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Lloyd V. Swanson

Fourteen multiparous Holstein cows were paired by stage of lactation and previous years milk yield and 14 Holstein first-calf heifers were paired by stage of lactation. One member of each pair was assigned to a 24L:0D or a 18L:6D photoperiod for 16 wk during winter 1981 (Experiment 1). A similar experiment comparing natural photoperiod (9-12 h light/day) and 18L:6D was conducted for 9 wk during winter 1982 (Experiment 2) in which 24 Holstein cows and 22 Holstein first-calf heifers were paired and assigned to groups as in the first experiment. Animals were housed in a free stall barn open on 2 sides. High pressure sodium vapor lamps provided light intensity at cow eye level of 254 26 lux during the day and 132 9 lux at night. In Experiment 1, concentration of serum prolactin (PRL) in response to thyrotropin releasing hormone (TRH)(33 μg/100 kg BW) was measured in 5 animals from each group. Prolactin response to TRH or saline was tested in 10 animals in each group in Experiment 2. Photoperiod had no effect on 4% fat corrected milk (FCM) in either age group in Experiment 1 although cows in the 18L:6D group averaged
2% higher monthly persistency in 4% FCM over the 12 wk that milk composition was monitored. Cows in the 18L:6D group averaged 5% higher monthly persistency in 4% FCM in Experiment 2 as compared to cows exposed to a natural photoperiod. Persistency in heifers was unaffected by photoperiod in this experiment. Basal concentration of serum PRL was not affected by either age or photoperiod in Experiment 1 (21.3±3.3 ng/ml). Peak concentration of serum PRL after TRH injection was not affected by photoperiod in the heifer group but cows exposed to 18L:6D had significantly higher concentrations of serum PRL after TRH injection than cows exposed to 24L:0D (560±133 vs. 229±54 ng/ml). Basal concentration of serum PRL in Experiment 2 was similar in TRH- and saline-injected animals (26.3±3.1 ng/ml) but was lower in cows than in heifers (17.1±2.0 vs. 35.5±5.0 ng/ml). Saline injection did not elicit a PRL increase nor were there any differences in concentration of serum PRL due to either photoperiod or age after TRH stimulation in Experiment 2. Weight gain of cows did not differ due to photoperiod in Experiment 1 although heifers exposed to 24L:0D gained more weight than those exposed to 18L:6D. Cows in Experiment 2 gained significantly more weight when exposed to 18L:6D. No difference in weight gain due to photoperiod was observed for heifers in Experiment 2. We conclude that milk yield in mature cows can be increased by using supplemental lighting during winter months when compared to natural photoperiod. No differences between 18L:6D and 24L:0D were observed. Prolactin does not appear to be involved in the mechanism of action of photoperiods stimulation of milk yield. Cost analysis of the above data reveal a $16.06 return
on each dollar invested for supplemental lighting. The additional income realized through supplemental lighting may allow the dairyman to reduce herd size and operating costs.
The Effect Of Photoperiod On Milk Production And Prolactin In Holstein Dairy Cows

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The Effect of Photoperiod on Milk Production and Prolactin in Holstein Dairy Cows

INTRODUCTION

Photoperiod or length of daily exposure to light, natural or artificial, has recently been studied as one of the important biological cues by which physiological changes are controlled in animals. Animals in the wild respond to changes in photoperiod in several ways. Hibernation and migration are examples of these responses although photoperiod is not the only environmental cue involved in these phenomena. The greatest potential application of these physiological changes for man's benefit is in farm animals. The use of gradually changing photoperiod, constant long or short photoperiod, and intermittent photoperiod have long been known to poultrymen. By manipulating photoperiod, growth, maturation rate, and other traits can be enhanced to increase production in chickens. Intermittent lighting provides a double savings by stimulating physiologic changes in chickens as well as decreasing the usage of electricity.

Photoperiod is also an important environmental cue in the regulation of sexual activity in seasonal breeding animals. There are two types of seasonal breeders, those that breed as daylength decreases (short day breeders, such as sheep) and those that breed as daylength increases (long day breeders, such as the horse). The seasonality of breeding is important for survival of the young. Sheep, which normally breed in autumn when photoperiod is decreasing, will lamb in spring when temperatures are warmer and grass is
becoming more abundant for the growing lambs. Horses have a much longer gestation period. They breed in spring as daylength is increasing and will foal the following spring when pasture is lush and abundant. Horses also provide an example of manipulation of breeding season through the use of artificial photoperiod. Most horse registry associations consider January 1 to be the beginning of a new registration year, making it advantageous to the breeder to have his horses foal as close to (but after) January 1 as possible. To do this the normal breeding season must be advanced from April or May to February or March. Enclosed photoperiod-controlled barns have made this possible.

The effects of photoperiod on reproduction are many. This thesis deals only with production traits of farm animals. Recent experiments in sheep have shown that by manipulating photoperiod, growth rate may be increased, possibly decreasing the length of time necessary to produce market lambs. Cattle also respond to increased photoperiod with increased growth rates. Reports of photoperiods effects on growth rate in swine are not yet conclusive.

In the past five years, evidence has been presented which indicates that supplemental lighting will stimulate lactation in the dairy cow. Increased length of photoperiod is a factor easily controlled in our modern dairies. The objective of this thesis is to investigate the effects of supplemental lighting on milk production in dairy cows during winter when natural photoperiod is short. The economic gains which may be realized by the dairyman through the manipulation of photoperiod are great, especially in
the large freestall barns typical of Oregon. Most cows in these barns are subjected to little or no supplemental light during winter months when daily photoperiods range from 9 to 12 hours of light per day. Although night lights are generally used, they may provide insufficient intensity to be stimulatory to milk production. In addition, the possible involvement of prolactin (PRL), a hormone which is known to be influenced by photoperiod and is essential for lactation in the bovine, will be investigated.
REVIEW OF THE LITERATURE

Chickens

The influence of photoperiod on growth and egg production in chickens has been known for many years. Photoperiod influences growth rate in chickens by changing feed intake patterns. Siegel et al. (1963) observed that chicks exposed to 6 hours of light: 18 hours of darkness per day (6L:18D) grew faster than those exposed to 14L:10D photoperiods. Feed intake data showed that chicks exposed to shorter photoperiod learned to eat during the dark portion of the cycle, whereas those exposed to a longer photoperiod fasted most of the night (Morris, 1967a). Total feed intake over the 24 hour period did not differ between the two groups. In contrast, Squibb and Collier (1979) have observed that feed intake occurs uniformly when chicks are exposed to continuous light. The constant flow of nutrients to the tissues can then be used more efficiently in the growing bird. Early experimenters observed that chicks can be reared in constant darkness without any reduction in body weight (Cherry and Bardwick, 1962; King, 1962). Later research, however, indicates that continuous light has a distinct advantage over light-dark sequences or constant darkness (Van Tienhoven and Ostrander, 1976).

