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PHOTOPERIODIC EFFECTS ON DIFFERENT CHARACTERISTICS OF DAIRY COWS

SHADMANESH ALI

Department of Veterinary Medicine, Eghlid branch, Islamic Azad University, Eghlid, Iran

ABSTRACT

Dairy producers are constantly searching out new management techniques to improve production efficiency and cash flow. Photoperiod management is a cost effective method to increase production in lactating cows. Photoperiod, or the daily sequence of light and dark, has dramatic effects on many physiological systems across animal species. Numerous studies confirmed that LDPP increases milk yield in lactating cows, and it is associated with decreased secretion of melatonin and increased secretion of prolactin (PRL) and IGF-1. LDPP also improved growth of neonatal calves from birth until 8 weeks of age. Relative to SDPP, heifers under LDPP had hastens puberty, leaner body at puberty, more mammary parenchyma growth, heavier and taller body conformation at parturition and more milk production in sequence lactation. Relative to LDPP, SDPP during the dry period increases mammary cell proliferation and decreases cell apoptosis. This enhanced mammary growth by SDPP during the dry period increases the number of functional mammary secretary cells at parturition and, in turn, increases the lactation performance. The SDPP effect on the mammary gland during the dry period is mediated by enhanced PRL signaling. Thus, photoperiod management can be used throughout the life cycle of the dairy cow.

KEYWORDS: Photoperiod, Milk Yield, Insulin-Like Growth Factor-I

ABBREVIATION KEY: LDPP=Long Day Photoperiod, **SDPP=** Short Day Photoperiod**, GH** = Growth Hormone, **IGFBP** = Insulin-Like Growth Factor Binding Protein, **PRL** = Prolactin

INTRODUCTION

Dairy producers are constantly searching out new management techniques to improve production efficiency and cash flow. According to reports researchers since 1978, Photoperiod management is a cost effective method to increase production in dairy cows (Dahl et al., 2000 & 2012, Thulasiraman et al., 2015. Toncho et al., 2014). Photoperiod, or the daily sequence of light and dark, has dramatic effects on many physiological systems across animal species. It is classified as long-day photoperiod (LDPP) and short-day photoperiod. LDPP and SDPP included of 16-18 hours of light & 8-6 hours of darkness and 6-8 hours of light &18-16 hours of darkness in 24 hour period respectively (Dahl et al., 2012).In many species, light intensity and photoperiod durations caused by seasonal changes, which influence their physiological events (Wright and Shelford, 2013). This is demonstrates in poultry reared in industrial production systems, where the egg production throughout the year is controlled via photoperiod alteration, in horse husbandry for prolonging or restarting the reproduction period. Cattle respond to shifts in photoperiod, and knowledge of that biology can be used to improve the efficiency of milk production, reproduction, growth and disease resistance (Dahl et al., 2012 & Toncho Penev et al., 2014).With this regard, a number of researchers (Phillips and Schofield, 1989; Dahl et al., 2000; Miller et al., 2000; Ulimbashev, 2011) investigated the effect of light day duration and light intensity on factors associated with better economic results in dairy cattle farms.

Light is one of primary components of microclimate of farm animal environment. It effects via eye on pineal gland in the brain. The light stimulus activity inhibits the rate-limiting enzyme of melatonin synthesis in the pineal gland, and, therefore, decreases circulating concentrations of melatonin. Numerous studies showed that melatonin concentrations decrease under long-day photoperiod and increase under short-day photoperiod (Dahl et al., 2000: Stanisiewski et al., 1988, Buchanan et al., 1992). Across sex and age in cattle, the duration of increased melatonin concentrations then drives shifts in secretion of other hormones, including prolactin (**PRL**), gonadotropins, and IGF-I, all of which increase under LDPP exposure relative to SDPP. The endocrine changes influence the long-term physiological responses in growth, reproduction, lactation and disease resistance. In summary, IGF-I has emerged as a possible mediator of the increase of milk yield in response to long-day photoperiod. The purpose of this paper is to review the evidence for a response of lactating and dry cows to photoperiod, describe the physiologic basis for those responses. Because, natural photoperiod condition in Iran is appropriate for using of this method.

