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Review Article

PHOTOPERIOD MANAGEMENT IN DAIRY HERD: A REVIEW

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Abstract: Photoperiod is virtual duration of light at eye level of cattle. Photoperiod divided into long day and short day photoperiod. Long day photoperiod (LDPP) consists of 16-18 hours of light and 6-8 hours of darkness and vice-versa for short day (SDPP). Secretion of melatonin which is stimulated by short day results in secretion of other hormones like prolactin, cortisol, IGF-1, GnRH and others. Milking cow reared in LDPP showed increase in production due to low melatonin and high prolactin hormones in body. Female calves under LDPP showed increased growth rate and mammary parenchyma cells. SDPP and SDPP + Prolactin showed better effect during dry period as compared LDPP. Multiparous dry animals showed a positive response with SDPP however photoperiod treatment during last two months of gestation did not increase production in primiparous cow. Photoperiodic response was reported clearly with fluorescent, metal halide, high pressure sodium lighting. For cow 15 foot candle/162 lux, 1m (3') from floor of the stall is recommended. In close house 30 foot candle is effective however in open house 45 foot candle produces the effect. Blue light suppress melatonin effectively i.e., reverse of sleep and rest. Red lights however are least likely to suppress melatonin level. BST showed a synergistic effect with LDPP and increase in milking rate. Semen quality of ram and bull are also affected by photoperiod variation. This shows the significance of photoperiodic management of cow for improving production and reproduction potential in dairy herds.
Keywords: Cattle, Dairy herd, Photoperiod, Milk production, Long day.

Introduction

Livestock sector has been considered back bone of agrarian economy of India having cattle and buffaloes population 190.90 and 108.7 million heads respectively responsible for milk production of country (19^{th} livestock census, 2012). Production per animal of India is not as much of exotic cows which may be improved by controlling photoperiod exposure to the retina of cow.

Photoperiod is defined as the virtual period of time during which animal receive illumination i.e. day length. Photoperiodism is defined as developmental response in animals to the relative length of light and dark period. India being tropical climate faces extreme of season.

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Seasonal extremes affects the animals negatively especially with respect to production performances. New management technique is always searched by researchers for improving production of herd. Therefore photoperiod exploitation came into scene to counterbalance the negativity caused by recurring variation of environmental setting. This technique received interest as it is cost effective and easy to achieve production from cattle in general lactating cow in particular. Photoperiod management deals with manipulation of light and dark exposure to the animals during 24 hours duration. Shifting cow from Short day photoperiod (SDPP) i.e., 8 hours of light to Long day photoperiod (LDPP) i.e.,16-18 hrs of light improved production by 2.0 kg i.e., 6.5 % milk (Dahl et al., 2000; Dahl, 2012). Milk composition not affected by photoperiod significantly however decreased fat% is reported (Dahl et al., 2000).

Photoperiod management used extensively by sheep, horse and poultry breeders to manipulate reproductive events and breeding season with additional light exposure. Though the cattle are regular breeder photoperiod can affect reproduction in cattle.

Measuring light intensity: Light is measured as foot candles i.e., lumen/square meter or Lux i.e., lumens/square foot. Dual range 'light meters' are available to read either unit. One foot candle is equal to 10.76 lux.

Types of lighting: Photoperiodic response was reported clearly with fluorescent, metal halide, high pressure sodium lighting. For cow 15 foot candle/162 lux, 1m (3') from floor of the stall is recommended. In close house 30 foot candle is good and open house 45 foot candle produce the effect. Effect was reported on 10 foot candle also; however additional 5 foot candle is aided for buffer for dirty lamp. It is practical that cows are not able to detect light below 5 foot candle.

When lighting is considered especially for calf housing, it should have colour rendition index (CRI) of more than 80. Incan-descent, halogen, fluorescent and metal halide lamp can be used. Mercury vapour and high pressure sodium lamp can be avoided.

Characteristics light sources (Kammel and Holmes, 2003)**:**

Lamp type	Lamp size, Watt	Colour Rendition Index (CRI)	Efficiency, Lunen/Watt	Lamp Hours
Incandescent	60-200	100	**15-20**	750-1000
Halogen	50-150	100	18-25	2000-3000
Fluorescent	32-95	70-95	81-98	15000-20000
Mercury Vapour	50-250	20-60	40-50	16000-24000
Metal Halide	100-250	60-80	80-92	7500-10000
High pressure Sodium	100-250	20-80	90-110	15000-24000

Effect of supplemental lighting with 20 foot candle fluorescent lamp at eye level of buffaloes was reported significant with production the light was controlled automatically with timer for 6.50 hours (Savalia et al., 2016).

