Interaction effect of photoperiod management and dietary grain allocation on productivity of lactating dairy cows

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Interaction effect of photoperiod management and dietary grain allocation on productivity of lactating dairy cows

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Abbreviations: LP, long photoperiod; SP, short photoperiod; LG, low grain; MG, medium grain; HG, high grain; IGF-I, insulin-like growth factor I; TMR, total mixed ration; CP, crude protein; NDF, neutral detergent fibre; NSC, non-structural carbohydrates; DM, dry matter; MP, metabolizable protein; BCS, body condition score; MUN, milk urea nitrogen; SCC, somatic cell counts; DMI, dry matter intake; FCM, fat-corrected milk yield; ECM, energy-corrected milk yield; bST, bovine somatotropin;
Abstract: The objective of this study was to determine the interaction effects of photoperiod management and dietary grain allocation on the productivity of lactating dairy cows. Sixty Holstein cows in mid-lactation (d in milk = 113 ± 36.0; mean ± SD) were assigned to either a long photoperiod (LP; 16-h light) or a short photoperiod (SP; 8-h light) treatment. After a 30-d light adaptation period, cows within each photoperiod treatment were fed three diets differing in the grain content (15, 25, and 35% of dietary dry matter) in a 3 × 3 Latin square design. Cows exposed to the LP increased milk yield compared with those exposed to the SP (39.0 vs. 36.8 kg d⁻¹) after a 30-d of light adaptation period. Although the positive effect of LP was not sustained after cows were assigned to dietary treatments in a 3 × 3 Latin square design, cows fed the 35% grain diet increased fat-corrected milk yield compared with those fed 25% or 15% grain diet (35.9 vs. 33.4 or 32.9 kg d⁻¹, respectively). The current study indicated that LP management and feeding high grain diets did not lead to synergistic effects on productivity of dairy cows.

Keywords: photoperiod management, dietary grain, milk production

INTRODUCTION

Photoperiod manipulation is an effective management approach to improve milk production in a safe and non-invasive manner (Dahl et al. 2000). 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 associated with greater plasma concentrations of prolactin (Peters et al. 1981) and insulin-like growth factor I (IGF-I; Dahl et al. 1997). The 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, resulting in a greater persistency of lactation compared with cow exposed to short photoperiod (Capuco and Akers 2002).

The interaction of long day photoperiod with other management practices has been studied previously. Miller et al. (1999) evaluated effects of long day photoperiod and administration of bovine somatotropin (bST), but reported no interaction effects for milk production. Bilodeau et al. (1989) evaluated interaction effects between photoperiod treatment and type of grain (barley vs. corn) on productivity of dairy cows, but did not detect significant interactions. Increasing dietary grain allocation is another management approach to increase milk production, but its interaction with photoperiod management has not been extensively studied. In addition, relative impacts of photoperiod management on productivity of dairy cows have not been compared with nutritional management within previous studies. Thus, the 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.

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 (CCAC 2009).
Experimental design, diet and treatment

Sixty Holstein cows in mid-lactation (milk yield = 38.1 ± 8.27 kg d⁻¹, days in milk = 113 ± 36.0, parity = 1.9 ± 1.10; mean ± SD) were blocked by milk yield, days in milk 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. The distance between the two locations was approximately 30 m, which minimized light leakage from the LP to SP location. The study was conducted during the winter months (November, 2013 – April, 2014, n = 15 for each treatment) and repeated in the following year (November, 2014 – April, 2015, n = 15 for each treatment) with location being switched to avoid the confounding effects of location in the barn with photoperiod treatment. For 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). 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. During a 30-d light adaptation period, cows were fed a common total mixed ration (TMR) containing 16.9% crude protein (CP), 33.8% neutral detergent fibre (NDF) and 37.0% non-structural carbohydrates (NSC) with the forage-to-concentrate ratio of 51:49 on a dry matter (DM) basis (Year one) and a TMR containing 16.5% CP, 36.1% NDF, and 36.5% NSC with the forage-to-
concentrate ratio of 43:57 (Year two). After the 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. 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 (15% for low grain, LG; 25% for medium grain, MG; 35% for high grain; HG; all on a DM basis). Barley silage and alfalfa silage were fed at the ratio of 2:1 on a DM basis. Although energy allowable milk was different for the three experimental diets, metabolizable protein (MP) allowable milk yield was similar for all dietary treatments (Table 1). We used a 3 × 3 Latin square design for evaluation of dietary treatments (n = 20 squares), in which 10 squares received LP while the other 10 squares received SP. This experimental design allowed us to test interactions between dietary energy content and photoperiod treatment by evaluating whether animals in LP squares respond to dietary treatments differently from those in SP squares.