EFFECT OF PHOTOPERIOD IN LACTATING COWS

Peters et al (1978) made the initial discovery that long days increased milk yield in cows relative to those exposed to an ambient photoperiod between September and April in Michigan, h, when natural light was limited to less than 12 hours each day. Over the first 100 days postpartum, cows on long days produced 2.0 L/d more milk than those on natural photoperiod. Subsequently, at least seven different laboratories across North America and Europe, in latitudes ranging from 39°Nto62°N, have confirmed that long-day photoperiod increases milk yield (Table 1). Based on those studies it is expected that cows on long days will produce an average of 2 liters more than control animals on natural photoperiod.

Table 1: Summary of Studies Reporting Effects of Supplemental Lighting on Milk Yield in Lactating Cows

Authors (reference)	Location(latitude) (latitude)	Light type	Responses to Long Days		
			Milk Yield Increase (kg/d)	Fat %[1]	DMI Increase
Peters, et al.	Michigan (42°N)	Fluorescent	2.0	NC	. . .
Peters, et al.	Michigan (42°N)	Fluorescent	1.4	NC	6.1%
Marcek and Swanson	Oregon (45°N)	Sodium vapor	1.8	Variable	. . .
Stanisiewski, etal.	Michigan (42°N)	Fluorescent	2.2	0.16	...
Bilodeau, et al.	Quebec (47°N)	Fluorescent	2.0	NC	4%
Evans and Hacker	Ontario (43°N)	Fluorescent	2.8	NC	NC
Philips and Schofield.	Wales (53°N)	Fluorescent	3.3	0.18	NC
Dahl, et al.	Maryland (39°N)	Metal halide	2.2	NC↓	NC
Reksen, et al.	Norway(60–62°N)	Fluorescent	0.5	…	. . .
Miller, et al.	Maryland (39°N)	Metal halide	1.9	NC	3.5%

[1] NC = no change; arrow indicates direction of change.

SOURCE: Journal of Dairy Science Vol. 83, No. 4, 2000

Reksen et al (1999), suggests that simply exposing cows to more than 12 h of light each day stimulates milk production relative to cows that receive less than 12 h of light/d. Milk composition is generally unaffected by photoperiod, although some studies indicate a slight depression of milk fat percentage may occur during exposure to long days [Table 1; (Stanisiewski, et al 1988, Philips et al 1989)]. Effects of long days on DMI in lactating cows are not always observed, but, generally, DMI increases in longer-term studies to meet the increased demand for energy output from the mammary gland (Table 1).

During lactation, the response to LDPP becomes significant relative to SDPP after 3- to 4-weeks exposure to the extended lighting schedule, and cows respond to LDPP during any stage of lactation with 3 kg/d more milk compared with their counterparts under SDPP (Dahl and Petitclerc, 2003). Of interest, there is no carry over effect after the treatment terminates and the production of cows previously on LDPP decreases to that of SDPP animals after all cows return to the same photoperiod (Dahl et al., 2000).Ulimbashev (2011) showed that the highest yields and good health status during the lactation was accomplished under light intensity of 150 lx, with additionally 614 kg produced milk or by 14.8% more vs. control group. This shows that practically, alighting of 150 lx could be regarded upon as optimum luminous flux for satisfying the physiological needs of lactating dairy cows.

