Effects of Photoperiod Management on Milk Production in Lactating Dairy Cows

by

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ABSTRACT

The goals of this research were to evaluate the interaction effects between photoperiod management and dietary grain allocation in lactating dairy cows and to determine if any relationships exist between photoperiod management and the persistency of lactation in selected dairy herds in Alberta. In study 1, there were no significant interaction effects between photoperiod management and dietary grain allocation on milk production, dry matter intake or body weight gain. Cows that were exposed to long day photoperiod (LP; 16 h of light, 8 h of darkness) increased milk yield by 2. 2 kg/d relative to the animals exposed to short day photoperiod (SP; 8 h of light, 16 h of darkness). However, galactopoietic responses to LP were only detected four weeks after initial light exposure; when cows were fed different diets, after adaptation to light treatment, the effect of LP on milk yield was not detected. Contrarily, cows fed high grain diets increased milk yield and dry matter intake compared with those fed low grain diets. In study 2, we found that animal exposure to light did not differ between summer and winter. Thus, farms that practiced photoperiod management were able to provide long day photoperiod throughout the year whereas cows in farms without photoperiod management were exposed to short photoperiod even in the summer months. The current study showed that persistency of lactation was not different for farms with photoperiod management compared with farms without it. Long day photoperiod can increase milk production in lactating dairy cows but animal responses may be affected to a greater extent by other management practices.

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PREFACE

This thesis is an original work of Oswaldo S. Espinoza. The first study of the project using lactating dairy cows received research ethics approval by the University of Alberta Animal Care and Use Committee (under protocol # AUP00891) in accordance with the guidelines issued by the Canada Council on Animal Care.

The research conducted for this thesis was a collaborative project led by Dr. Masahito Oba at the University of Alberta. The experimental design and data analysis in Chapter 2 and 3 were conducted by Santiago Espinoza, with the assistance and contribution of Dr. Masahito Oba. DHI data for Chapter 3 was provided by DHI Canwest (Ontario, Canada).

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List of Abbreviations

ADF	Acid detergent fibre
AI	Artificial insemination
BCS	Body condition score
BST	Bovine somatotropin
BW	Body weight
CP	Crude protein
CVMA	Canadian Veterinary Medical Association
DIM	Days in milk
DM	Dry matter
DMI	Dry matter intake
EBVs	Estimated breeding variables
ECM	Energy corrected milk
FCM	Fat corrected milk
GH	Growth hormone
HG	High grain diet
HID	High intensity discharge
HPS	High pressure sodium
IGF-I	Insulin like growth factor
IMF	Increased milking frequency
LED	Light emitting diode
LG	Low grain diet
LP	Long photoperiod
LRC	Lighting research centre
Lx	Lux
ME	Metabolizable energy
MEC	Mammary epithelial cell
MG	Medium grain diet
MH	Metal halide
MP	Metabolizable protein

MUN	Milk urea nitrogen
NDF	Neutral detergent fibre
PCR	Polymerase chain reaction
PRL-r	Prolactin receptor
rBST	Recombinant bovine somatotropin
SCC	Somatic cell count
SCN	Suprachiasmatic nuclei
SP	Short photoperiod
ST	Somatotropin
VFA	Volatile fatty acids

1.0 Literature review

1.1 Introduction

Daylight and seasonal changes are fundamental elements for organisms that live on the earth. Throughout the ages animals have developed the ability to adapt to light intensity, variation and duration of daylight caused by seasonal changes, influencing their physiological conditions and mode of survival (Penev et al., 2014). In agriculture, egg production in poultry is controlled via photoperiod alteration (Leeson and Summers, 2008), in horse husbandry long day photoperiod prolongs or restarts the reproduction period (Aurich, 2011), whereas in dairy cattle long photoperiod increases milk yield (Peters et al., 1978; Bilodeau et al., 1989; Dahl et al., 1997). With this regard, a number of researchers investigated the effect of light day duration and light intensity on factors associated with better economic results in dairy cattle farms (Dahl and Petitclerc, 2003; Dahl 2005). Light is one of primary components of microclimate of farm animal environment. Proper illumination of animal premises is important for both animal welfare and safe and healthy working conditions for farm personnel.

1.2 Lactation persistency

1.2.1 Description

In dairy production, the capacity for mammary tissue to synthesize and secrete milk components is maximal at peak lactation and declines linearly thereafter (Collier et al, 2011). Persistency of lactation refers to extent of maintaining peak lactation yield with advancing lactation (Capuco et al., 2003). Gengler (1996) also defined persistency as a function of the flatness of the lactation curve, and this means that an animal with a flatter lactation curve is more persistent than others. Lactation persistency is determined by capabilities to maintain mammary epithelial cell (MEC) number and cellular secretory activity (Collier et al, 2011). According to Grossman et al. (1999), lactating dairy cows with the same peak yield can have different total annual yield (milk yield in 305-d lactation) due to differences in persistency, in other words, if cows are able to maintain their peak yield throughout the lactation, cows are considered more persistent.

1.2.2 Improvement of lactation persistency

Lactation persistency is influenced by management practices, such as administration of bovine somatotropin (bST), light manipulation, and milking frequency (Dahl et al., 2000; Capuco et al., 2003). Persistency is also affected by nutritional management (Sorensen et al., 2008), or by physiological status such as reproductive status (pregnant vs. open cows) (Bachman et al., 1988) or calving period (winter vs summer calving) (Gengler, 1996). Increasing the mammary gland ability to replace MEC cells that die during lactation is a key to enhanced persistency (Capuco et al., 2003). In addition, management and disease can potentially impact the proliferation or loss of MEC during lactation (Capuco et al., 2003). If persistency of lactation is increased, considerable economic benefits will be achieved by dairy producers (Mostert et al., 2008).

1.2.2.1 Use of bST

Somatotropin is a protein hormone produced by the anterior pituitary, and transported by the blood and it stimulates growth or cell reproduction.

Milk yield increases by 10 to 15%, and lactation persistency is improved when cows are treated with bovine somatotropin (bST) (Bauman et al., 1999; Tarazon-Herrera et al., 2000).

Milk yield gradually increases over the first few days of bST treatment and reaches a maximum during the first week. If treatment is terminated, milk yield gradually returns to pretreatment levels in approximately 2 to 3 days (Bauman and Vernon, 1993). However, milk composition is not affected by administration of bST (Bauman et al., 1999).

According to Bauman and Vernon (1993) and Gohary et al. (2014), the mechanism of bST action includes an increase in gluconeogenesis in the liver, a reduction in glucose oxidation, an increase in mobilization of glycogen reserves, and a decrease in the inhibitory effects of insulin on synthesis of glucose in the liver. Injections of bST act to supplement naturally-released somatotopin in the circulation of the cow (Tyler and Ensminger, 2006). This circulating bST binds to the receptors in the liver of the cow and stimulates production of insulin like growth factor (IGF-I); IGF-I mediates the nutrient partitioning, which results in increased milk production (Tyler and Ensminger, 2006).

Recombinant bovine somatotropin (rbST) is the bST commercial product used on dairy farms and it is slightly different that bST produced in the pitituary gland in the number of amino acids attached to the end of the bST molecule (Bauman, 1992). Since rbST was developed through recombinant DNA technology, consumers concerns regarding animal health and milk safety has been inmersed in controversy since 1980s (Dobson, 1996).

A meta-analysis was conducted by an expert panel established by the Canadian Veterinary Medical Association (CVMA). The panel was established by the CVMA in response to a request from Health Canada in 1998 and their report was made public in 1999 (Health Canada, 1999). The results from this meta-analyisis were also published at the Canadian Journal of Veterinarian Research in 2003 (Dohoo et al, 2003). The outcomes of the meta-analyisis indicated that cows treated with rbST increased the risk of clinical mastitis by approximately 25%, increased the risk of cow failing to conceive by approximately 40% (Dohoo et al, 2003). Further, cows treated with rbST had an estimated 55% increase in the risk of developing clinical signs of lameness (Dohoo et al, 2003). In January 1999, Health Canada announced that it would not approve the sale of rbST in Canada due to the negative effects of rbST in dairy cattle (Health Canada, 1999).

1.2.2.2 Milking frequency

Multiple hormones are released during milking including glucocorticoids, oxytocin and prolactin (Wall and McFadden, 2008). Bar-Peled et al. (1995) found higher concentrations of growth hormone, IGF-I, oxytocin and prolactin for cows that were milked three times daily compared with animals milked twice daily. Increasing milking frequency from twice a day to three times a day increases milk production approximately by 2.5 to 3.5 kg/d regardless of the level of milk production or parity (Tyler and Ensminger, 2006). Dahl et al. (2004) proposed a model in which frequent milking affects cow physiology through prolactin sensitivity, cows that are milked frequently have greater number of prolactin surges compared with those milked less than 3 times a day. As each milking induces a surge of prolactin; thus, cows milked four times a day would have twice the number of prolactin surges relative to cows milked twice daily. The greater number of prolactin pulses in cows milked more often, stimulates the sensitivity within mammary gland to prolactin (Dahl et al., 2004).

Dahl et al. (2004) and Wall and McFadden (2008) reported no effect of frequent milking on milk composition. Contrary to their observations, Smith et al. (2002) found a decreased milk fat concentration (3.52 vs. 3.74%, $P < 0.05$) for cows milked 3x per day compared with 2x. In addition, due to the increase in milk production in response to frequent milking, there is often an increase in the total yield of fat and protein (Wall and McFadden, 2008). More frequent milking reduced the incidence of clinical and subclinical mastitis by removing pathogens from the mamaty gland more frequently (Tyler and Ensminger, 2006).

1.2.2.3 Genetic improvement

Genetic evaluations for milk production and composition, somatic cell score and lactation persistency are calculated using each cow's 24-hour yields on each monthly test day. The main reason of genetic evaluations is to select superior bulls and cows as parents of the next generation. For production traits, bull proofs and cow indexes are expressed as Estimated Breeding Values (EBV), reflecting the animal's genetic potential for the specific trait, of which half is transmitted to their progeny (Van Doormaal, 2007).

According to the Canadian Dairy Network (2004), bull proofs reflect the average daughter milk yield expected at day 280 in lactation compared to day 60 in lactation (Holsteins), and expressed as a percentage. For each bull, proofs for lactation persistency are calculated separately for the first, second and third lactation and these are combined into an overall proof, which is commonly published by artificial insemination (A.I.) organizations and breed associations. For an example, bulls with an above average persistency proof have daughters with a flatter lactation curve compared to bulls with daughters that have an average decrease in daily milk yields after peak lactation. Thus, bull proofs for lactation persistency basically reflect expected daily milk yield of daughters at 280 days in lactation expressed as a percentage of their daily milk yield at day 60 (or day 90 for breeds other than Holstein).

1.3 Photoperiod management

1.3.1 Photoperiod description

Photoperiod is defined as the repetitive cycle of light and darkness within a 24-h period (Collier et al., 2006). According to Gwinger (1986), photoperiod is the relative duration of light and dark exposure within a day and it is the most commonly adapted environmental cue used by animals to predict changes in and alter physiological responses to shifts in their physical environment. Seasonal reproductive status, body growth, composition, and pelage changes are some examples of physiological consequences associated with photoperiod (Dahl and Petitclerc, 2003).

The length of photoperiod is affected by the latitude. At the equator, daylight is constantly 12 h a day throughout the year, but when latitude increases, photoperiod changes dramatically between seasons; daylight period is longest at the summer solstice and shortest at the winter solstice in the Northern Hemisphere (Webster et al., 1998).

According to Dahl et al. (2011), a long day photoperiod (LP) is considered as 16 to 18 h of light followed by 6 to 8 h of darkness in a 24-h period, and short photoperiod (SP) usually refers to 8 h of light and 16 h of darkness. The effects of photoperiod have been described during lactation in some species such as dairy cows (Dahl et al., 2000), sheep (Bocquier et al., 1990), goats (Terqui et al., 1984), and pigs (Stevenson et al., 1983).

The lactation of cows on long-day photoperiods (16-18 h of light/d) appears more persistent than that of cows on short days (6-8 h of light/d). Responses of photoperiod stimulation have been observed approximately 4 wk after initial exposure to long day (Dahl and Petitclerc, 2003).

1.3.2 Implementing photoperiod management

Lighting has become a new management practice on a dairy operation. Even though cows exposed to 6-8 h of light/d, does not result in disease or injury, it compromises reproduction and lactation performance (Tyler and Ensminger, 2006). According to Dahl (2005), the initial step in adoption of photoperiod management is assessment of the light presently available in the barn and other areas of housing.

To observe production responses in lactating cows, an intensity of 150 lx at 3 feet from the floor of the stall is recommended (Dahl, 2006; Tyler and Ensminger, 2006). Dahl (2005) mentioned that responses to LP have been observed at 100 lx average, and his recommendation of 150 lx is in case of dirty lamps or burned out bulbs. Darkness is also an important role in lighting manipulation; there was no difference on milk production between cows exposed to continuous lighting (24 h of light) and cows exposed to natural photoperiod (8-12 h of light/d) (Marcek and Swanson, 1984). The recommendation for facility lighting for lactating dairy cows is to provide continuous light for 16 hours followed by 8 hours of darkness (Dahl, 2006; Tyler and Ensminger, 2006).

1.3.3 Light intensity assessment

1.3.3.1 Units

Luminance is a measure of the *brightness* of a source. It is used to characterize the brightness of lamps and illuminated signs. Luminance is a useful measure in identifying sources that produce glare. Luminance is measured in candelas per square metre *(*Flesch, 2006; Hiscocks, 2008).

Illumination or illuminance is a measure of light falling on a surface; it is measured in lx and is used to quantify the light level. The technical definition of one lx is one lumen per square meter; lumens are a measure of the available lighting energy, and lx is the brightness after that energy is spread over a surface (Clarke and House, 2006; Hiscocks, 2008). That is, lighting a living room with one sixty-watt bulb gives a low level of brightness on the room surfaces whereas lighting a closet with the same bulb gives a higher level of brightness on the room surfaces because the available light energy is spread over a smaller area. Foot-candle is a similar unit of illuminance measurement; 1 foot-candle (fc) = 10.76 lx (Hiscocks, 2008). One foot candle is equivalent to the brightness produced by one candle at a distance of one foot (Clarke and House, 2006). Some common terms and units are shown in Table 1.1.

A light source is a device for converting electrical energy into light energy, the efficiency of that process is the luminous efficiency, measured in lumens per watt. Higher the number is, more efficient the light fixture is (Hiscocks, 2008).

1.3.3.2 Devices and technologies

The most common device to measure light intensity is a light meter or also known as photometer, illuminance meter, lux meter. This device is a single element detector that measures photometric brightness falling upon a surface using the unit of foot-candle or lx (Figure 1.1). Some common examples of illuminance are shown in Table 1.2

Another device called dimesimeter or daysimeter (Figure 1.2) was developed by the Lighting Research Center (LRC Troy, New York). Dimesimeter is a small, encapsulated data logging device that measured approximately 2 cm of diameter (Figueiro et al., 2012). Moreover, a dimesimeter is able to measure light/dark and activity levels continuously over many days. Through the light sensor is able to determine light spectrum and also measure illuminance levels (lx). Activity levels are measured using three orthogonal accelerometers, contained within a single electronic sensor package. Recordings of acceleration allow researchers to estimate the rate of energy expenditure of animals in their habitat (Wilson et al., 2006). Dimesimeter was designed to measure and record circadian light exposure for extended periods of time and its purpose was to determine circadian entrainment and disruption in humans (Figueiro et al., 2012).

1.3.3.3 Natural and artificial lighting.

Light sources can be natural or artificial depending on the purpose and quality of light required, and natural lighting is suitable in work areas where tasks can be adequately lit during the daytime such as open feedlots, naturally ventilated facilities, or areas within buildings that can be illuminated through windows (ASAE, 2005). Natural light may be supplemented with artificial light, especially in enclosed buildings (ASAE, 2005).

According to Tyler and Ensminger (2006), adequate lighting exerts beneficial physiological and behavioral effects in dairy cows. Cows cannot see well through areas of extreme shadow. Areas that are either very bright or very dark can induce avoidance behaviors and affect cow movement or stall use. In addition, proper lighting (light intensities > 150 lx) can provide safer and more pleasant work environment and better lights improve cow movement, observation and care (Janni, 2000)

1.3.3.4 Light fixtures

Janni (2000) suggested that light intensity, duration, color characteristics and uniformity are some of the criteria that farmers should consider in order to select and install a lighting system. The most common light fixtures used in dairy facilities are incandescent, fluorescent, high intensity discharged (HID), light emitting diode (LED), and induction (Table 1.3).

Incandescent lamps are only about 5% efficient at converting energy to light. The rest is wasted as heat energy. Incandescent lights also attract flies and other insects, and are quickly coated with dirt that further reduces the amount of light available. Incandescent lights also have a relatively short- life compared to other lighting types (Clarke and House, 2006).

Fluorescent lamps are very energy efficient compared to incandescent, and has long life cycle and can provide good light output for livestock. There are two kinds of fluorescent systems used on farms: compact and tube fluorescents (Clarke and House, 2006). The compact fluorescents can be used to replace incandescent lights, and are a very good choice in dairy barns when low levels of light are required. Fluorescent tubes come in a variety of lengths and diameters. Typically, farms use 4-foot lengths (1.2m). Tube diameter is measured in eighths of an inch: T12 (1.5 in.), T8 (1 in.) and T5 (0.6 in.) (Clarke and House, 2006). Fluorescent lights have ballasts that start and keep the bulbs lit. Electronic ballasts are recommended because they are more energy efficient, generate less heat, have a longer life expectancy, and operate and start at colder temperatures (0° F) than other ballasts (Janni 2000). It is very commonly used in dairy facilities; a few reasons to switch to fluorescent lighting from incandescent are energy savings, price, duration, and sooner payback (Clarke and House, 2006).