All cows were individually fed experimental diets as TMR, and had free access to water. Cows were fed 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 fed once daily at 0800 h, and milked in their stalls twice daily at 0400 and 1500 h.

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 body condition score (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 22 to 28 and composited for each period to determine the chemical composition of the diet. All samples were dried for 72 h at 55ºC 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), and analyzed for crude protein (method 990.03) and ash (method 942.05) contents. The NDF concentration was determined using heat stable α-amylase and sodium sulfite (Van Soest et al. 1991), fat was determined using a Tecator Soxtect 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 was sampled (approximately 50 mL) from six consecutive milkings on d 26 to 28, mixed with 2-bromo-2-nitopropane-1,3diol, and stored at 4ºC until milk composition analysis. Milk samples were analyzed at the Alberta Central Milk Testing Laboratory (Edmonton, AB, Canada) for milk fat, milk protein, lactose, MUN, and SCC concentrations by infrared spectroscopy (AOAC International, 2002; method 972.16; Milko Scan 605, Foss North America, Brampton, ON, Canada). Yield of 3.5% FCM ([0.4324 × milk yield, kg] + [16.126 × fat yield, kg]) and 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° C for 20 min immediately after collection and plasma was harvested and stored at -20° C until analysis. Four plasma samples, representing every 6 h of a 24-h period and accounting for diurnal variation, were composited to yield one sample per cow per period.

Plasma samples were analyzed for overall means of 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 (SpectraMaz 190, Molecular Devices Corp., Sunnyvale, CA) at a wavelength of 450 nm. Intra-assay and inter-assay CV were 2.5 and 4.3%, respectively. 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. Intra-assay and inter-assay CV were 2.9 and 8.9% for radioimmunoassay, and 6.2 and 10.6 for ELISA assay, respectively. Insulin analysis was performed at the end of the experiment each year and the Coat-A-Count kit was not commercially available for year 2; thus, plasma samples were analyzed using ELISA assay. Both plasma IGF-I and prolactin concentrations were analyzed at Prairie Diagnostic Services (University of Saskatchewan, Saskatoon, Canada). 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). Intra-assay and inter-assay CV were 6.6 and 6.4%, respectively. Plasma prolactin
concentrations were determined by double antibody radioimmunoassay as previously described by Miller et al. (1999). Intra-assay and inter-assay CV were 8.6 and 9.6%, respectively.

Statistical analysis

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

\[ Y_{ijk} = \mu + L_i + P_j + G_k + \text{Cov} + e_{ijk}, \]

where \( Y_{ijk} \) is the dependent variable, \( \mu \) 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), \( \text{Cov} \) is the milk yield before light adaptation, 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 (\( P > 0.10 \)) for primary response variables.

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

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

where \( Y_{ijklm} \) is the dependent variable, \( \mu \) 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, \( C(LG)_{m(l)} \) is random effect of cow nested in photoperiod treatment and group, and \( e_{ijklm} \) is residual. Effects of year × photoperiod × diet treatment interaction had been originally included in the model, but removed from the final statistical model as their effects were not significant (\( P > 0.10 \)) for primary response variables. In addition, although significant year effect was detected for some
response variables, we chose not to report the data separately for each year as treatment by year interactions were not significant. Significance was declared when $P < 0.05$ and tendencies were discussed when $0.05 < P < 0.10$.

**RESULTS**

Cows exposed to the LP increased milk yield (39.0 vs. 36.8 kg d$^{-1}$; $P < 0.01$) compared with those exposed to the SP before they were assigned to dietary treatment. However, after cows were assigned to three experimental diets in a $3 \times 3$ Latin square design, effects of photoperiod treatment were not sustained. No significant photoperiod by diet interaction was detected on any of the variables evaluated in the study, but a tendency of the interaction was detected for protein yield ($P = 0.09$; Figure 1); protein yield was not different between LG and MG diets for cows exposed to the LP whereas protein yield increased for MG compared with LG diet for cows exposed to the SP ($P < 0.05$; 0.99 vs. 0.91 kg d$^{-1}$).

