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Photoperiodic Regulation of Hormones, Growth and Lactation

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Photoperiodic Regulation of Hormones, Growth and Lactation

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It gives me a great deal of pleasure to present this Lecture in honor of Dr. Samuel Brody, especially since I believe I have a University of Missouri heritage. Dr. Ralph P. Reece, who was my major professor at Rutgers University, received his Ph.D. degree from the University of Missouri in 1937 where his major professor was Dr. C.W. Turner. Moreover, 21 years ago Dr. Reece arranged for me to learn from Dr. Turner the technique for measuring deoxyribonucleic acid (DNA) content of mammary tissue, an index of cell numbers. On my way to present my first scientific paper at the American Dairy Science Association meetings in Logan, Utah, my wife and I visited with Dr. Turner in his laboratory. What was most impressive to me was that Dr. Turner immediately took this inexperienced graduate student under his wing like a long-lost chick. He introduced us to faculty and students, showed us the laboratories, bought our meals, and arranged to have Dr. David Griffith teach me the techniques for measuring DNA. I used this technique as a major cornerstone of my Ph.D. Thesis research, and my use of the technique continued for approximately 10 years. Even today we sometimes need to measure cell numbers, and the basic technique we use was learned at the University of Missouri.

Some of my colleagues also have a University of Missouri heritage. One famous graduate of your Department of Dairy Husbandry is Dr. Joseph Meites, who has been a professor at Michigan State University for many years. Dr. Meites and I have collaborated in research for many years. In addition, Dr. Edward Convey, one of my closest associates, received his Ph.D. under the direction of Dr. Reece. There are several ways to interpret my academic background. There are those who might say that I am narrowly trained. But I prefer to think that if done properly narrow training can lead to super brilliance!

Fifteen years ago we knew many of the hormones that controlled mammary function in several laboratory mammals. For example, we knew that estradiol and progesterone induce mammary growth, and that prolactin is essential for mammary growth, lactogenesis and lactation. It was known that adrenal glucocorticoids are lactogenic and also are essential for maintenance of lactation, and that growth hormone and thyroid hormones are necessary for maximal milk production. But the laboratory species may not necessarily be good models for the hormonal control of mammary function in cattle. In other words, rats, even black and white rats, are not simply miniature dairy cows.

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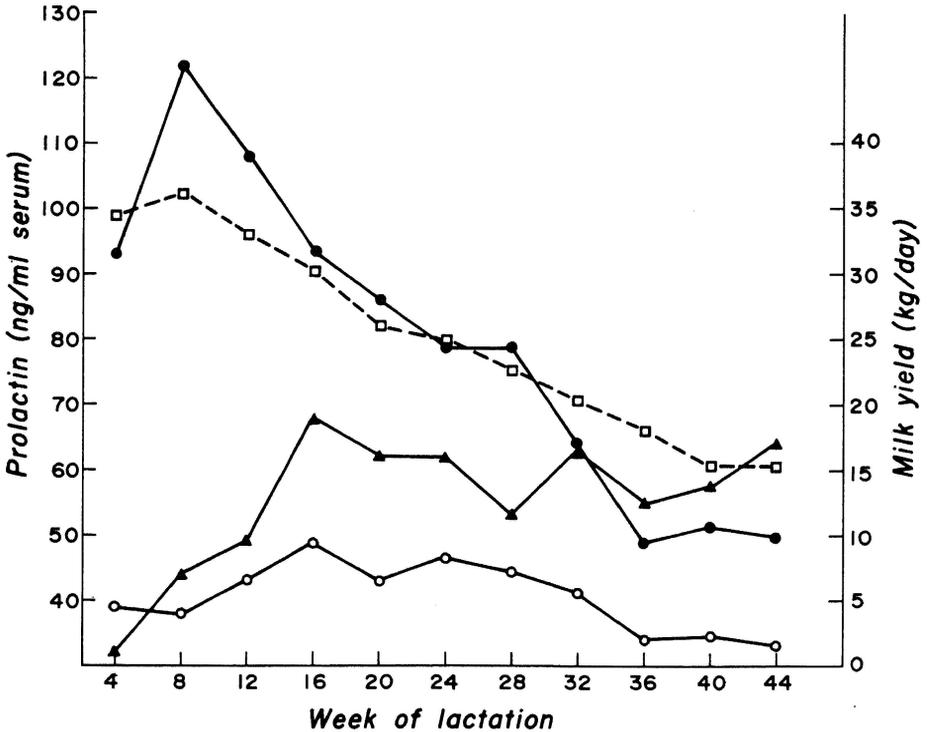


Figure 1. Average prolactin concentrations during lactation in serum collected 2-4 h before (\blacktriangle — \blacktriangle), 5 min after (\bullet — \bullet), and 1 h after (\circ — \circ) milking. Average daily milk yields are plotted as \square — \square . Standard errors of mean for serum prolactin ranged from 2.9 to 11.5 ng/ml and generally were proportional to the mean. Number of observations per point ranged from 55 during early lactation to a minimum of 29 at the end of lactation. (From Koprowski and Tucker, 1973.)