Intermittent lighting has been used by commercial broiler producers mostly as an energy saving mechanism. Barott and Pringle (1951) observed a stimulatory effect of intermittent lighting when compared to 12L:12D; however continuous light still maintained the
highest weight gains (Beane et al., 1962). Generally, any system of lighting that does not impose periods of rest, which decreases feed intake, will increase growth rate. This is done most easily with continuous light or continuous dark (Morris, 1967a).

Light intensity is an important factor regulating growth rate. Cherry and Bardwick (1962) and Skoglund and Palmer (1962) reported decreased weight gains associated with higher intensity lighting. Intensities in these experiments ranged from 0.4 to 1200 lux. In a commercial flock where lighting sufficient for feeding, maintaining equipment and observation of birds must be maintained, management is the key factor to determine the lower limit of light intensity to be used. Cherry and Bardwick (1962) observed no difference in growth rate attributable to red or white light at two intensities. Green light (545 nm) also was effective as a growth stimulant (Menaker, 1971).

Altered photoperiod also can stimulate or retard age at sexual maturity. Data from several experiments suggests that chicks respond to varying lengths of photoperiod in a curvilinear fashion with the earliest sexual maturation occurring in chicks exposed to 10 hours of light per day (Morris, 1967a). The influence of photoperiod on sexual maturation is most evident when a changing photoperiod is used. Chicks reared on increasing or decreasing photoperiods will respond with an increased or decreased rate of maturation, respectively (Morris, 1979; Tucker and Ringer, 1982). The important factor in this instance is not the length of day but the rate of change (Morris and Fox, 1958). Chicks hatched in winter and early spring will
mature precociously if exposed to the slowly increasing natural photoperiods seen in higher latitudes during this time of year. Although it may appear advantageous for birds to begin laying at a younger age, smaller eggs, higher incidence of uterine prolapse, increased mortality, and overall decreased egg production have been reported (Morris and Fox, 1958; Morris 1967a, 1979). Delaying maturation by supplying extra light or decreasing daily photoperiod will increase the weight of eggs subsequently laid (Morris and Fox, 1958; Tucker and Ringer, 1982), as well as increase the number of eggs laid in the first year of production (Morris and Fox, 1959). By manipulating photoperiod, age at maturity and subsequent maximum egg yield can be obtained. Best yields have been obtained by choosing a photoperiod designed to maximize ovulation rate (Morris, 1979). Gradually increasing the photoperiod as chicks approach maturity (i.e. 18-20 weeks of age) results in increased egg production. Increasing the photoperiod at this age has more profound effects than if increased at an earlier age because the birds are more sensitive to photoperiod changes as they approach maturity (Morris, 1967a). The intensity of light does not seem to be a major factor in determining age at initiation of egg laying as pullets have been reared successfully in both high and low intensity light (Morris, 1967b).

Egg production is maximized by exposing birds to increasing photoperiods to a maximum of 16 hours of light per day; further increases do not result in increased egg production (Morris, 1967a; Tucker and Ringer, 1982). Pullets therefore must be raised on short
photoperiods so that increases in daily photoperiod may be implemented. Constant photoperiods of 6 to 10 hours of light per day stimulate egg production compared to shorter photoperiods (Morris, 1979).

Intermittent lighting is a topic of interest to many producers. Experiments by Van Tienhoven and Ostrander (1976) have shown that birds exposed to 2L:10D:2L:10D or 2L:12D:2L:8D maintain equal egg production, egg weight, and feed efficiency when compared to birds exposed to 14L:10D. The savings of 10 hours of electricity per day without reduction in production would have significant impact on the poultry industry. A minimum intensity of 2 to 10 lux is required to maintain maximum egg production in chickens (Morris and Owen, 1966).

Ahemeral or non 24 hour light cycles have been used in an attempt to increase egg production. Success in these ventures depends on breeding a chicken which is productive on a light cycle shorter than 24 hours. To date, however, selection for this trait has not been successful (Foster, 1972; Tucker and Ringer, 1982). Cycles longer than 24 hours have been used to increase egg weight and shell thickness (Morris, 1978). Long photoperiod cycles will reduce overall yield but may be useful for commercial producers if market conditions for production of large eggs are favorable.

Sheep

The effects of photoperiod on production traits in sheep have been studied extensively. Long days increase growth rate in wethers and ram and ewe lambs (Forbes et al., 1975, 1979;
Schanbacher and Crouse, 1980). Forbes et al. (1979, 1981) observed that 16L:8D tended to stimulate deposition of muscle in lambs fed ad libitum or restricted diets. Pelt weights and gut fill of sheep also increased with longer photoperiods. Lambs exposed to 16 hours light also increased feed intake on both diets in this experiment. The physiological mechanism by which photoperiod increases feed intake is unclear. In these studies, however, metabolic weight increased in animals exposed to 16L and the increase in feed consumption may have been necessary to maintain the increased maintenance requirements.

Lambs do not increase body weight due solely to an increase in feed intake as was observed in chickens (Morris, 1967a). Feed efficiency was also increased by use of long days (Forbes et al., 1975, 1979; Schanbacher and Crouse, 1980, 1981). Hackett and Hillers (1979) did not observe increases in growth rate, feed efficiency, or carcass composition when lambs were exposed to longer photoperiods. In this experiment lambs were exposed to night lighting in open range conditions. The environmental differences between the studies (open range vs. confinement rearing) may account for the discrepancies observed. Ambient temperature is also important in regulating feed intake and interactions between photoperiod and temperature have been observed (Schanbacher et al., 1982). Lambs exposed to a longer photoperiod at higher temperatures did not decrease feed intake as much as lambs exposed to a short photoperiod.

Constant photoperiod is not essential for the increased growth rate of longer photoperiod to be observed. Intermittent photo-
periods of 7L:9D:1L:7D were as effective as 16L:8D in growth stimulation (Schanbacher and Crouse, 1981). This supports the hypothesis that physiological responses will occur if light occurs coincident with endogenous daily rhythms in photosensitivity (Bunning, 1960). This phenomenon will be described in a later section of this review.