High intensity discharged (HID) lights are commonly used where barn ceilings are more than 3.7 m high. Two types of HID fixtures are metal halide (MH) and high pressure sodium (HPS). HID fixtures require ballasts for their operation (ASAE, 2005). Mercury vapor lights give off a bluish light and have been commonly used as yard lights (Janni 2000; Clarke and House, 2006). They are not recommended for use in dairy facilities because the mercury in burned-out lights can be an environmental hazard (Janni 2000; Clarke and House, 2006).

Light emitting diode (LED) is a semiconductor light source. On average LED has a longer life compared with fluorescents (100,000 vs. 20,000 h), environment friendly, and energy efficient with five times less power consumption of incandescent lamps. Thus, LED performs well in cold conditions and contains no mercury, which eliminates potential gaseous hazards from broken lamps (Clarke and House, 2006; Sieniewicz, 2013). Although LED consumes less power it is still the most expensive option in the market (Sieniewicz, 2013).

Induction lights are a new technology, also known as electrodeless. It is a type of fluorescent lamp which uses magnetic coil to excite the gases instead of passing the current through the gases. Induction lights are more affordable than LED and normally last double the time (Sieniewicz, 2013). However, this fixture is sensitive to cold environment and requires a warm-up period (Sieniewicz, 2013).

1.3.4 Photoperiod effects in agriculture animals (Small ruminants, pigs, poultry)

Even though photoperiod effects have been studied mostly in dairy cows, other domestic's species such as sheep, goats and pigs respond to light manipulation (Dahl and Petitclerc, 2003).

Morrissey et al. (2008) reported Australian crossbred dairy ewes exposed to long day photoperiod (LP, 16 h of light/d) produced 15.4% more milk relative to ewes housed under naturally declining day length during winter. Furher, Morrisey et al. (2008) observed that plasma prolactin concentrations increased by 3 folds for ewes in LP, whereas milk composition was not affected by photoperiod treatment. Long day photoperiod increased fat content 5.2 % in lactating goats, whereas milk protein concentration was slightly decreased – 2.2% compared to goat exposed natural photoperiod (Garcia-Hernandez et al., 2007). However, the milk composition of goats in subtropical areas is not affected by photoperiod (Flores et al., 2011).

Reproduction in small ruminants follows a seasonal pattern; photoperiod is the essential factor driving reproductive seasonality. Sheep and goats are short-day breeders, and decreasing day length stimulates the seasonal onset of cycling activity (Fleisch et al., 2015). Long days are achieved by providing artificial light whereas short days are simulated through melatonin implants. In goats, natural short day has been shown to be as effective as melatonin application (Chemineau et al., 1992; Fleisch et al., 2015).

Stevenson et al. (1983) indicated that long day photoperiod (LP; 16-h light/d) influenced productivity of swine where litter weight is increased 3.3 kg/d and return to postweaning estrus more synchronous when sows were exposed to LP during 4 weeks of lactation compared with sows in the control (< 1h supplemental light/d). Milking frequency and total milk solid contents were greater in sows exposed to long photoperiod, which also had heavier piglets at weaning and weaned more pigs per litter relative to sows on short photoperiod (8 h of light, 16 h of darkness; Niekamp et al., 2006). Supplemental light appeared to influence subsequent sow reproductive performance; the average interval to rebreeding tended to be shorter in LP than sows in natural lighting (Stevenson et al., 1983; Niekamp et al., 2006).

In poultry, Leeson and Summers (2008) have shown that the color of light can exert variable effects on behavior, growth, and reproduction. Birds sense light through their eyes (retinal photoreceptors) and through photosensitive cells in the brain (extra-retinal photoreceptors). Since long wavelengths of light (towards red end of the spectrum or near infra-red) penetrate the skin and skull more efficiently than short wavelengths (toward blue end or

Ultra-violet), and it has been observed that growth and behavior are positively linked to retinal photoreception whereas shorter wavelengths where lead of reproduction has been linked to extra-retinal photoreceptors. From these observations, it has been suggested that blue light has a calming effect on birds, but red light has been used to reduce cannibalism and feather picking (Leeson and Summers, 2008). It has also been shown that blue-green light stimulates growth in chickens while orange-red stimulates reproduction (Leeson and Summers, 2008).

1.3.5 Photoperiod effects in dairy cattle

Environmental factors, including thermal stress and photoperiod, affect feeding behavior, health, growth and milk production of dairy cattle (Casey et al., 2014). In the dairy industry, light manipulation is important because this approach is "a safe, non-invasive and effective method to increase milk production" (Auchtung et al., 2004).

1.3.5.1 Lactating cows

In 1978, Peters and colleagues were the first ones who reported that dairy cows exposed to 16 to 18 h of light and 6 to 8 h of darkness increased milk yield (Peters et al., 1978). This effect was consistent whether cows were in early lactation or late lactation (Peters et al., 1981). However, in the study of Peters et al. (1981), data were collected for only 20 wk after initial exposure to light treatments.

After the findings of Peters et al. (1978), Marcek and Swanson (1984) exposed dairy cows to continuous light 24-h light: 0-h dark, long day 18-h light: 6-h dark, or natural day 9 to12-h light/day photoperiod. They showed that cows that were initially exposed to natural photoperiod increased milk yield after exposure to long day photoperiod; however, cows that were initially on continuous lighting were not affected by long day photoperiod (Marcek and Swanson 1984).

Extensive research has been done to confirm the effects of photoperiod on milk production. Dahl et al. (2000) summarized many studies published between 1978 and 2000, and showed that most studies reported an increase in milk yield by 0.5 to 3.3 kg/d for cows exposed to long day photoperiod. A summary of the effects of photoperiod during lactation is presented in Table 1.4.

Not only increasing milk production but also milk components are important to dairy producers. Dahl et al. (2000) stated that the fat concentration in milk was not affected in cows exposed to long day photoperiod but a study in commercial dairy herds reported small decreases (0.16 - 0.18%) in milk fat concentration (Stanisiewski et al., 1985).

Furthermore, long day photoperiod also affects secretion of prolactin, IGF -I, and dry matter intake (DMI). Both heifers and cows exposed to long day photoperiod increased their DMI compared with those in short or natural photoperiod, however the effect on DMI is not sufficient to explain the increase in milk production, indicating that feed-to-milk conversion may be more efficient under long day photoperiod (Bilodeau et al., 1989, Dahl, 2006).

1.3.5.2 Dry cows

The dry period commonly refers to the 40-60 day prepartum of a lactating dairy cow. Optimal management of dry cows is of biological and economic importance because several factors, including the length of the dry period, can influence milk production in the subsequent lactation. Manipulation of photoperiod during the dry period is a management tool that affects subsequent milk yield in dairy cows (Lacasse et al., 2014).

Miller et al. (2000) hypothesized that LP during the dry period would increase milk yield in the subsequent lactation, based on studies conducted on lactating animals. However, they found that SP during dry period significantly increased milk yield by 3.2 kg/d in the subsequent lactation compared with those exposed to LP. Auchtung et al. (2005) observed similar response, where dry cows exposed to short photoperiod produced ~3 kg/d more milk in the subsequent lactation than dry cows exposed to long photoperiod.

Following studies evaluated effects of length of photoperiod treatment during the dry period on milk production. Velasco et al. (2008) tested the hypothesis that a 42-day dry period would be sufficient to detect an effect on milk production using short photoperiod (SP; 8 h of light, 16 h of darkness). Velasco et al. (2008) found an increase of 3.5 kg/day more milk for cows in SP in the subsequent lactation than animals exposed to LP (16 h of light, 8 h of darkness) during the dry period. Miller et al. (2000) and Auchtung et al. (2005) found similar galactopoietic response to Velasco's study, but in these two studies, cows were given a 60-day dry period. In contrast, a study conducted by Reid et al. (2004) reported that reducing photoperiod exposure to 21 d during the dry period; the galactopoietic effects of short photoperiod on the subsequent lactation were not found.

Increasing milk production by photoperiod manipulation is beneficial if it does not negatively affect milk composition (Dahl et al., 2000). Short days (16 h darkness, 8 h of light) during the dry period improved DMI (1.3 kg/d) relative to long days (8h darkness, 16 h of light) (Miller et al., 2000). Thus, greater intake during late gestation may account for some of the response to light, but shifts in mammary cell commitment during the transition are also likely to contribute to the response of milk yield. One potential mechanism to explain greater mammary epithelial cell commitment is a relative increase in sensitivity to prolactin, the hormone that drives cellular differentiation during the transition into lactation (Collier et al., 2006). Aharoni et al. (2000) reported slight increase in milk fat and protein concentrations in response to SP for three weeks prior to parturition. This study, however, was based on correlations between day length and milk components of dairy cows in hot climates (Israel). Other studies have reported no change in primary milk components (fat, protein, lactose content) in cows exposed to SP during the dry period (Miller et al., 2000; Auchtung et al., 2005; Velasco et al., 2008).

Although DMI was greater 1.3kg/d for cows is short photoperiod (Miller et al., 2000) than cows in long photoperiod, there was no effect of photoperiod on body weight for those cows with increased DMI (Auchtung et al., 2005; Crawford et al., 2005). Nevertheless, the increase in DMI may be beneficial to the subsequent lactation through an increase in tissue energy reserves, which could then be mobilized to support milk production after parturition (Miller et al., 2000).

1.3.5.3 Heifers

Exposure of young animals to different photoperiods can affect their growth. Peters et al. (1978) evaluated the effect of LP on weight gain in heifers and reported increased weight gain of 10-15% compared to heifers exposed to natural photoperiod (~9.8 h light). The authors also found that DMI increased by 6.1%, and the feed-to-gain ratio for heifers on long day photoperiod was low relative to controls (Peters et al., 1980, 1981). From these studies, the authors concluded that heifers on long day photoperiod were more efficient at converting feed to body mass than heifers on natural photoperiod.

In dairy heifers, exposure to LP relative to SP also decreased the time to reach puberty. Subsequently, heifers exposed to LP grew more rapidly than heifers on SP and ultimately produced more milk in their first lactation (Rius and Dahl, 2006). In summary, long day photoperiod can lead to leaner growth, greater mammary development, and lower the age to puberty by an average of one month.

1.3.5.4 Immune system

Holstein calves exposed to long day photoperiod increased lymphocyte proliferation relative to short day photoperiod calves (Auchtung et al., 2003). However, short day photoperiod during the dry period has a positive impact on the immune system of dairy cows compared to long day photoperiod; neutrophil chemotaxis and lymphocyte proliferation increased under SP during the periparturient period relative to LP (Auchtung et al., 2004). From this finding, it was suggested that SP might have a protective effect on the mammary gland, which could increase milk production in the subsequent lactation (Auchtung et al., 2004).

In addition, Collier et al. (2006) suggested that prolactin and prolactin receptor (PRL-r) expression are inversely related in bovine hepatic, mammary and immune tissues. Therefore, SP reduces circulating prolactin but increases PRL-r compared with cows exposed to LP. Further research found that prolactin sensitivity was directly proportional to in vitro and in vivo indices of immune system; greater PRL-r expression under SP was linked with increased lymphocyte proliferation, neutrophil chemotaxis and a reduction in somatic cell count.

1.3.6 Photoperiod physiology

Light information captured by the retina is conveyed to the brain through the retinohypothalamic tract and converted to chemical signals in the suprachiasmatic nuclei (SCN) of the anterior hypothalamus (Reppert and Weaver, 2001). The SCN translates light information to hormonal and autonomic outputs by way of the pineal gland and the paraventricular nucleus. Melatonin is secreted from the pineal gland during the dark. Light inhibits activity of the rate-limiting enzyme in melatonin synthesis, N-acetyltransferase (Reppert and Weaver, 2001). Thus, secretion of melatonin from the pineal gland is low during exposure to light. But, when lights are off, the melatonin secretion rapidly increases; therefore, elevated concentration of melatonin is observed during the dark period (Dahl et al., 2000).

1.3.6.1 Melatonin

Melatonin (N-acetyl-5-methoxy tyrptamine) is a hormone secreted from the pineal gland during the dark phase. The secretion of melatonin provides the body with information on the time of day by amplitude of melatonin concentration, and the time within the year by duration of enhanced melatonin concentrations (Lincoln et al., 2003).

Blood melatonin concentration is commonly used as a response measure of light exposure. As reviewed by Arendt (1986), animals require varying amounts of light to inhibit melatonin secretion. Humans require relatively high levels of light intensity (1,500-2,500 lx) to suppress nocturnal melatonin secretion (Lewy et al., 1980). In contrast, in dairy heifers, the minimum intensity of light needed to depress night time blood melatonin concentrations to daytime levels is 400 lx whereas 50 lx is sufficient to inhibit the initial rise in plasma melatonin levels (Lawson and Kennedy, 2001).

Melatonin affects immune function both through direct action on immune cells and through systemic adjustments (Walton et al., 2011). Carrillo-Vico et al. (2005) summarized extensive research on the effects of melatonin on immune function, and concluded that melatonin enhances both acquired and innate immunity across numerous species. Exogenous treatment with melatonin increases thymus weight in gerbils and proliferation of mouse splenocytes and rat lymphocytes (Carrillo-Vico et al., 2005).

1.3.6.2 IGF – I

Dahl et al. (1997) postulated the galactopoietic effects of LP exposure during lactation may be mediated by IGF-I. Circulating IGF-I increases in dairy cows exposed to long day photoperiod (16 to 18 h/d) compared to natural day (≤ 13 h light) photoperiod (Dahl et al., 1997). The increase in circulating IGF-I precedes the increase in milk yield by approximately 4 weeks, suggesting that IGF-I may mediate long-term changes in mammary function (Dahl et al., 2000). Furthermore, Pre-pubertal heifers exposed to LP for 4 months increased circulating IGF-I concentration compared with heifers on SP (Spicer et al., 2007).

1.3.6.3 Prolactin

Prolactin has been the most intensely studied hormone related to mammary function. Prolactin is a peptide hormone secreted from the par tuberalis of the pituitary gland (Freeman et al., 2000). Named for its predominant role in lactation, prolactin has additional actions in water/salt balance, immune function, and seasonal time-keeping. Seasonal prolactin release regulates metabolism, food intake, pelage, and reproductive functions including gonadal activity, pregnancy, and lactation (Lincoln et al., 2003). Parturition is associated with a major peak in prolactin concentration, and the suppression of prolactin prevents lactogenesis; suckling and milking are also powerful inducers of prolactin release, but this response decreases as lactation progresses (Lacasse et al., 2015). The hypothesis that prolactin is galactopoietic in ruminants is also supported by the fact that a long-day photoperiod increases prolactin concentration and milk production (Peters et al., 1981; Bilodeau et al., 1989).

The circulating level of prolactin might also affect mammary gland responsiveness to prolactin. A short-day photoperiod during the dry period reduced circulating prolactin concentration during the dry period and increased subsequent milk production (Auchtung et al., 2005; Lacasse et al., 2014). Auchtung et al. (2005) reported that the mammary glands of cows exposed to a short day photoperiod during the dry period had a higher expression of prolactin receptors than did the mammary glands of cows exposed to a long-day photoperiod. This difference was observed for both the long and short receptor isoforms and persisted throughout the dry period and during the first days of lactation (Auchtung et al., 2005). Accordingly, the infusion of recombinant prolactin into cows exposed to a short-day photoperiod during the dry period reduced the milk response (Crawford et al., 2005).

1.4 Lighting technology in dairy barns

According to Clarke and House (2010), an average 14% of electrical consumption in dairy operation is attributed to lighting. Further, in Ontario the average consumption of electricity in dairy farms is between 800 – 1400 kWh/cow/year. Energy costs can be reduced by providing the most efficient lighting system on the farm, since light fixtures with new technologies are more efficient energetically, and last longer than incandescent lights (Clarke and House, 2006).

1.4.1 Recommended light levels for dairy facilities

In order to stimulate milk production, the lighting system must provide a minimum of 150 lx of illuminance at 3 feet from the floor of the stall throughout the barn for 16 to 18 h per day continuously (ASAE, 2005; Dahl, 2005). Providing light for 24 h a day does not produce a sustainable increase in milk yield, and operating use of the lighting system more than necessary wastes energy (ASAE, 2005; Stanisiewski, et al,. 1988).

In addition to providing adequate levels and duration of light for animals, a high level of uniformity is required in the parlor pit, office and milk room washing area. These areas require high uniformity to perform demanded tasks. More recommendations about light levels on dairy facilities are shown in Table 1.5.

1.4.2 Light installations and designs

Clark and House (2006) pointed out four factors that dairy producers should look at before they choose a lighting system: room temperature, mounting height from floor to ceiling, size of area to be lit, and payback period. The placement of the lamps should ensure that all areas of the barn reach this illumination requirement (Dahl, 2006; Tyler and Ensminger, 2006). Lamps are sold with a recommended range of mounting height, and a rule of thumb for placement of lamps is a mounting distance that is 1.5 times the mounting height, mounting height is measured from the bottom of the lamp to a level 3 feet from the floor of the stall. (Chastain, 2000). Regardless of lighting design, all lighting systems should be tested with a light meter, because photoperiod management requires light intensity to be monitored, a light meter should be used continuously after the initial installation (ASAE, 2005; Dahl 2005).

For smaller tie-stall or stanchion barns, lighting requirements can be accomplished using standard 40-watt fluorescent light as long as the mounting height is less than 10 feet, separation distances should not exceed 15 feet, and lamps should be in front of the animal rather than in the alley (Tyler and Ensminger, 2006). Larger free stall barns with higher sidewalls and mounting heights of over 20 feet in general require metal halide or high pressure sodium fixtures (Tyler and Ensminger, 2006).