About 13 years ago we embarked upon a series of experiments to determine the limiting hormones for milk yield in dairy cattle. The long-term goal of my research program was very simple: I wished to devise means to manipulate the endocrine system and thereby control lactation. The approach we used was to develop specific assays for several hormones that, based on data from laboratory species, were believed to be important for the function of the mammary gland. The assays we developed were sufficiently sensitive to detect concentrations of hormones in blood. We measured these hormones in cattle in a variety of physiological or experimental conditions.

Initially we focused on prolactin. As shown in Figure 1, concentrations of prolactin released into serum in response to milking cows (solid circles) decrease with advancing lactation and parallel the quantity of milk produced. The cause of the decline in the ability of cattle to release prolactin during lactation has not been established. The overall correlation between yield of milk and concentrations of prolactin in blood was 0.36. As an aside to the main thrust of the experiment, we rearranged the prolactin data in Figure 1 according to month of the year when the samples were collected (Figure 2). Twenty consecutive months were represented.

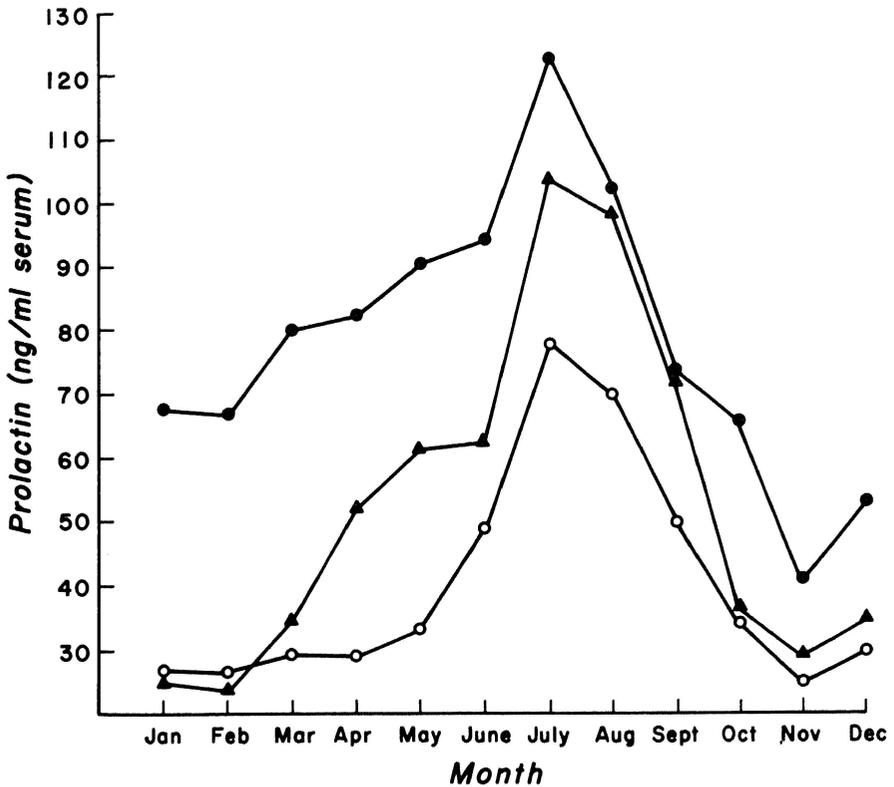


Figure 2. Adjusted average concentrations of serum prolactin in lactating dairy cows during the seasons, using stage of lactation and stage of pregnancy as covariates. Serum was collected 2-4 h before (▲—▲), 5 min after (●—●), and 1 h after (○—○) milking. (From Koprowski and Tucker, 1973.)

Arranged this way it was clear that concentrations of prolactin two to four hours before, immediately after, or one hour after milking were greater in summer than in winter. However, the quantity of prolactin released during milking (immediate post-milking concentrations minus premilking values) was not reduced in winter. More recently, we have determined that ambient temperatures do not affect milking-induced releases of prolactin (Peters *et al.*, 1981).

To investigate which component of season affected secretion of prolactin, Dr. Robert Wettemann of Oklahoma State University and I exposed heifers to five days of 21° C ambient temperatures, followed by five days of exposure to 27° C ambient temperatures. Prolactin in serum increased from 8 to 22 ng/ml during the four-hour interval when temperatures were being increased (Figure 3). Conversely, when temperatures were decreased from 21 to 10° C, prolactin decreased from 13 to four ng/ml of serum. Thus, cattle acutely monitor ambient temperature and adjust their secretion of prolactin accordingly. The physiological reason for this acute sensing of ambient temperatures is unknown. Nevertheless, the prolactin response of cattle to changes in ambient temperature represents a very sensitive thermometer system.