The first hormone impacted by photoperiod is melatonin, which is secreted in response to darkness. Thus, in cows and other animals, a long day actually reduces the duration of elevated melatonin (Dahl et al., 2000). Animals use this pattern of melatonin to track day-length, and then alter secretion of other hormones (Dahl, 2003). In dairy cows, the prolonged photoperiod is associated with increased secretion of insulin-like growth factor (IGF-1) (Dahl et al., 1997). Higher blood IGF-1 in cows leads to increased milk yields (Dahl, 2003). Growth hormone (GH) is another product of the endocrine system probably related to increased milk yield in longer photoperiod conditions (Dahl et al., 2000). Increased exogenous (Bauman and Vernon**,** 1993) or endogenous (Dahl et al., 1991) GH levels are beneficial for milk yields of dairy cattle, but the exact mechanism of GH secretion change according to photoperiod duration is not still clear. Anderson et al. (1999) reported seasonal differences in GH concentrations in cattle, but it is not indicated whether this was related to photoperiod length or not. So far, there are no studies on the variations of GH secretion in cattle related to the light and resulting higher milk yields. Collier et al. (2008) observed that cows treated with recombinant bovine somatotrophin (rbST) had variable IGF-I responses dependent on the season of treatment, with greater IGF-1 associated with the longer days of the summer and lesser values during the short days of winter. Lacasse et al., (2011) conducted a study in lactating cows using Quinogolide (PRL release inhibitor) treatment last for 8 weeks. The milking induced PLR surg was decreased in Quinagolide treated cow’s results in less milk production than control group. This reveals that the depression of the milking- induced PRL surge can alter yield even in the absence of effects on basal PRL (Lacasse et al., 2011).

Apart its effects during the lactation, photoperiod has also a significant impact on the growth of replacement heifers and dry cows. It is proved that during the months with long days, heifers exhibited better body growth and attained earlier sexual maturity (Dahl et al., 2000). A similar effect was observed in heifers (16 L: 8 D) higher weight gain, earlier sexual maturity and higher blood prolactin vs heifers reared in conditions of shorter photoperiod (from 8 to 15 h light) (Small et al., 2003).

EFFECT OF PHOTOPERIOD IN DRY COWS

However, photoperiod only is not influence the annual milk production cycle. Studies suggest that appropriate photoperiod treatment of the dry cow can markedly enhance milk yield in the subsequent lactation (Miller et al., 2000, Auchtung et al., 2005, Crawford et al., 2015). Miller et al. (2000) established that dry cows reared under short photoperiod (8 L: 16 D) during the first 120 lactation days had higher milk yields vs cows reared under long photoperiod during the dry period. Under the same conditions Velasco et al. (2008) demonstrated higher daily lactation yield by 3.6 kg/day in cows reared under short vs long photoperiod during the dry period. The tendency was confirmed by other investigations that stated clearly that during the dry period unlike lactation, cows should be kept under short photoperiod conditions (Petitclerc et al., 1998; Aharoni et al., 2000).

The enhanced milk output is due to increased mammary gland development during the dry period under SDPP

(Wall et al., 2005a). Relative to LDPP, SDPP during the dry period increases mammary cell proliferation and decreases cell apoptosis (Wall et al., 2005a). This enhanced mammary growth by SDPP during the dry period increases the number of functional mammary secretory cells at parturition and, in turn, increases the lactation performance. The SDPP effect on the mammary gland during the dry period is mediated by enhanced PRL signaling. In response to SDPP, circulating concentrations of PRL decline and there is a concomitant increase in expression of PRL receptor (**PRL-r**) in many tissues, including the liver, mammary gland, and lymphocytes (Auchtung et al., 2003, 2005). Although PRL-r signaling influences several intracellular systems, one specific pathway altered by SDPP is the expression of suppressors of cytokine signaling (**SOCS**). A decrease in SOCS expression would be expected to enhance mammary growth because expression of the SOCS family of genes is generally associated with feedback inhibition of PRL signaling (Wall et al., 2005b). According to Todorov and Mitev (2000) the short photoperiod during the dry period facilitated the more rapid body condition recovery of pregnant animals up to BSC of 3 3.5 on the five-point score system. According to Todorov and Mitev (2000) the short photoperiod during the dry period facilitated the more rapid body condition recovery of pregnant animals up to BSC of 3 3.5 on the five-point score system.

Crawford et al. (2005) placed cows on LDPP or SDPP at dry off and confirmed that exposure to LDPP increased circulating PRL approximately 2-fold relative to SDPP. Circulating PRL was increased after constant subcutaneous infusion of PRL for the last 6 wk of the dry period, and the SDPP+PRL cows had circulating concentrations of PRL of 7.8 ± 1.4 ng/mL, intermediate to the concentrations observed in LDPP (10.8 ± 2.5 ng/mL) and SDPP (4.2 ± 1.0 ng/ mL) cows. After calving, milk production followed a similar pattern to that of PRL, with SDPP+PRL yields intermediate to those of SDPP and LDPP cows (Figure 1). Administration of melatonin implants to suppressed prepartum PRL concentration, but did not affect milk production (Garcia-Ispierto etal. 2013).