Cattle

Similar to sheep, increased weight gains due to increased photoperiod have been observed in cattle. Average daily gains of Holstein heifers in Michigan increased by 10 to 15% when exposed to longer photoperiods during winter months. Heifers exposed to continuous photoperiod did not increase weight gains in comparison to heifers exposed to natural photoperiod (Peters et al., 1978, 1980). Several weeks of exposure to increased photoperiod were required before body growth increased. Like sheep, heifers ate more and were more efficient in converting feed to gain when exposed to longer photoperiods (Peters et al., 1980). Even when intake is restricted, animals exposed to 16L gained weight faster (Petitclerc et al., 1981). Similar to results in sheep, 16L caused an increase in protein deposition compared to 8L (Tucker and Ringer, 1982). Zinn et al. (1983) observed no difference in average daily gain or feed intake in prepubertal heifers due to photoperiod; however, postpubertal heifers grew faster when exposed to a shorter photoperiod. Postpubertal heifers exposed to 16L had significantly higher feed intake and carcass protein percentage whereas heifers exposed to 8L had significantly higher carcass fat percentage. The increase
in weight gain observed in postpubertal heifers may have been due to overfeeding as was evidenced by a 1.24 kg average daily gain in heifers exposed to 8L. Increased photoperiod in this experiment increased feed intake but did not consistently affect weight gain. Longer photoperiod may stimulate protein deposition. Animals exposed to shorter photoperiods did not achieve the same rate of protein deposition and excess energy intake may have been diverted into body fat (Tucker, personal communication).

Growth rate was not increased when steers and bulls up to 98 days of age were subjected to 16L (Roche and Boland, 1980; Tucker, personal communication). However, Tucker (personal communication) observed a 9% increase in body weight in older bulls exposed to 16L. A different mechanism of action, possibly involving the gonads, may be responsible for increased weight gain in cattle than in sheep. Sheep are short day breeders and the gonads are most active during periods of decreasing photoperiod. Longer photoperiods inhibit gonadal development and secretion. Serum testosterone concentrations were lower in rams exposed to 16L compared to rams exposed to 8L at 22 weeks of age (Schanbacher and Crouse, 1980). Cattle are not seasonal breeders and photoperiod has no effect on gonadal development. Serum androgen concentrations increased at a faster rate as photoperiod increased in cattle (Tucker, personal communication).

Swine

The stimulation of growth by longer photoperiods may be limited to ruminants and poultry. In several recent studies with swine, no
differences in growth rate or feed efficiency in boars, barrows, or gilts were observed (Berger et al., 1980; Mahone et al., 1979; Ntunde et al., 1979). Puberty occurred at an earlier age in young male pigs exposed to increasing or decreasing photoperiods (Berger et al., 1980); however, the effect of photoperiod on puberty in gilts is not known. Ntunde et al. (1979) has found that gilts exposed to very short photoperiods of 1.5L had delayed puberty whereas 18L did not stimulate puberty when compared to 9-11L.

Lactation

Milk yield is another economically important trait affected by photoperiod. Cows in Michigan increased milk yield 6 to 10% without affecting milk composition when given supplemental lighting during winter (Peters et al., 1978, 1981). The effect occurred in both early and late lactation. Dry matter intake increased in cows receiving supplemental lighting which may have been responsible for the increased milk yield (Peters et al., 1981). Results from experiments investigating the effect of photoperiod on lactation in swine are inconsistent. Mabry et al. (1982) demonstrated an increase in milk yield and litter weight at weaning in sows exposed to 16L whereas Greenberg and Mahone (1982) failed to observe an effect of photoperiod on milk yield. Photoperiod did, however, have a stimulatory effect on litter weight gain in mice (Sorenson and Hacker, 1979).

Pineal and Photoperiod

Research has been conducted to investigate the effects of the
pineal gland and its products on growth and milk secretion in laboratory animals. Short photoperiods or blinding are considered to stimulate secretion of pineal products while long photoperiods are inhibitory (Reiter, 1977). Blind anosmic rats, in which the inhibitory effects of the pineal on the neuroendocrine axis appear to be maximal, grew at a slower rate than intact animals (Reiter, 1974). The effect of the pineal on feed consumption and feed efficiency must be considered, however, before these results may be fully interpreted. Neither mammary development (Mishkinsky et al., 1966) nor lactation (Nir et al., 1968) were affected by pinealectomy in rats maintained on 12L:12D photoperiods. Mizuno and Sensui (1970) also observed no effect of pinealectomy on litter weights in rats exposed to 14L:10D on day 16 postpartum. The validity of these experiments has been questioned, however, by Reiter (1977) who suggests that animals exposed to more than 12 hours of light per day are "physiologically pinealectomized". The effect of the pineal on lactation in rats, therefore, is subject to further interpretation.

Sorenson and Hacker (1979) recently studied the effects of purified bovine pineal extract and light duration on lactation in mice. Litter weights of mice exposed to 16L were increased as compared to controls (8L). If photoperiod influences lactation through its effects on the pineal an interaction between light duration and administration of pineal extracts would have been expected. The lack of interaction between photoperiod and pineal products observed in this experiment may indicate that the pineal
is not an important part of the control mechanism and that some other light sensitive site may be responsible for increases in milk yield due to photoperiod.

The administration of pineal extracts as well as the pineal indoles, serotonin and melatonin, lowered the milk yield curve in rabbits (Shani et al., 1971); however, Mizuno and Sensui (1970) found no inhibitory effect of melatonin on litter weight gain in rats. Again, long photoperiods were used and animals may have been physiologically pinealectomized. Serotonin has an inhibitory effect on oxytocin release in response to suckling (Mizuno et al., 1967) thus suppressing milk yield. In another study, Mizuno and Sensui (1970) did not observe an effect of pinealectomy or melatonin administration on the amount of residual milk in rats. Conclusions on the effect of the pineal gland on milk ejection and lactation await further investigation.

Pineal extracts have been evaluated for their effects on the lactogenic hormone PRL. The primary site of action of the pineal is considered to be the brain (Reiter, 1973). Pineal products may also act either at the hypothalamo-hypophyseal axis or directly on the anterior pituitary. Bovine pineal extracts both increased and decreased PRL secretion from rat hemipituitaries cultured in vitro (Blask et al., 1976). Similarly, in vivo administration of bovine pineal extracts elevated (Blask et al., 1976) and suppressed (Ebels and Benson, 1978) plasma PRL levels in rats. Recent experiments in blind anosmic rats indicate that the pineal inhibits PRL synthesis, storage, and release (Leadem and Blask, 1982).
Prolactin and Photoperiod

The effects of PRL in mammals are many. Specific effects of interest in this review are growth and lactation, two traits also affected by photoperiod.