Milk yield was greater ($P < 0.05$; Table 2) for cows fed HG diet compared with those fed MG and LG diets (33.1 vs. 30.6 and 29.4 kg d$^{-1}$, respectively). Milk protein and lactose yield had similar response as milk yield, where the greatest yield was found for HG diet and the lowest for cows fed LG diet. Cows fed HG had greater milk fat yield compared with those fed MG or LG diets, milk fat yield did not differ for cows fed MG and LG diets. Dietary grain allocation had a significant effect on milk composition; milk fat concentration decreased for animals fed HG compared with LG diet (3.95 vs. 4.19%; $P < 0.05$). Milk protein concentration was greater for cows fed HG compared with MG and LG diets (3.39 vs. 3.32 and 3.24%, respectively; $P < 0.05$).
Dry matter intake was greater for cows fed the HG diet compared with those fed the MG or LG diets (23.6 vs. 22.3 and 21.7 kg d\(^{-1}\), respectively; \(P < 0.05\); Table 3) although it was not affected by photoperiod treatment. Likewise, ECM (35.5 vs. 32.9 and 32.1 kg d\(^{-1}\), respectively; \(P < 0.05\)) and FCM yields (35.9 vs. 33.4 and 32.9 kg d\(^{-1}\), respectively; \(P < 0.05\)) were greater for animals fed HG diet compared with those fed MG and LG diets. However, no difference in ECM or FCM yield was detected between MG and LG treatments. Neither photoperiod nor dietary treatment effect was detected on feed efficiency, BW change, and BCS change.

Photoperiod treatment affected plasma glucose concentrations (\(P = 0.02\)); animals exposed to LP had greater concentrations of glucose compared with those exposed to SP (63.7 vs. 62.0 mg dL\(^{-1}\); Table 4). However, the effect of photoperiod treatment was not observed for plasma concentrations of insulin, IGF-I, and prolactin. Cows fed HG diet had greatest plasma concentrations of glucose, insulin, and IGF-I.

**DISCUSSION**

One of the primary objectives of the current study 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\(^{-1}\) compared with animals with short photoperiod (Dahl et al. 2000). Similarly, cows fed high grain diet increased milk production (Ametaj et al. 2009). The positive effects of long day photoperiod on milk production are associated with greater concentrations of plasma IGF-I (Dahl et al. 1997) or prolactin (Peters et al. 1981) whereas high grain diets are rich in fermentable carbohydrates, and can provide more energy to rumen microbes and the host animal,
increasing milk production (NRC 2001). As such, we had hypothesized that cows on the combination LP and HG would increase milk production synergistically, but we did not detect significant interaction effects between two main treatments on milk yield. 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 main treatments on milk yield. However, we observed a tendency of interaction effect on milk protein yield; feeding more grain in the diet increased milk protein yield to a greater extent for cows on SP than LP treatment. Macmillan et al. (2015) reported cows exposed to LP reduced sorting and increased eating time in the early morning when supplemental light was provided. These feeding behaviors for LP cows may have contributed to more consistent rumen fermentation throughout the day, and to maintaining similar milk protein yield between LG and MG diets while cows on SP treatment had less milk protein yield when they were fed LG diets.

In the current study, cows exposed to LP had greater milk yield relative to those exposed to SP (39.0 vs. 36.8 kg d\(^{-1}\)) after 30 d of adaptation to light treatment but before animals were assigned to dietary treatments. This galactopoietic response to LP is consistent with previous reports (Dahl et al. 1997; Dahl and Petitclerc 2003) where long day photoperiod increased milk yield after 3 to 4 weeks of exposure to the light treatment. However, after wk 5 of the current study when cows were fed three different diets in a 3 × 3 Latin square design, positive effects of LP on milk yield did not continue. The mechanism to explain why effects of photoperiod management disappeared after cows were fed different diets is not clear.

