ADG and G:F during backgrounding when mean daily ambient temperature was the coldest of the two winters in which experiments were conducted. This suggests limit-feeding heifers in the evening during periods of cold temperature is beneficial. That there was no benefit of evening feeding during finishing of Exp. 1, or during Exp. 2 may be because mean daily ambient temperatures were above the thirty year normal for Winnipeg. The results suggest that evening feeding during prolonged cold periods is beneficial, however, doing so when temperatures are mild provides no benefit and would not justify a change in management to accommodate evening feeding. The nature of outdoor feedlot research, especially that which depends on environmental conditions, makes it difficult to adequately test the effect of evening feeding on heifer growth and efficiency during a cold prairie winter. With regard to suggestions for further research on evening feeding it is difficult to make one, other than to hope for a winter typical of the prairies.

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APPENDIX I

Figure 1: Mean (n = 5) plasma melatonin concentrations for samples collected at frequent intervals starting at 14:30 h until the end of the treatment period for all treatment intensities.

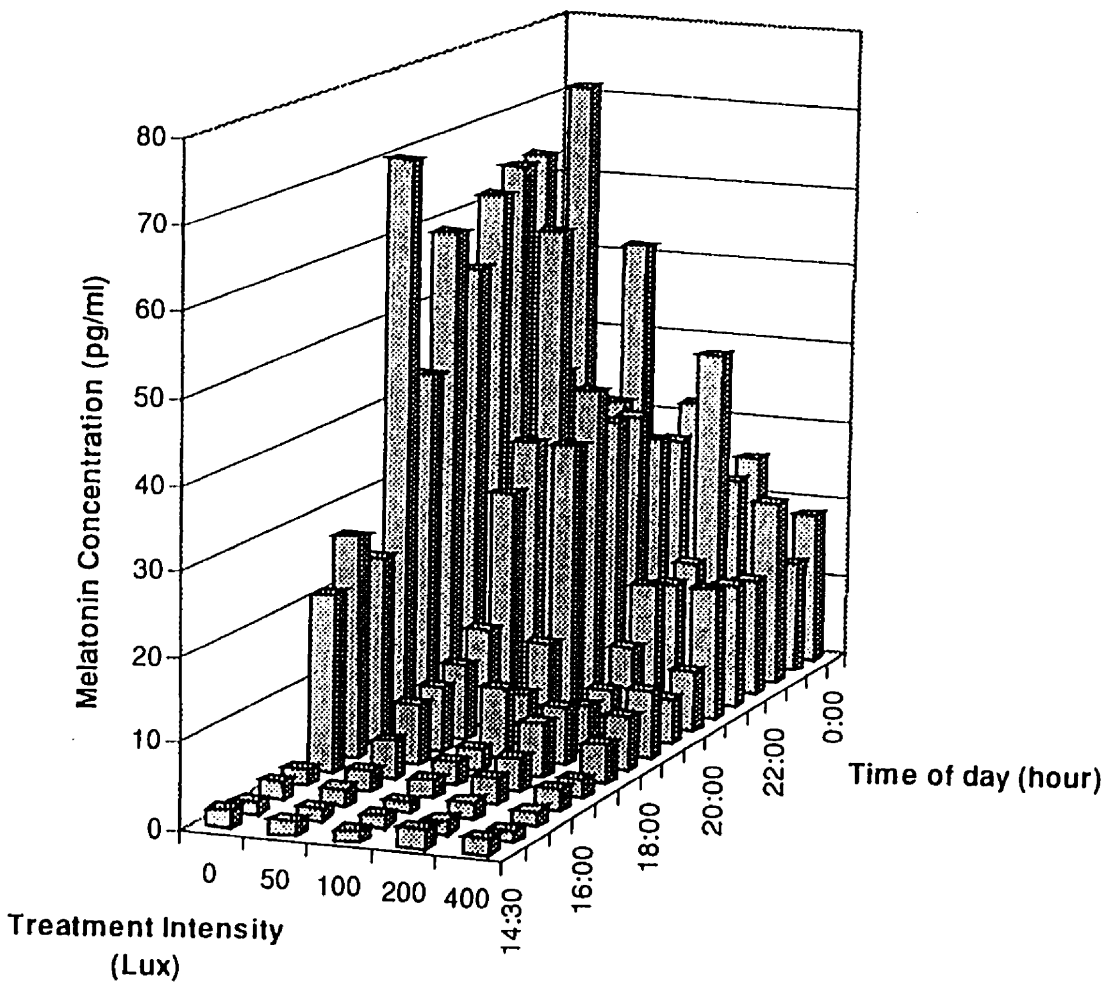

Melatonin Concentration (pg/ml)
80
70
60
50
40
30
20
10
0
0
50
100
200
400
Treatment Intensity
(Lux)
14:30
16:00
18:00
20:00
22:00
0:00
Time of day (hour)

Figure 2: Individual animal response to 0 lx treatment intensity during the pre-treatment period (14:30 h – 16:00 h) and the 8 h treatment period (16:00 h – 24:00 h).