Dry cow:

Dry period in cow should be optimized between 40 to 60 days (Kuhn and Hutchison, 2005) as if it is below 30 days significant production loss in coming lactation was observed. Providing dry cow with SDPP for entire dry period produces more milk (up to 3 kg) along with protein and fat in coming lactation. SDPP also increases feed intake by more than 1 kg and also improved the immunity (Auchtung et al., 2005; Auchtung and Dahl, 2004). SDPP exposure during dry period might help in setting responsiveness of cow to long day. Stall comfort is also very important for dry cow equally as in production (Dahl et al., 2006).

Cows reared under SDPP during dry stage gave birth to calves approx. 5 days earlier as compared to LDPP (Velasco et al., 2008).

Data related to time budget in dry cow reveals that stall comfort is more important in dry as compared to lactating cows. As dry cows sit 15 hours per day which is quite higher than lactating cow (11-12 hours). Dry cows will sit for longer period if dry place is available and therefore clean comfortable stall is essential for dry cows without competition.

Photoperiod Physiology:

Generally animals use circadian oscillator to sense day length. It depends on timing of light rather than total amount of light exposure. In mammals, a circadian oscillator present in the suprachiasmatic nucleus of the hypothalamus receives photic stimuli via the retinohypothalmic tract. The circadian system regulates the rhythmic secretion of the melatonin i.e., pineal hormone. Melatonin is secreted at night and duration of secretion varies inversely with day length. It shows light sensitivity encoded in melatonin signal. Melatonin signal decoded at melatonin target tissue that are involved in the regulation of a variety of seasonal responses. These seasonal changes appears to be due to differences in responsiveness to melatonin, in other cases, variation in photoperiod responsiveness may depend on differences in pattern of melatonin secretion related to circadian variation. In mammals sit of action of melatonin is located at pars tuberalis of pituitary gland and suprachiasmatic nuclei.

Light suppresses secretion of melatonin in cattle like other animals. Melatonin accordingly affect hormones like prolactin and IGF-1.

Light never stimulates overfeeding rather it puts a physiological stimulus to produce more milk followed by increase in dry matter to support milk production.

Round the clock light exposure has not similar effect as LDPP rather it has negative effect.

Extending photoperiod using 160 lux light for additional 4 hrs during winter season resulted in better growth rate and early onset of puberty in Buffalo heifers (Roy et al., 2016).

Increased duration of light hours (16 hours) increases the production of prolactin which increases milk production and decreases secretion of melatonin. Artificial light seem to work similar as natural light in this event (Tiilikainen, 2015).

Melatonin: Melatonin is biological amine characterized and named by Aaron B. Lerner, 1958 (Yale University). It is chemically (N-[2-(5-Methoxyindol-3-yl) ethyl] acetamide. Common name of melatonin is 5-methoxy-N-acetyltryptamine. It is produced by small endocrine gland of rice grain size named pineal gland, located at center of brain outside blood brain barrier. It is also secreted by gut, retina, skin and leucocyte (Hardeland, 2005). It regulates sleep-wake cycle, mood, learning, memory and reproduction. Chemically it causes drowsiness and lowers body temperature. Sleep-wake rhythm regulating effect of melatonin is attributed to its action on MT and melatonin receptor present in the suprachiasmatic nucleus (SCN) of hypothalamus. Ramelton (melatonin) and Agomelatine (melatonergic)is used as sleep promoter antidepressant activityin human medicine (Srinivasan et al., 2009). It is a common free radical scavenger and antioxidant. Interaction of melatonin with nuclear receptor site and intracellular protein like calmodulin or tubulin associated proteins as well as direct antioxidant effect of melatonin may explain function of pineal hormone (Cardinali et al., 1997). Melatonin provides hormonal signal transducing day length. Duration melatonin inversely related to day length its secretion changes hypothalamic pituitary axis, hypothalamic pituitary gonadal axis, brain gut axis, autonomic nervous systemalso immune system (Walton et al., 2011). Prolactin also maintains body's circadian rhythm.