Regardless the type of light fixtures, lamps should be mounted above stalls and above feedbunk to provide light where the cows spend most of their time, the total lumens required are calculated by multiplying the square footage of the facility times the desired foot-candles of intensity times a constant (K). The K is a constant that accounts for light reflected in and escaping from the barn; K = 2 in enclosed barns including tie-stall or stanchion barns and K = 3 in open sided free stall barns (Tyler and Ensminger, 2006). If a dairy producer desires to calculate the number of fixtures required, the calculation uses the following formula (Buyserie et al, 2001):

$$Number\ of\ fixtures\ required = \frac{Square\ footage\ of\ barn\ x\ 15\ FC\ x\ K}{Lumen\ output\ per\ lamp}$$

Square footage of barn = dimensions of the barn (length by wide)

15 FC = minimum intensity required (15 FC = 150 lx)

K = constant that accounts for light reflected in and escaping from the barn.

Lumen output per lamp = It varies depending on the light fixture

For example, 10,000 square foot open sided barns lit by 250 watt metal halides require 22 fixtures.

A photocell (a sensor that detects light) and a timer can decrease annual energy cost and increasing lamp life. The photocell should be placed where it is exposed to light of similar intensity as inside the barn, such as under a side eave outside. It should not be exposed to the barn's artificial lighting. When sunlight provides the required 150 lx, the photocell will turn off the lights. The timers will assure that the lights and photocell are on for a desired length of period (Buyserie et al. 2001).

Dim red lighting may be used to facilitate visual inspection of cows during darkness. For example, 15-W red incandescent bulbs placed at 20- to 30-feet intervals in a barn provide enough illumination to inspect animals as they approach calving (Dahl et al., 2004)

1.4.3 Cost analysis

Dahl (2003) summarized the financial investments and gains of using long day photoperiod for lactating animals. Assuming a milk response of 2 kg/d from each cow, income in response to long day yields a gross return of $ 1.60/cow/d (1 kg = $0.80). It is expected that an increase of 1 kg/d in DMI would be needed to support the higher milk yield ($0.31/cow/d). Additionally, cost of quota should be estimated but it was not consider by the calculation. In a free-stall barn housing 250 cows, Dahl (2003) estimated 72 fixtures would be required at a cost of $200/ metal halide fixture plus the additional $200 for the installation of each fixture and also adding the installation of timers $1000. This resulted in a $119 capital cost per cow. Additional non-cash associated cost is $0.86/cow/d. Calculation of the payoff of implementing this lighting regimen, including the costs of additional feed and electricity, yields a net return of $0.43/cow/d or \$107.5/farm/d. Based on the initial investment of \$116/cow it would take a farmer 270 d to recover the expense. Dahl (2005) noted that the returns on investment are greater in larger dairies, although it is still a profitable management strategy for dairy farms of all sizes. Overall, exposure of cows to long day photoperiod by supplemental lighting during lactation requires a significant initial investment, but in the long-term, it may increase profitability of dairy operations.

1.5 Combination of photoperiod with other management practices

It is also of interest to consider the interaction effects of photoperiod treatment in combination with other management practices, particularly the use of bST, milking frequency or nutritional management. Galactopoietic effects of bST, milking frequency, and long-day photoperiod are additive (Dahl et al., 2000; Capuco et al., 2003). It is reasonable to assume that effects on persistency will be additive as well, and that the greatest persistency can be achieved by a combination of the three management practices (Capuco et al., 2003).

Producers may have considerable flexibility in incorporating these practices. For example, increased milking frequency (IMF) at the beginning of lactation has been shown to increase milk yield not only during IMF, but also after its cessation (Bar-Peled et al., 1995). Although no controlled studies have been conducted to verify that cows milked 3×/d will respond to long day photoperiod, a number of producers have combined these two approaches with success (Dahl, 2005). In photoperiod management, it is very important to keep a 6 h of uninterrupted darkness period between two of the three milkings. This may require coordination of milking schedules and darkness in different sections or barns (Dahl, 2005).

Long day lighting can also be combined with bST for an additive response (Miller et al., 1999, Dahl, 2005). In an experiment reported from the University of Maryland, cows were treated with bST, long days or the combination, and milk yield was compared with that of control cows exposed to natural photoperiod (Miller et al., 1999). Long days alone increased milk yield by approximately 1.9 kg/d, bST increased milk yield by 5.3 kg/d, and the cows receiving both treatments produced an average of 6.5 kg/d more milk than the control cows. In addition, cows on long day photoperiod and bST increased DMI sooner than cows receiving bST under natural photoperiod (Miller et al., 1999). Although milk production was greater for cows in long photoperiod and bST, Miller et al. (1999) did not detect an interaction effect ($P = 0.78$) between photoperiod treatment and bST administration.

Photoperiod management was also combined with nutritional management. Bilodeau et al. (1989) conducted an experiment with lactating Holstein cows fed corn or barley grain in total mixed rations (TMR) and exposed to either long or short day photoperiod. Bilodeau et al. (1989) reported that milk production increased for cows exposed to long photoperiod compared to the cows in short photoperiod. The response was observed 4 weeks after initial exposure; although cows were fed ad libitum, there were no significant interaction between photoperiod treatments and type of grain on DMI, milk yield and composition (Bilodeau et al., 1989).

To meet the energy requirements of high producing lactating dairy cows, diets typically contain relatively high proportions of concentrate and high quality forages. Greater diet concentrations of starch from feeding more grain in the diets may increase milk production, but it can also lead to a variety of metabolic disorders, including subclinical ruminal acidosis, reduced fiber digestion, milk fat depression, displaced abomasum, laminitis, and fat-cow syndrome (NRC, 2001).

1.6. Nutritional management

Feeding high grain diets is one approach to meet the energy requirements of a lactating dairy cow especially due to shortage or scarcity of high quality forage. Further, as the proportion of grain in the diet increases, rumen pH, rumen acetate: propionate ratio, and milk fat percentage decrease (Solorzano et al., 1989).

In a study conducted by Emmanuel et al. (2008), dairy cows were fed barley grain in the ration at 4 different proportions (0%, 15%, 30 %, and 45 % of DM), and they found the greatest milk yield (31 kg/ for cows) for cows fed 45% barley grain, followed by cows fed the 15% and 30% diets (28.1 and 28.9 kg/d) and with lowest milk yield for cows that were not fed barley grain (27.1%). Diets with greater content of barley had greater concentration of starch. Starch is degraded by rumen microorganism to provide high amounts of glucose and microbial protein (Reynolds, 2006). Glucose is the precursor for synthesis of lactose in the mammary gland; thus, increasing concentrations of propionate in the rumen improve milk yield (Rigout et al., 2003).

1.7. Summary

Management practices such as photoperiod manipulation, milking frequency, administration of bST, or nutritional management can influence persistency. The effect of combination of photoperiod manipulation with other management practices has been studied previously, but the combination between photoperiod management with dietary grain allocation has not been evaluated yet. Further, although photoperiod management is expected to influence persistency of lactation in dairy cows, information regarding photoperiod management practice on commercial dairy farms in Alberta is limited. A relationship between photoperiod that cows are exposed to and persistency of lactation at commercial dairies in Alberta needs to be evaluated. The purposes of this thesis work are to evaluate the interaction effects of photoperiod management and dietary grain allocation in lactating dairy cows (Chapter 2), and to determine if any relationships exist between photoperiod management and the persistency of lactation in selected dairy herds in Alberta (Chapter 3).

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Table 1.1 Lighting terms and Units

Term	**Unit**	**Description**
Luminous Flux	Lumen	Total light source output in all directions; the flow of light
Luminous Intensity	Candela	A point source of light shining in a particular direction
Illuminance	lx (lumens/m^2) Foot candles ^{2})	Density of light reflecting off a plane surface
Luminance	Candela/m^2	Density of light reflecting off a plane into our eye
Color Rendering Index (CRI)	Scale 50 to 100	Measure of color accuracy 50 is a warm white fluorescent and 100 is an incandescent at a particular color temperature.
Color Temperature	Kelvin	Measure of warmth or coolness of the color of light 7500 K is blue-white and <2000 K is red.

Adapted from (Hooper, 2009)

Table 1.2 Examples of illuminance

Item	**Light Intensity (lx)**
Sun, summer day	32000 to 100000
Sun, winter day	3000 to 4000
Bright office	400
Domestic lighting	40 to 150
Street lighting	3 to 30

Table 1.3 Comparison of lamp types

Lamp Type	Lamp size (Wattage)	CRI	Color	Efficiency (lumens/W)	Typical lamp life (hr)
Incandescent	25-200	100	White	7-20	750-1000
Halogen	45-500	100	White	12-21	2000-6000
Fluorescent T12	30-75	52-90	White	62-80	9000-12000
Fluorescent T8	25-59	60-86	White	76-100	15000-20000
Fluorescent T5	24-80	80-85	White	85-105	20000-24000
Compact Fluorescent	14-29	82	White	45-55	6000-1000
Induction	40-400	80	White	80	60000-100000
Metal Halide	35-1000	60-80	Bluish	60-94	7500-20000
High Pressure Sodium	35-1000	22-70	Yellow-orange	66-90	24000
LED	2.5-100	70-95	White	4.5-150	30000-100000

Adapted from (Clarke and House, 2006)

Table 1.4 The effects of photoperiod manipulation during lactation in dairy cows

		Response to long day photoperiod			
Author (reference)	**Photoperiod Treatments (h light: h dark)**[1]	**Milk yield**	**DMI**	**Fat %**	**Hormone response / Additional information**
Peters et al. (1978)	LP vs natural (9.8 h/d)	↑ 2.0 kg/day	NR[2]	No change	NR
Peters et al. (1981)	LP vs natural (9.8 h/d)	↑ 1.4 kg/day	↑ 6.1%	No change	↑ prolactin secretion
Marcek and Swanson . (1984)	LP 18:6: vs. natural (9 -12)	No effect heifers ↑ 7 % FCM cows	NR	No change	prolactin secretion = SP
Stanisiewski et al. (1985)	16-16.25 h vs natural (9-12 h/day)	↑ 2.2 kg/day	No change	↓ 0.16 %	NR
Bilodeau et al. (1989)	LP vs (8l:2d:2l:12 d)	↑ 2.0 kg/day	↑ 4 %	No change	No interaction effect between type of grain and photoperiod
Evans and Hacker (1989)	Natural (12-13 h) vs skeletal photoperiod	↑ 2.8 kg/day	No change	No change	↑ prolactin secretion
Newbold et al. (1991)	LP vs SP	No change	NR	NR	↑ prolactin secretion ↑ secretion melatonin under SP
Dahl et al. (1997)	Natural (<13 h/d) vs 18:6	↑ 2.2 kg/day	No change	No change	↑ IGF-I secretion
Reksen et al. (1999)	Natural vs LP	↑ 0.5 kg/day	NR	NR	NR, evaluated in commercial dairy herds in Norway
Miller et al. (1999)	LP (18 :6) vs SP (9.5-14.5:14.5-9.5)	No change	↑ 3.5 %	No change	IGF-I no change Prolactin no change No interaction effect bST and photoperiod

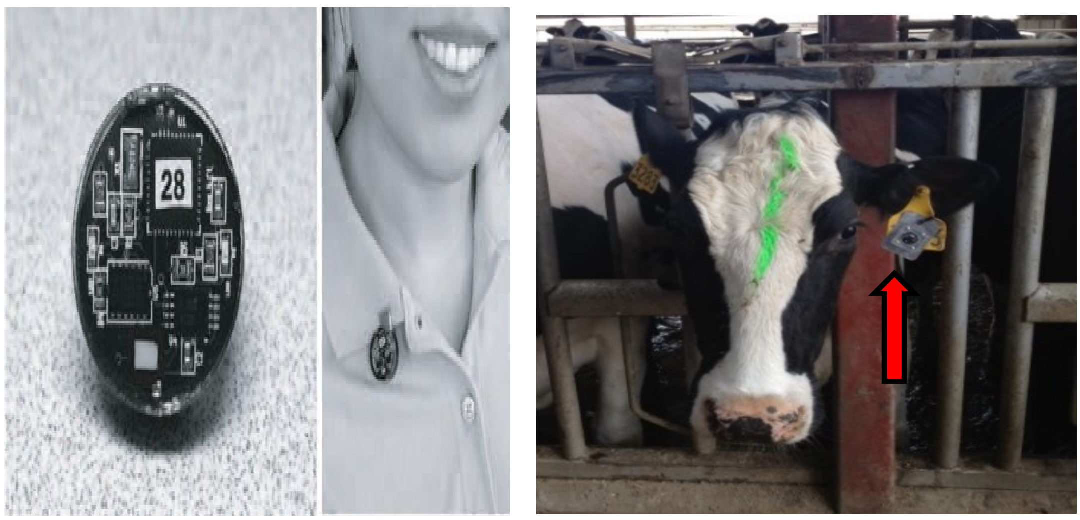
[1] l = hours of light/d; d = hours of darkness/d
[2]NR = No reported

Table 1.5 Recommended light level for Dairy Livestock Facilities

Work area or Task	Illuminance (lx)
Parlor, pit and near under	500
Parlor, stalls & return lanes	200
Parlor, holding area	100
Milk room, general	200
Milk room, washing	750-1000
Stall barn, manger alley	100
Stall barn, milking alley	200
Drive-through- feed alley	200

Adapted from (ASAE, 2005)

Figure 1.1. Light meter. Extech SDL 400 (Extech Instruments, Nashua, NH)



a) Dimesimeter*

b) Cow with dimesimeter on ear tag**

Figure 1.2. Common devices that measure light intensity. Dimesimeter

* Adapted from Figueiro et al. (2012).

** Provided by LRC (personal communication)

2.0 STUDY 1: Effects of photoperiod and dietary grain allocation on productivity of lactating dairy cows.

2.1 Introduction

Milk production in dairy cows is influenced by management factors such as administration of bovine somatotropin (bST), photoperiod manipulation, milking frequency (Dahl et al, 2000) and nutritional management (Sorensen et al., 2008). However, bST cannot be used in Canada and frequent milking may not be feasible in some dairies due to labor shortage.

The importance of photoperiod manipulation in the dairy industry is because it is a management practice that improves milk production in a safe, non-invasive manner (Auchtung et al., 2004). Previous studies showed that lactating dairy cows exposed to 16 h of light and 8 h of dark increased milk yield by 8 to 10 % relative to cows on natural photoperiod (8 -12 h of light) (Bilodeau et al., 1989; Dahl and Petitclerc 2003). The galactopoietic effects of long day photoperiod have been attributed to the greater plasma concentrations of insulin as a growth factor (IGF-I) (Dahl et al., 1997) and prolactin (Peters et al., 1981; Miller et al., 1999).

The interaction of long day photoperiod with other management practices has been studied previously. Miller et al. (1999) found that the combination of long day photoperiod and administration of bST increased milk yield compared with cows exposed to short photoperiod or treated with bST. Bilodeau et al. (1989) evaluated interaction effects between photoperiod treatments and type of grain (rolled barley and cracked corn) on dry matter intake (DMI), milk yield and composition, and did not detect significant interactions. Nevertheless, information regarding interaction of dietary grain allocation and photoperiod management is limited. Thus, the primary objective of the current study was to determine the interaction effects of photoperiod management and dietary grain allocation on the productivity of lactating dairy cows. We hypothesized that the combination of high grain diet and long photoperiod would increase milk production synergistically.

2.2 Materials and Methods

The current experiment was conducted at the Dairy Research and Technology Center at the University of Alberta (Edmonton, Alberta, Canada). All procedures were pre-approved by the Animal Care and Use Committee for Livestock at the University of Alberta and conducted according to the guidelines of the Canadian Council of Animal Care (Ottawa, Ontario, Canada).

2.2.1 Experimental Design, Diet and Treatment

Sixty Holstein cows in mid-lactation (milk yield = 38.1 ± 8.27 kg/d, DIM = 113 ± 36.0, lactation = 1.9 ± 1.10; mean ± SD) were blocked by milk yield, DIM and parity and randomly assigned to either a long photoperiod (LP; 16-h light from 0300 to 1900 and 8-h darkness; n = 30) or a short photoperiod (SP; 8-h light from 0800 to 1600 and 16-h darkness; n = 30) treatment. Animals were housed in a tie-stall barn with metal halide light fixtures controlled by timers and assigned to different locations of the barn according to the photoperiod treatment. In order to minimize light leakage (cross lighting between barn sections) the distance between the groups was approximately 30 m. The study was conducted during the winter months (November, 2013 – April, 2014, n = 30) and repeated in the following year (November, 2014 – April, 2015, n = 30) with location being switched to avoid the confounding effects of location in the barn with photoperiod treatment; in the first year, animals on the LP treatment (n = 15) were housed at the end of the barn and animals on the SP treatment (n = 15) were housed in the middle section of the barn, and for the second year, stalls at the end of the barn were used for the SP treatment (n =

15) and stalls in the middle section were used for the LP treatment (n = 15, Figure 2.1). Light intensity was recorded with light meter/data loggers (Extech SDL 400, Extech Instruments, Nashua, NH) in both sections at a height of 1.6 m at the beginning of the study and during the data and sample collection weeks. Light intensity measured at 1.5 m height was 202 ± 33 lx (mean ± SD) and 9 ± 5 lx, respectively when lights were on and off. After a 30-d light adaptation period, cows within each photoperiod treatment were fed three diets in a 3 × 3 Latin square design, balanced for carryover effects, with 4-wk periods (Figure 2.2). The first 3 wk were used for diet adaptation and the last week was used for data and sample collection. The dietary treatment was the content of steam rolled barley grain at 15 (low grain; LG), 25 (medium grain; MG), and 35% (high grain; HG) of dietary DM. Barley silage and alfalfa silage were fed at the ratio of 2:1 on a DM basis. Although energy allowable milk (kg/d) was different for the three diets, metabolizable protein allowable milk yield was similar for all dietary treatments (Table 1). All cows were individually fed experimental diets as total mixed ration (TMR) and had free access to water. Cows were fed once daily at 105 to 110% of actual feed intake of the previous day. Feed ingredient samples were collected daily during sample collection periods. The DM concentrations of alfalfa silage and barley silage were determined weekly and as-fed diet formulation was adjusted if necessary. Cows were milked in their stalls twice daily at 0400 and 1500 h.