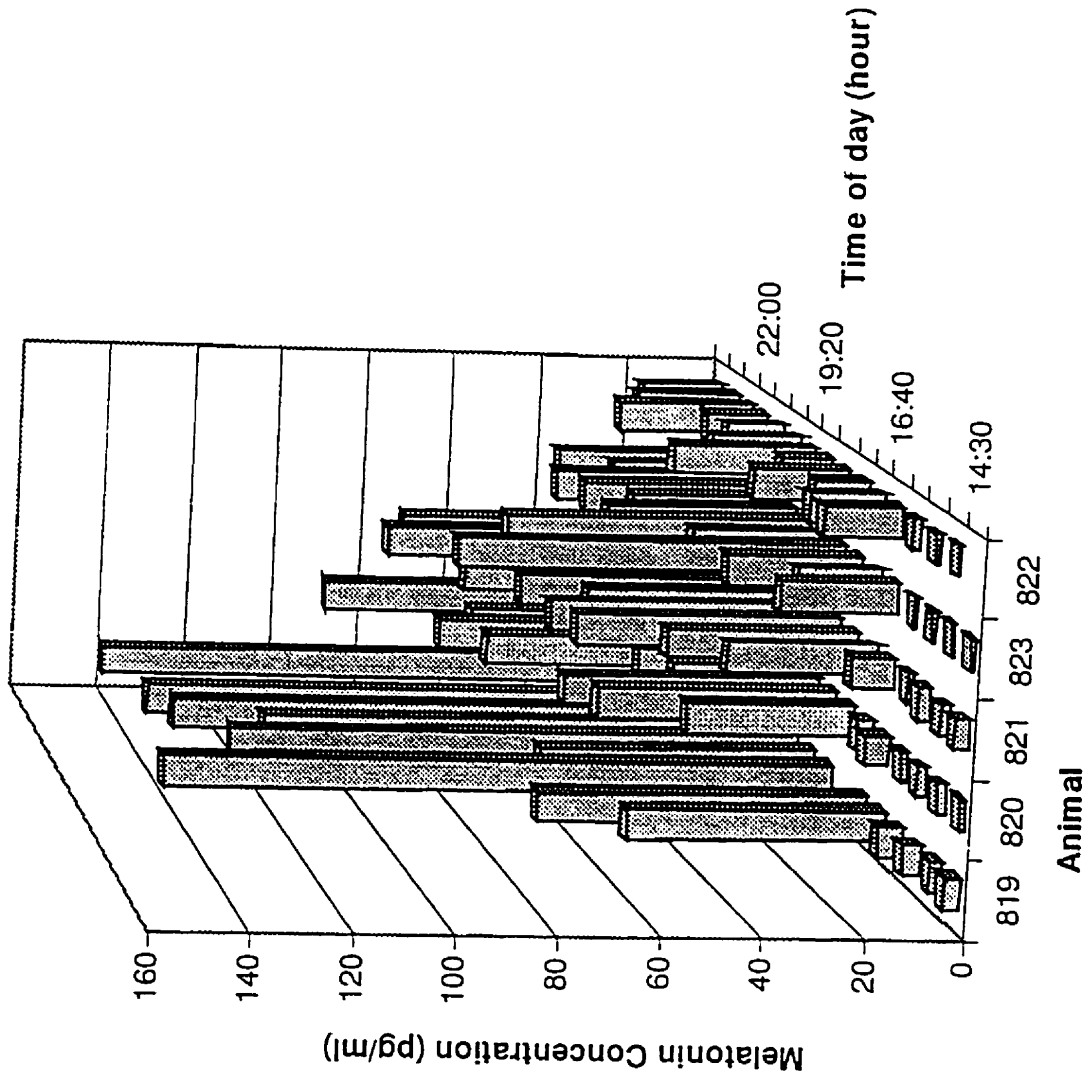
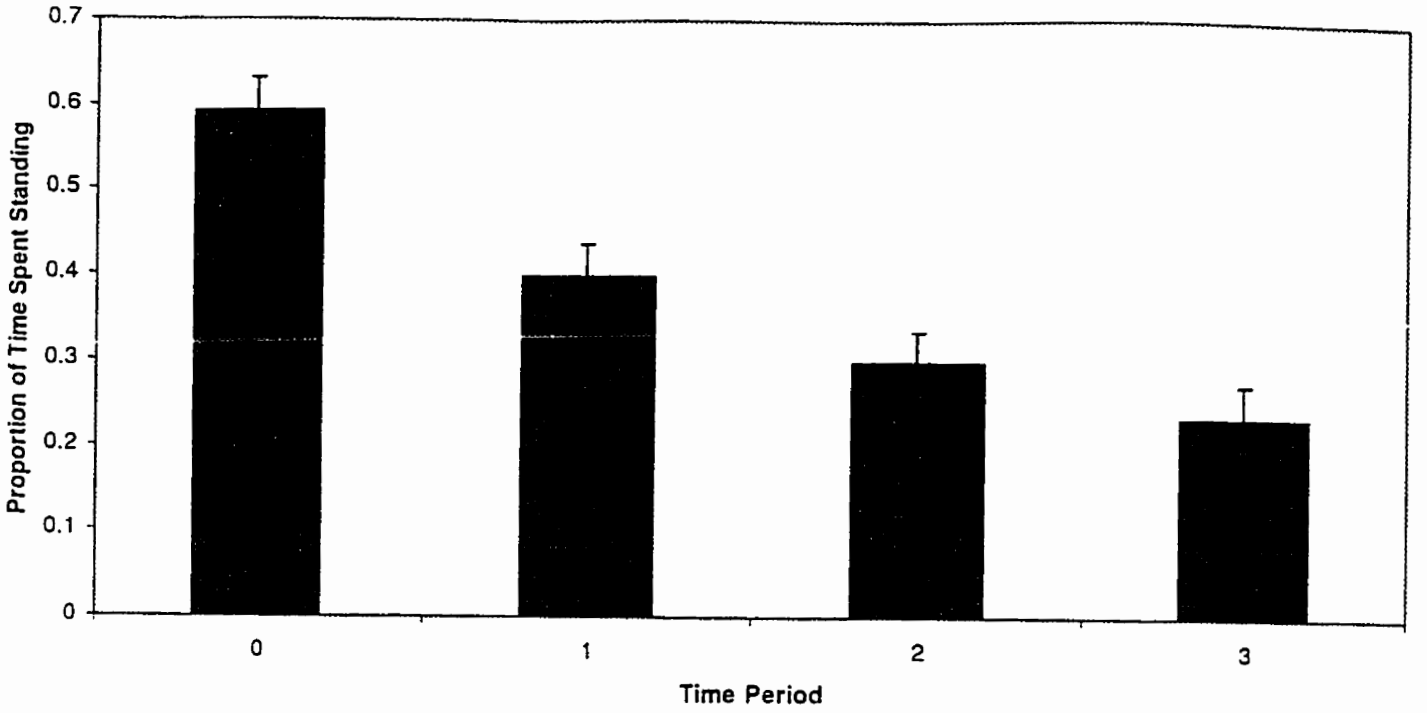