Prolactin is anabolic in some systems (Nicoll, 1980). Growth was depressed in sheep immunized against PRL (Ohlson et al., 1981). But treatment with ergot alkaloids, which also decrease PRL levels substantially, did not affect growth (Ravault et al., 1977). Animals in this experiment were exposed to natural photoperiods during seasons of both increasing and decreasing photoperiods. The effects of suppression of PRL by ergot alkaloids on growth of animals exposed to constant long or short photoperiods has not been studied.

The pineal gland is also important. Pinealectomy inhibits normal fluctuations in blood PRL concentrations in response to photoperiod (Brown and Forbes, 1980); pinealectomized lambs did not grow faster when exposed to longer photoperiods.

Prolactin affects milk production by stimulating several key biochemical processes during lactogenesis in cattle (Akers et al., 1981). In addition, PRL is necessary for the maintenance of lactation in the bovine although it is not thought to be a limiting factor (Tucker, 1979).

Serum concentrations of PRL fluctuate seasonally in cattle (Bourne and Tucker, 1975), sheep (Pelletier, 1973) and goats (Hart, 1975). Length of photoperiod is positively correlated with serum PRL concentrations in bulls (Leining et al., 1979).
Serum PRL concentrations change more quickly in response to decreasing photoperiod than to increasing photoperiod (Bourne and Tucker, 1975). Abrupt increases in photoperiod from 8 hours of light to 16 to 20 hours of light per day increased PRL concentration after one week and maximal PRL concentrations were attained at 9 weeks (Leining et al., 1979). Continuous light resulted in decreased PRL levels similar to that observed under a natural photoperiod. Experiments using gradual and abrupt changes in photoperiod have yielded similar results in sheep (Pelletier, 1973; Ravault and Ortavant, 1977). Photoperiods of 15L did not, however, increase PRL levels in swine when compared to natural photoperiods of 8L (Hoagland et al., 1981).

Components of light also have been studied in relation to PRL release. Most experiments studying the effects of photoperiod on PRL in the bovine have been conducted using cool white fluorescent lights with high intensity (e.g. 600-800 lux) (Bourne and Tucker, 1975; Leining et al., 1979; Peters et al., 1981). The threshold of light intensity necessary to elicit PRL release remains to be determined. A longer photoperiod (16 hours) utilizing high intensity fluorescent lighting (200 to 300 lux) elicited increased PRL secretion as compared to a shorter photoperiod (9 to 11 hours) utilizing low intensity indirect natural light (35 to 40 lux)(Peters and Tucker, 1978). Various wavelengths of light studied have not been more or less effective than white light in eliciting PRL release in response to photoperiod (Leining et al., 1979).
Prolactin levels are affected by other environmental conditions. Increased ambient temperature will increase PRL concentration in cows. Peters and Tucker (1978) observed wide fluctuations in serum PRL in heifers exposed to 16L:8D. Increases and decreases in PRL concentration were synchronized with changes in ambient temperature. Tucker and Wettemann (1976) observed lower basal PRL levels in heifers exposed to 4.5°C when compared to 21°C and 32°C. Prolactin response to thyrotropin releasing hormone (TRH) injection was also decreased in heifers exposed to 21°C when compared to heifers exposed to 32°C and was not evident in heifers exposed to 4.5°C. Prolactin was not affected by relative humidity. The PRL response to temperature supersedes any response to photoperiod. No differences were observed in serum PRL concentration in heifers exposed to natural, 16L:8D, or 24L:0D when ambient temperature approached 0°C (Peters et al., 1980). Thus the effect of photoperiod on PRL and its relationship to growth and lactation is questionable. Increased weight gains in response to 16L:8D persisted throughout winter in Michigan (Peters et al., 1978, 1980) and milk yields did not decrease during exposure to cold (Petitclerc et al., 1981).

Stressful stimuli such as pain will elicit increases in PRL secretion in cattle (Tucker, 1971), but not swine (Hoagland et al., 1981). Feeding also has been implicated in the release of PRL in the bovine (McAtee and Trenkle, 1971) and ad libitum feeding causes increased serum PRL levels in sheep (Forbes et al., 1975). Interpretation of PRL levels must be made carefully
therefore, as many factors contribute to its secretion.

**Photosensitivity**

Recently, several experiments have tested the theory of Bunning (1960) that animals measure time from the degree of coincidence of their daily endogenous rhythm and the external photoperiod. Period of uninterrupted light or uninterrupted dark may be the signals which entrain the cycle of endogenous photosensitivity (Pittendrigh and Minis, 1964).

Schanbacher and Crouse (1981) exposed ram lambs to short (8L:16D), long (16L:8D), and split (7L:9D:1L:7D) photoperiods. Increased weight gains and feed intake were observed in animals exposed to the long and split photoperiod. Light was proposed to be the Zeitgeber for feed intake. The exposure to 1 h of light 16 h after dawn was observed to be in the photosensitive phase and physiologic responses such as increased weight gain and feed intake occurred, even though the total photoperiod was only 8 h.

Ravault and Ortavant (1977) and Thimonier et al. (1978) used Bunning's theory in investigating photosensitivity and PRL secretion in rams. A split photoperiod (7L:9D:1L:7D) again was as effective as 16L:8D in eliciting increased PRL secretion. Insertion of the one hour pulse of light at other times of the day was ineffective in stimulating PRL secretion. A normal diurnal rhythm of PRL secretion is present in sheep (Ravault and Ortavant, 1977) with PRL secretion increasing when lights are turned off. No such endogenous rhythm is present in cattle
although a diurnal rhythm of photosensitivity has been observed (Petitclerc et al., 1983). A 6L:8D:2L:8D photoperiod was as effective as 16L:8D in increasing PRL secretion in bulls. A 2 h pulse of light between 14 to 16 and 20 to 22 hours after dawn increased PRL levels although light at 20 to 22 hours after dawn was much less effective. Further experimentation with photosensitivity and its application to production traits is important to the animal industry. Significant savings, as those observed in the poultry industry, may be realized through the manipulation of photoperiod.
EFFECT OF PHOTOPERIOD ON MILK PRODUCTION
AND PROLACTIN IN HOLSTEIN DAIRY COWS