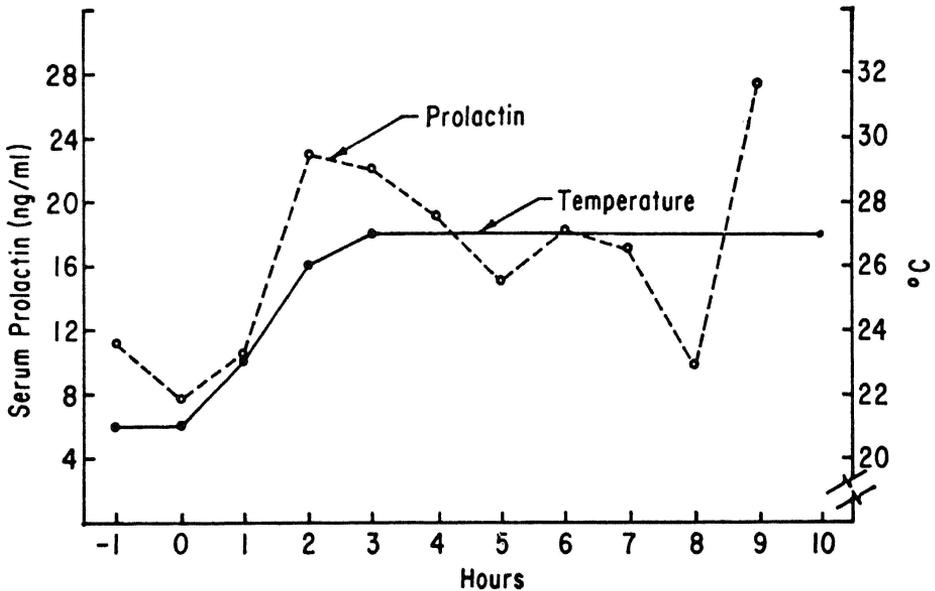


Figure 3. Average serum prolactin and ambient temperature during a change from 21°C to 27°C. Each point for serum prolactin is the mean of four heifers. Standard error of the overall mean for prolactin was 4.4 ng/ml serum. (From Wettemann and Tucker, 1974.)

Thyrotropin releasing hormone (TRH) causes an acute release of prolactin in cattle (Convey *et al.*, 1973), and we have used this peptide to quantify the capacity of the anterior pituitary to release prolactin under a variety of physiological conditions. In heifers subjected to 4.5, 21 or 32° C, the quantity of prolactin released after TRH was dependent upon the ambient temperature (Figure 4). Thus, in contrast to the relative lack of effects of cold ambient temperature on milking-induced release of prolactin, cold temperatures clearly suppress the ability of TRH to induce prolactin release.

Since prolactin secretion was dependent upon ambient temperature and research of Drs. Brody, Johnson and others at the University of Missouri showed that breed of cattle affected tolerance to heat stress, Dr. Wettemann and I decided to compare prolactin secretion in heat tolerant (Brahama x Hereford) and heat susceptible (Holstein) breeds of cattle subjected to seven, 21 and 31° C. Prolactin increased from nine to 30 ng/ml as temperature increased, and breed did not affect the response.

Several years after we discovered the relationship between ambient temperature and prolactin, Dr. Raymond Bourne, a post-doctoral trainee in my laboratory, decided to investigate the effects of daily lighting on prolactin secretion. The only temperature-controlled facility I had available was an air conditioned room in which rabbits were housed. Since we knew we must control ambient temperature if we wished to study the effects of light, we pushed the rabbits to one side of the room and built a temporary pen to house young bull calves. Prepubertal bulls have proven to be an excellent model to study the effects of photoperiod on prolactin secretion. Dr.