Melatonin Concentration (pg/ml)
0
20
40
60
80
100
120
140
160
Animal
819
820
821
823
822
Time of day (hour)
14:30
16:40
19:20
22:00

Figure 3: Proportion of time spent standing before (T0) and during (T1, T2, T3) the treatment period when exposed to 0 lx.


0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Proportion of Time Spent Standing
0
1
2
3
Time Period

APPENDIX II

Table 1: Interaction (feeding time × light treatment) means for ADG, FI, and GF during finishing of experiment 1 (1998).

Table 1: Interaction means for ADG, FI, and G:F during finishing of experiment one (1998).

	Morning Fed		Evening Fed		
Parameter	Natural	SL	Natural	SL	SE
ADG (kg d^{-1})[Z]	1.44	1.35	1.42	1.48	0.07
FI (kg $hd^{-1}d^{-1}$)[Y]	7.0	7.0	7.3	7.4	0.3
G:F (g kg^{-1})	207	185	188	199	6

Note: FI and G:F derived using pen as the experimental unit.

[Z] Values based on regression analysis of individual animal weights.

[Y] Dry matter basis.

Figure 1: Weight of morning and evening fed heifers during experiment one (1998).

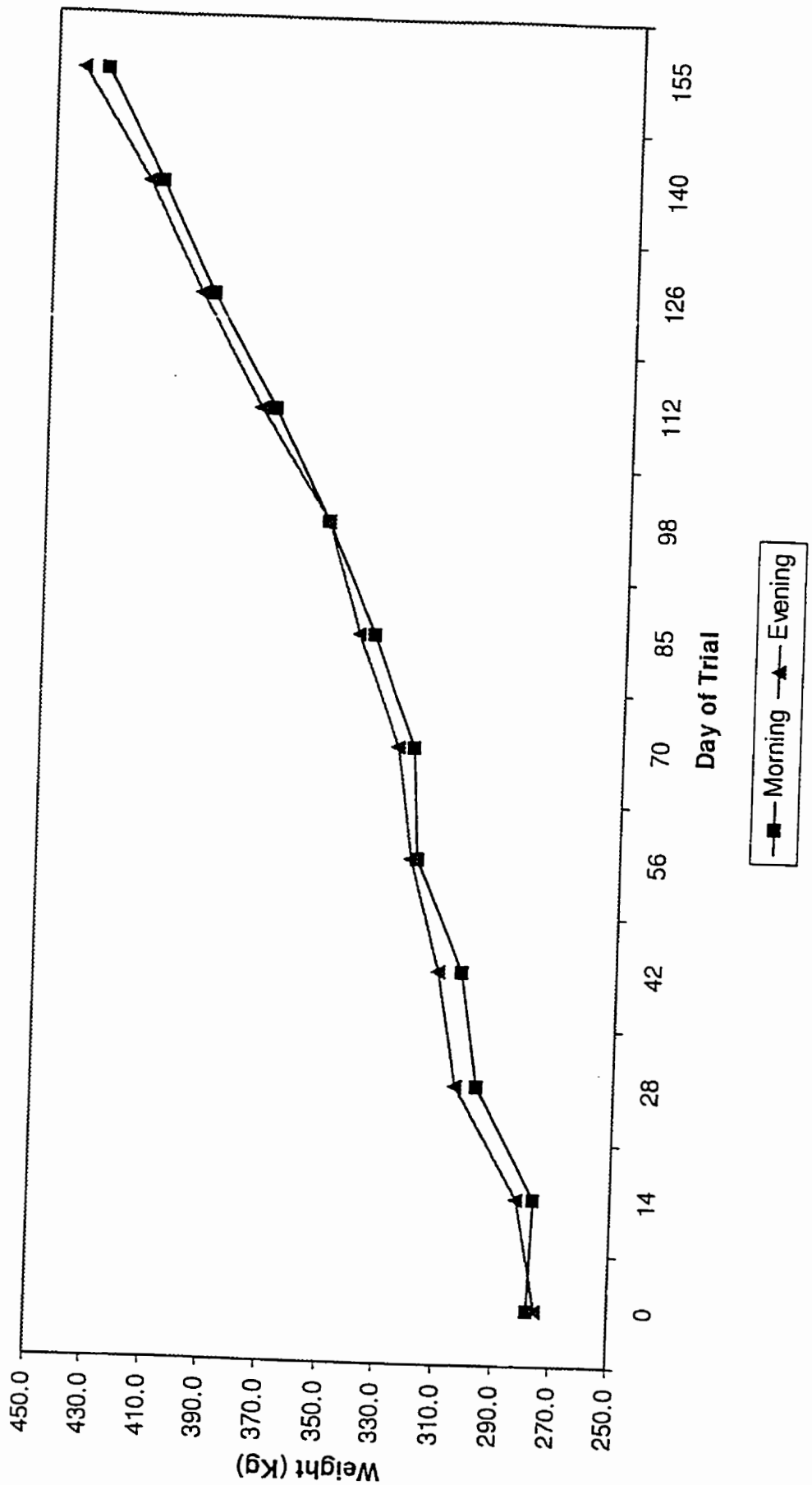

Weight (Kg)
450.0
430.0
410.0
390.0
370.0
350.0
330.0
310.0
290.0
270.0
250.0
0
14
28
42
56
70
85
98
112
126
140
155
Day of Trial
Morning
Evening

Figure 2: Weight of heifers exposed to natural and supplemental light during experiment one (1998).