Secretion of melatonin (indolic hormone) is stimulated by darkness. Light inhibits the rate limiting enzyme hydroxyl indol-o-methyl transferase in pineal gland which leads to decrease concentration of melatonin in circulation (Buchanan et al., 1992).

Photoperiodic reaction initiated with light perception at screen of retina, which directs signals to supra chiasmatic nucleus (SCN), after that the superior cervical ganglion (SCG). Finally it reaches pineal gland, where melatonin is secreted (Reiter, 1991).

Melatonin is lipophilic in nature; therefore easily pass through cellular membranes in living system generating the ability to act on cells throughout the body (Chowdhury et al., 2008). Melatonin is very unique in sense that it protects the body against free radicals via direct or indirect pathway. Melatonin binds directly to cell membrane and help to stabilize membrane against oxidation and indirectly helping in up-regulating antioxidant defense system (Reiter et al. 1995). It also activates macrophages, proliferate NK cells and produces IL-2.

Transcription factor NF-κB is the main factor responsible for shift between pineal and extra pineal production of melatonin. NF-Kb inhibit (pinealocyte) or induce (macrophages) the transcription of key enzyme (AA-NAT) in melatonin synthesis through immune-pineal axis (Markus et al., 2013).

Melatonin reduces mammary development during lactation in cows (Wall and McFadden, 2012).

Significance of colour of light:

Research have shown that Blue light suppress melatonin most effectively (West et al., 2011) i.e., reverse of sleep and rest. Red lights however are least likely to suppress melatonin level and affect circadian rhythms. This makes red light a perfect option for night light in farms also.

Maintenance of routine time scheduled operation is very important at farm as melatonin begin to increase before two hours animals goes for sleep or rest, therefore sticking to rigid sleep/ resting time schedule will further aid in melatonin secretion.

Hormone cortisol work just reverse of melatonin i.e., it decreases just before sleeping or resting and increases as animal rise.

Blue and green light benefitted the intense protein metabolism leads to improve growth rate (Yurkov, 1980).Red orange and yellow light delay protein utilization and white light is intermediate between blue and red with respect to protein metabolism.

Adequate light decreases milking time by 8-12% (Abrosimova, 1978).

Pathway of synthesis of melatonin:

L-tryptophan

↓ Tryptophan 5-hydroxylase

5-hydroxy tryptophan

↓ Aromatic L-aminoacid decarboxylase

Serotonin

↓ Serotonin N-acetyl transferase (NAT)

N-acetyl serotonin

↓ Hydroxyindole O-methyl transferase (HIOMT)

Melatonin Konturek et al. (2006)

Prolactin Vs. Melatonin:

Natural melatonin response appears in darkas melatonin secretion from pineal is inhibited by light therefore concentration is naturally high during night and undetectable during day hours. When light reach cow's eye, it signals the cow's body to produce less melatonin. Concentration of melatonin maintain endogenous circadian rhythm which further influence and modulates secretion of other hormones to show a clear cut shift in lactation, growth, health and reproduction especially in seasonal breeder (Beltramo et al., 2014; Dardente et al., 2014).

Long day exposure increases prolactin (PRL) in blood as compared to short day. IGF-1 and Bromocriptine has reverse action as compared to PRL. IGF-1 supposed to inversely affect milk production (Abribat et al., 1990). Others also reported IGF-1 increases milk production (Dahl, 2005). IGF-1 is an indicator of somatic maturity which triggers puberty (Santos et al., 2014; Pinilla et al., 2012). Prolactin secretion was more with high ($20^{o}C$) as compared lower ($5^{o}C$) ambient temperature of keeping duration of photoperiod constant (Yaegashi et al., 2012).

Melatonin acts on anterior pituitary activate or suppress gene expression controlling thyroid stimulating hormone (TSH) as well as enzymes de-iodinase II and III which direct the transformation of T4 to T3 and its degradation (Beltramo et al., 2014; Dardente et al., 2014).

Melatonin also plays a crucial role in modulation of the somatotropic and adrenocortical axis (Tsang et al., 2014). Melatonin using retrograde pathway TSH/de-iodinase involved in regulation of reproduction by GnRH release acting on neurons which secretes Kisspeptin, a potent GnRH secretagogue. Melatonin releases Kisspeptin which acts on Kisspeptidergic cells (Beltramo et al., 2014). Melatonin stimulates prolactin release by means of TSH/ De-iodinase system or through triggering tuberalin. Salsolinol, a dopamine derivative is commonly used prolactin secretagogue (Yaegashi et al., 2012).