J.M. Marcek and L.V. Swanson

Department of Animal Science
Oregon State University
Corvallis, OR 97331

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2Reprint requests.
ABSTRACT

Fourteen multiparous Holstein cows were paired by stage of lactation and previous years milk yield and 14 Holstein first-calf heifers were paired by stage of lactation. One member of each pair was assigned to a 24L:0D or an 18L:6D photoperiod for 16 wk during winter 1981 (Experiment 1). A similar experiment comparing natural photoperiod (9-12 h light/day) and 18L:6D was conducted for 9 wk during winter 1982 (Experiment 2) in which 24 Holstein cows and 22 Holstein first-calf heifers were paired and assigned to groups as in the first experiment. Animals were housed in a free stall barn open on 2 sides. High pressure sodium vapor lamps provided light intensity at cow eye level of 254±26 lux during the day and 132±9 lux at night. In Experiment 1, concentration of serum prolactin in response to thyrotropin releasing hormone (33 μg/100 kg body weight) was measured in 5 animals from each group. Prolactin response to thyrotropin releasing hormone or saline was tested in 10 animals in each group in Experiment 2. Photoperiod had no effect on 4% fat corrected milk (FCM) in either age group in Experiment 1 although cows in the 18L:6D group averaged 2% higher persistently in 4% fat corrected milk. Cows in the 18L:6D group were 7% more persistent in 4% fat corrected milk in Experiment 2 as compared to cows exposed to a natural photoperiod. Persistency in heifers was unaffected by photoperiod in this experiment. Basal concentration of serum prolactin was not affected by either age or photoperiod in Experiment 1 (21.3±3.3 ng/ml). Peak concentration of serum prolactin after
thyrotropin releasing hormone injection was not affected by photoperiod in the heifer group, but cows exposed to 18L:6D had significantly higher concentrations of serum prolactin after thyrotropin releasing hormone injection than cows exposed to 24L:0D (560±133 vs. 229±54 ng/ml). Basal concentration of serum prolactin in Experiment 2 was similar in thyrotropin releasing hormone and saline-injected animals (26.3±3.1 ng/ml) but was lower in cows than in heifers (17.1±2.0 vs. 35.5±5.0 ng/ml). In Experiment 2 saline injection did not elicit a prolactin increase, nor were there any differences in concentration of serum prolactin after thyrotropin releasing hormone stimulation due to either photoperiod or age. Weight gain of cows did not differ due to photoperiod in Experiment 1 although heifers exposed to 24L:0D gained more weight than those exposed to 18L:6D. Cows in Experiment 2 gained significantly more weight when exposed to 18L:6D. No difference in weight gain due to photoperiod was observed for heifers in Experiment 2. We conclude that milk yield in mature cows can be increased by using supplemental lighting during winter months when compared to natural photoperiod. No difference in milk yield between 18L:6D and 24L:0D were observed. Prolactin does not appear to be involved in the mechanism of action of photoperiods stimulation of milk yield.
18L:6D and 24L:0D. The effect of these photoperiods on concentrations of serum PRL at rest and after TRH stimulation also was studied.
MATERIALS AND METHODS

Experiment 1

Fourteen multiparous Holstein cows and 14 Holstein first-calf heifers were used. Cows were paired according to previous year's production and days in lactation (38 to 207 days), whereas heifers were paired according to days in lactation (31 to 197 days). One member of each pair was assigned randomly to 18L:6D and the other to a 24L:0D photoperiod. All animals were on a 24L:0D photoperiod prior to the experiment. Cows were housed in a free stall barn open on the north and south sides. Treatment groups were separated from each other by a length of 28 m within the barn. Mean intensity of light at cow eye level was 254±26 lux during the day and 132±9 lux at night. Identical completely mixed rations consisting of corn silage, alfalfa hay cubes, whole cottonseed, and a 16% crude protein dairy concentrate were fed once daily to cows and heifers in their respective treatment groups.

Cows and heifers were assigned to treatment groups in December 1981 and the experiment was conducted for 16 wk through April 1982. All animals were maintained on a 24L:0D photoperiod before the beginning of the experiment. Milk yield and milk composition (fat, protein) were monitored weekly. All animals were weighed on two consecutive days each month during the experiment.

To determine if photoperiod had an effect on pituitary PRL, 5 animals from each group were selected randomly for a TRH challenge experiment. Cows were locked in stanchions and feed was removed 2 h prior to the experiment. Blood samples were collected via tail
venipuncture at -30, -15, 0, +5, +10, and +15 min relative to intravenous injection of a standard dose (33 ug/100kg BW) of TRH (Sigma Chemical Co., St. Louis, Mo.). Samples were allowed to clot at room temperature, then centrifuged and the serum decanted. Serum was stored at -20°C until assayed for PRL content by double antibody radioimmunoassay (5). NIH-P-B3 was used as the reference standard.

Experiment 2

A similar experiment was conducted beginning November 1982 for 9 wk through January 1983. For 2 months prior to the start of the experiment, cows at the Oregon State University Dairy Center were maintained on a natural photoperiod schedule. Twenty-four Holstein cows and 22 Holstein first-calf heifers were paired as in the previous experiment. One member of each pair was assigned at random to a natural photoperiod and the other to an 18L:6D photoperiod at 10 days postpartum or later. Cows ranged from 10 to 159 days and heifers ranged from 35 to 283 days in lactation at the beginning of the experiment. Natural photoperiod during the experimental period ranged from 9 to 11.5 h light per day. Housing and feeding schedules were consistent with the previous experiment. Milk yield, milk composition, and cow weight were monitored as in Experiment 1.

The effect of photoperiod on PRL was studied as in the first experiment except that 5 saline-injected animals were included in each group as controls. Blood samples were collected at -30, -15, 0, +10, +15, and +20 min relative to administration of the
standard dose of TRH.

Persistency of milk yield is defined as the percentage of a current month's yield relative to the previous month's yield. Statistical analysis of milk yield, milk composition, and cow weight data was accomplished using split-plot analysis of variance. Basal concentrations of PRL in serum and differences between basal levels and peak TRH-induced concentrations of PRL in serum were analysed by analysis of variance.
RESULTS AND DISCUSSION

Milk yield and 4% FCM were not changed due to altered photoperiod in the heifers for Experiments 1 and 2, respectively, (Figures 1 and 2) perhaps due to the higher persistency normally observed in heifers (1). Heifers maintained average monthly persistencies of 98 to 100% in milk yield and 98 to 101% in 4% FCM during the experiments.

Milk yield (Figure 3) and 4% FCM were not significantly different in cows exposed to 18L:6D compared to 24L:0D (Experiment 1) although monthly persistency of milk yield was 2% higher in the 18L:6D group.