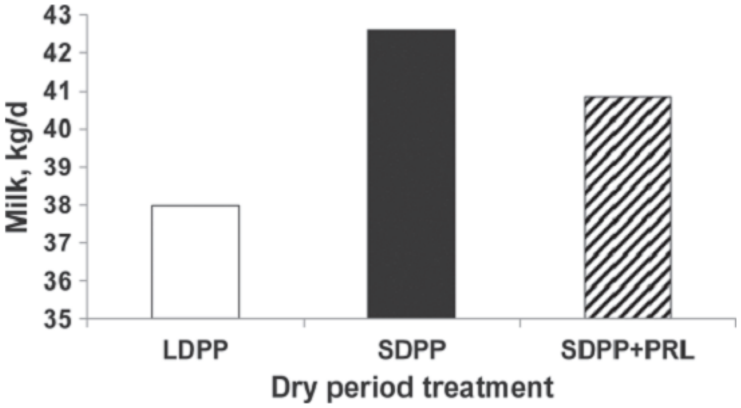

Figure 1: Effect of photoperiod and Prolactin (PRL) Treatment during the Dry Period on Subsequent Milk Production (Crawford et al., 2005). The SDPP Cows Produced More Milk than LDPP cows (P = 0.02), and SDPP+PRL Cows Tended to Produce More Milk than LDPP cows (P = 0.14). SED 2.50 kg/d

The effect in cattle is dependent on the duration of treatment because cows that were exposed to SDPP for only the final 21 d of the dry period did not exhibit the improvement in milk yield in the subsequent lactation (Reid et al., 2004). However, Velasco et al. (2008) reported that treatment with SDPP during a shortened dry period of about 42 d did result in greater milk yield relative to cows on LDPP. Indeed, the SDPP cows in the study of Velasco et al. (2008) averaged 35 d dry despite the target of 6 weeks dry. Thus, SDPP during the dry period improve milk yield in the next lactation in ruminants, and that effect takes between 35 and 60 d to be fully expressed.

The studies of Aharoni et al. (2000) provided additional information about the observed difference between summer and winter periods. They rejected the thesis that lower summer milk yield of cows was due to heat stress and showed that longer photoperiod during the dry period was of greatest significance. Milk losses of cows that had calved in the summer, according to researchers, were by1.5 to 2 L/day by reason of the longer photoperiod during the last three weeks of the dry period (Toncho Penev et al., 2014). Calving season had a significant impact on days open (interval in days between calving and conception) in Iranian crossbred dairy cows (Bahmani et al., 2011). The maximum and minimum values (121.1±3.3 and 108.5±2.7) for days open were belonging to the winter and summer seasons, respectively (Bahmani et al., 2011). This difference can be causing exchanges of long day in seasons. Thus, SDPP during the dry period decreases days open in dairy caws. To identify more effective photoperiod on days open, more research must be conducted in the future.

EFFECT OF PHOTOPERIOD IN GROWTH

A portion of the acceleration of puberty may be related to the increase in lean body growth observed in heifers grown under LDPP compared with SDPP. That is, calves on LDPP schedule gain more BW, achieve greater withers height, and have more lean tissue than those on a SDPP, and that growth is achieved at the same DMI (Petitclerc et al., 1984; Rius et al., 2005: Dahl et al., 2006, 2012). The effects of LDPP on growth are consistent with the greater concentrations of IGF-I relative to SDPP treatment (Kendall et al., 2003; Spicer et al., 2007).