Cow with long day during dry period might reduce PRL-r (Prolactin receptor) expression and depress PRL secretory stimulus due to negative feedback. As increase in PRL during transition stage layered over PRL-r should increase cell number and lactation.

Dietary melatonin supplementation:

Dietary supplementation of melatonin resulted in 40% increase in total antioxidant capacity in melatonin supplemented heifers as compared to control (Fleming et al., 2014). Melatonin helps in protecting dam and fetus from stress and cellular damage during pregnancy due to heat and oxidative stress (Rensis et al., 2003). Short day photoperiod during pregnancy showed a positive effect on production in following lactation; however melatonin feeding did not show its effect to mimic a short day photoperiod during dry period (Lacasse et al., 2014).

Molecular mechanism of melatonin function:

Melatonin in concentration of 10^{-7}M in granulosa cell culturedown regulatep53and up-regulate Bcl-2 and LHR gene expression of granulosa cells under thermal stress there by increasing colony forming efficiency and decreasing apoptosis rate in ewe (Fu et al., 2014).

Additional roles of melatonin:

- Scientists believe that melatonin reduces incidence of tumor (mammary cancer) formation especially stimulated by light at night (LAN), probable mechanism is inhibition of angiogenesis in cancer. Nude mice with breast cancer xenograft treated with melatonin showed significantly reduced tumor size and cell proliferation. Expression of VEGF receptor 2 also decreased significantly (Jardim- Perassi et al., 2014).
- Modulation of immunity and haemopoietic system: Melatonin acts as immune buffer acting as stimulant under immunosuppressive/basal situation or as anti-inflammatory in presence of exacerbated immune responses like inflammation (Carrilo-Vico et al., 2013).

BST (Bovine somatotropin): BST showed a synergistic effect with LDPP (Long day photoperiod) and increase in milking frequency (Miller, 1999).

Photoperiod and Production performances:

Cows facing LDPP increased prolactin concentration resulting in slower loss of mammary cells due to inhibition of IGFBP-5 (Insulin like growth factor-5 responsible for cell death of mammary gland) leads to slow decrease in milk production (Dahl et al., 1997). IGFBP-5 expressed better in cultured mammary explants in absence of prolactin (Accorsi et al., 2002).

In an experiment with different light exposure i.e., 17 hours Vs 12 hours, it was observed that Light significantly increase milk production in multiparous cow but no significant effect was observed with uniparous cow (Vanbaale et al., 2007). Increase in milk production in LDPP exposed cattle is due to lower melatonin concentration and higher prolactin concentration.

Effect of 18 hours photoperiod i.e., LDPP along with showering on buffalo produced 27.68% more milk as compared to control i.e., normal day length. More over LDPP alone contributes 24% hike in milk yield (Savalia et al., 2016). Author also reported increase in net income per animal considering milk price Rs. 45/kg.

200 lux of light intensity is very good for milking parlour (Clarke and House, 2006; Miteva, 2012) as it influences oxytocin mediated milk let-down (Macuhova and Bruckmaier, 2004). Above findings suggest sensitivity of cows for light during the time of milking.

Photoperiod and Dry matter intake: Dry matter intake reported to increased up to 6% with LDPP. However weight gain is not increasing at the same rate. This might be due to increase in cow efficiency to produce milk with LDPP. Dry matter intake also increases in heifer with increasing photoperiod however intake reduces in dry cow.

Effect of photoperiod on growth: Calves up to eight weeks of age if reared under LDPP showed increased growth rate due to increased ruminal volatile fatty acid (VFA) as compared to calves reared under SDPP (Osborne, 2007). Increased photoperiod also increases lean tissue (Rius et al., 2005) and body weight due to increased IGF-1 concentration (Spicer et al., 2007) and increased feed intake. Artificial lighting with 160 lux for 4 hours daily during winter season result in better growth and early onset of puberty in buffalo heifers (Roy et al., 2016). Heifers with supplemented light showed increase heart girth along with daily additional gain.

Effect of photoperiod on immunity:

During last 60 days of pregnancy exposure to SDPP enhances production and immunity prominently during dry period or transition phase (Dahl and Petitclerc, 2003; Dahl, 2004). Calves raised under LDPP during growth yield larger and leaner body weight with greater mammary parenchyma growth in heifers.