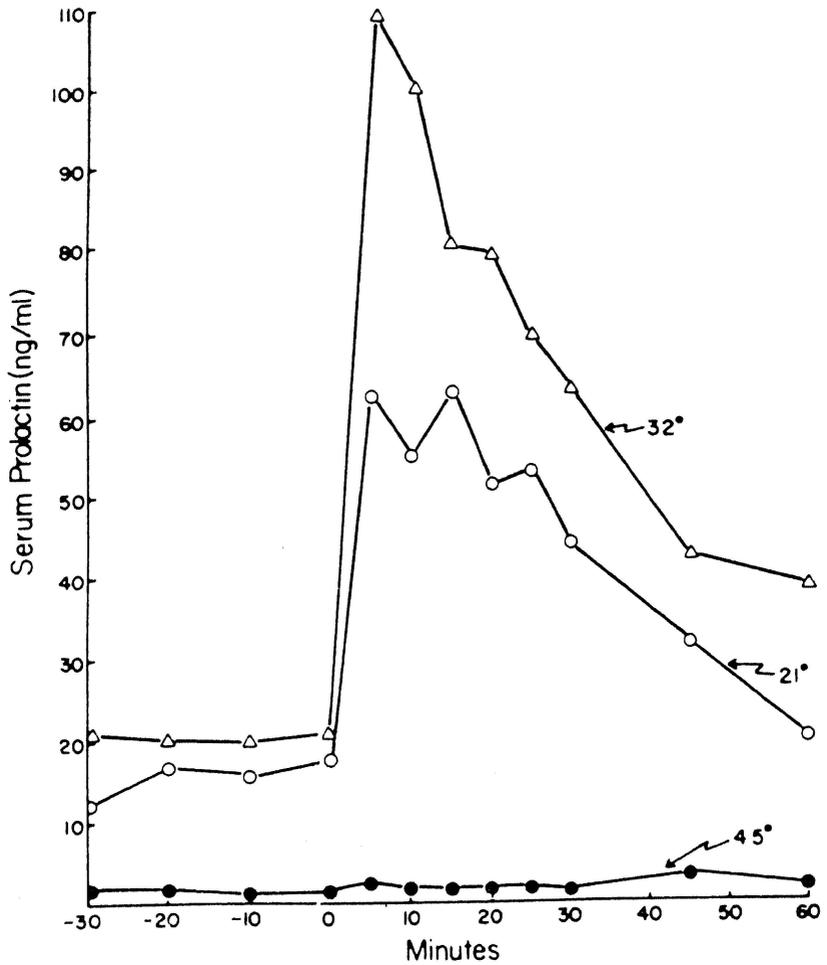


Figure 4. Average serum prolactin response to injection of 10µg of thyrotropin releasing hormone (at 0 min) into each of four heifers at 4.5, 21 and 32°C. (From Tucker and Wettemann, 1976.)

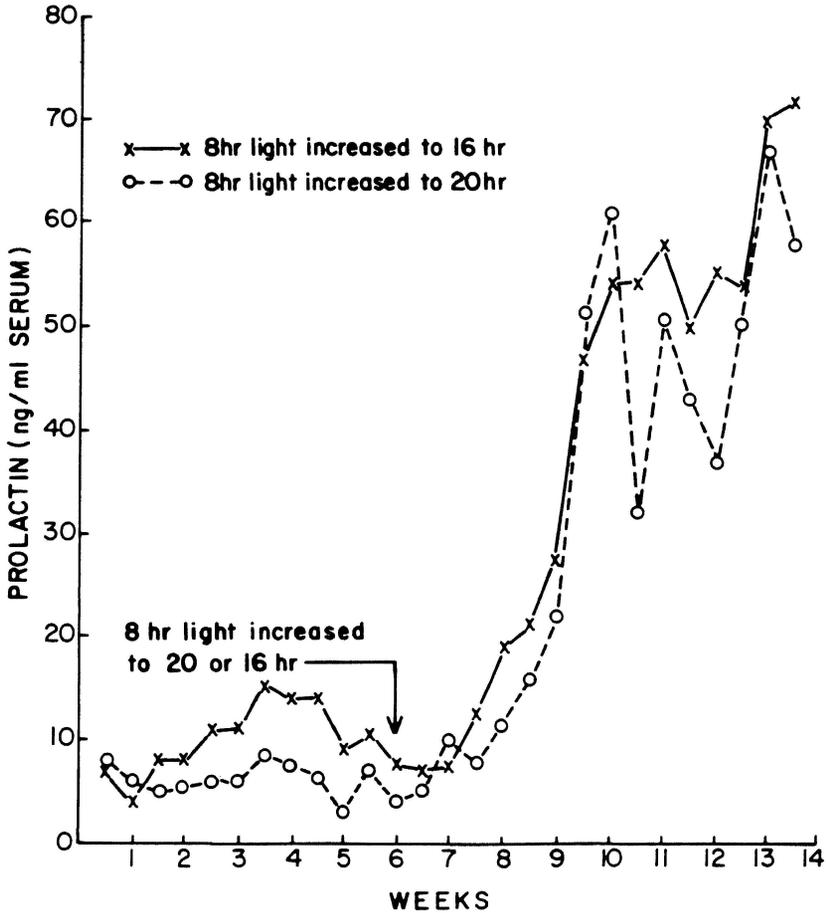


Figure 5. Average serum prolactin of prepubertal bulls during daily light exposure which was increased from 8 to 16 h (X—X) or from 8 to 20 h (O—O). There were four bulls per observation. Overall pooled SE was 3 ng/ml between weeks 1-6 and 6 ng/ml between weeks 7-14. (From Leining et al, 1979.)

Bourne clearly showed that increasing daily light from eight to 16 hours increased prolactin approximately four fold, whereas decreasing daily light from 16 to eight hours decreased prolactin from 57 to 8 ng/ml (Bourne and Tucker, 1975).