2.2.2 Data and sample collection

Cows were weighed after the morning milking on two consecutive days immediately before the start of the experiment and at the end of each period. Body weight and BCS (5-point scale; 1 = thin and 5 = fat; Wildman et al., 1982) were measured at the beginning of the study and end of each period. Dietary ingredients (approximately 500 g) were collected daily on d 21 to 27 and composited for each period to determine the chemical composition of the diet. All samples were dried for 72 h at 55^o C in a forced air oven (V-31 STD, style II; Despatch Industries Inc., Nashua, Mississauga, ON, Canada). Dried feed samples were ground through a 1-mm screen using a Wiley Mill (model 3; Arthur H Thomas Co., Philadelphia, PA) and sent to Cumberland Valley Analytical Services (Hagerstown, MD) for analysis of nutrient composition. Dry matter was determined by drying samples at 135ºC for 2 h (AOAC International, 2000; method 930.15), crude protein (method 990.03) and ash (method 942.05). The NDF concentration was determined using heat stable α-amylase and sodium sulfite (Van Soest et al., 1991), fat was determined using a Tecator Soxtec System HT 1043 extraction unit (Tecator, Eden Prairie, MN, USA) according to the AOAC International, method 2003.05 (AOAC International, 2006) and starch concentration was determined as described in Hall (2009).

Milk yield was recorded at each milking and milk (approximately 50 mL) was sampled from six consecutive milkings on d 25 to 27, mixed with 2-bromo-2-nitopropane-1,3diol, and stored at 4^o C until milk composition analysis. Milk samples were analyzed at the Alberta Central Milk Testing Laboratory (Edmonton, AB, Canada) for milk fat, milk protein, lactose, milk urea nitrogen (MUN), and somatic cell count (SCC) concentrations by infrared spectroscopy (AOAC International, 2002; method 972.16; Milko Scan 605, Foss North America, Brampton, ON, Canada). Yield of 3.5% fat corrected milk (FCM) ([0.4324 × milk yield, kg] + [16.126 × fat yield, kg]) and energy corrected milk (ECM) yield ([12.82 × fat yield, kg] + [7.13 × protein yield, kg] + [0.323 × milk yield, kg]) were calculated according to the equation described by Tyrell and Reid (1965). Feed efficiency was calculated as 3.5% FCM divided by DMI.

Blood samples were collected during the last week of each period every 18 h for a 72-h period (at 1300 h on d 25, 0700 h on d 26, 0100 h and 1900 h on d 27) from the coccygeal vessels using vacutainer tubes (Becton Dickinson Co., Franklin Lakes, NJ) containing sodium heparin. Samples were centrifuged at 3,000 × *g* at 4^o C for 20 min immediately after collection and plasma was harvested and stored at -20^o C until analysis. Four plasma samples collected were composited to yield one sample per cow per period; however samples analyzed for prolactin concentration were not composited.

Plasma samples were analyzed for glucose, insulin, IGF-I and prolactin concentrations. Plasma glucose concentration was measured using a glucose oxidase peroxide enzyme (P7119, Sigma, St. Louis, MO) and dianisidine dihydrochloride (F5803, Sigma). Absorbance was determined by a plate reader (SperctraMaz 190, Molecular Devices Corp., Sunnyvale,CA) at a wavelength of 450 nm. Plasma insulin concentration was determined using two commercial kits (Coat-A- Count; Diagnostic Products Corp., Los Angeles, CA) through radioimmunoassay analysis for Year one and using ELISA assay (ALPCO 80-INSBO-E01, Salem, NH) for Year two. Insulin analysis was performed at the end of the experiment each year and the Coat-A-Count kit was not commercialized for year 2; thus, plasma samples were analyzed using ELISA assay. The coefficient of variation (CV) between the radioimmunoassay and ELISA analysis was 2.8%, using internal standards as a reference. Plasma IGF-I concentrations were determined with a solid-phase, enzyme-labeled, chemiluminescent immunometric assay using a commercial kit (Immulite 1000 analyzer, Siemens AG, Erlangen, Germany). Plasma prolactin concentrations were determined by double antibody radioimmunoassay as a previously described by Miller et al. (1999).

2.2.3 Statistical Analysis

Data before dietary treatment was applied was analyzed using the fit model procedure of JMP (version 10; SAS Institute Inc., Cary, NC) according to the following model:

$$Y_{ijk} = \mu + L_i + P_j + G_k + Cov + e_{ijk},$$

where Y_{ijk} is the dependent variable, μ is overall mean, L_i is fixed effect of photoperiod treatment, P_j is fixed effect of parity, G_k is fixed effect of group (Year 1 and 2), Cov is the milk yield before light adaptation used as a covariate and e_{ijk} is residual. Effects of interactions between photoperiod treatment with parity or group had been originally included in the model, but removed from the final statistical model as their effects were not significant for primary response variables.

For evaluation of effects of dietary treatments and their interactions with photoperiod treatments, data was analyzed according to the following model:

$$Y_{ijklm} = \mu + L_i + D_j + P_k + G_l + LD_{ij} + C(LG)_{m(il)} + e_{ijklm},$$

where Y_{ijklm} is the dependent variable, μ is overall mean, L_i is fixed effect of photoperiod treatment, D_j is fixed effect of dietary treatment, P_k is fixed effect of period, G_l is fixed effect of group (Year 1 and 2), LD_{ij} is the effects of photoperiod × diet treatment interaction, C $(LG)_{m(il)}$ is random effect of cow nested in photoperiod treatment and group, and e_{ijkl} is residual. Effects of year, parity and photoperiod × diet treatment interaction had been originally included in the model, but removed from the final statistical model as their effects were not significant for primary response variables. Significance was declared when $P < 0.05$ and tendencies were discussed when $P < 0.10$ but $P \geq 0.05$.

Prolactin samples at different time were analyzed using PROX MIXED of SAS (version 9.2, SAS Institute., Cary, NC) according to the prior model but adding time (T_n) as the fix effect of the time as a repeated measure. The covariance structure with the minimum values of Akaike's Information Criterion (AIC) was determined to be compound symmetry and used for all variables. Significance was declared when $P < 0.05$ and tendencies were discussed when $P < 0.10$ but $P \geq 0.05$.

2.3 Results

Cows exposed to the LP treatment increased ($P < 0.01$) milk yield by 2.2 kg/d relative to those exposed to the SP treatment (Figure 2.3) before they were assigned to dietary treatment. However, after cows were assigned to three experimental diets in a 3 × 3 Latin square design, effects of photoperiod treatment was not detected. There was no significant photoperiod by diet treatment interaction on any of the parameters studied, but a tendency of the interaction was detected for protein yield ($P = 0.09$). Protein yield was similar for cows fed LG and MG diets and exposed to the LP ($P > 0.05$; 0.96 vs. 1.00 kg/d) whereas protein yield increased kg/d for MG compared to LG diets for cows exposed to the SP ($P < 0.05$; 0.99 vs. 0.91).

Milk yield was greater ($P < 0.05$) for cows fed HG diets compared to cows fed MG and LG diets with means of 33.1, 30.6 and 29.4 kg/d for HG, MG and LG, respectively. Milk protein and lactose yield had similar response as milk yield, where the highest yield was found for HG diets and the lowest for cows fed LG diets. Although cows fed HG had a greater milk fat yield compared to animals fed LG or MG, milk fat yield is the same for cows fed LG and MG (Table 2.2)

Dietary grain allocation had a significant effect on milk composition, for instance milk fat concentration decreased for animals fed HG compared to LG diets (3.95 vs. 4.19%; $P < 0.01$; Table 2.2). Milk protein content was higher for cows fed HG compared to LG and MG groups (3.39 vs. 3.32 and 3.24 % respectively; $P < 0.01$). Consistently ECM and FCM yields were greater ($P < 0.01$) for animals fed HG diets relative to cows fed LG or MG. However, there was no difference in ECM or FCM yield between LG and MG diets.

Dry matter intake was greater for cows fed the HG diet compared with those fed the LG or MG diets (23.6 vs. 21.7; 23.6 vs. 22.3 kg/d respectively; $P < 0.01$; Table 2.3) although it was not affected by photoperiod treatment. Neither photoperiod nor dietary treatment effect was detected on BW and BCS changes.

Although effects of photoperiod treatment on milk yield or DMI were not detected, photoperiod treatment affected plasma glucose concentrations ($P = 0.02$); animals exposed to LP had greater concentrations of glucose compared to those exposed to SP (63.7 vs. 62.0 mg/dL; Table 2.4). In addition, the effect of photoperiod treatment was not observed for prolactin plasma concentrations. However there was a significant difference for time ($P < 0$ 01) and the interaction time by photoperiod treatment ($P < 0.01$; Table 2.5).

2.4 Discussion

In this study, one of the primary objectives was to determine the interaction effects between photoperiod management and dietary grain allocation on productivity of dairy cows. Previous research reported that cows exposed to long day photoperiod increased milk production by 0.5 to 3.3 kg/d compared to animals with short photoperiod (Dahl et al., 2000). In addition, cows fed high grain diet increase milk production, but have greater risk of subclinical ruminal acidosis or milk fat depression (Beauchemin et al., 2003). The positive effects of long day photoperiod on milk production are mediated by higher concentrations of plasma IGF-I or prolactin (Dahl et al., 1997; Dahl et al., 2000) whereas high grain diets (rich in fermentable carbohydrates) can provide more energy to rumen microbes and the host animal, and increase milk production (NRC 2001). We had hypothesized that cows on the combination LP and HG would increase milk production synergistically. However, we did not detect significant interaction effects between these two management practices on milk production, DMI, body weight change or BCS change. Previous studies that have evaluated the combination of photoperiod management with bST (Miller et al., 1999), or type of grain (Bilodeau et al., 1989) did not find any significant interactions between treatments. Miller et al. (1999) hypothesized that the combination of long day photoperiod with use of bST may have an additive effect on milk yield of lactating cows; as the galactopoietic responses to these two management practices are expected to be mediated by increased circulating IGF-I concentration (Dahl et al. 1997; Glimm et al. 1988). Miller et al. (1999) and our findings suggested that the effects of LP combined with other management practice were not synergistic where effects of LP were not detected when cows were treated with bST (Miller et al., 1999) or cows fed different proportion of grain in the diet (present study). In our study and Miller et al. (1999), cows were adapted to light first and management practice (bST and dietary grain allocation respectively) was applied later. In other words, positive responses to LP may be detected when animals are first adapted to another management practice. If management practices change after light adaptation, effects of LP may not be detected. Overall the three studies (Bilodeau et al 1989; Miller et al., 1999 and ours) found no interaction effects between long photoperiod and other management practices and our results suggested that the effects of LP may be positive if it is applied independently.

2.4.1 Milk yield and composition

In this study, cows exposed to LP had greater milk yield relative to those exposed to SP (39.0 vs. 36.8 kg/d) before animals were assigned to dietary treatments. The galactopoietic response of LP was observed four weeks after animals were exposed to light treatments, which is consistent with previous reports (Dahl et al., 1997; Dahl and Petitclerc, 2003) where long day photoperiod increased milk yield after 2 to 4 weeks of exposure to the light treatment. After wk 5 when cows were fed three different diets in a 3 × 3 Latin square design, LP did not affect milk yield. The mechanism how effects of photoperiod management disappeared after cows were fed different diets is not clear. A possible reason why photoperiod treatment effects were not found in this study is that the cows may have been resistant to the stimulus of LP during our experimental period. Resistance to the stimulus of LP has been reported in cattle (Stanisiewski et al., 1987) where plasma prolactin level began to decline after 9 weeks exposure to long photoperiod. Perhaps, in our study, animals might have become resistant to the LP after 5 weeks of exposure to the light treatment. In addition, it should be noted that previous research has not confirmed the effects of long day photoperiod on milk production for an entire lactation (Dahl and Peticlerc, 2003). In other words, the duration of the galactopoietic response induced by photoperiod management in lactating cows has not been clearly determined. Our second speculation for the lack of responses to LP treatment is related to stage of lactation. A recent study (Lacasse et al., 2014) found that effects of long day photoperiod on milk production decreased after 20 weeks of lactation. In our study, cows were at 20 weeks of lactation on average when they were assigned to dietary treatments; thus, cows might not have responded to LP treatment after dietary treatments were applied. Although Peters et al. (1981) indicated that long day photoperiod increased milk yield regardless of stage of lactation, we cannot exclude the possibility that the effect of LP declined at late stage of lactation. At late stage of lactation, concentrations of plasma prolactin declined (Miller et al., 2006), and photoperiod manipulation may not increase milk production.

Bilodeau et al. (1989) showed that long day photoperiod increased milk yield by 1.5 kg/d compared with cows exposed to short photoperiod. Although Bilodeau's study (1989) reported a difference in milk yield, it should be noted that animals in SP decreased milk yield whereas animals in LP maintained milk production. The diference between Bilodeau's experiment and other photoperiod studies (Dahl et al., 1997; Peters et al. 1978; 1981) is pre-trial photoperiod management; in the study of Bilodeau et al. (1989), all animals were initially exposed to LP (16 h of light, 8 hours of darkness) and 5 weeks later one group was reduced to 8 h of light (SP tretament) whereas in the other studies (Dahl et al., 1997; Peters et al., 1978; 1981) including ours, cows were exposed to short/natural photoperiod (< l3 h/d) prior to application of the LP treatment. As such, we cannot exclude the possibility that the effects of LP may depend on how and when the treatment is applied. Additional studies will be needed to determine the mechanism of action and the optimal time in the lactation cycle that LP should be implemented.

Milk composition was not affected by photoperiod management in our study, which is consistent with previous studies (Dahl et al., 1997; Miller et al., 1999). However, Stanisiewski et al. (1985) reported a 0.17% unit reduction in milk fat concentration for cows exposed to long photoperiod compared to those exposed to short photoperiod, and Philips and Schofield (1989) found that long day photoperiod tended to reduce milk fat concentration compared with short day photoperiod (3.87 vs. 4.16 %). Although light treatments did not influence milk composition in our study, dietary grain allocation affected milk production and composition. Nutritional management is considered one the main factors to alter milk fat and protein concentration (Jenkins and McGuire, 2006). Fat concentration is the most sensitive to dietary changes and can vary over a range of nearly 3% units while dietary manipulation can result in milk protein concentration changes by up to 0.50 % units (Sutton 1989; Jenkins and McGuire, 2006). Cows fed HG diets increased milk protein content compared to MG and LG, but decreased milk fat content. The increase in the protein content of milk may be a response to the increased energy intake as a result of the higher grain intake (Kennelly et al., 1999).

The decrease in milk fat concentration may result from decrease of fibre digestion (Kaslcheur et al., 1997). The digestion of fiber in the rumen produces volatile fatty acids (VFA) acetate and butyrate (Sutton, 1989), about half of milk fat is synthesized in the udder from these two VFA (Heinrichs et al.,2005); thus, a reduction of milk fat concentration might be partly attributed to decreased production of acetate and butyrate (Kaslcheur et al., 1997). Feeding more grain enhanced the production of the *trans*-10 fatty acid by ruminal micro organisms, and the production of *trans*-10 fatty acids is associated with milk fat depression (Bauman et al. 2006; Jenkins and Mcguire, 2006). In addition, we observed an increase in lactose yield for cows on the HG and MG diets compared to LG, suggesting that HG diet provided more glucose precursors for milk production. Increasing the starch concentration might have also increased microbial protein production, thereby increasing milk protein yield, similar to results reported by Grum et al. (1996).

2.4.2 DMI, body weight

Data from this study showed that DMI was not affected by photoperiod management. This is in agreement with the data reported by Dahl et al. (1997) and Lacasse et al. (2014). However, some studies (Bilodeau et al., 1989; Miller et al., 1999) found that cows on long photoperiod treatment increased DMI by 1.0 and 0.8 kg/d, respectively, relative to cows exposed to short photoperiod. Both studies (Bilodeau et al., 1989; Miller et al., 1999) speculated that the increased DMI is due to the higher demand for enhanced milk yield.

In our experiment, feed efficiency was not affected by photoperiod treatment. Bilodeau et al. (1989) calculated gross feed efficiency as the relationship between milk yield and DMI, and their results were similar to ours where there was no significant effect of photoperiod treatments on feed efficiency.

In our study, the highest DMI was observed for cows fed HG, followed by MG and LG treatments. The greater DMI for the HG treatment might be attributed to reduced physical fill in the rumen. Moreover, in our study, LG and MG diets contained greater NDF compared to HG. It has been suggested that high NDF concentrations in diets limit DMI due to feed bulkiness and rumen fill (Allen, 2000: NRC, 2001). Changes in BW and BCS were not affected by either photoperiod or dietary treatment. Similar responses were reported by Dahl et al. (1997) and Miller el al. (1999) where long photoperiod treatment had no effect on BW and net energy balance; apparently all cows increased BW as they approached the end of lactation.