Prolactin concentration was not affected by photoperiod treatment in our study, which is in agreement with other studies (Marcek and Swanson 1984; Miller et al. 1999). Low ambient temperatures can decrease prolactin concentrations, and temperatures below 0°C may block the
effect of LP due to low circulating prolactin (Peters et al. 1980). However, a lack of treatment effects on plasma prolactin concentration may not be attributed to the low temperature in the current study because animals were housed in a closed barn except for exercise time and the lowest barn temperature was 8°C during the animal study. Johke (1970) reported that stressful stimulus from venipuncture can increase plasma prolactin concentration. In the current study, we collected blood samples from the coccygeal vessels, and stress from frequent bleeding may affect prolactin concentrations. In addition, plasma prolactin concentration declines at a late stage of lactation (Miller et al., 2006), and we cannot exclude the possibility that animals have become resistant to LP at the later stage of our study, and photoperiod manipulation have exerted less sustained effects on milk production. 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 Petitclerc 2003). The duration of the galactopoietic response induced by photoperiod management in lactating cows has not been clearly established.

Another possible explanation for the lack of animal response to LP at the later stage of our study is that dietary treatment exerted greater effects on milk production, masking effects of LP. In the past, Miller et al. (1999) and Bilodeau et al. (1989) evaluated effects of photoperiod treatment combined with another management practice, and reported inconsistent results. Miller et al. (1999) evaluated effects of bST administration and photoperiod manipulation, and reported no effects of LP on milk production, which is consistent with our findings. It is noteworthy, for both studies (our study and Miller et al. 1999), that cows were adapted to light treatment first, then another treatment was applied later (i.e., bST administration and dietary grain allocation, respectively). Contrarily, Bilodeau et al. (1989) evaluated effects of type of grain and photoperiod treatments, and reported that LP increased milk yield by 1.5 kg d⁻¹ compared with
In the study of Bilodeau et al. (1989), animals were adapted to dietary treatments first, then photoperiod treatment was applied. These observations may indicate that 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 be masked or more difficult to be detected. In addition, 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 treatment) while Miller et al. (1999) and the current study provided supplemental light for animals on LP treatment. Although Bilodeau et al. (1989) reported greater milk yield for LP compared with SP treatment, it should be noted that animals in SP treatment decreased milk yield over time whereas animals in LP maintained milk production.

Furthermore, in the current study, animals did not respond to photoperiod treatment once they were assigned to dietary treatment. With a 3 × 3 Latin square design, animals received 3 diets differing in nutrient contents within a 3-month period, and this finding may indicate that the extent of animal responses to photoperiod manipulation would greatly vary among farms. If a farm practices poor nutritional management such as huge variations in diet nutrient composition, which is mimicked to some extent intentionally by our dietary treatments, animals may not respond to photoperiod manipulation. Contrarily, we speculated that animals in a farm providing consistent nutritional management would benefit more from photoperiod manipulation. Our observations along with previous reports (Bilodeau et al. 1989; Miller et al. 1999) indicate that the effects of LP on milk production may vary depending on how and when another treatment (e.g., diet, bST administration) is applied, and the variation in animal responses to photoperiod manipulation should be noted for field application of photoperiod management.
Milk composition was not affected by LP 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 LP compared with those exposed to SP, and Philips and Schofield (1989) found that cows exposed to LP tended to reduce milk fat concentration by 0.29% unit compared with those exposed to SP (3.87 vs. 4.16 %).

Photoperiod treatment did not affect DMI in the current study. 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 LP treatment increased DMI, relative to cows exposed to SP. Bilodeau et al. (1989) speculated that the increased DMI is due to the greater demand for enhanced milk yield. In the current study, feed efficiency was not affected by LP. Bilodeau et al. (1989) calculated gross feed efficiency as the relationship between milk yield and DMI, and their results were similar to ours where no significant effect of photoperiod treatments was detected for feed efficiency. Changes in BW and BCS were not affected by photoperiod treatment, either. Similar responses were reported by Dahl et al. (1997) and Miller et al. (1999) where LP treatment had no effect on BW and net energy balance.

Previous photoperiod research has 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. 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 LP and fed high grain diets had the greatest concentration of glucose.
among all treatment combinations. Osborne et al. (2007) reported that glucose supplementation increased serum glucose concentration, but that no difference in serum glucose concentrations was detected between LP and SP treatments. In a study using lambs (Francis et al. 1997), greater plasma glucose concentration was observed for animals exposed to LP compared with those exposed to SP. The greater 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 greater for LP animals compared with SP, but photoperiod treatment did not affect DMI.