A significant photoperiod by week interaction (P<.01) was observed in 4% FCM when 18L:6D was compared with natural photoperiod (Figure 4), whereas milk yield did not differ (Experiment 2). Cows exposed to 18L:6D maintained monthly persistencies of 99% in 4% FCM while those exposed to natural photoperiod averaged 92%. Cows exposed to 18L:6D had average monthly persistency of 101% in milk yield whereas those exposed to natural photoperiod averaged 97% persistency. These results are in agreement with Peters et al. (9, 10) who observed that cows exposed to longer photoperiods during winter months responded with an increase in milk yield; however, in the present experiment the increase in milk yield was not statistically significant.

In these experiments, 18L:6D increased milk yield in mature cows in comparison to a natural photoperiod. Continuous lighting was as effective in maintaining persistency of milk yield as
18L:6D, however direct comparisons between the results of Experiments 1 and 2 cannot be made because they were conducted in different years and animals were maintained on different control photoperiods prior to beginning the experiments.

Mechanisms by which photoperiod stimulates increased milk yield are not known. One possibility is the effect of photoperiod on feed intake. Peters et al. (9) observed an increase in feed intake when lactating cows are exposed to longer photoperiods. This would be an economical method to increase milk yield since additional feed consumed would exceed maintenance requirements and be available for milk synthesis. Other experiments indicate that heifers increase feed intake when exposed to longer photoperiods but not when exposed to continuous lighting (8, 10). In a concurrent behavioral study during Experiment 1, Tanida et al. (14) observed no difference in total time spent eating in cows exposed to either 18L:6D or 24L:0D. Feeding patterns did not differ from what previously has been observed for cattle exposed to natural photoperiod who exhibit diurnal rhythms, eating more during daylight hours and having peaks of eating activity both in the morning and afternoon (2). In contrast, Zinn et al. (18) concluded that lights on, lights off, and presentation of fresh feed increased feeding activity in prepubertal heifers. Heifers exposed to short photoperiods began eating about 2 h before lights on, indicating that entrainment to the light cycle had occurred. Hafez and Bouissou (4) have suggested that feeding behavior responds to the influence of ambient temperature as well as to other
environmental conditions. It is possible that, if animals were placed in an environmentally controlled chamber, photoperiod would be the key Zeitgeber for entrainment of feeding behavior. In natural barn conditions, however, additional factors such as daily fluctuations in temperature, humidity, presentation of feed, and milking activity may influence feeding behavior.

The intensity of light used in this experiment was lower than that used previously (9, 10). Stevenson et al. (13) observed that milk production increased linearly in sows as intensity of light increased. The interaction of light intensity and duration may also be important in the bovine and warrants further examination.

The effect of photoperiod on percent fat and percent protein in milk was examined. In Experiment 1, milk samples were analysed during weeks 1 to 12 of the experiment but data from week 1 were not included in the analysis due to an error in sampling procedure. Percent milkfat and percent protein were not affected by photoperiod in heifers in Experiment 2 or cows in Experiment 1. Differences did exist in the other two groups. A significant photoperiod by week interaction was observed for percent milkfat (P<.05) and percent protein (P<.01) in heifers in Experiment 1. Both traits increased at a more rapid rate during weeks 2 to 12 of the experiment in heifers exposed to 18L:6D. Significant interactions also were observed for percent milkfat (P<.05), kg milkfat (P<.01), and percent protein (P<.05) in cows in Experiment 2. Percent milkfat and kg milkfat (Figure 5) decreased at a slower rate in cows exposed to 18L:6D as compared to cows exposed to
natural photoperiod. This contributed to increased persistency in 4% FCM and to the interaction observed in kg milkfat. Percent protein, on the other hand, decreased at a faster rate in cows exposed to 18L:6D.

We believe that the differences in percent milkfat and percent protein observed in this experiment are not biologically important because overall yields of milkfat and protein were not affected. The one instance in which kg milkfat was affected may have been due to the increase in milk yield observed. Other researchers reported no difference in percent milkfat in response to photoperiod (9). Variations in percent milkfat and percent protein throughout the lactation are normal (12). Both components decrease during the beginning of lactation, level off, and then gradually increase in the latter half of lactation. Many other factors are also responsible for variation in milk composition including season, age, stage of lactation, pregnancy, mastitis, feeding and management practices, as well as individual cow variation (6). Further examination of our data revealed that inherent differences between cows may have been responsible for the differences observed, since cows were not paired on milk composition traits at the beginning of the experiments.

Data from the PRL experiments in 1981 are presented in Table 1. No differences in basal PRL concentration due to photoperiod or age were observed although cows tended to have higher basal PRL levels (P=.10) than heifers (27±6 vs. 15±2 ng/ml). Peak PRL levels after TRH injection were significantly higher (P<.05) in cows
exposed to 18L:6D as compared to cows exposed to 24L:0D but did not differ for the heifers. In the 1982 experiment basal PRL concentration in saline-injected animals did not differ from basal PRL levels observed for TRH-injected animals; therefore, the data were pooled for analysis. Peak PRL concentration after saline injection was not included in the analysis since saline injection did not elicit an increase in serum PRL. Basal PRL levels in this experiment did not differ due to photoperiod although serum PRL concentrations were higher (P<.01) in heifers than in cows (Table 2). No differences due to photoperiod or age were observed in PRL concentration after TRH stimulation.

Endogenous hormone secretion has been hypothesized to be one mechanism by which photoperiod influences milk yield. Several hormones are involved in lactogenesis and galactopoiesis in the bovine. These include placental lactogen, PRL, growth hormone, glucocorticoids, and thyroxine (15). Of these, PRL is the most responsive to changes in photoperiod. Peters et al. (9) observed increased basal concentrations of PRL and increased concentrations of PRL after TRH stimulation in lactating cows exposed to 16L:8D as compared to cows exposed to 8L:16D. Growth hormone and thyroxine are not influenced by photoperiod (7, 8, 9). Some evidence that glucocorticoid concentration is negatively correlated with photoperiod has been reported in some (7) but not all experiments (8, 9). Vanjonack and Johnson (17) observed that high producing cows had higher glucocorticoid levels at lower temperatures but that corticoid levels decreased faster in high producing cows at
higher temperatures. Prolactin is positively correlated with temperature (16) and low temperatures (approximately 0°C) over- ride any photoperiod-induced increase in PRL concentration (8).

In our experiment no consistent differences in PRL concentration due to photoperiod were observed. This is contrary to that observed previously (7, 8, 9) although the milder climate in which the experiment was conducted and light source (although wavelength of light has not been observed to affect PRL concentration (7)) may account for these differences. We do not believe temperature was an important factor as it was consistent (10°C) throughout the sampling periods. The lower intensity of lighting may have accounted for the decreased PRL response to photoperiod, although Peters and Tucker (11) used low intensity lighting (i.e. 300 lux) and observed an increase in serum PRL concentration in heifers in response to longer photoperiod. Because of the nonspecific nature of prolactin release, other factors of which we were not aware may have produced the significant differences observed.

