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THE EFFECT OF LAMP TYPE, AND DURATION OF PHOTOPERIOD ON PROLACTIN AND MILK PRODUCTION IN CATTLE

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Edward Peter Stanisiewski

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H. Allen Tucker
Major professor

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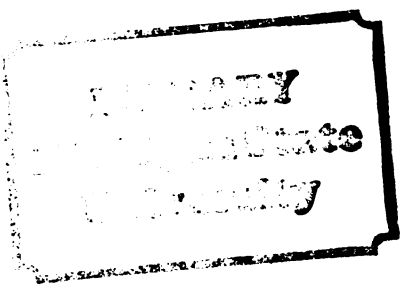

THE EFFECT OF LAMP TYPE, AND DURATION OF PHOTOPERIOD ON PROLACTIN AND MILK PRODUCTION IN CATTLE

By

Edward Peter Stanisiewski

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ABSTRACT

THE EFFECT OF LAMP TYPE, AND DURATION OF
PHOTOPERIOD ON PROLACTIN AND
MILK PRODUCTION IN CATTLE

By

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In comparison with 8 h of cool-white fluorescent light, prolactin in serum increased 2 to 7 fold when given 16 h of light per day from cool-white fluorescent, incandescent, Vita-Lite fluorescent, mercury vapor, or high pressure sodium lamps for 6 weeks. Each lamp was as effective as cool-white fluorescent in stimulating prolactin.

Relative to 8L:16D, prolactin in serum increased approximately 2-fold in bull calves given 24-lo L:OD or 8-hi L:16-lo L photoperiods.

Milk production, composition and feed intakes were not different in cattle exposed to 24-lo L:OD or 16-hi L:8-lo L photoperiods. However, milk production in cows of 13 commercial dairy herds given 16 h of light daily was 2.2 kg/day greater than production in herdmates given 10 h of light.

I conclude that daily light exposure of at least 16 h stimulates prolactin release, and increases milk yield under commercial dairy farm conditions.

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INTRODUCTION

Perhaps the most important industry in the world today is agriculture. As the world population increases, a greater demand will be placed on farmers, researchers, and other agricultural specialists to develop and carry out practices leading to greater food producing efficiency. Dairy cattle are able to convert feed nutrients to a storable and consumable product, milk, more efficiently than most domestic animals. Dairy cows are also capable of producing large quantities of protein (in milk) at a relatively small cost when compared with other protein sources. Milk is also one of the best dietary sources of calcium.

The number of dairy animals in the U.S. has decreased by nearly 50% since 1950, however, absolute milk production has remained nearly constant or increased. Although there has been a significant increase in the efficiency of dairy cattle, they have not yet reached the limit of their milk producing capabilities.

Several workers showed that a 16L:8D photoperiod will stimulate milk production by 10 percent (Peters et al., 1978; Bodurov, 1979). Turning lights on in a barn can be a simple and cost-efficient way to stimulate milk production. The mechanism by which this procedure works is not understood. A reasonable hypothesis is that hormone concentrations in serum may be involved, and prolactin has been shown to be influenced consistently by photoperiod (Bourne

and Tucker, 1975; Peters et al., 1978). Prolactin will favorably stimulate various aspects of lactation in several species of animals.

The objectives of the work contained in this thesis were to first, examine light sources with different efficiencies and spectral properties for their abilities to stimulate prolactin release in comparison with cool-white fluorescent light. A second objective was to determine if a 16L:8D photoperiod would stimulate milk production under practical farming conditions, and to determine if a period of total darkness was required in a 16L:8D photoperiod to detect increases of milk production and serum prolactin. Some farmers may desire to have lights on at night for security or other management purposes.

REVIEW OF LITERATURE

A. Function of Prolactin

1. During Gestation

Growth is the primary physiological process in the mammary gland during gestation. Mammary gland growth is highly correlated with subsequent milk production (Bath et al., 1978). The mammary epithelium is composed of ducts and alveoli. A considerable proportion of mammary growth and development takes place throughout gestation (Bouin and Ancel, 1909). Normally, the mammary duct system forms during early gestation, followed by rapid proliferation of the alveolar system (Tucker, 1969).

A variety of hormones have been implicated in stimulating mammary growth. For example, in the pseudopregnant rabbit, exogenous administration of prolactin (PRL) alone will stimulate duct and lobule-alveolar growth (Delouis et al., 1980). In other species PRL must synergise with estradiol, progesterone, growth hormone (GH), and glucocorticoids to promote mammary growth (Lyons, 1958; Cowie, 1971; Forsyth, 1971). A combination of either estrone and PRL, or estrone and growth hormone stimulate duct development in rats and mice (Gardner and White, 1941; Lyons et al., 1955). Administration of PRL and GH induced substantial mammary development in rats, but development was greater if supplemented with ovarian steroids (estradiol and progesterone) (Lyons, 1942; Talwalker and Meites,

1961). Mammary grafts from mid-pregnant cows placed into athymic nude mice (immunodeficient) remain viable for at least 40 days (Welsch et al., 1979). Greatest growth and differentiation of grafted mammary tissue occurred when the mice were injected with GH, PRL, estradiol, and progesterone. Growth was about 50% less in animals given either the peptides or steroids alone. Sinha and Tucker (1969) showed that pituitary PRL markedly increased during periods which coincide with greatest mammary growth of Holstein heifers from birth to 12 months of age.