Heifers raised under LDPP photoperiod manipulation during its pre-pubertal (growth phase) till first lactation were showing increased mammary parenchyma growth relative to SDPP (Petitclerc et al., 1984, 1985), more milk production, heavier and taller body conformation at parturition, that were associated with increased production(Rius and Dahl, 2006). It is acknowledged that increased photoperiod enhanced growth until the onset of sexual maturity (Hansen et al., 1983). Before that age, the enhanced growth was due to lower protein recovery rate (Zinn et al., 1986), and that caused animals to use more efficiency the ration (Petitclerc et al., 1983; Mossberg and Jonsson, 1996). After the puberty, body fat deposition in animals was higher in short photoperiod conditions (Zinn et al., 1986).

A study of Osborne et al. (2007) compared LDPP and SDPP effects on performance of neonatal calves from birth until 8 weeks of age. Relative to SDPP, calves under LDPP had greater starter intake and overall body growth before weaning, and LDPP calves generated more ruminal VFA than SDPP, with most of the photoperiodic effects observed after 4 weeks of age. These data support the conclusion that LDPP during the neonatal period enhances overall body growth, possibly through an acceleration of rumen development, compared with calves under SDPP.

The studies of Tihomirova and Kolchin (1978) showed that calves born from cows reared under 16 L: 8 D photoperiods with higher light intensity (50-100 lx) had a higher average body weight by 2.1 kg and higher resistance to diseases. The morbidity rate during the first month was 29% in experimentalcalvesvs43% in the control group, whose dams were reared under natural photoperiod conditions (10-15 lx).

EFFECT OF PHOTOPERIOD IN REPRODUCTION

Effect of photoperiod on reproduction cows is lesser importance than seasonal breeders (Dahl at al., 2012). LDPP exposed heifers achieve puberty faster than the heifers exposed on normal dau length because of greater release of Luteinizing Hormone (LH)in response to estradiol (Hansen et al., 1982: 1983) and decrease time to the first breeding(Rius and Dahl, 2006). During summer, the time required for return to estrous cycle after parturition is shorter when compared with those calved during winter and natural short days (Hansen, 1985). The data reported by Mohammad-zadeh et al. (2014) showed that in rat, light regime had a significant effect on prolactin concentration. Prolactin was significantly lower in permanent light than other treatments. Permanent light will reduce the prolactin level. It seems to be one of the causes of short estrous cycles in permanent light is prolactin levels.

The data reported by Petrusha et al. (1987) showed that lighting intensity was essential for improving the reproduction status of cows. According to the authors, the increased light intensity in the barn of 100, 150 and 200 lx shortened the service period with 12, 22 and 21 days vs. the control group exposed to 35 lx. It should be mentioned that the optimum results were not obtained with the highest light intensity of 200 lx. Probably, the excessively bright light has a negative effect, being perceived by animals as a stressor. Velasco et al. (2008) showed that cows reared under short photoperiod (8 L: 16 D) during the dry period gave birth to calves 4.8 days earlier as compared to animals reared under longer photoperiod (16 L: 8D). According to other studies, the supplementary light resulted in lower activity and clinical manifestation of estrous in cows (Phillips and Schofield, 1989). The opinion of Phillips and Schofield (1989) about long-term effects of supplementary lighting on reproduction traits of cows should be confirmed by additional studies in modern conditions and current cow breeds. Such investigations are mandatory before outlining recommendations for the practice because the problem with detection of cows in estrous is extremely important and with serious impact on financial results of dairy cattle farms (Toncho Penev et al 2014). The conflicting scientific results are also substantiated by the results of Rautala (1991) which showed no relationship between cow fertility and photoperiod variations.

EFFECT OF PHOTOPERIOD IN COWS' BEHAVIOR

According to Phillips and Schofield (1989) LDPP (16 L: 8 D) in dairy cow barns results in two types of changes short-term and long-term. The first type included in increased activity, increased feed intake, longer time spent standing and reduced time spent lying, stronger estrous and aggression signs, and photoperiod duration did not influence the lying time, milk yield and body weight of dairy cows but had an insignificant impact on the amount of consumed feed(Philips et al., 1998). On the other side, Tanida et al. (1984) affirmed no relationship between photoperiod and feeding behavior and milk yield of cows. Light stimulates milk production in cows, increased energy requirements makes feeding behavior predominant and caused greater feed consumption (Dahl et al, 2000; Dahl, 2005).