The inconsistencies observed in serum concentrations of PRL do not seem to be related to the increases observed in milk yield. This adds further evidence that prolactin is not a limiting factor for milk yield in the bovine.

First-calf heifers, but not cows, exposed to 24L:0D gained weight faster (P<.05) than those exposed to 18L:6D in Experiment 1 (Table 3). There were no differences in heifers in Experiment 2. Cows in Experiment 2 gained significantly more weight (P<.01) when exposed to 18L:6D. Peters et al. (9) did not detect differences
in weight gain due to photoperiod in lactating cows. We may have encountered genetic differences or environmental factors such as competition for bunk space or competition between cows. Diets, however, were the same for the two heifer and two cow groups.

From these data we conclude that increased photoperiod during winter months stimulates milk yield in cows but not in first-calf heifers. Milk yield, however, did not differ in cows or heifers exposed to continuous lighting as compared to those exposed to 18L:6D. Increased percentages of protein and fat were observed in some experiments; however, total fat and protein yields did not differ.

Serum PRL concentration did not increase in response to photoperiod as had been observed previously. This may have been due to different climatic conditions or different intensity of lighting. These data do not indicate that PRL is responsible for the increase observed in milk production due to photoperiod.
Table 1. Serum prolactin concentration (ng/ml) in cows and heifers at rest (basal) and after thyrotropin releasing hormone (TRH) challenge (33 ug/100 kg) Experiment 1.

<table>
<thead>
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<th>TRH Stimulated&lt;sup&gt;a&lt;/sup&gt;</th>
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<td></td>
<td>24L:0D 18L:6D</td>
<td>24L:0D 18L:6D</td>
</tr>
<tr>
<td>Cows</td>
<td>23±6&lt;sup&gt;bc&lt;/sup&gt; 31±11&lt;sup&gt;c&lt;/sup&gt;</td>
<td>229±54&lt;sup&gt;d&lt;/sup&gt; 560±133&lt;sup&gt;e&lt;/sup&gt;</td>
</tr>
<tr>
<td>Heifers</td>
<td>17±3&lt;sup&gt;c&lt;/sup&gt; 14±2&lt;sup&gt;c&lt;/sup&gt;</td>
<td>390±65&lt;sup&gt;d&lt;/sup&gt; 390±86&lt;sup&gt;d&lt;/sup&gt;</td>
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</tbody>
</table>

<sup>a</sup> Data represent peak concentration minus basal concentration
<sup>b</sup> Mean ± SE
<sup>c,d,e</sup> Means in rows not sharing a common superscript differ (P<.05)
Table 2. Serum prolactin concentration (ng/ml) in cows and heifers at rest (basal) and after thyrotropin releasing hormone (TRH) challenge (33 ug/100 kg) Experiment 2.

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<tr>
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<td>Natural Photoperiod</td>
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<td>Heifers</td>
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<td>30±7</td>
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</table>

a Data represent peak concentration minus basal concentration

b Mean ± SE
Table 3. Mean monthly body weights (kg) of cows and first-calf heifers exposed to various photoperiods.

**Experiment 1**

<table>
<thead>
<tr>
<th>Month</th>
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<th>Heifers</th>
</tr>
</thead>
<tbody>
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<td>673±11</td>
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**Experiment 2**

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<th>Heifers</th>
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<td>Natural Photoperiod&lt;sup&gt;a&lt;/sup&gt;</td>
<td>18L:6D&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>1</td>
<td>667±22</td>
<td>658±13</td>
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<tr>
<td>2</td>
<td>668±20</td>
<td>664±14</td>
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<tr>
<td>3</td>
<td>669±20</td>
<td>686±16</td>
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</table>

<sup>a,b,c</sup> Photoperiod treatments within experiments not sharing a common superscript differ (P<.05) over time.

<sup>d</sup> Mean ± SE
FIGURE 1. Mean weekly milk yields for heifers in Experiment 1 exposed to two photoperiods (18L:6D and 24L:0D). Straight lines represent regressions computed from the data.
FIGURE 2. Mean weekly four percent fat corrected milk (4% FCM) for heifers in Experiment 2 exposed to two photoperiods (18L:6D and natural). Straight lines represent regressions computed from the data.
FIGURE 2

KG 4% FCM/DAY

WEEKS

Natural Photoperiod

18L:6D
FIGURE 3. Mean weekly milk yield for cows in Experiment 1 exposed to two photoperiods (18L:6D and 24L:0D). Straight lines represent regression lines computed from the data.
FIGURE 4. Mean weekly 4% FCM for cows in Experiment 2 exposed to two photoperiods (18L:6D and natural). Straight lines represent regressions computed from the data.
FIGURE 4

Kg 4% FCM/day vs weeks for different photoperiods: Natural Photoperiod and IBL:6D.

WEEKS

0 2 4 6 8
FIGURE 5. Mean weekly kilograms milkfat per day for cows in Experiment 2 exposed to two photoperiods (18L:6D and natural).
FIGURE 5

Graph showing the change in KG milkfat/day over weeks. The graph includes two lines, one labeled "Natural Photoperiod" and another labeled "IBL-6D." The x-axis represents weeks, ranging from 0 to 8, and the y-axis represents milkfat per day, ranging from 0.8 to 1.8.
REFERENCES


CONCLUSIONS

This and other studies have demonstrated that 16 to 18 h light per day increase milk yield in mature dairy cows when compared to natural photoperiod. Cows exposed to continuous lighting in this experiment did not differ in milk yield from cows exposed to 18 h light. Further study is needed to determine the optimum photoperiod as well as minimum intensity required for maximum stimulation of milk yield in the dairy cow. Recent experiments using split photoperiods in bulls indicate a photosensitive phase for PRL release in the bovine (Petitclerc et al., 1983). Research investigating the use of a split photoperiod to stimulate milk production should also be conducted.

The mechanism by which photoperiod stimulates milk yield is not understood. Results of this experiment add further evidence that PRL is not responsible for the increases observed. The effects of the pineal on PRL and lactation have just begun to be studied. This endocrine organ may have significant impact on lactation through products which have not, as yet, been identified. The effects of photoperiod on other parts of the brain should be examined to determine if other light sensitive areas of the brain exist, and if so, what impact they may have on physiologic processes such as growth and lactation.