Although PRL was implicated in control of mammary growth, concentrations in sera have not been shown to be related to increased mammary development. In general, PRL concentrations in serum remain relatively low throughout gestation in several domestic food producing animals, but markedly increase in the periparturient period. Oxender et al. (1972) did not detect any PRL changes throughout pregnancy in cattle. Vines et al. (1977) showed similar trends of basal PRL in heifers during concurrent pregnancy and lactation, and TRH-induced PRL release was unaffected by stages of gestation. In first pregnancy goats, concentrations of PRL remained low throughout gestation before rising at parturition (Buttle et al., 1972).

2. Lactogenesis

Lactogenesis is defined as the differentiation of mammary epithelial cells from the non-secretory to the secretory state during the periparturient period. In goats, the first stages of lactogenesis begin 2 to 10 weeks prepartum when fluid in teats changes from an

extracellular-like to a milk-like composition (Fleet et al., 1975). During the last days of gestation, secretion rates of the milk-like fluids were only a few percent of the rates immediately postpartum. Similar results were observed in the cow (Hartmann, 1973).

As early as 1928, Stricker and Grüter (1928) showed that administration of anterior pituitary extracts induced lactogenesis in the mammary gland of pseudopregnant rabbits. The active hormone in the preparation was PRL (Riddle et al., 1933). Prolactin is required for initiation of lactogenesis in the cow and goat (Cowie et al., 1964a, 1964b). Cowie (1969b) showed that PRL was required to restore full lactation in a hypophysectomized goat treated with glucocorticoid, GH, and triiodothyronine.

Ingalls et al. (1973) showed a periparturient surge of PRL (111 ng/ml) in cows beginning 9 days before parturition culminating in a greater surge (280 ng/ml), one day before, and at parturition. Johke et al. (1970) also showed that the highest mean value of PRL in plasma occurred during late pregnancy, one day before calving. In addition, these same researchers showed in goats a rise of PRL from 89 ng/ml of plasma 30 days before, to 475 ng/ml 3 days before parturition. Peak concentrations were observed (848 ng/ml) 20 h before kidding. Others have observed PRL rises beginning 5 to 37 h before parturition, with a sharp peak associated with the explusion of each kid from the goats having multiple births (Hart, 1972). Plasma PRL concentrations of ewes increase sharply, from 15 ng/ml 3 days before parturition to concentrations as high as 640 ng/ml just before parturition (Davis et al., 1971; Chamley et al., 1973).

Lactogenesis is depressed in cows given CB-154 throughout the periparturient period, and milk yields are 47 to 95% lower through the first 10 days postpartum, when compared with previous lactations (Schams et al., 1972; Johke and Hodate, 1978). Akers et al. (1981a) found an 11.4 kg/day decrease in milk production in cows given CB-154 during the periparturient period. This decreased yield of milk was associated with decreased total mammary RNA content, a-lactalbumin, fatty acid synthetase, and acetyl-CoA carboxylase activities of the mammary tissues. However, there was no change in mammary cell numbers or total epithelial area (Akers et al., 1981b).

Casein is a group of phosphoproteins which constitute 70 to 80% of total milk protein in rats (Jenness, 1974) and cows (Bath et al., 1978). Evidence suggests that PRL may play a role in inducing casein synthesis. For example, concentration of casein in mammary secretions of cows increased about five fold before parturition (and declined by the second day postpartum), closely following the pattern of periparturient PRL changes (Hartmann, 1973). Both the total percentage, and number of casein mRNA molecules per alveolar cell significantly increase beginning 1 h after addition of PRL to mammary explants from midpregnant rats (Matusik and Rosen, 1978). Total casein mRNA activity increased 18 fold from day 5 to 20 of gestation in rat mammary glands (Rosen et al., 1975), and it increases an additional four fold between the late stages of gestation and early lactation, coincident with changes in PRL secretion. Teyssot and Houdebine (1980) demonstrated in rabbit mammary glands that PRL progressively enhanced the transcription

rate of the B-casein gene, suggesting a possible mode of action for PRL on the protein composition of milk. Endogenous or exogenous PRL increases the concentration of casein, the major protein component of milk.

3. Lactation

The role of PRL in maintenance of lactation is controversial. In some species it is essential for maintenance of maximal milk yield (Cowie et al., 1969), whereas in others PRL is needed for only a short time following parturition, and has little effect on yield after that time. Prolactin administered to rabbits twice daily for 2 days (about day 50 of lactation) augmented daily milk yield (Cowie, 1969a). Injection of PRL in cattle for 10 days following separation of dam and offspring resulted in continued milk output by some animals which normally would have ceased lactating (Hayman, 1973). Rat mammary glands were emptied by oxytocin and suckling. Complete refilling occurred within 6 h by either suckling or PRL injection at 1 minute intervals for 5 minutes whereas glands of non-suckled or non-injected rats failed to completely refill even after 16 h (Grosvenor et al., 1975).