To determine the speed with which prolactin responds to abrupt changes in daily light, Dr. Kay Leining subjected bull calves to six weeks of 8L:16D followed by eight weeks of 16L:8D or 20L:4D (Leining *et al.*, 1979). Basal concentrations of prolactin averaged eight ng/ml at the end of six weeks of 8L:16D (Figure 5). The first detectable increase in prolactin concentration occurred one week after the photoperiod was shifted from eight to 16 or 20 hours of light per day. Maximal concentrations were achieved five to eight weeks after switching to 16L:8D or 20L:8D. Thus, in contrast to the rapid response of prolactin to change in ambient temperatures, prolactin

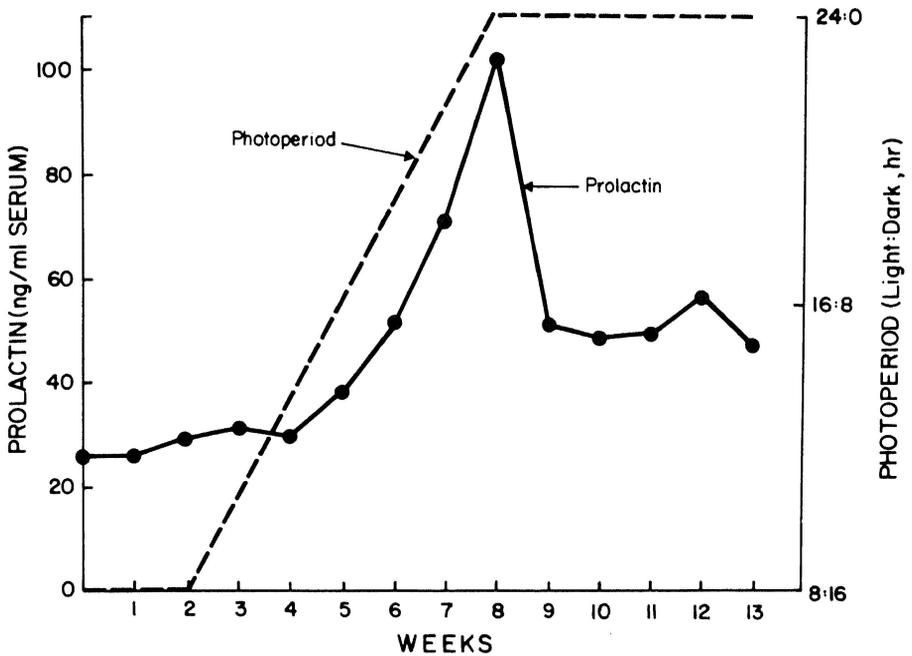


Figure 6. Serum prolactin of prepubertal bulls during daily light exposure which was increased from 8 to 24 h. There were four bulls per observation. Overall pooled SE was 11 ng/ml. (From Leining et al, 1979.)

response to change in increasing daily light is rather sluggish. Moreover, 16 and 20 hours of light per day are equally effective in stimulating prolactin secretion. However, subjection of cattle to continuous illumination does not sustain increased secretion of prolactin (Figure 6). Consequently, to maintain high secretion rates of prolactin four to eight hours of darkness must be inserted each day.

Animals measure time. They know whether it is a long day or a short day. The degree of synchrony between endogenous rhythms and external cues has been hypothesized to be part of the mechanism whereby animals measure day length (Bunning, 1960). Frequently, this cue is photoperiod. This hypothesis assumes that during part of the day animals are sensitive to light, whereas at other times they are unresponsive to light. If this hypothesis is true, it should be possible to provide light intermittently at appropriate times and trick the animals into increasing secretion of prolactin as if they were exposed to 16 hours of continuous light followed by eight hours of continuous darkness. To test this hypothesis Petitclerc *et al.* (1980) exposed bull calves to 8L:16D for six weeks. Prolactin averaged 10 ng/ml. When the photoperiod was shifted to 6L:8D:2L:8D prolactin increased six fold, similar to increases observed when controls were shifted to 16L:8D. So 16 hours of continuous light is not required to achieve a large increase in secretion of prolactin.

On the other hand, in another experiment we showed that insertion of two hours of light 20-22 hours after initial dawn (6L:14D:2L:2D) stimulated prolactin secretion