The greater concentrations of plasma glucose observed in cows exposed to LP may be explained by the daily rhythms of glucose metabolism. Diurnal rhythms are synchronized by numerous environmental cues such as the light-dark cycle and/or feed availability (Jha et al. 2015). Feeding time, considered as an environmental cue, can reset the daily rhythms of glucose and insulin plasma concentrations of dairy cows without affecting DMI or 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, diurnal rhythms of glucose may be altered by melatonin concentrations (Varcoe et al. 2014). Thus, increased light exposure may increase glucose concentration; however, the exact mechanism whereby LP results in greater plasma glucose concentrations is not known.

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). However, we did not find positive effects of photoperiod treatment on plasma IGF-I concentration, which agreed with a
previous report (Miller et al. 1999). Lacasse et al. (2014) also suggested that increased plasma IGF-I concentration would not be solely responsible for the galactopoietic effect of LP.

Although light treatments did not affect many response variables in the current study, dietary grain allocation affected milk production and composition, as expected. Cows fed HG diets increased milk protein content compared with MG and LG diets, 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 greater grain intake (Kennelly et al. 1999). In addition, we observed an increase in lactose yield for cows on the HG and MG diets compared with 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).

In our study, the greatest 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 (Allen 2000). In our study, LG and MG diets contained greater NDF compared with HG. It has been suggested that high NDF concentrations in diets limit DMI due to feed bulkiness and rumen fill (Allen 2000; NRC 2001). The greater plasma glucose concentration in cows fed greater proportions of grain can be explained not only by greater DMI but also by possible enhanced production of propionate in the rumen as well as its conversion to glucose in the liver by gluconeogenesis (Reynolds 2006). Greater concentrations of plasma insulin for cows fed HG diets compared with those fed LG or MG diets is consistent with plasma glucose concentration. In contrast to photoperiod effect, IGF-I concentrations were greater ($P < 0.01$) for cows fed HG diets compared with the cows fed LG or MG diets in the current study. 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 greater DMI and greater energy intake for cows fed the HG diets compared with those fed LG or MG diets.

CONCLUSION

The results of this experiment showed that no significant interactions were detected 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 were exposed to light treatment, and the light effect was abolished after dietary treatments were applied in a Latin square design.

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Table 1. Ingredients and chemical composition of experimental diets.

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<td>10.3</td>
<td>10.1</td>
</tr>
<tr>
<td>Corn gluten meal</td>
<td></td>
<td>5.8</td>
<td>5.4</td>
<td>5.1</td>
<td>5.7</td>
<td>5.6</td>
<td>4.9</td>
</tr>
<tr>
<td>Canola meal</td>
<td></td>
<td>0.0</td>
<td>1.9</td>
<td>4.1</td>
<td>0.0</td>
<td>1.3</td>
<td>4.9</td>
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<tr>
<td>Dicalcium phosphate</td>
<td></td>
<td>0.45</td>
<td>0.20</td>
<td>0.09</td>
<td>0.96</td>
<td>0.55</td>
<td>0.27</td>
</tr>
<tr>
<td>Sodium chloride</td>
<td></td>
<td>0.45</td>
<td>0.45</td>
<td>0.32</td>
<td>0.46</td>
<td>0.41</td>
<td>0.41</td>
</tr>
<tr>
<td>Limestone</td>
<td></td>
<td>0</td>
<td>0.25</td>
<td>0.49</td>
<td>0.55</td>
<td>0.64</td>
<td>0.96</td>
</tr>
<tr>
<td>Potassium carbonate</td>
<td></td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0.14</td>
</tr>
<tr>
<td>Vitamin premix&lt;sup&gt;d&lt;/sup&gt;</td>
<td></td>
<td>0.03</td>
<td>0.03</td>
<td>0.03</td>
<td>0.03</td>
<td>0.03</td>
<td>0.03</td>
</tr>
<tr>
<td>Trace mineral premix&lt;sup&gt;e&lt;/sup&gt;</td>
<td></td>
<td>0.02</td>
<td>0.02</td>
<td>0.02</td>
<td>0.02</td>
<td>0.02</td>
<td>0.02</td>
</tr>
<tr>
<td>Selenium premix&lt;sup&gt;f&lt;/sup&gt;</td>
<td></td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
</tr>
<tr>
<td>Nutrient Composition</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DM</td>
<td></td>
<td>35.6</td>
<td>39.1</td>
<td>43.2</td>
<td>40.1</td>
<td>42.5</td>
<td>48.2</td>
</tr>
<tr>
<td>Ash, %DM</td>
<td></td>
<td>10.3</td>
<td>9.8</td>
<td>9.0</td>
<td>9.1</td>
<td>8.1</td>
<td>7.5</td>
</tr>
<tr>
<td>CP, %DM</td>
<td></td>
<td>18.4</td>
<td>17.9</td>
<td>17.5</td>
<td>17.9</td>
<td>17.7</td>
<td>17.4</td>
</tr>
</tbody>
</table>
NDF, %DM 
37.9 35.4 31.7 35.7 34.1 29.7