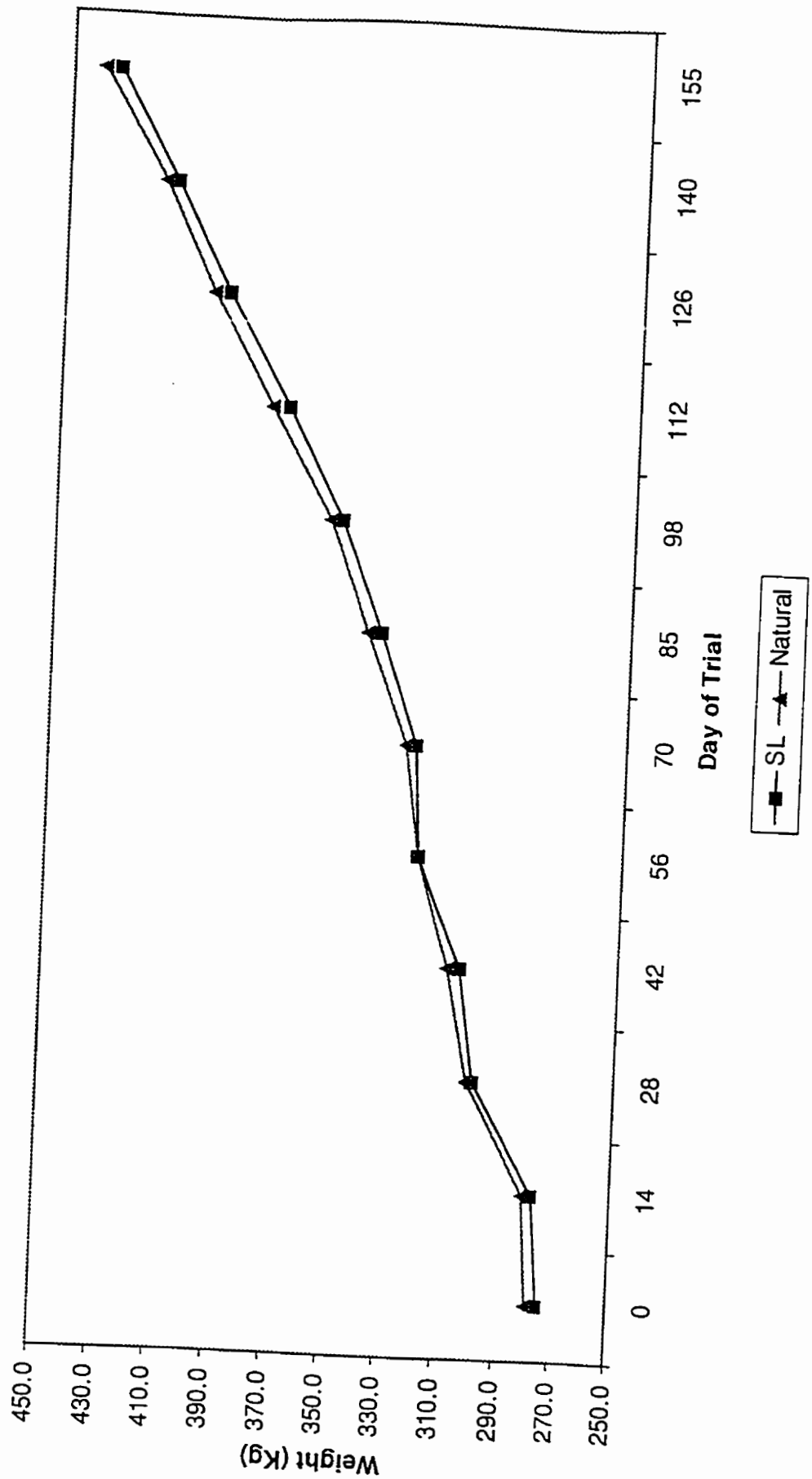

Weight (Kg)
450.0
430.0
410.0
390.0
370.0
350.0
330.0
310.0
290.0
270.0
250.0
0
14
28
42
56
70
85
98
112
126
140
155
Day of Trial
SL
Natural

Figure 3: Hair shedding of morning and evening fed heifers during experiment one (1998).