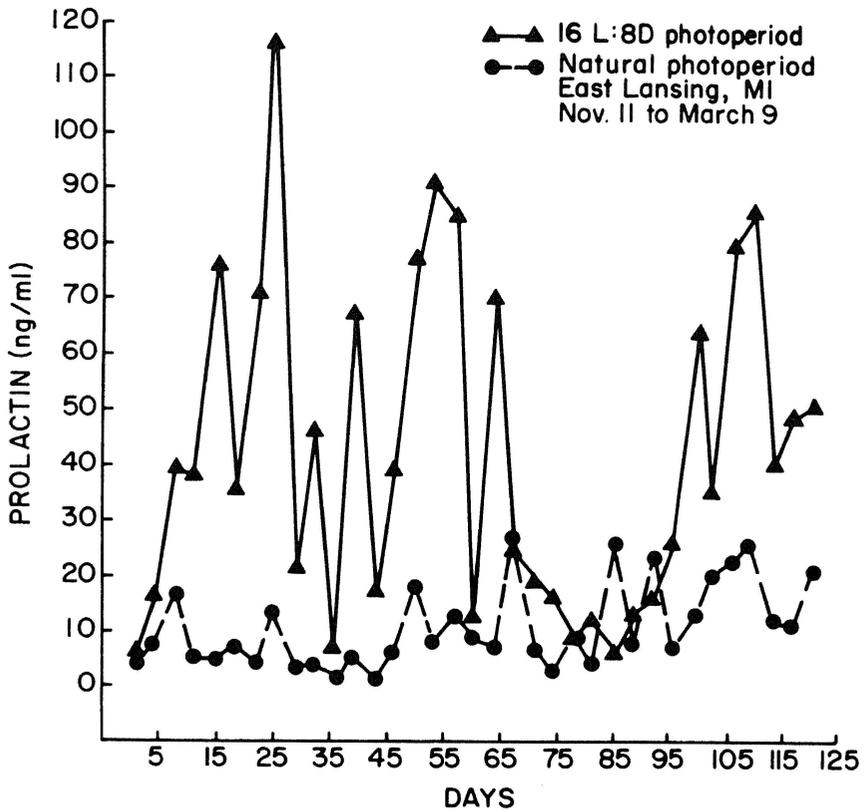


Figure 7. Average serum prolactin of heifers subjected to natural duration or 16L:8D photoperiods from November to March in East Lansing, MI. Standard errors pooled within treatment were 1.7 and 8.1 ng/ml, respectively. (From Peters and Tucker, 1978.)

only about 10 ng/ml whereas prolactin in serum of bulls given 6L:8D:2L:8D increased approximately 40 ng/ml over that in controls given 8L:16D. Thus, the amount of prolactin secreted was dependent upon when the two-hour interval was inserted relative to dawn. We conclude that if cattle are exposed to light during the photosensitive phase, the animals respond as if it was a long day; i.e., prolactin secretion is stimulated.

We have compared several lamps with respect to their ability to affect secretion of prolactin. Light from red fluorescent, blue fluorescent, Vita-Lite fluorescent, incandescent, high pressure sodium or mercury vapor lamps applied for 16 hours each day was equally as effective as cool-white fluorescent light in stimulating prolactin secretion (Leining *et al.*, 1979; Stanisiewski *et al.*, 1981). The conclusion is that prolactin secretion in cattle appears to be sensitive to a broad spectrum of light.

TABLE 1. Growth hormone insulin, total glucocorticoids, thyroxine and thyroid stimulating hormone in serum of prepubertal bulls after 6 week exposure to 8 or 16 to 20 h of light per day.

Daily light (h)	Hormone (ng/ml)				
	Growth hormone	Insulin	Glucocorticoids	Thyroxine	Thyroid stimulating hormone
8	12.7	2.3	2.8	56.4	3.5
16-20	13.1	2.3	1.4	64.7	3.2

Dr. Robert Peters, while a graduate student in our laboratory, decided to determine whether photoperiod and ambient temperature synergistically control seasonal changes in prolactin secretion (Peters and Tucker, 1978). To accomplish this objective two groups of heifers were maintained on 16L:8D photoperiods or natural duration photoperiods between November and March under conditions in which ambient temperatures were allowed to fluctuate naturally and identically in both groups. As shown in Figure 7, heifers subjected to natural photoperiods averaged less than 10 ng/ml at the beginning of the experiment and gradually increased to approximately 20 ng/ml at the end of the experiment. Prolactin concentrations in serum of heifers exposed to 16L:8D were approximately four fold those in heifers given short duration periods of natural light. However, concentrations of prolactin were similar in both groups of heifers on several days, but especially between days 67 to 92. These days corresponded to the coldest days of the experimental period when ambient temperatures were consistently below 0 C. Thus, cold temperatures reduce the ability of 16 hours of light per day to stimulate prolactin secretion.

As previously presented, cold temperatures also inhibit the ability of TRH to cause prolactin release. In contrast, cold temperatures do not inhibit milking-induced (Figure 2; Peters *et al.*, 1981) or parturition-induced (Chew *et al.*, 1979) release of prolactin. Consequently, the ability of cold temperatures to block prolactin release depends upon the stimulus used to attempt to evoke increased secretion of prolactin. More recently we (Petitclerc *et al.*, 1981) have shown that increasing light from eight to 16 hours daily does not affect prolactin secretion in blind animals, but seasonal changes in secretion of prolactin persisted in blind steers. Thus, we speculate that ambient temperature predominates over photoperiod in the normal control of prolactin secretion.