After many years of research, Varlyakov (1991) and Varlyakov et al. (1993, 2007, 2010a, 2010b) showed that in industrial production systems, the time for intake and conversion of feed and indirectly, the productivity, were influenced at a higher extent by the physiological state and hierarchy in the group than by the season and photoperiod. Dahl (2006) demonstrated that cows reared under short photoperiod schedule from the beginning to the middle of the dry period ingested more dry matter as compared to cows in the same physiological condition exposed to long photoperiod. This circumstance could be used practically by farmers to bring dry animals into optimum body condition for the next lactation (Toncho Penev el at., 2014).

Light spectrum had a various effect on protein utilization and deposition in tissues. Blue and green light benefited the intense protein metabolism, accompanying the growth (Yurkov, 1980). At the same time, red, orange and yellow light were found to delay dietary protein utilization and protein accumulation in the animal body. The effect of white light on protein metabolism held an intermediate position between red and blue light from the visible spectrum (Yurkov, 1980). The cause is the fact, the cows perceive better long-wavelength light spectrum (about 600 nm and more) yellow, orange and red (Phillips, 1993). Therefore, additional research is needed to elucidate light spectrum effect on physiological processes. It is acknowledged that in men, blue light with wavelength between 446-477 nm was most effective for inhibition of melatonin synthesis from the pineal gland (West et al., 2011). This is extremely important proving that different light properties could have an impact on human and animal physiology (Wright and Shelford, 2013)

Some authors propose minimum lighting in the different parts of the barn, pointing out a light flux of 100 lx in the waiting room before entering the parlor, and 200 lx in the milking parlor (Miteva, 2012). Proper lighting could influence oxytocin release and hence, milk let-down (Ma uhova and Bruckmaier, 2004).

EFFECT OF PHOTOPERIOD IN IMMUNE

In addition to well-described effects of photoperiod on mammary gland, lactation and other reproductive tissues, PRL influences immune function. Therefore, it is not surprising that photoperiod affects cattle immune function via shifts in PRL secretion. Seasonal shifts in immune function are observed in many species and these effects on immune tissues are related to photoperiod in rodents (Yellon et al., 1999). Steer calves under SDPP had increased peripheral blood mononuclear cell (**PBMC**) proliferation in response to mitogens in vitro and enhanced neutrophil chemotaxis to IL-8 in vitro compared with LDPP-treated calves (Auchtung et a., 2004). Similar PBMC responses were observed in cows exposed to SDPP when dry (Auchtung et al., 2004).Dry cows on short days had similar responses to the steers, and had lower rates if intra-mammary infection and metritis during the first 10 days of lactation. In addition, cows on short days had a significant reduction in SCC from dry off to parturition, whereas those on long days had an increase over that time (Auchtung et al., 2004). These data suggest that short days are associated with greater resistance to pathogenic insult during an immune-compromised period in the production cycle.

Shifts in secretion of and sensitivity to the hormone prolactin (PRL) may explain the effects of short day photoperiod during the dry period. Data have shown that long days increase whereas short days decrease PRL secretion (Auchtung et al., 2002b). However, the lower PRL concentrations of cows on short days is associated with higher amounts of PRL-receptor expression, and likely sensitivity to that hormone (Auchtung et al., 2002b). Because PRL is critical to the process of mammary cell activation that occurs at parturition, and PRL has immune-stimulatory effects, we speculate that the shifts in sensitivity that accompany short day treatment are producing the changes observed in production and mammary health.

CONCLUSIONS AND RECOMMENDATIONS

From the preceding discussion, it is clear that photoperiod has substantial effects on reproduction, growth, lactation, health across the life cycle and with little effect on milk composition. In lactating cows and heifers, there is evidence that the physiological basis of the response to long days may be an increase in circulating IGF-I. During lactation, LDPP increases milk production and the efficiency of lactation. In the growing calf, LDPP stimulates lean growth, mammary development and hastens puberty. In the final, two months late of gestation in heifers and the dry period of multiparous cows, short-day photoperiods are recommended to enhance responsiveness to photoperiod in the subsequent lactation and immune status. Long days are recommended during lactation to improve milk yields.

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