Starch, %DM 
11.8 15.5 20.7 13.5 19.6 25.1

Ether extracts, %DM 
3.4 3.3 3.2 2.9 2.8 2.3

Energy allowable milk yield, kg d\(^{-1}\) 
33.9 34.8 35.6 35.0 35.6 36.4

MP allowable milk yield, kg d\(^{-1}\) 
36.0 36.0 36.0 36.5 36.5 36.5

Note: DM, dry matter; CP, crude protein; NDF, neutral detergent fibre; MP, metabolizable protein.

\(^a\) Dietary treatments: LG = low grain diet, MG = medium grain diet, HG = high grain diet

\(^b\) alfalfa silage 2014: DM = 24.7%, CP = 20.6%, NDF = 38.8%; 
alfalfa silage 2015: DM = 31.7%, CP = 20.6%, NDF = 38.6%.

\(^c\) 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%.

\(^d\) Vitamin premix contained 30,000,000 IU kg\(^{-1}\) of vitamin A, 3,000,000 IU kg\(^{-1}\) of 
vitamin D, and 100,000 IU kg\(^{-1}\) of vitamin E.

\(^e\) Trace mineral premix contained 1,350 mg kg\(^{-1}\) of Co, 66,700 mg kg\(^{-1}\) of Cu, 3,000 mg 
kg\(^{-1}\) of I, 120,000 mg kg\(^{-1}\) of Mn, 200,000 mg kg\(^{-1}\) of Zn.

\(^f\) Selenium premix contained 1,000 mg kg\(^{-1}\) of Se.
Table 2. Effects of photoperiod management and dietary grain allocation on milk yield and composition.

<table>
<thead>
<tr>
<th>Item</th>
<th>Long Photoperiod&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Short Photoperiod&lt;sup&gt;b&lt;/sup&gt;</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>LG&lt;sup&gt;c&lt;/sup&gt;</td>
<td>MG&lt;sup&gt;d&lt;/sup&gt;</td>
<td>HG&lt;sup&gt;e&lt;/sup&gt;</td>
</tr>
<tr>
<td>Yield, kg/d</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Milk</td>
<td>30.1</td>
<td>30.7</td>
<td>33.2</td>
</tr>
<tr>
<td>CP</td>
<td>0.96</td>
<td>1.00</td>
<td>1.08</td>
</tr>
<tr>
<td>Fat</td>
<td>1.30</td>
<td>1.26</td>
<td>1.37</td>
</tr>
<tr>
<td>Lactose</td>
<td>1.36</td>
<td>1.38</td>
<td>1.48</td>
</tr>
<tr>
<td>Milk composition</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CP, %</td>
<td>3.23</td>
<td>3.33</td>
<td>3.35</td>
</tr>
<tr>
<td>Fat, %</td>
<td>4.23</td>
<td>4.07</td>
<td>3.96</td>
</tr>
<tr>
<td>Lactose, %</td>
<td>4.56</td>
<td>4.57</td>
<td>4.57</td>
</tr>
<tr>
<td>MUN, mg dL&lt;sup&gt;-1&lt;/sup&gt;</td>
<td>21.0</td>
<td>18.9</td>
<td>17.5</td>
</tr>
<tr>
<td>SCC, cells mL&lt;sup&gt;-1&lt;/sup&gt;</td>
<td>109</td>
<td>125</td>
<td>83</td>
</tr>
</tbody>
</table>

Note: CP, crude protein; MUN, milk urea nitrogen; SCC, somatic cell counts.