2.4.3 Hormone concentrations

Previous photoperiod research evaluated plasma concentrations of hormones such as prolactin (Peters et al., 1981; Miller et al., 1999; Lacasse et al., 2014), IGF-I (Dahl et al., 1997; Spicer et al., 2007), growth hormone (Mollet and Malven, 1982; Dahl et al., 1997) and melatonin (Stanisiewski et al., 1988; Lacasse et al., 2014), but the effects of photoperiod on plasma glucose and insulin concentrations in lactating cows have not yet been reported. Interestingly, this study showed that LP or HG diets increased plasma glucose concentrations compared to SP or LG and MG diets, respectively. Animal responses in plasma glucose concentration observed in this study suggested that the combination of photoperiod management ($P = 0.02$) and dietary grain allocation (*P*= 0.04) had an additive effect, and cows exposed to long day photoperiod and fed high grain diets had the highest concentration of glucose among all treatment combinations. Osborne et al. (2007) evaluated the effects of photoperiod and glucose-supplemented water on the performance of dairy calves, and showed that the concentration of serum glucose was greater for calves supplemented with glucose compared to the group without glucose supplementation. However, there was no difference in serum glucose concentrations between long day photoperiod treatment (18 h of light, 6 h of darkness) and short day photoperiod(10 h of light, 14 h of darkness) (Osborne et al. 2007). In a study using lambs (Francis et al. 1997), higher plasma glucose concentration was observed for animals exposed to long photoperiod compared to those exposed to short photoperiod. The higher glucose concentration observed for long photoperiod might be attributed to greater feed intake for LP lambs (Francis et al, 1997). In our study, glucose concentrations were higher for LP animals compared to SP, but photoperiod treatment did not affect DMI as discussed above.

The greater concentrations of plasma glucose observed in cows exposed to LP may be explained by the daily rhythms of glucose metabolism. Circadian rhythms are synchronized by numerous environmental cues such as the light-dark cycle and/or feed availability (Kumar et al., 2015). Feeding time, considered as an environmental cue, can reset the daily rhythms of glucose and insulin plasma concentrations of dairy cows, but had no effect on DMI and milk production (Niu et al., 2014). Light is another environmental cue which may reset the daily rhythms of glucose similar to the effect of feeding time. In an experiment with rats, Challet et al. (2004) found that blood glucose concentration increased during the exposure to light and decreased in darkness. Circulation of melatonin decreases when light exposure increases; further, circadian rhythms of glucose may be altered by melatonin concentrations (Varcoe et al., 2014). Thus, increased light exposure may increase glucose concentration; however, the mechanism whereby LP may result in greater plasma glucose concentrations is not known.

The greater plasma glucose concentration in cows fed higher proportions of grain can be explained by possible enhanced production of propionate in the rumen as well as its conversion to glucose in the liver by gluconeogenesis (Reynolds, 2006). Furthermore, this is supported by Ametaj et al. (2009) where cows fed barley grain at 45% of DM had the greatest glucose concentrations in plasma and greatest propionate proportion in rumen fluid compared to cows fed barley grain diets at 0, 15%, and 30% of diet DM. It is not surprising that cows fed HG diets had greater concentrations of plasma insulin compared to cows fed LG or MG diets. The greater concentration of insulin in HG diets may be a result of high concentrations of plasma glucose. When the plasma glucose concentration level is high, β cells in the pancreas release insulin to decrease blood glucose concentration level (Hill et al, 2008).

It has been suggested that the galactopoietic effects of photoperiod is attributed to the increase in plasma IGF-I concentration (Dahl et al., 1997; 2000). IGF-I is a mammary mitogen and survival factor and can enhance cell survival (Capuco and Akers, 2002). Thus, greater IGF-I concentrations due to exposure to long day photoperiod may reduce mammary epithelial cells apoptosis. Apoptosis, death of cells, would be lower in animals exposed to long photoperiod; hence, cows in LP will have a greater persistency of lactation compared to cow exposed to short photoperiod (Capuco and Akers, 2002). In contrast, our study and other studies (Miller et al., 1999; Lacasse et al., 2014) do not support the idea that increased plasma IGF-I concentration is solely responsible for the galactopoietic effect of LP. For example, in the study of Miller et al. (1999), IGF-I concentrations were not different between LP and SP treatments and the IGF-I response was greater in cows that were treated with bST compared to animals exposed to LP

(Miller et al., 1999). In contrast to photoperiod effect, IGF-I concentrations were higher (P<0.01) for cows fed HG diets compared to the cows fed LG or MG diets. Cohick (1998) indicated that nutrient intake can influence the levels of circulating IGF-I in dairy cattle, high energy intake, protein intake, or both will increase circulating IGF-I concentrations. In our experiment, differences in plasma IGF-I concentration among dietary treatments can be explained by the higher DMI and greater energy intake for cows fed the HG diets compared with those fed LG or MG diets.

In lactating dairy cows, prolactin has been also suggested as a hormone responsible for enhanced milk yield for cows exposed to long photoperiod (Dahl et al., 2000). Previous research (Peters et al 1978; 1981; Stanisiewski et al., 1985) had suggested that greater concentrations of plasma prolactin in cows on LP treatments were responsible for greater milk yield. However, interestingly, it is shown that lactating dairy cows did not increase milk yield when prolactin was administrated (Plaut et al., 1987). Evans et al. (1991) showed that 24-h profiles of prolactin were circadian in lactating dairy cows, suggesting that day length influenced the circadian rhythm of prolactin, which may explain the effects of day length on milk production. However, in the study of Evans et al. (1991), animals were not exposed to LP or SP. In the present study, there were no significant differences between LP and SP treatments in prolactin concentrations and consequently effects of LP on milk yield were not found, either. Previous research showed that prolactin concentrations in blood of cattle vary with season (Koprowski and Tucker, 1973). It has been suggested that low ambient temperatures decreased prolactin concentrations in LP, and temperatures below 0^{o}C may block the effect of LP due to low circulating prolactin (Peters et al.,1980). We excluded the possibility that temperature affected prolactin concentration because animals in our study were housed in a closed barn and the lowest temperature reached 8^{o}C.

Our findings suggest that prolactin concentrations may not be affected by long exposure to light, which is in agreement with other studies (Marcek and Swanson, 1984; Miller et al., 1999) that LP did not affect prolactin plasma concentrations.

2.5 Conclusion

The results of this experiment showed that there were no significant interactions between photoperiod management and dietary grain allocation in lactating dairy cows. Responses to long day photoperiod on milk yield were only detected at 4 weeks after animals for initial exposure to light treatment, and the light effect was abolished after dietary treatments were applied. High grain diets increased milk production in the current study, but the duration or specific stage of lactation that long day photoperiod exerts positive effects on milk production of lactating dairy cows needs to be investigated.

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Table 2.1 Ingredients and chemical composition of experimental diets

	Dietary treatment[1]					
	2014			2015		
Item	**LG**	**MG**	**HG**	**LG**	**MG**	**HG**
Ingredients % DM						
Alfalfa silage[2]	43.3	36.6	30.0	42.1	37.4	28.8
Barley silage[3]	21.6	18.3	15.0	21.1	18.7	14.4
Steam-rolled barley grain	15.0	25.0	35.0	15.0	25.0	35.0
Beet pulp	13.1	11.6	9.8	14.1	10.3	10.1
Corn gluten meal	5.8	5.4	5.1	5.7	5.6	4.9
Canola meal	0.0	1.9	4.1	0.0	1.3	4.9
Dicalcium phosphate	0.45	0.20	0.09	0.96	0.55	0.27
Sodium chloride	0.45	0.45	0.32	0.46	0.41	0.41
Limestone	0	0.25	0.49	0.55	0.64	0.96
Potassium carbonate				0.00	0.00	0.14
Vitamin premix[4]	0.03	0.03	0.03	0.03	0.03	0.03
Trace mineral premix[5]	0.02	0.02	0.02	0.02	0.02	0.02
Selenium premix[6]	0.01	0.01	0.01	0.01	0.01	0.01
Nutrient Composition, %DM						
DM	35.6	39.1	43.2	40.1	42.5	48.2
Ash	10.3	9.8	9.0	9.1	8.1	7.5
CP	18.4	17.9	17.5	17.9	17.7	17.4
NDF	37.9	35.4	31.7	35.7	34.1	29.7
Starch	11.8	15.5	20.7	13.5	19.6	25.1
Ether extracts	3.4	3.3	3.2	2.9	2.8	2.3
Energy allowable milk yield, kg/d	33.9	34.8	35.6	35.0	35.6	36.4
Protein allowable milk yield, kg/d	36.0	36.0	36.0	36.5	36.5	36.5

[1] LG = low grain diet containing 15% of steam rolled barley on a DM basis, MG = medium grain diet containing 25% of steam rolled barley on a DM basis, HG = high grain diet containing
35% of steam rolled barley on a DM basis

[2] alfalfa silage 2014: DM = 24.7%, CP = 20.6%, NDF = 38.8%;
alfalfa silage 2015: DM = 31.7%, CP = 20.6%, NDF = 38.6%

[3] barley silage 2014: DM =31.4 %, CP = 13.1 %, NDF = 49.8%, starch = 8.3%;
barley silage 2015:DM =30.9 % CP = 12.3 %, NDF = 49.9%, starch = 11.3%

[4] Vitamin premix contained 30 KIU/kg of vitamin A, 3 KIU/kg of vitamin D, and 100 KIU/kg
of vitamin E.

[5] Trace mineral premix contained 1350 mg/kg of Co, 66,700 mg/kg of Cu, 3000 mg/kg of I, 120,000 mg/kg of Mn, 200000 mg/kg of Zn

[6] Selenium premix contained 1000 mg/kg of Se

Table 2.2 Effects of dietary grain allocation and photoperiod management on milk yield and composition

Item	Photoperiod Treatment[1]				Dietary Treatment[2]				
	LP	SP	SE	*P*-value	LG	MG	HG	SE	*P*-value[3]
Yield, kg/d									
Milk	31.3	30.7	0.95	0.62	29.4[c]	30.6[b]	33.1[a]	0.71	< 0.01
Protein	1.01	1.00	0.03	0.80	0.94[c]	0.99[b]	1.09[a]	0.02	< 0.01
Fat	1.31	1.23	0.04	0.19	1.24[b]	1.24[b]	1.33 [a]	0.03	0.01
Lactose	1.40	1.39	0.04	0.79	1.33[c]	1.38[b]	1.48[a]	0.03	< 0.01
Milk composition									
Protein, %	3.30	3.33	0.04	0.63	3.24[c]	3.32[b]	3.39[a]	0.03	< 0.01
Fat, %	4.09	4.05	0.08	0.74	4.19[a]	4.06[ab]	3.95[b]	0.06	< 0.01
Lactose, %	4.57	4.60	0.02	0.26	4.58	4.59	4.59	0.01	0.37
ECM[4], kg/d	34.2	32.9	0.97	0.35	32.1[b]	32.9[b]	35.5[a]	0.76	< 0.01
FCM[5], kg/d	34.8	33.3	1.00	0.29	32.9[b]	33.4[b]	35.9[a]	0.79	< 0.01
Feed efficiency[6]	1.49	1.47	0.02	0.58	1.45	1.48	1.49	0.01	0.34
MUN, mg/dL	19.1	19.8	0.41	0.24	21.3[a]	19.5[b]	17.7[c]	0.38	< 0.01
SCC, cells/mL	105	277	85.7	0.16	22	147	203	89.5	0.78

[1]Photoperiod treatments: SP = short photoperiod (8 h darkness, 16 h light), LP = long photoperiod (16 h light, 8 h darkness)

[2] Dietary treatments: LG = low grain diet, MG = medium grain diet, HG = high grain diet.

[3] Student's t-test was conducted if P was < 0.10. Treatment means within a row with no common superscript differ (*P* < 0.05).

[4] Energy corrected milk: ECM = [12.82 x fat yield (kg)] + [7.13 x protein yield (kg)] + [0.323 x milk yield (kg)] (Tyrell and Reid, 1965)

[5] Fat corrected milk: FCM = [0.4324 x milk yield (kg)] + [16.126 x fat yield (kg)] (Tyrell and Reid, 1965)

[6] Feed efficiency = FCM/DMI

Table 2.3 Effects of dietary grain allocation and photoperiod management on DMI and changes in BW and BCS

Item	Photoperiod Treatment[1]				Dietary Treatment[2]				
	LP	SP	SE	*P*-value	LG	MG	HG	SE	*P*-value[3]
DMI, kg/d	22.9	22.2	0.56	0.40	21.7[b]	22.3[b]	23.6[a]	0.43	< 0.01
BW change, kg/d	0.64	0.59	0.04	0.42	0.06	0.55	0.71	0.14	0.79
BCS change/28d	0.00	0.03	0.01	0.14	0.00	0.01	0.05	0.02	0.33

[1]Photorperiod treatments: SP = short photoperiod (8 h darkness, 16 h light), LP = long photoperiod (16 h light, 8 h darkness)

[2] Dietary treatments: LG = low grain diet, MG = medium grain diet, HG = high grain diet.

[3] Student's t-test was conducted if P was < 0.10. Treatment means within a row with no common superscript differ ($P < 0.05$).

Table 2.4 Effects of dietary grain allocation and photoperiod management on plasma metabolite concentrations

Item	Photoperiod Treatment[1]				Dietary Treatment[2]				
	LP	SP	SE	*P*-value	LG	MG	HG	SE	*P*-value[3]
Glucose, mg/dL	63.7	62.1	0.50	0.02	62.5[ab]	62.0[b]	64.1[a]	0.60	0.04
Insulin, µIU/mL	7.06	6.81	0.34	0.61	6.24[b]	6.81[b]	7.75[a]	0.31	< 0.01
IGF-I, ng/mL	141	133	6.9	0.41	133[b]	133[b]	146[a]	5.3	< 0.01

[1]Photorperiod treatments: SP = short photoperiod (8 h darkness, 16 h light), LP = long photoperiod (16 h light, 8 h darkness)

[2] Dietary treatments: LG = low grain diet, MG = medium grain diet, HG = high grain diet.

[3] Student's t-test was conducted if P was < 0.10. Treatment means within a row with no common superscript differ ($P < 0.05$).

Table 2.5 Effects of time and photoperiod treatment on prolactin plasma concentrations

	Photoperiod Treatment[1]								*P* value[2]		
	LP				SP						
	0100h	**0700h**	**1300h**	**1900h**	**0100h**	**0700h**	**1300h**	**1900h**	**P**	**T**	**T × P**
Prolactin, ng/ml	23.8	18.7	16.4	17.3	23.0	17.8	16.4	25.9	0.43	< 0.01	< 0.01

[1]Photorperiod treatments: SP = short photoperiod (8 h darkness, 16 h light), LP = long photoperiod (16 h light, 8 h darkness)

[2] *P* values: P = effect of photoperiod treatment, T = effect of time, T × P = time by treatment interaction.

Year 1 **Year 2**

Figure 2.1 Light treatments assignment in each year.

In order to account for the confounding effect of location, light treatments were assigned in two years. In year 1, LP cows were located at the end of the barn while SP cows were located in the middle section. In year 2, SP cows were located at the corner of the barn while SP cows were located in the middle section.

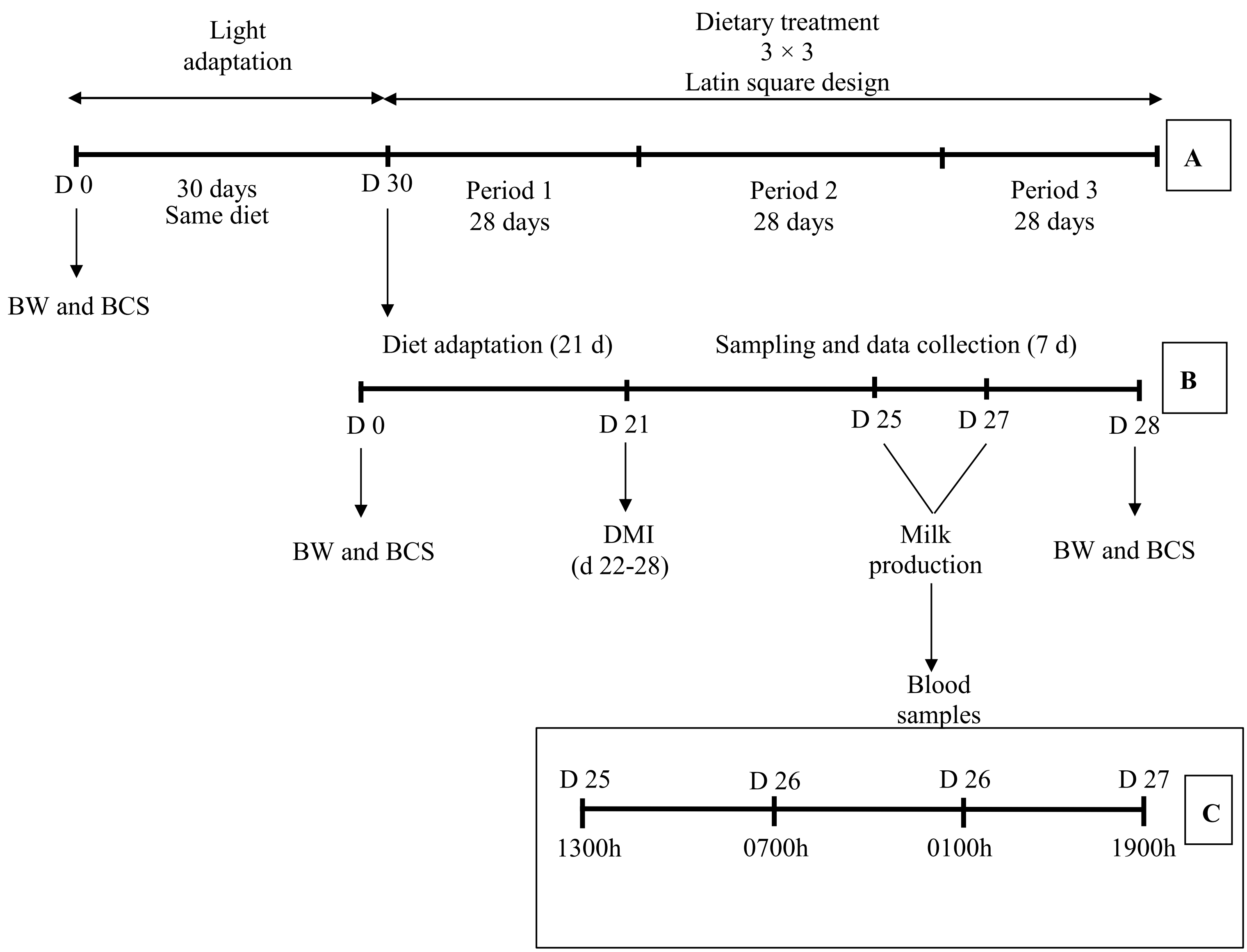

Figure 2.2 Experimental design and blood sample collection

Animals were assigned to one of the two photoperiod treatments for 30 d and fed the same diet. After 30 d adaptation period, animals within long and short photoperiod were fed three different diets in in a 3×3 Latin square design with 4 wk periods (**A**). Within each period, the first 3 wk were used for dietary adaptation and the last week for sample collection .Samples for DMI were taken for 7 days (d 22-28), BW and BCS were measured at the beginning of the study and the end of each period. (**B**). Milk samples were collected for 6 consecutive milkings and blood samples every 18 h in a 3 d-window (**C**).