Does photoperiod affect hormones other than prolactin? To answer this question, we have measured growth hormone, insulin, thyroxine, and thyrotropin releasing hormone in several experiments in which animals were exposed to eight or to 16-20 hours of light per day. Increasing the daily light was without effect on the average concentrations of these hormones (Table 1). In contrast, Leining *et al.* (1980) observed that 16 hours of light suppressed serum glucocorticoids in prepubertal bulls approximately 50% (Table 1). In lactating cows, photoperiods did not affect concentrations of glucocorticoids in serum. Thus, the significance of the glucocorti-

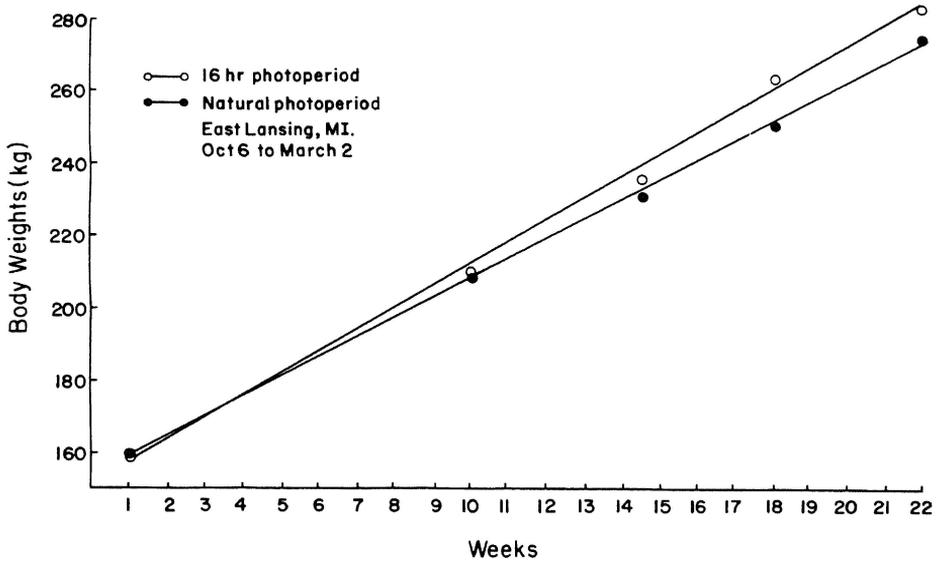


Figure 8. Body growth of Holstein heifers given 16 h or natural duration photoperiods from October to March in East Lansing, MI. (From Peters et al, 1978.)

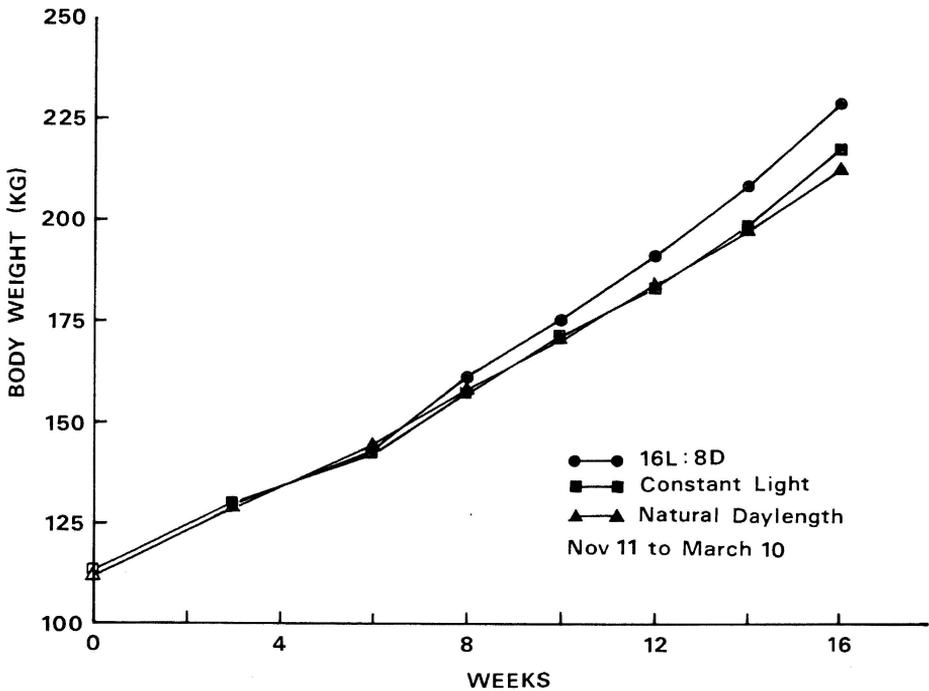


Figure 9. Body growth of Holstein heifers exposed to 16L:8D, 24L:0D, or natural duration photoperiods from November to March in East Lansing, MI. (From Peters et al, 1980.)

coids in prepubertal bulls remains to be answered. We conclude that among hormones measured prolactin is the primary hormone that changes in response to changes in duration of daily light.

Next, we (Peters *et al.*, 1978) determined that a 16L:8D photoperiod increased weight gains of Holstein heifers 10% to 15% in comparison with heifers subjected to nine to 12 hours of natural duration lighting between October and March in Michigan (Figure 8). Later, Peters *et al.* (1980) showed that continuous lighting was no more effective than eight hours in stimulating rates of body weight gain (Figure 9), whereas 16 hours of light per day resulted in the greatest rate of growth. It should be noted (Figures 8, 9) that heifers usually required at least two months on the photoperiod regimen before differences in growth rate were discernible. Photoperiod induction of a faster body growth rate is a relatively slow process. The reason for this sluggishness has not been determined.