Photoperiod and Reproduction:

During post-weaning period in heifers LDPP increase lean growth, mammary parenchyma development (Petitclerc et al., 1985) there by reducing age at puberty by around one month. Reduction in age of puberty is associated with greater release of LH hormones in response to estradiol (Hansen et al., 1983). Heifer showed heavier conformation, taller length and after parturition production is also higher (Rius and Dahl, 2006).However if herd provided light for 24 hours showed adverse effect on reproduction by increasing days open and number of insemination per cow.

Petrusha et al., (1987) reported increased light intensity (35 Vs. 100, 150 and 200lux) has reduced the service period by 12, 22 and 21 days respectively. Author reported best result with 150 lux luminance.

Significant increase in heart girth, weight gain, udder biometry and lower risk of dystocia was reported in LDPP exposedpre-pubertal heifers as compared to natural lighting management protocol (Valenzuela-Jimenez et al., 2015). LDPP heifers are more feed efficient.

Post-parturient return to estrus and photoperiod:

Seasonality in return to estrus was observed as summer calvers return to estrus earlier as compared to winter calvers (Hansen, 1985).

Effect of photoperiod on mammary gland growth and development:

During pre-weaning period the parenchymal growth induced by increasing level of protein and energy in diet however during pre-pubertal period (lobulo-alveolar duct formation period) the increase in protein and energy diet increase mammary growth towards a higher adiposity (Capuco and Ellis, 2013). Development of mammary gland and its function is controlled by serotoninergic and circadian system (Suarez-Trujillo and Casey, 2016) through Prolactin mediated homeostatic-homeorhetic processes.

More mammary parenchymal growth was observed in heifers exposed to LDPP (Dahl et al., 2000). Mammary cell proliferation was better in SDPP dry cows as compared to LDPP or SDPP + PRL dry cows on biopsy of mammary tissue 20th day of parturition (Crawford et al., 2015).

Cow facing heat stress during dry period have increased prolactin through parturition, reduced mammary growth and produces less milk in succeeding lactation (Tao et al., 2011;

Tao et al., 2013). However basal metabolic profiles in heat stressed cow remain unchanged as compared to cool cow (Tao et al., 2012).

Effect of photoperiod on health status: Cows calving during winter (SDPP) shown longer delay in return to estrous cyclicity as compared to cow calved in summer(SDPP).Said result support post parturient uterine involution is earlier during LDPP (Dahl, 2005).

Photoperiod and welfare:

Artificial lighting system during winter causes change of winter with summer coat. Energy losses for body temperature related to thinner coat during winter. Cows prefer light as compared to dark provided free will. Better illumination in herd provide better visual contact among cows for social hierarchy build up within pen which results in less fighting and trauma. Proper illumination is also essential for animal welfare and safe healthy working condition at farm (Penev et al., 2014).

Cow uses more feeding alley with LDPP exposure (Karvetski et al., 2006). Varlyakov et al. (2010) reported production depends on physiological state and hierarchy in group rather photoperiod and season.

Reducing light intensity to 11 as compared to 33 & 74 lux does not affect general activity as gate passages remain same in all three groups. Moreover milk yield decreases with reducing light intensity which show lower feed intake in low intensity. Author claims that night light offered to the dairy cows related to production rather than welfare aspects (Hjalmarsson et al., 2014).

Heat production:

Cows under LDPP regimen produces 34-41% more heat and also increases heart and respiratory rate as compared to control (Abrosimova, 1978).

Milking frequency: Cow milking three times a day respond to LDPP positively as compared to cow milking twice a day (Dahl, 2005). Milking three times per day reduces stress on herd might support cow for positive stimulus of LDPP.

Conclusion

Milk production depends on secretory cells and metabolic activity of mammary gland. Interventions like photoperiod i.e., sequence of light and dark has a very positive effect on physiology of animals including cell number and secretory activity and ultimately milk production. Different protocols for milk production may be used by progressive farmers like manipulating light available round the clock. Light pattern manipulation works via altering melatonin profile and also influencing several other hormones affecting physiology of animals especially production. Prolactin administration reverses the effect of short day partially by affecting production in coming lactation; this shows interconnection between melatonin-prolactin with respect to photoperiodic response. In dairy cows long day photoperiod (like summer) during lactation or short day photoperiod (like winter) during dry-period enhances milk production.

Gathered evidence suggests that photoperiod manipulation can be exploited to improve production of dairy cows.

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