<sup>a</sup> Long photoperiod (16 h light, 8 h darkness)

<sup>b</sup> Short photoperiod (8 h darkness, 16 h light)

<sup>c</sup> LG = low grain diet

<sup>d</sup> MG = medium grain diet

<sup>e</sup> HG = high grain diet

<sup>f</sup> Int = Photoperiod and diet interaction
Table 3. Effects of photoperiod management and dietary grain allocation on DMI, feed efficiency, and changes in BW and BCS.

<table>
<thead>
<tr>
<th>Item</th>
<th>Long Photoperiod</th>
<th>Short Photoperiod</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>LG</td>
<td>MG</td>
<td>HG</td>
</tr>
<tr>
<td>DMI, kg/d</td>
<td>22.3</td>
<td>22.7</td>
<td>23.7</td>
</tr>
<tr>
<td>ECM, kg/d</td>
<td>33.2</td>
<td>33.2</td>
<td>36.1</td>
</tr>
<tr>
<td>FCM, kg/d</td>
<td>34.1</td>
<td>33.8</td>
<td>36.7</td>
</tr>
<tr>
<td>Feed efficiency</td>
<td>1.49</td>
<td>1.46</td>
<td>1.51</td>
</tr>
<tr>
<td>BW change, kg d⁻¹</td>
<td>0.79</td>
<td>0.46</td>
<td>0.68</td>
</tr>
<tr>
<td>BCS change, 28d⁻¹</td>
<td>-0.04</td>
<td>0.02</td>
<td>0.04</td>
</tr>
</tbody>
</table>

Note: DMI, dry matter intake; BW, body weight; BCS, body condition score; ECM, energy corrected milk; FCM, fat corrected milk.

- Long photoperiod (16 h light, 8 h darkness)
- Short photoperiod (8 h darkness, 16 h light)
- LG = low grain diet
- MG = medium grain diet
- HG = high grain diet
- Int = Photoperiod and diet interaction
- ECM = [12.82 × fat yield (kg)] + [7.13 × protein yield (kg)] + [0.323 × milk yield (kg)] (Tyrell and Reid, 1965).
- FCM = [0.4324 × milk yield (kg)] + [16.126 × fat yield (kg)] (Tyrell and Reid, 1965).
- Feed efficiency = FCM / DMI
Table 4. Effects of photoperiod management and dietary grain allocation on plasma metabolite concentrations.

<table>
<thead>
<tr>
<th>Item</th>
<th>Long Photoperiod&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Short Photoperiod&lt;sup&gt;b&lt;/sup&gt;</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>LG&lt;sup&gt;c&lt;/sup&gt;</td>
<td>MG&lt;sup&gt;d&lt;/sup&gt;</td>
<td>HG&lt;sup&gt;e&lt;/sup&gt;</td>
</tr>
<tr>
<td>Glucose, mg dL&lt;sup&gt;-1&lt;/sup&gt;</td>
<td>63.3</td>
<td>63.3</td>
<td>64.4</td>
</tr>
<tr>
<td>Insulin, µIU mL&lt;sup&gt;-1&lt;/sup&gt;</td>
<td>6.42</td>
<td>7.07</td>
<td>7.66</td>
</tr>
<tr>
<td>IGF-I, ng mL&lt;sup&gt;-1&lt;/sup&gt;</td>
<td>135</td>
<td>138</td>
<td>151</td>
</tr>
<tr>
<td>Prolactin, ng mL&lt;sup&gt;-1&lt;/sup&gt;</td>
<td>20.1</td>
<td>17.1</td>
<td>19.8</td>
</tr>
</tbody>
</table>

Note: IGF, insulin-like growth factor.

<sup>a</sup> Long photoperiod (16 h light, 8 h darkness)

<sup>b</sup> Short photoperiod (8 h darkness, 16 h light)

<sup>c</sup> LG = low grain diet

<sup>d</sup> MG = medium grain diet

<sup>e</sup> HG = high grain diet

<sup>f</sup> Int = Photoperiod and diet interaction
Figure 1. Effect of photoperiod management and dietary grain allocation on milk protein yield; means differ significantly ($P < 0.05$) if letters differ. Dietary treatments: LG = low grain diet, MG = medium grain diet, HG = high grain diet.