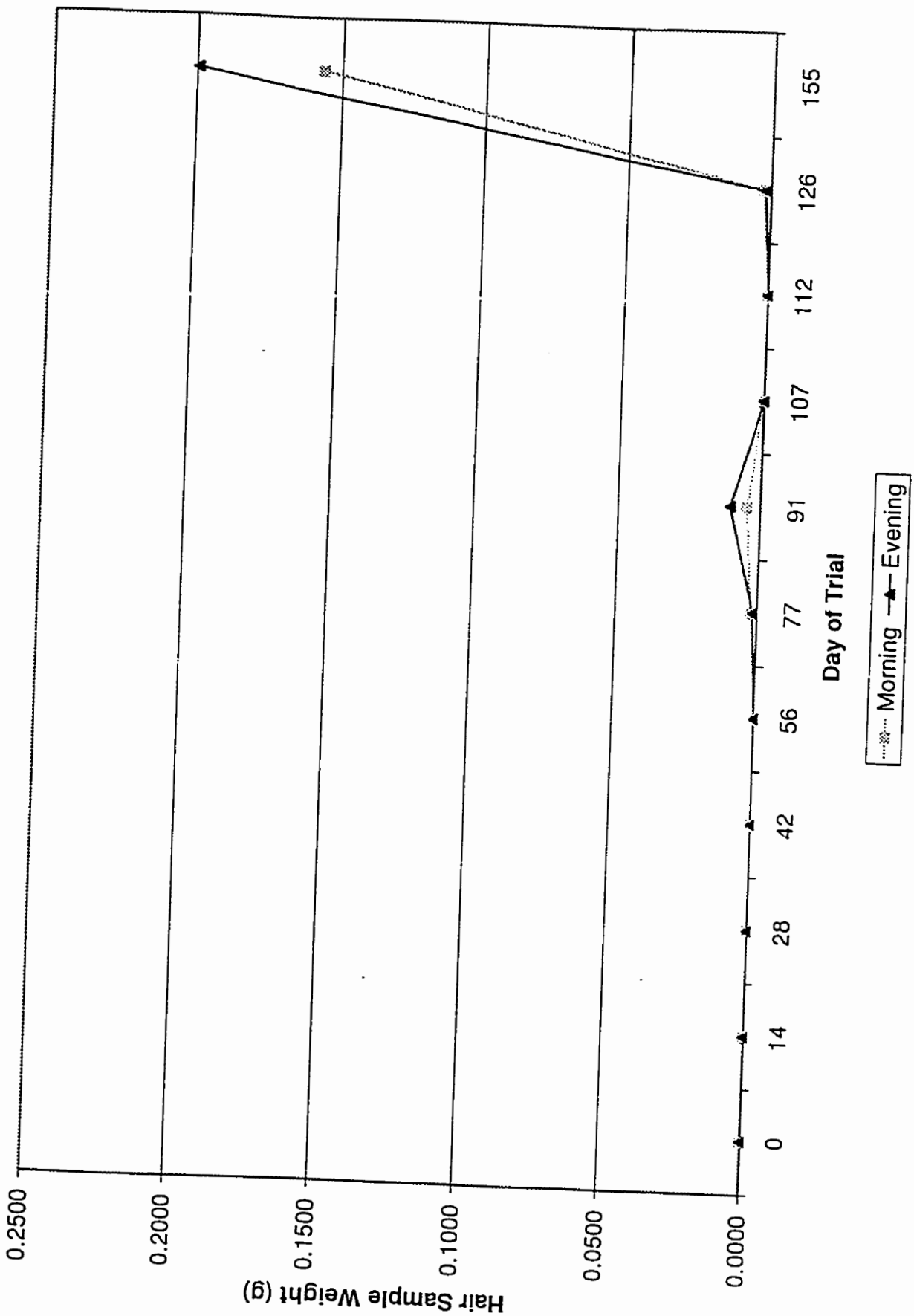