We have measured feed intake in growing heifers subjected to various photoperiods. Unfortunately, the data are not consistent among experiments. In some experiments, the heifers consumed the same amount of dry matter yet continued to grow faster (Peters *et al.*, 1978), whereas in other experiments they grew faster but also consumed additional feed (Peters *et al.*, 1980). In a recent study Petitclerc *et al.* (1981) showed that in comparison with eight hours of light per day, 16 hours of light increased rates of daily gain approximately 0.1 kg in heifers when daily feed intake was restricted (average daily gain of 0.7 kg) to identical quantities in both groups. In other words, it is possible to stimulate rates of gain with supplemental lighting when feed intake is restricted.

We (Petitclerc, Chapin and Tucker, unpublished) have measured onset of puberty in heifers exposed to 16 hours of light or to short days in several experiments. Our index of puberty is based on the concentrations of progesterone in serum. In nonpregnant animals, progesterone concentrations of one ng/ml or more is indicative of a previous ovulation and an active corpus luteum. In several experiments we have observed that 16 hours of light enhances the onset of puberty, i.e., heifers subjected to 16 hours of light reach puberty at a lighter weight than animals exposed to short durations of light.

To determine the effects of light on milk production, Peters *et al.* (1978) exposed four pairs of multiparous cows to either 16 hours of light per day or to natural duration photoperiods between September and March. Cows exposed to natural photoperiods produced an average of 3.1 kg less milk per day for the first 100 days of the experiment than cows given 16 hours of supplemental light (Figure 10). This difference was maintained for 100 days postpartum. After day 100 the treatments were reversed, and the decline in milk yield with advancing lactation was retarded in the group receiving 16 hours of light per day. In more recent studies, Peters *et al.* (1981) observed 6% to 7% increases in yields of milk in cows initially subjected to 16 hours of supplemental lighting during early (37 to 74 days postpartum) and late (94-204 days postpartum) lactation. Thus, stage of lactation does not appear to alter the ability of lactating cows to increase their production of milk in response to supplemental lighting.

To date we have observed only one side effect of 16 hours of lighting. Exposure to long days in winter results in the growth of a short haircoat typical of summer. Fortunately, the cattle have had no adverse health problems when this has occurred in the winter.

When we embarked on the research just described we had no plans to investigate the effects of lighting on cattle. But by following the clues provided from our basic research on the hormonal regulation of lactation, we have been led to potentially

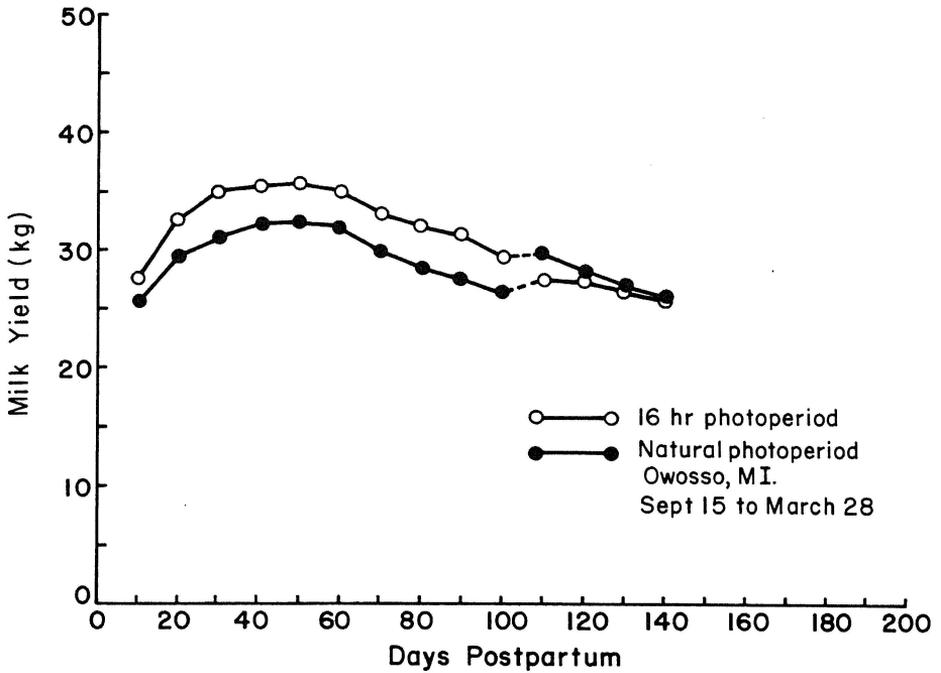


Figure 10. Milk production of Holstein cows exposed to 16 h (O) or natural duration (●) photoperiods between September and March in Owosso, MI. (From Peters et al., 1978.)

practical uses of our research. Personally, this has been and continues to be a most gratifying and exciting endeavor.

In closing, I do thank you very much for the honor to present this lecture.

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