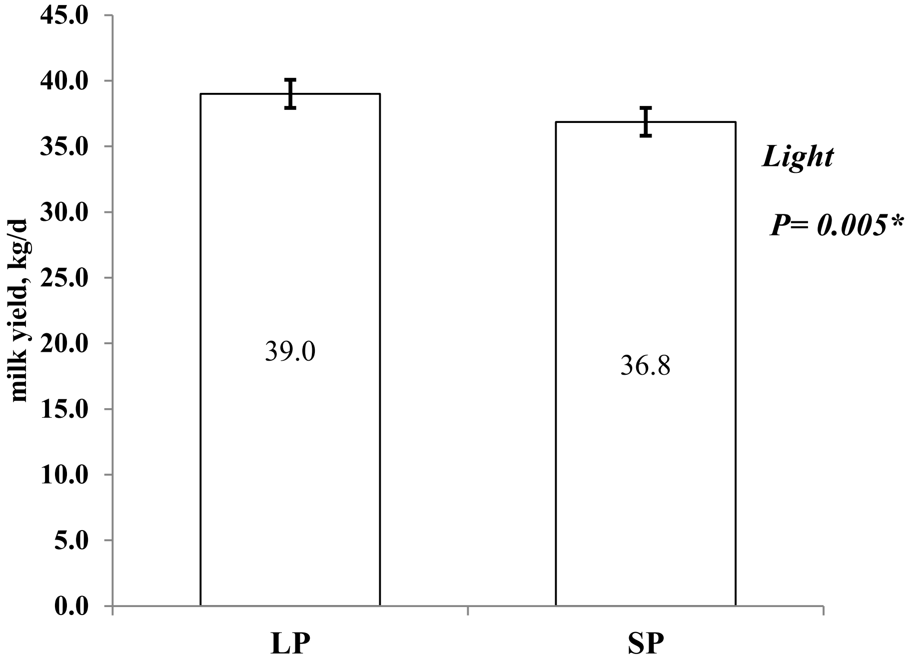

Figure 2.3 Milk yield measured after four weeks of light exposure. LP = long photoperiod (16-h light, 8-h darkness); SP = (8-h light, 16-h darkness).

3.0 STUDY 2: Relationship between photoperiod management and persistency of lactation on Albertan dairy herds.

3.1 Introduction

Persistency is defined as a cow's ability to maintain milk production at a high level after the peak yield (Jamrozik et al., 1997). Photoperiod manipulation is one of the management tools that have been used to increase persistency of lactation in dairy cows (Capuco et al., 2003). Dahl (2005) described long day photoperiod as the continuous exposure to 16-18 h of light followed by 6-8 h period of darkness and an experimental short day is 8 h of light and 16 h of darkness. In normal field conditions anything below 12 h of light will be considered short day photoperiod (Dahl, 2005). Effects of light in dairy cattle may occur in Alberta due to geographical location (high latitude; 55 ^{o} North). For example, in winter the shortest day is December 20 with 7 h 27 min of daylight whereas in summer the longest day is June 21 with 17 h 3 min of daylight. To observe production responses to long photoperiod in lactating cows, an intensity of 150 lx at 1.2 m from the floor of the stall is recommended (Dahl, 2005). Thus, supplemental lighting should be provided in dairy barns for the winter months in order to achieve the recommended light intensity and length. The most common lamps used in dairy facilities are incandescent lamps, fluorescents, metal halides lamps or light emitting diode (LED) lamps (ASAE, 2005).

Previous research had evaluated the effect of photoperiod on commercial farms. For instance, Stainisiewski et al. (1985) evaluated the effect of photoperiod in Michigan dairy farms, and Reksen et al. (1999) assessed the effects of photointensity and photoperiod in farms in Norway. Both studies collected data from tie stall farms, and DHI data showed that cows exposed to long photoperiod increased milk yield by 2.2 kg/d (Stainisiewski et al., 1985) or by

0.5 kg/d (Reksen et al., 1999) compared to cows exposed to short photoperiod. In addition, Dahl (2005) suggested that dairy producers can use DHI records (150 day or management level milk report) to measure the effect of long days on milk production if other factors (e.g., nutritional management) are held constant.

Although photoperiod management has been studied since 1978, there is limited information about photoperiod management in Alberta dairy herds. The main objective of this project was to identify any relationship between actual photoperiod that animals are exposed to and the persistency of lactation for cows that calved in summer or winter.

3.2 Materials and methods

Twenty dairy farms near Edmonton (AB, Canada) who met the following criteria were selected: 1) herds with DHI (dairy herd improvement) record; 2) farmers who allowed installation of light meters on their facilities during the assessment; 3) farmers who signed a consent form to allow examination of their DHI records. The data was analyzed with mainly 2 sources of variation: calving seasons and photoperiod management.

3.2.1 Light intensity assessment

The first farm visit was from November to December 2013, dairy operation information such as herd size, type of stall (free or tie), breed, milk frequency, milking system, light fixtures type and number, light schedule was collected from each farm. Additionally light intensity was measured in each pen (free or tie stalls), scraper alleys and feed alleys at a height of 1.0 m (cows' eye level), where lactating cows were housed, with a light meter/data logger (Extech SDL 400, Extech Instruments, Nashua, NH). In this visit, light intensity was measured after dusk (1700 h) or before dawn (0700 h) when the lights in the barn were turned on. The measurement was intended to provide an estimate of the light intensity only from light fixtures. Light meter recorded light intensity every second for 10-30 min period. Light intensity data of the barn was sent to each dairy producer.

Sunlight may change light intensity and duration of brightness inside of the barn as sunlight can enter through the barn openings (i.e., windows, doors, roof openings, curtains); thus, we evaluated the light intensity continuously for 48 h period for both summer and winter months. In the second visit, light intensity was measured during the short days (December 2013 – March 2014) and a third visit during the long days (July – August 2014). Light meters were placed in areas of the average light intensity for each farm, which was determined during the first visit. Light meters were mounted in a wood platform and light intensity was recorded at 1.5 m height. Although the recommendation is to measure light intensity at 1 m height, there was no difference in light intensity measured at 1.5 or 1 m. The number of light meters per farm (2-4) was determined by barn size and number of pens where lactating cows were housed. According to the light intensity data, and the light requirements described by Dahl (2005), farms were categorized into two groups: farms with photoperiod management providing 16 - 18 h of light with light intensity greater than 150 lx followed by 6-8 h of darkness (LP) and farms without photoperiod management (SP) where light intensity was lower than 150 lx for more than 8 h/d. For the second group, the dairy farms were further divided into two sub-categories: SP 1= farms with light intensity greater than 50 lx for 8-16 h/d, and SP 2 = farms with light intensity lower than 50 lx for 16 h or more per day. After the second and third visits, light assessment reports were sent to each farm, showing the light intensity recorded over a 48-h period at several locations in each farm. Photoperiod data was summarized as the duration (h/d) in four different categories according to light intensity: a) lower than 50 lx, b) between 50 - 150 lx, c) between 150 - 400 lx, d) greater than 400 lx.

3.2.2 DHI data

The two primary groups for DHI analysis were cows that calved from Jun 01, 2012 to Aug 31, 2012 (summer calving) and from December 01, 2012 to February 28, 2013(winter calving). For both groups, DHI data (milk yield, peak yield, milk fat content and milk protein content) and persistency of lactation were calculated from the DHI milk tests between 90 to 230 DIM, which is likely a representation of mid-lactation. Thus, DHI data was collected in short days (September 2012 to Feb 2013) for cows that calved in summer and in long days (March 2013 to Aug 2013) for cows that calved in winter.

Milk tests varied among farms but on average milk tests were performed every 30 to 45 days. Cows that were sold or died after 230 DIM were also included in the calculations. Persistency of lactation was calculated as the average percentage of milk that is maintained between 90 to 230 DIM. That is, persistency was calculated for each milk test, where milk yield at one test expressed as a percentage of milk yield at a previous test, adjusted for a 30-d interval between tests. When tests are not exactly 30 d apart, the equation shown below was used to calculate the persistency of lactation.

$$\text{Persistency}\ \% = \left[1 - \frac{(\text{milk kg earlier test} - \text{milk kg later test}) \text{ x } \frac{30 \text{ days}}{\text{days between tests}}}{\text{milk kg earlier test}} \right] \text{x } 100$$

Persistency = measured in %

Milk kg earlier test = Milk yield previous test, kg/d

Milk kg later test = Milk yield current test, kg/d

Peak yield is the highest milk yield during the lactation. The first milk yield, taken after 90 DIM used for the calculation of persistency, was referred as the first weight. The average per cow per farm was calculated for all the observed variables between 90 and 230 DIM for each season.

3.2.3 Statistical analysis

DHI data collected from the twenty farms (i.e., milk yield, milk composition, persistency of lactation, peak yield and first weight) were first analyzed using the fit model procedure of JMP (version 10; SAS Institute Inc., Cary, NC) to test the fixed effect of photoperiod management and season according to the following model:

$$Y_{ij} = \mu + L_i + S_j + L{\times}S_{(ij)} + \varepsilon_{ij}$$

where Y_{ij} is the dependent variable, μ is overall mean, L_i is the effect of photoperiod management category, S_j is the effect of season, $L \times S_{(ij)}$ is the effect of photoperiod management category × season interaction and ε_{ij} is the residual. Interactions between photoperiod management category and season were not significantly different ($P > 0.05$) for any of the response variables; thus, it was removed from the model. Further, two farms changed their lighting system during the study and their data for cows that calved in the winter was not used. The final model was analyzed using two-way ANOVA using the fit model of JMP to test the effect of photoperiod management and calving season. Orthogonal contrasts were used to test the main effect of photoperiod management category (LP vs. SP and SP1 vs. SP2). Significance was declared at $P \leq 0.05$ and tendencies were declared at $0.05 < P \leq 0.10$.

3.3 Results

After the first visit in December 2013, we found that only two farms had light intensity greater than 150 lx (average entire barn) whereas the other eighteen had intensity lower than 150 lx. Eleven farms used metal-halide fixtures in their barns, 6 farms used fluorescent lamps and 3 farms used incandescent fixtures. Light reports were submitted to the producers showing the light intensity average for all the areas where lactating cows were housed (See an example in Appendix I). In our second visit, which was during the winter months, we found that only 2 farms practiced photoperiod management according to the requirements for lactating dairy cows. Cows in these herds were exposed to a light intensity greater than 150 lx for 16 to 19.7 h/d, followed by less than 8 h of darkness. The other 18 farms did not practice photoperiod management. Three farms managed their operations with dim lights (SP 2) where light intensity was lower than 50 lx for greater than 16 h/d. The remaining 15 farms managed their lighting system in accordance to their needs (SP 1), where light intensities were greater than 50 lx for 8 to 16 h/d. Light reports for a 48-h period were submitted to the producers (see an example in Appendix 2). In our third visit which was during the summer months, we found that the same two farms that practiced photoperiod management in winter continued to practice light management throughout the summer. Two farms that had not have photoperiod management installed new lighting system in their barns after our second assessment and lactating cows on those two farms are currently exposed to long day photoperiod. The other sixteen farms had similar photoperiod to the previous visit (winter). Although sunlight in the long days penetrates through openings in the barn, light intensity inside of the barn was not greater than 150 lx, and even if it was greater than 150 lx the length was shorter than 16 h/d. Moreover, two SP 2 farms in winter become SP 1 during summer due to sunlight. After summer light reports were submitted to the producers, three more producers decided either to replace light bulbs or change the lighting system. Characteristics of each farm and photoperiod data are shown in Table 3.1.

We found that there was not significant effects of season on milk and peak yield, first weight, milk fat and protein yield and persistency but milk fat (*P* = 0.08) and protein (*P* = 0.09) content tended to be greater during winter months compared with summer months (Table 3.2).

Regardless of the calving season, herds where photoperiod management was practiced (LP) had greater milk yield compared to farms without photoperiod management (SP; 39.3 vs 34.8 kg/d; *P* < 0.05; Table 3.3). Peak yield tended to be greater (*P* = 0.08) for farms with photoperiod management but the first weight had greater yield (*P* = 0.02) in farms with LP compared with SP farms.

Milk fat yield was not affected by photoperiod management category, but animals in LP had a 0.35 % unit lower milk fat content than animals in SP (3.35 vs. 3.70%; *P* = 0.02). Although milk protein content was not affected by light management, milk protein yield tended (*P* = 0.09) to be higher for the LP herds compared with the SP farms without photoperiod management (Table 3.3).

Interestingly, persistency of lactation was not different between LP and SP farms. However SP 2 farms showed a greater (*P* = 0.04) persistency of lactation compared to farms SP 1.

3.4 Discussion

In this study, one of the objectives was to identify current light management practice at dairy farms in Alberta. Previous research (Stainisiewski et al., 1985; Reksen et al., 1999) reported the effects of photoperiod in commercial dairy farms, but our study is the first report that assessed light intensity in commercial dairy herds in Canada. Furthermore, in our study, we assessed current photoperiod management for free and tie stall farms whereas the studies of Stainisiewski et al. (1985) and Reksen et al. (1999) assessed light intensity only for tie stall farms. According to recommendations of Dahl (2005), the first step to implement photoperiod management is evaluation of light intensity in the barn or other housing areas. We found that 90 percent of the farms that were evaluated in the current study had not implemented photoperiod management. Those farms were categorized as SP farms due to low light intensity (< 50 lx) or greater than 150 lx but less than 16 h/d).

Farms in SP 2 had the lowest light intensity on their facilities (< 50 lx for more than 16 h/d), which may not promote a friendly environment for dairy workers. According to the American Society of Agricultural and Biological Engineers (ASABE), the lighting requirement for dairy cattle and workers in a barn should be greater than 200 lx (Hooper, 2009). During our visits, producers from SP 1 and SP 2 farms mentioned that the lights inside the barn were turned off because sunlight can illuminate the facilities. However, we found that sunshine does not provide the required light intensity throughout the barn even in summer. To meet the lighting requirements for cattle, lighting fixtures should be implemented in order to achieve 16 h/d with the required intensity. For instance, if the light intensity is not sufficient, increasing or replacing number of lamps can fix this issue. If the duration of light provision is not sufficient, photocells (light sensors) can be installed and programmed with timers; thus, lamps will turn off if the intensity is higher than 150 lx, otherwise lamps stay on to ensure optimum light distribution in the barn (Clark and House, 2006). Overall, among the twenty dairy farms in Alberta, we found that photoperiod that animals had did not change between winter and summer months. In other words, LP farms were able to provide long photoperiod in the winter time but SP farms provided short photoperiod even in the summer months.

Previous research has reported seasonality of milk yield and components in Canadian dairy herds (Ng-Kwai-Hang et al., 1984; Quist et al., 2008). According to Alberta Milk (2013), the lowest daily average volume of milk shipped was in fall (September – October) whereas the highest volume of milk shipped was in winter (January – February). The volume of milk shipped reported by Alberta milk showed a seasonal trend but this represent the volume of milk shipped in the entire province. Collier et al. (2011) agreed that month of parturition has a pronounced impact on subsequent milk yield and composition; highest yields occur following January and February parturition, whereas lowest yields occur following August and September calving. In our study, although milk yield was not affected by season, milk fat and protein content tended to be lower during the summer months (cow that calved in winter) compared to the winter months (cows that calved in summer). Season effects in cattle are influenced by climate variation, breed, and management factors such as feed quality (Collier et al. 2011). Perhaps, lack of seasonality in average milk yield for the twenty herds may be attributed to lower variation of these factors; for instance, forage quality was consistent between seasons, cows were not under heat stress during the summer, and milk production remained constant, and/or actual exposure to photoperiod was constant throughout the year.

In this study, milk yield was greater for herds with LP relative to herds with SP. However, these results should be interpreted carefully because milk yield difference can be attributed to many other factors such as nutritional management, average herd DIM, parity, milking frequency, genetics, stocking density and other factors which were not identified in this study. Moreover, we expected that milk yield will be greater for SP 1 farms compared to SP 2 farms; however, there was no difference on milk yield between these two categories. Contrary to our results, the study of Reksen et al. (1999) showed that milk production was greater ($P < 0.01$) by 0.5 kg/d for cows in photoperiod > 12 h/d and dim illumination at night (mean 36 lx, range 4 to 150 lx) compared to cows exposed to short photoperiods (< 12 h/d). Although both studies evaluated milk production in commercial dairy farms, the response in milk yield was not consistent primarily because both experiments were not conducted under a controlled experimental setting.