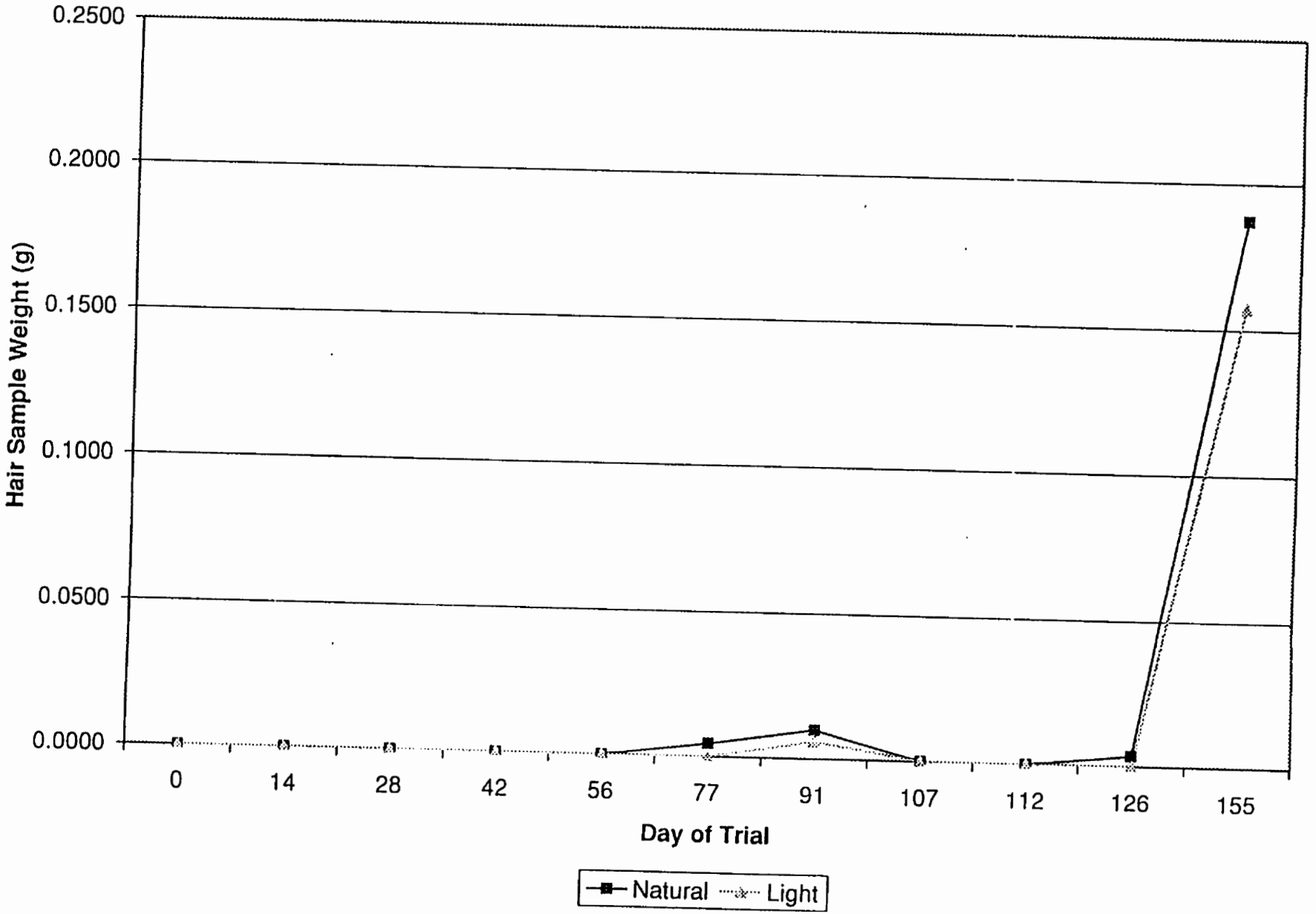