The manipulation of photoperiod and the resulting increase in milk yield are of potential benefit to the dairyman. Electricity for one 400 watt high pressure sodium vapor lamp would cost the
dairyman $49.70 per year if used for 18 h per day for six months each year (based on March 1983 electricity prices for the Northwest (3.78¢/kwh). Each lamp provides sufficient light to illuminate 251 square m at approximately 100 lux if positioned 6.5 m above the barn floor. Each cow requires 8.7 square m of space, including free stall, cow alley, feed manger, and feed alley space. One fixture therefore would provide enough light for 29 cows.

As an example, assume that Joe Farmer has 100 cows with a rolling herd average of 6306 kg milk with 3.5% butterfat. His cows, on the average, are producing 5833 kg 4% FCM per year. If, by providing supplemental light, 4% FCM is increased by 7% as observed in our experiment, each cow will produce 204 kg more 4% FCM if increased lighting is effective for 6 months. At current milk prices of $13.50 per cwt (29.76¢ per kg) and 17¢ fat differential (for each 0.1% change from 3.5%) per cwt (.375¢ per kg), income would increase by $64.55 per cow. Approximately 30% of most herds are first calf heifers and would not benefit from the additional light. So additional income per year for the 70 mature cows would be $4518. Additional costs per year would include the four lamps ($165 per lamp over 10 years expected life = $66 per year) and electricity ($49.70 per lamp X four lamps = $198.80), giving a total cost per year of $264.80. Net additional income would be $4253.20 or $42.54 per cow and a return per dollar invested of $16.06. Additional savings in electricity may be realized if future experiments using intermittent lighting, or light for 1-2 hours at specific periods of time after dawn, prove successful.
Our experiment has provided information useful to the dairy farmer in Oregon. Providing cows with supplemental photoperiod can provide substantial increases in income, which, in view of the current milk surplus, would allow the dairyman to decrease herd size and thus operating costs.
BIBLIOGRAPHY


APPENDIX
APPENDIX 1

Feed Intake

Feed intake data for Experiments 1 and 2 are presented in Appendix Table 1. The amount of feed cows received was recorded daily and amount of feed refused was recorded once weekly from which total feed intake per group was calculated. Number of cow days per group per week was used to calculate mean intake per cow per day.

Data were analysed within experiments using a two by two factorial design with photoperiod and age as the main effects. As expected, cows ate significantly more (P<.01) than heifers in both experiments. This can be attributed to higher metabolic body weights and feed requirements of the cows. A significant treatment by age interaction (P<.01) was observed in Experiment 2. Cows exposed to 18L:6D ate less than cows exposed to natural photoperiod (43.0±0.6 vs. 44.4±0.7 kg feed/day) whereas heifers exposed to 18L:6D ate more than heifers exposed to natural photoperiod (40.3±0.6 vs. 38.3±0.5 kg feed/day).

Regression analysis indicated that cows in Experiment 1 exposed to 24L:0D increased feed intake while those exposed to 18L:6D decreased weekly feed intake over the length of the experiment (Appendix Figure 1). Heifers in Experiment 2 ate less when exposed to 18L:6D and increased feed consumption when exposed to natural photoperiod (Appendix Figure 2).

Interpretation of these data must be made with care. In both
experiments dry matter intake was not calculated. Corn silage was stored in a bunker silo which was partially open to environmental conditions. During periods of heavy rains, dry matter in corn silage, and therefore in the total ration, decreased. Other commodities used in the ration were not subject to these open conditions and maintained uniform dry matter.

Another important factor in interpreting these data is that although experimental animals remained in the alleys for the length of the experiment, nonexperimental animals were moved in and out of the alleys at various times. Competition between cows and competition for feed manger space therefore, changed from time to time throughout the experiment. Prior to being introduced into the groups, new cows were not always exposed to the same photoperiod as animals in the alley. The effect of photoperiod on feed intake in these new animals would not be the same as the effect on experimental animals because acclimation time to the new photoperiod was different. Therefore, it is not possible to draw firm conclusions on the effect of photoperiod on feed intake from these data.

Estrus detection during Experiment 1 was conducted using both visual observation by experimenters and herd staff and KaMar Heat-mount Detectors (KaMar, Inc., Steamboat Springs, CO). A summary of the accuracy of the KaMar heat detectors is presented in Appendix Table 2. Estrus was determined by visual observation (e.g. standing to be mounted, mucus discharge), rectal palpation at time of insemination, and subsequent rectal palpation of pregnancy.
Sixty-six percent of all cows in estrus had KaMar aids activated. Thirty-seven percent of all KaMars activated were false positive. Eighty-eight percent of first calf heifers in heat had KaMar aids activated and 55% of all KaMars activated in this age group were false positive. The increased activity of the younger animals may account for the difference observed between age groups. Other factors which may have affected the accuracy of the estrus detection aids include the steep slope of the barn floor (4°), which may have deterred the cows willingness to mount, and the reproductive condition of the animals. This herd had a relatively high incidence of cystic ovaries as diagnosed by rectal palpation (39% of cows and 11% of heifers). Nymphomania and anestrus are clinical signs of cystic ovaries and would affect the number of false positive readings and total number of cows in observed estrus, respectively. Nineteen percent of cows with activated KaMars and 24% of heifers with activated KaMars were not observed in estrus visually. Accuracy of estrus detection was determined here by interval from previous estrus, or subsequent pregnancy from breeding. These results indicate that KaMar estrus detection aids can be used to assist in estrus detection, however due to the high number of false positive readings, they should not be used as the only method of estrus detection.
Appendix Table 1. Mean daily feed intake (kg feed as fed/cow/day) for Cows and Heifers in Experiment 1 and 2.

### Experiment 1

<table>
<thead>
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<th>Week</th>
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### Experiment 2

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Appendix Table 2. Accuracy of KaMar Heatmount Detectors in Cows and First Calf Heifers in Experiment 1.

<table>
<thead>
<tr>
<th></th>
<th>Number of cows in estrus</th>
<th>Number of KaMar activated cow not in estrus (False positive)</th>
<th>Number of cow in estrus without KaMar activated</th>
<th>Number of cows in estrus with KaMar activated but no visual observation of heat</th>
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</thead>
<tbody>
<tr>
<td>Cows</td>
<td>30</td>
<td>17</td>
<td>15</td>
<td>7</td>
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<tr>
<td>First calf heifers</td>
<td>30</td>
<td>37</td>
<td>4</td>
<td>16</td>
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</table>
Appendix Figure 1. Mean kilograms feed consumed (as fed) per day for cows exposed to two photoperiods (18L:6D and 24L:0D).
Appendix Figure 2. Mean kilograms feed consumed (as fed) per day for heifers exposed to two photoperiods (18L:6D and natural).