Dairy cows in the LP farms had lower milk fat content compared to those in the SP farms. Dahl et al. (2000) mentioned, in his review, that there is no effect of photoperiod on milk fat, protein, or solids content, but Stanisiewski et al. (1985) found a 0.16 % milk fat depression for cows exposed to long days. Similar to milk yield responses, milk fat differences between the LP and SP farms may be explained by nutritional management. Nonetheless, we did not collect dietary information for this survey.

In our study, the main objective was to identify a relationship between current light management practices at dairy farms and persistency of lactation. We had expected to find a greater persistency of lactation for cows that calved in the winter months compared to summer because of the difference in the daylight length that animals are exposed to during mid to late lactation. However, our results showed that persistency of lactation were not affected by calving season. Contrarily, lactation persistency was greater on SP 2 compared to SP 1 farms. In other words, herds managing cows with lower light intensity had a greater persistency of lactation. Increased milking frequency is another management approach to enhance persistency of lactation (Collier et al., 2011) but farms with 2x milking (SP 2 farms) had greater persistency than farms that milked 3x (SP 1 farms), as such milking frequency does not explain why SP 2 farms had greater lactation persistency. Another possible explanation for lower persistency in SP 1 farms may be related to factors that decrease milk production such as mastitis and reproductive status of the cow. As most of SP 1 farms were large herds compared to SP 2 farms, and herd size may have affected udder health or reproductive efficiency. However, we did not collect those data in this survey, and cannot make such speculations..

Nevertheless, increasing milking frequency and mastitis infections are not the only factors that affect persistency, as there are many others factors such as nutritional management, genetics and age that also affect lactation persistency.

3.4 Conclusion

Photoperiod that cows were exposed to was similar between summer and winter within farms, and persistency of lactation did not differ between cows calved in summer and those calved in winter months. Although sunlight partly illuminates inside of the barn during the summer months, SP farms did not meet the criteria of recommended photoperiod. Farms with photoperiod management had greater milk yield than SP farms, but persistency of lactation did not differ between LP and SP farms. The current survey did not provide exclusive evidences for the relationship between photoperiod management and persistency of lactation in selected dairy farms in Alberta.

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Table 3.1 General characteristics of Alberta dairy herds with photoperiod management (16 h of light, greater or equal 150 lx and 8 h of darkness) measured in two different seasons

Herd	Herd size	Lamp Type	Breed	Milk frequency & barn design	Photoperiod (h/d)											
					Winter[1]						Summer[2]					
					<50 lx	50-150 lx	150 - 400 lx	>400 lx	<150 lx	>150 lx	<50 lx	50-150 lx	150 -400 lx	>400 lx	<150 lx	>150 lx
Farms with Photoperiod Management (LP)[3]																
A	160	Fluorescent T5	Holsteins	2.7x, Robotic	8.0	0.0	14.7	1.3	8.0	16.0	1.8	0.0	21.9	0.3	1.8	22.2
B	66	Fluorescent T8	Holsteins	2x, tie Stall	4.2	0.1	19.7	0.0	4.3	19.7	7.0	0.7	16.3	0.0	7.7	16.3
C[6]	115	Incandescent/ Fluorescent T5	Holsteins	2x, free Stall	21.9	2.1	0.0	0.0	24.0	0.0	6.2	1.8	5.9	10.1	8.0	16.0
D[6]	58	Metal halide / LED	Holsteins	2.8x, Robotic	12.0	1.0	7.1	3.9	13.0	11.0	8.3	0.6	1.2	13.8	9.0	15.0
Farms without Photoperiod Management (SP 1)[4]																
E	40	Fluorescent T8	Ayrshire	2x, stanchion	14.8	4.6	4.6	0.0	19.4	4.6	9.1	4.4	2.6	8.0	13.5	10.5
F	270	Metal halide	Holsteins	2x, free Stall	10.8	9.3	4.0	0.0	20.0	4.0	6.9	10.4	5.2	1.5	17.3	6.7
G	150	Fluorescent T8	Holsteins	2x, free Stall	16.0	4.8	2.5	0.6	20.9	3.1	13.8	4.1	1.7	4.4	17.9	6.1
H	140	Metal halide	Holsteins	2x, free Stall	9.8	7.9	6.3	0.0	17.7	6.3	4.9	10.5	7.0	1.6	15.4	8.6
I	79	Metal halide	Holsteins	2x, free Stall	12.7	3.7	5.2	2.5	16.4	7.6	10.2	1.9	7.9	3.9	12.1	11.8
J	150	Metal halide	Holsteins	2x, free Stall	13.9	5.0	4.2	0.9	18.9	5.1	9.6	8.8	2.5	3.1	18.4	5.6
K	280	Metal halide	Crossbred	3x, free Stall	13.6	7.8	2.6	0.0	21.4	2.6	7.9	10.2	5.4	0.5	18.1	5.9
L	500	Metal halide	Holsteins	3x, free Stall	11.6	11.5	0.9	0.0	23.1	0.9	7.0	13.4	3.6	0.0	20.4	3.6
M	260	Metal halide	Holsteins	3x, free Stall	14.9	2.6	6.5	0.0	17.5	6.5	9.2	6.5	4.5	3.8	15.7	8.3

N	161	Metal halide	Holsteins	2.7x, Robotic	9.0	10.3	4.7	0.0	19.3	4.7	7.3	8.6	8.1	0.0	15.9	8.1
O	80	Incandescent	Holsteins	2x,tie Stall	15.1	9.0	0.0	0.0	24.0	0.0	8.4	12.9	2.8	0.0	21.2	2.8
Farms without Photoperiod Management (SP 2) [5]																
P	60	Incandescent	Holsteins	2x, free Stall	22.5	1.5	0.0	0.0	24.0	0.0	21.5	2.2	0.0	0.3	23.7	0.3
Q	60	Fluorescent T8	Holsteins	2x, tie Stall	21.4	2.6	0.0	0.0	24.0	0.0	18.0	3.0	3.0	0.0	21.0	3.0
R	40	Incandescent	Holsteins/ Jersey	2x, tie Stall	21.5	2.5	0.0	0.0	24.0	0.0	20.4	3.6	0.0	0.0	24.0	0.0
S[7]	73	Metal halide	Holsteins	2x, free Stall	16.3	2.4	5.4	0.0	18.6	5.4	13.1	5.2	4.7	1.0	18.3	5.7
T[7]	70	Metal halide	Holsteins	2x, free Stall	18.7	1.6	1.2	2.5	20.3	3.7	11.3	5.6	0.6	6.5	16.9	7.1

[1] Winter = Photo intensity measured in December 2013- February 2014.

[2] Summer = Photo intensity measured in July – August 2014.

[3] LP = Farms with light intensity greater than 150 lx for more than 16 h/d.

[4] SP 1 = Farms with light intensity greater than 50 lx for 8-16 h/d.

[5] SP 2 = Farms with light intensity lower than 50 lx for 16 or more hours per day.

[6] Farms that changed lighting system after winter visit

[7] Farms which belong to SP 1 in winter but belong to SP 2 in summer according to photo intensity.

Table 3.2 Relationship between calving season and milk production, milk composition and persistency of lactation for Alberta dairy cows.

	Data collection[1]		*P*-value[2]
Item	**Winter**	**Summer**	**Season**
Peak yield, kg/d	42.6 ± 0.98	43.9 ± 1.08	0.37
First weight, kg/d[3]	38.1 ± 1.10	39.3 ± 1.21	0.46
Persistency, %[4]	95.9 ± 0.52	97.0 ± 0.58	0.17
Milk yield, kg/d[5]	36.0 ± 0.93	36.7 ± 1.02	0.59
Milk fat, %	3.69 ± 0.08	3.47 ± 0.09	0.08
Milk protein, %	3.22 ± 0.04	3.11 ± 0.04	0.09
Milk fat, kg/d	1.32 ± 0.03	1.27 ± 0.04	0.46
Milk protein, kg/d	1.15 ± 0.02	1.14 ± 0.03	0.70

[1] Data collection: DHI data was collected in short days (September 2012 to Feb 2013) for cows that calved in summer; DHI data was collected in long days (March 2013 to Aug 2013) for cows that calved in winter.

[2] *P*- value: Season = effect of season

[3]First weight = First milk yield after 90 DIM that was used to calculate persistency.

[4]Persistency = It represents the average percentage of milk yield that is maintained between 90 to 230 DIM

[5]Average milk yield between 90 to 230 DIM

Table 3.3 Relationship between photoperiod management and milk production, milk composition and persistency of lactation for Albertan dairy cows.

	Photoperiod[1]			***P*-value**[2]	
Item	**LP**	**SP 1**	**SP 2**	**LP vs. SP**	**SP 1 vs. SP 2**
Peak yield, kg/d	45.4 ± 1.70	43.1 ± 0.69	41.3 ± 1.20	0.08	0.18
First weight, kg/d[3]	41.8 ± 1.91	37.6 ± 0.76	36.5 ± 1.35	0.02	0.48
Persistency, %[4]	97.3 ± 0.91	95.2 ± 0.36	96.7 ± 0.64	0.17	0.04
Milk yield, kg/d[5]	39.3 ± 1.61	34.8 ± 0.64	34.8 ± 1.13	0.01	0.98
Milk fat, %	3.35 ± 0.14	3.77 ± 0.05	3.63 ± 0.10	0.03	0.22
Milk protein, %	3.12 ± 0.07	3.25 ± 0.03	3.13 ± 0.05	0.37	0.07
Milk fat, kg/d	1.32 ± 0.06	1.31 ± 0.02	1.26 ± 0.04	0.60	0.33
Milk protein, kg/d	1.23 ± 0.04	1.13 ± 0.01	1.09 ± 0.03	0.03	0.33

[1] Photoperiod: LP = farms with photoperiod management (16h/d). SP = farms without photoperiod management, SP_1= farms with light intensity greater than 50 lx for 8-16 hours per day,

SP_2 = farms with light intensity lower than 50 lx for 16 or more hours per day

[2] *P*- value: effect of season. LP vs. SP = orthogonal comparisons between farms with photoperiod management and without it, SP 1 vs. SP 2 = orthogonal comparison between SP 1 and SP 2.

[3]First weight = First milk yield after 90 DIM that was used to calculate persistency.

[4]Persistency = It represents the average percentage of milk yield that is maintained between 90 to 230 DIM

[5]Average milk yield between 90 to 230 DIM

4.0 General discussion

4.1 Summary of findings

The combinations of photoperiod with other management practices have been studied in the past. For instance, Miller et al. (1999) did not find any significant interactions between photoperiod treatments and administration of bovime somatotropin (bST) on milk production. In the study of Bilodeau et al. (1989), there were no significant interactions between the type of grain and photoperiod treatment on milk yield and composition and dry matter intake (DMI). However, no studies had been reported the interaction between photoperiod management and dieterary grain allocation in dairy cows prior to this thesis work.

Study 1 evaluated the interaction effects between photoperiod management and dietary grain allocation on milk production in dairy cows. Results of this study showed that cows exposed to long day photoperiod (LP) produced 2.1 kg more milk than cows exposed to short photoperiod (SP) after 4 wk of the initial light exposure. However, after cows were assigned to three experimental diets in a 3 × 3 latin square design, effects of photoperiod were not detected. There were no significant interaction effects between photoperiod management and dietary grain allocation on milk production, DMI, body weight gain, but a tendency of the interaction was detected for milk protein yield. However, cows fed HG diets had greater milk production and DMI than cows fed LG and MG diets. Milk composition was affected by dietary treatment, where the lowest milk fat content was found in cows fed HG diets. Although we did not detect significant interaction effects between nutritional and photoperiod management on any of the variables, HG diets increased milk production and DMI in lactating dairy cows.

Our second study aimed to assess photoperiod management in twenty dairy herds in Alberta and determine if any relationships exist between photoperiod management and persistency of lactation. Among the twenty dairy herds studied, only two farms had implemented photoperiod management in their operations, where lactating dairy cows were exposed to 16 – 20 h of light (> 150 lx) followed by 4 - 8 h of darkness in both winter and summer months. The remaining eighteen farms managed their lighting system according to their needs (average 8 h/d). Their DHI data showed that calving season did not affect milk yield, milk composition and persistency of lactation. However, animals in farms exposed to artificial long day photoperiod had greater milk yield compared with those herds that were exposed to short day photoperiod. In addition, there was no interaction effect between calving season and photoperiod management on milk production, and persistency of lactation was not different between LP and SP.

4.2 Implications of current research

Previous research (Bilodeau et al 1989; Miller et al., 1999; Dahl et al., 2000) showed that galactopoietic effects of bST administration, increased milking frequency, nutritional management, and long-day photoperiod can be additive. It is reasonable to expect greater positive effects on animal productivity from the combination of long day photoperiod with other management practice on milk production, and that the greatest milk production would be achieved by a combination of the four treatments. However, effects of photoperiod management and other management practices appear to work in an additive manner. The lack of additive effects may be related to the implementation of the 2 different practices at the same time. Probably, the additive effects might have been found if animals have adapted to the other management practice first, before long day photoperiod is implemented. For instance, if there are many changes in nutrition within a short period of time, it is not likely that effects of LP are detected as cows were not adapted to the nutritional changes first.

Study 2 showed that animals were under similar light exposures between summer and winter, within farm. Producers did not turn on the light during summer because natural sun light provided sufficient brightness inside the barn, but we found that cows were not exposed to long days in 18 farms even in the summer months. After we sent the light assessment reports, five producers decided to either replace or fix the light intensity in their barns through incentives of Growing Forward 2. Producers took advantage of this Federal and Provincial program which shares the cost of investments that improve energy efficiency on Alberta farms (Growing forward 2, 2015). One of the criteria of this program is to conserve energy; definitely improving lighting system of the barn will reduce energy consumption. In regards to the season, not only milk yield but also persistency of lactation was not different. Also persistency of lactation was similar regardless of light exposure; but, SP 2 farms (farms with light intensity < 50 lx for ≥16 h/d) had greater persistency than SP 1 farms (farms with light intensity > 50 lx for 8-16 h/d). In other words, cows exposed to poor lighting conditions (SP 2) had less reduction in milk yield during mid lactation than those exposed to longer photoperiod above 50 lx (SP 1). Nevertheless, the greater reduction in milk yield after the peak for SP 1 farms can be attributed to other factors such as nutritional management, reproductive status, age of the cows, composition of the herd that are involved in reduction of milk yield.

4.3 Future research

Although effects of photoperiod management have been researched for decades, literature has not shown specific stage of lactation where photoperiod management exerts the biggest impacts on milk yield or how long it positively affects milk production. Most of the studies conducted in the past evaluated the effect of photoperiod only for 20 weeks after light exposure. However, dairy producers need to know stage of lactation at which cows should be managed under long day photoperiod, and this question still remains to be answered.

It seems that other management practices block the effect of LP. The effects of LP were not detected when photoperiod management was combined with bST administration (Miller et al., 1999) or different dietary grain allocation (Chapter 2). Reasons for the lack of positive responses to long day photoperiod when it is combined with other management practices are unknown. Perhaps, additive or synergistic effects between photoperiod management and other practice managements might be detected if photoperiod management is applied after cows adapt to changes of the other management practice first. This hypothesis needs to be evaluated in future studies to maximize the benefits of photoperiod management at commercial dairies.

Previous research showed that lactating dairy cows exposed to 16 to 18 hours of light increased milk production by approximately 2 kg/d (Dahl et al., 2000). The endocrine mediators of this response are not clear. It is thought that LP suppresses the release of melatonin, which in turn increases the release of prolactin and IGF-I, both of which are associated with improved mammary function. However, prolactin administration does not increase milk yield of lactating dairy cows (Plaut et al., 1987). In addition, previous research showed that IGF-I may not be responsible for the galactopoietic activity (Tucker, 2000). Thus, if those two hormones that are possibly associated with the response to photoperiod management are not directly responsible for galactopoietic effects, there should be another hormone or mechanism involved, and specific modes of action on how animals respond to long day photoperiod needs to be investigated further.

Although the light intensity recommended is 150 to 200 lx (Dahl, 2005), the threshold that suppresses melatonin secretion in mature cows is still not known (Reksen et al. 1999; Lawson and Kennedy, 2001; Bal el al. 2008). Research showed that metal halide, high pressure sodium and fluorescent light fixtures can increase milk yield. However it appears that not all light is created equal to supress melatonin. For instance, in humans, West et al. (2011) showed that blue light, wave length between 446 and 477 nm, is the most effective light spectrum at supressing melatonin secretion. Although each light fixture has different light spectrum (different characteristics and wavelength distribution), there is limited information about the type of light fixture that is able to suppress melatonin and improve milk production in dairy cows, and this is the knowledge gap that needs to be addressed in future research.

In my thesis work, I was looking for the best approach to measure light intensity on commercial dairy farms. To date the only approach to measure light intensity is through the light meter, but the light meter measures the light intensity on a surface and does not necessarily measure light intensity that each cow is actually exposed to. In a dairy barn, animals move during the day, and light intensity in a barn is not always same in all the areas. In other words, data from the light meter may not represent actual light intensity which dairy cows are exposed to. Accurate measurement of individual light exposure is challenging. However, the Lighting Research Center (LRC) has developed the dimesimeter which is a small data logging device that is able to measure individual light exposure in humans (Figueiro et al., 2012). Perhaps this device can be used in dairy cows, which will allow us to determine light exposure of individual cows.

4.5 Conclusion

Although research indicated that provision of supplemental light to extend the photoperiod increased milk yield, my thesis work showed that effects of light on milk production were not detected when photoperiod was combined with another management practice such as increasing the proportion of grain in the diet. In addition, the mode of action for possible positive effects of photoperiod management is still not clear and should be investigated further. Moreover, information regarding the best time, in the lactating cycle, to apply photoperiod management needs to be determined.