0.2500
0.2000
0.1500
0.1000
0.0500
0.0000
Hair Sample Weight (g)
0
14
28
42
56
77
91
107
112
126
155
Day of Trial
Morning
Evening

Figure 4: Hair shedding of heifers exposed to natural or supplemental light treatment during experiment one (1998).


0.2500
0.2000
0.1500
0.1000
0.0500
0.0000
Hair Sample Weight (g)
0
14
28
42
56
77
91
107
112
126
155
Day of Trial
Natural
Light

APPENDIX III

Figure 1: Weight of morning and evening fed heifers during experiment two (1999).

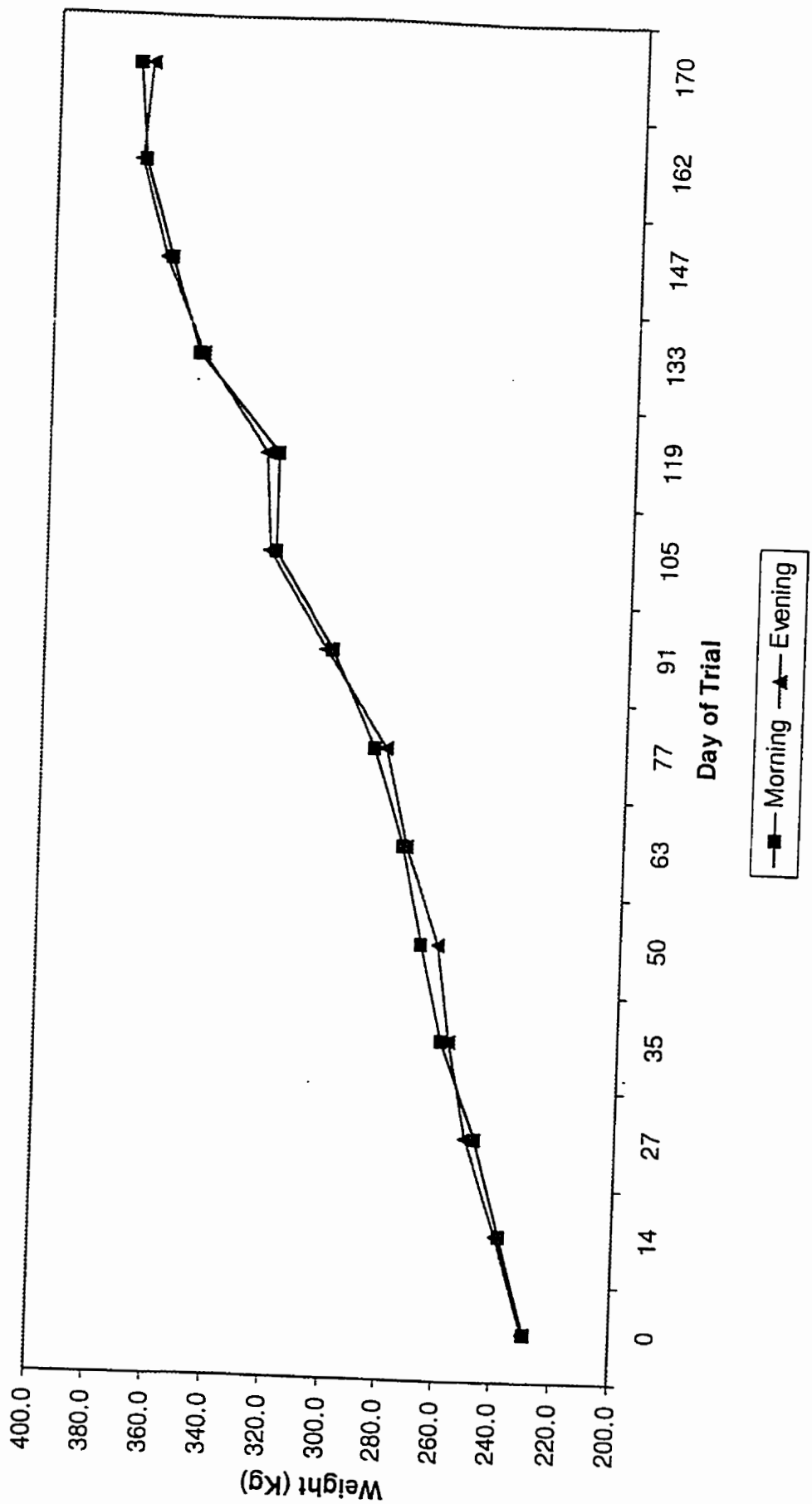
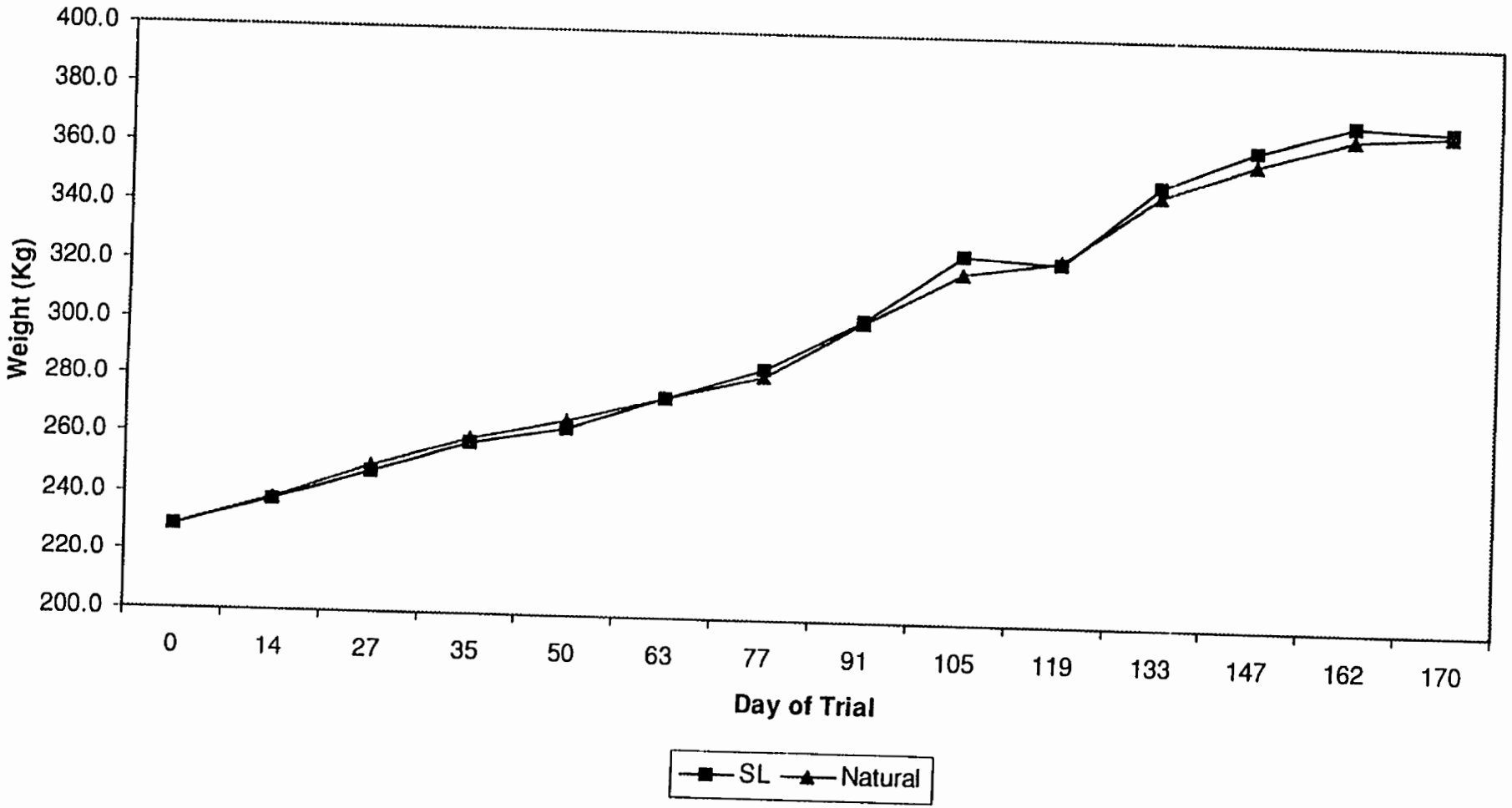

Weight (Kg)
400.0
380.0
360.0
340.0
320.0
300.0
280.0
260.0
240.0
220.0
200.0
0
14
27
35
50
63
77
91
105
119
133
147
162
170
Day of Trial
Morning
Evening

Figure 2: Weight of heifers exposed to natural and supplemental light during experiment two (1999).


400.0
380.0
360.0
340.0
320.0
300.0
280.0
260.0
240.0
220.0
200.0
Weight (Kg)
0
14
27
35
50
63
77
91
105
119
133
147
162
170
Day of Trial
SL
Natural