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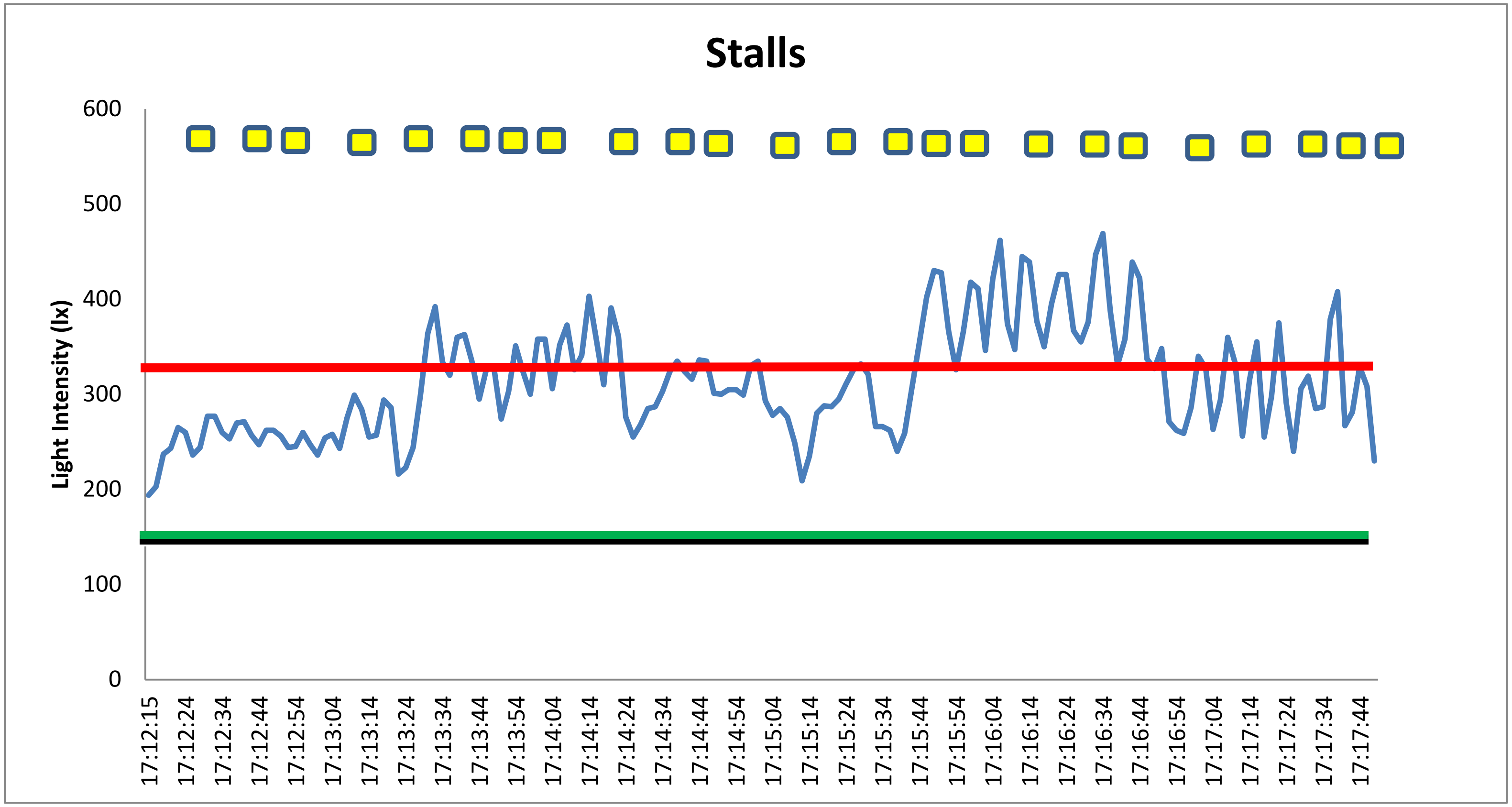
APPENDIX

Appendix I. An example of light reports after the first visit. Light intensity was assessed for 5 min in all areas where lactating dairy cows were housed

Farm A – Light Report

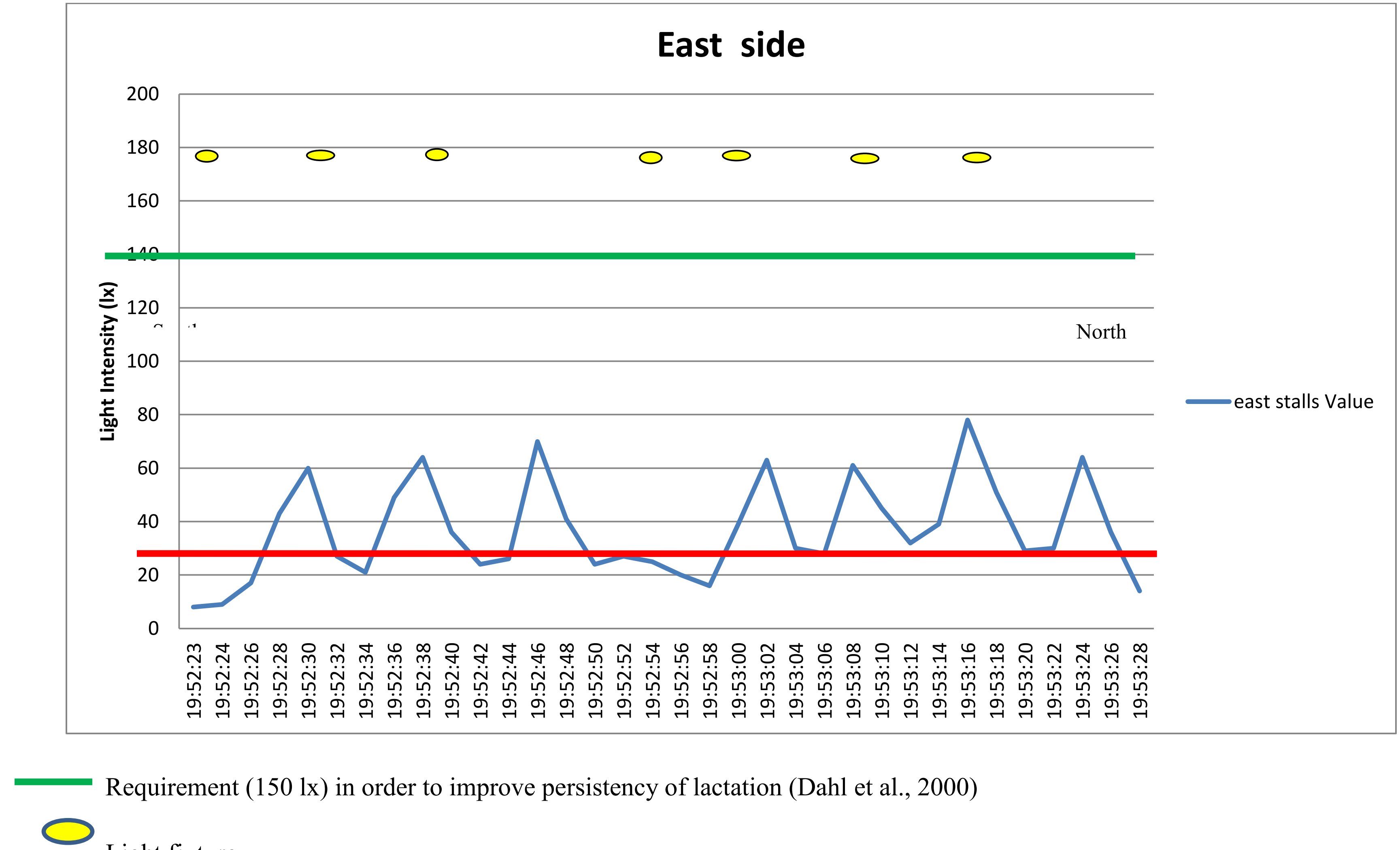


Stalls average = 313 lxx. Starting point was South Robot on December 17 2013.

Requirement (150 lx) in order to improve persistency of lactation (Dahl et al., 2000)

Light fixture.

Farm R – Light Report



Requirement (150 lx) in order to improve persistency of lactation (Dahl et al., 2000)

Light fixture.

East side Average = 36 lx. Taken at feed alley. Starting point was South side dairy barn on January 02 2014. .

Appendix II. An example of light reports after the second visit. Light intensity was assessed for 48 h

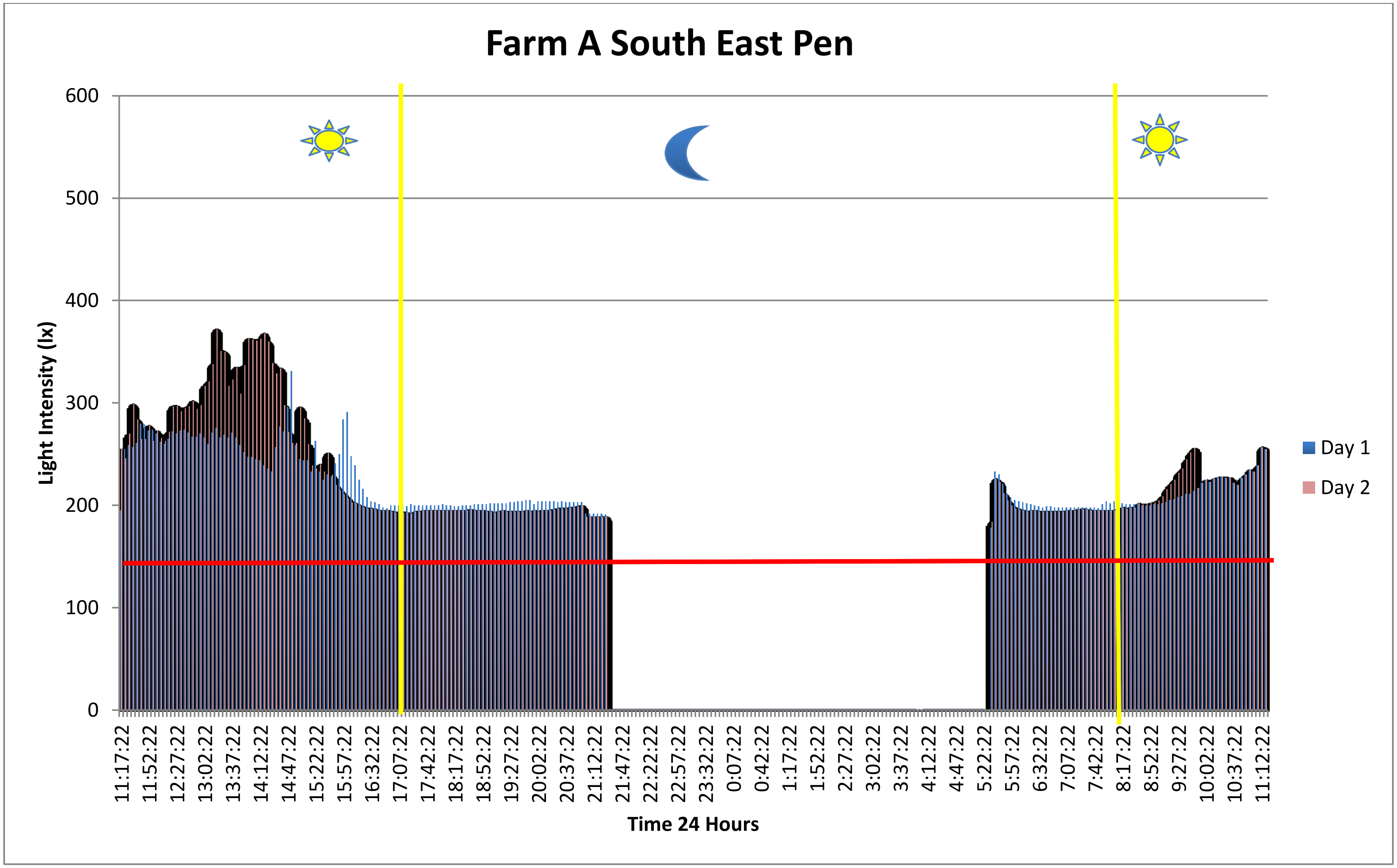
Light Assessment: Farm A Winter 2014

Data collection started on January 13, 2014 at 11:17 am using 3 photometers that measure the light intensity every 5 minutes and store it in a data logger. Two light meters were located in the lactating pens of the dairy barn; one in the South East (SE) pen and the other in the North West (NW) pen. The third meter was located in the dry cow pen. Data collection continued for 48 hours until January 15, 2015 at 11:35 am.

Weather Conditions:
January 13, 2014 – Cloudy with some precipitation, 1 degrees Celsius
January 14, 2014 – Cloudy with some precipitation, 0 degrees Celsius
January 15, 2014 – Partly cloudy, 4 degrees Celsius

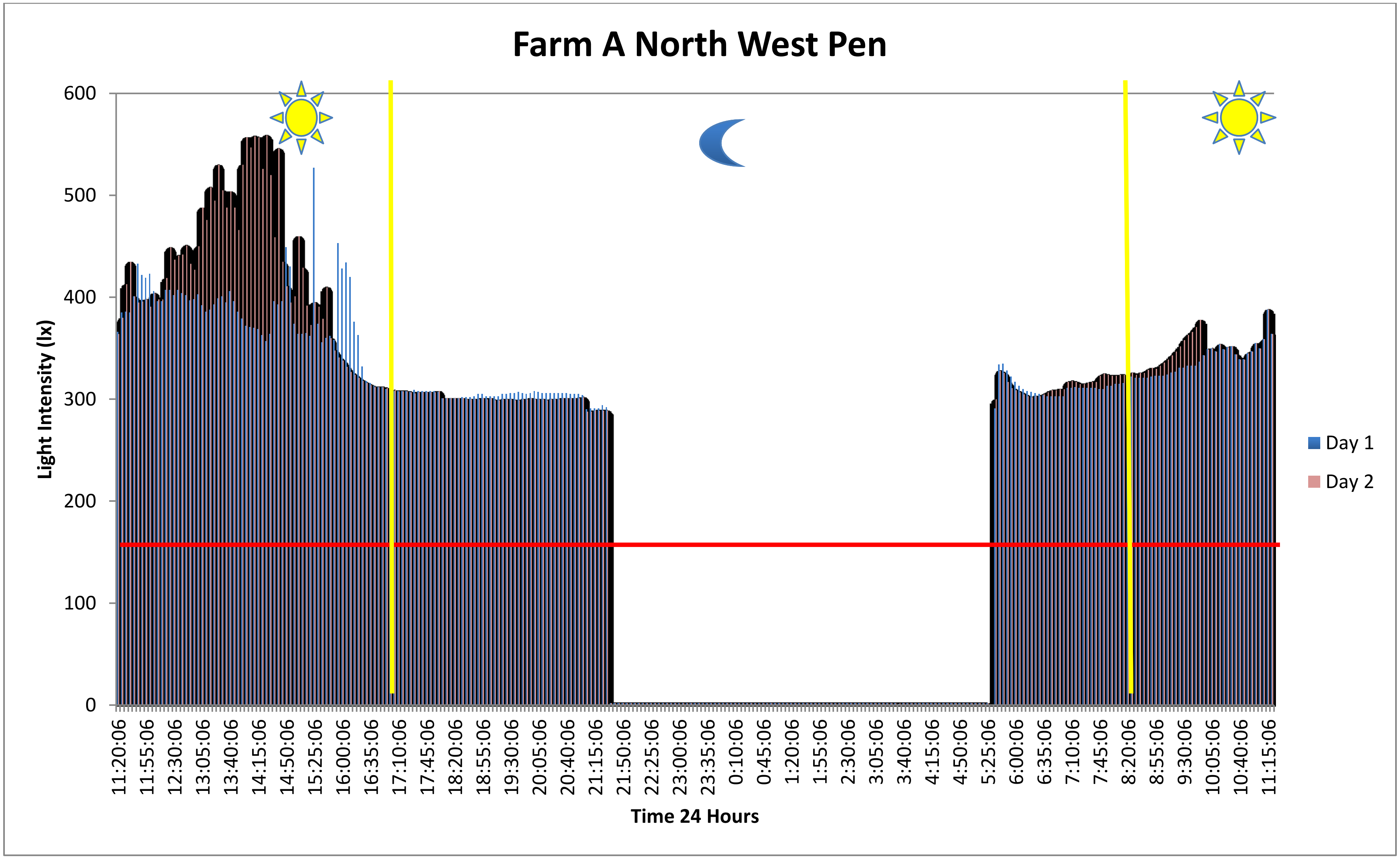
Table 1: Light Intensity at Farm A. Lactating Pens over 48 Hours

	Photoperiod					
Light Intensity (lx)	**SE Pen**	**NW Pen**	**SE Pen**	**NW Pen**	**SE Pen**	**NW Pen**
	Day 1 (hour/d)	**Day 1 (hour/d)**	**Day 2 (hour/d)**	**Day 2 (hour/d)**	**Avg (hour/d)**	**Avg (hour/d)**
<50	8.0	8.0	8.0	8.0	8.0	8.0
50-100	0.0	0.0	0.0	0.0	0.0	0.0
150-400	16.0	14.2	16.0	12.8	16.0	13.5
>400	0.0	1.8	0.0	3.3	0.0	2.5
Total	**24.0**	**24.0**	**24.0**	**24.0**	**24.0**	**24.0**
<150 lx	**8.0**	**8.0**	**8.0**	**8.0**	**8.0**	**8.0**
>150 lx	**16.0**	**16.0**	**16.0**	**16.0**	**16.0**	**16.0**



Threshold Value 150 lx

Sunrise/Sunset



Threshold Value 150 lx

Sunrise/Sunset