Milk yields are reduced at all stages of lactation in women, mice and rats when PRL in serum is decreased with CB-154 (Shani et al., 1975). However, depressed PRL concentrations (70% reduction) have no effect on milk yield after a lactation has been established in cows (Karg and Schams, 1972; Smith et al., 1974; Beck et al., 1979) or goats (Hart, 1973).

During the first 60 days of lactation in cows, daily milk yield increased 6 kg for every 1 ng/ml of serum rise in PRL (Walsh et al., 1980). Prolactin clearance rates were 75% greater, and secretion rates were 140% higher in early lactating versus non-lactating cattle (Akers et al., 1980). During late lactation, clearance and secretion rates were 25 and 40% greater when compared with non-lactating cows. Activity (secretion and clearance) of PRL is high in lactating cows, but direct cause-effect relationships remain to be established. The correlation of post-milking concentrations of PRL in cattle with milk yield is positive, albeit low (Koprowski and Tucker, 1973). In addition, Hart (1975) showed a small but positive, correlation between average PRL concentration released at milking and average monthly yield in goats. No significant correlation was shown between PRL concentration and milk yield during early lactation in goats.

Evidence indicates that PRL concentrations in serum are markedly increased by milking (Tucker, 1971; Schams, 1972) and reach a peak 4 to 20 minutes after the start of milking (Johke, 1970). Koprowski and Tucker (1973) showed that milking-induced release of PRL was greatest in cows at 8-weeks of lactation. An important consideration however, is that udder manipulation alone without milk removal will cause a release of PRL (Koprowski et al., 1971). This lends credence to the hypothesis that milk yields may not be related to PRL concentrations. However, a distinct decrease of PRL in serum in response to milking occurs as lactation advances (Johke, 1970; Koprowski et al., 1971).

Specific binding sites (receptors) for PRL have been quantified in mammary tissue (Turkington, 1970; Birkenshaw and Falconer, 1972; Shiu and Friesen, 1976). Prolactin receptors in the mammary gland of rabbits increased from 25 fmol/mg at day 14 of gestation to 111 fmol/mg during lactation (Djiane et al., 1977). Receptors were undectable in non-lactating mammary tissue of the tammar wallaby, but increased to 930 fmol/mg of protein during lactation (Sernia and Tyndale-Biscoe, 1979). Prolactin concentrations in serum increase as lactation is being established, which coincides with increased receptor numbers in the milk-synthesizing tissue. Therefore, a major site of action for PRL could be in the mammary gland, where it influences milk output and/or composition.

B. Environmental Regulation of Prolactin

1. Season

Season of the year consists of many climatic components, two of the most prominent being temperature and photoperiod (relative lengths of alternating daily periods of light and dark). Photoperiod shows an absolutely consistent pattern from year to year, whereas temperature fluctuates in a less consistent yearly pattern. Thus, animals use photoperiod as a primary cue to change their physiological state in accordance with changing seasons.

Prolactin is highly influenced by season in several domestic mammals. Prolactin in serum of cattle can be four to six fold greater during the summer months (e.g. Michigan or Florida latitude) when compared with concentrations during the winter (Schams, 1972;

Koprowski and Tucker, 1973; Thatcher, 1973; Karg and Schams, 1974). Similar seasonal patterns of PRL secretion have been detected in goats (Buttle, 1974; Muduuli et al., 1979) and sheep (Sanford et al., 1978). Previous studies showed that photoperiod and temperature may account for a large proportion of the seasonal variation of PRL (Wettemann and Tucker, 1974; Bourne and Tucker, 1975; Lincoln et al., 1978).

2. Photoperiod

Several studies showed in calves that as daily illumination increased from 8 to 16 h, PRL in serum increased about three fold (Bourne and Tucker, 1975; Peters and Tucker, 1978). Conversely, decreasing photoperiod from 16 to 8 h of light per day decreases serum PRL by a similar magnitude. When light is acutely increased from 8 to 16 h per day, significant changes in PRL concentration take a week or more to detect; thus demonstrating that the PRL response to light is relatively sluggish (Leining et al., 1979). Using castrated or intact rams, Pelletier (1973) showed that a 16L:8D photoperiod in comparison with 8L:16D, resulted in a 10-fold increase in serum PRL. Other studies have confirmed the stimulatory effects of long versus short-light photoperiods on PRL in mature rams and ewes (Lincoln et al., 1978; Sanford et al., 1978; Howles et al., 1980) and lambs (Forbes et al., 1975).

At 20°C PRL in serum can be markedly increased in prepubertal bulls using 16 to 20 h of light per day relative to that in bulls given 8 h of light (Bourne and Tucker, 1975). Prolactin in serum

of bull calves increased as light was gradually increased from 8 to 24 h, but within a week of continuous light, PRL declined to levels comparable to those detected using 8 h (Leining et al., 1979). In contrast, continuous illumination stimulates a rise in plasma PRL in the rat (Relkin et al., 1972; Vaticon et al., 1979).

Little is known about the threshold of light perception in domestic animals. Light intensities between 207 and 600 Lux at eye level of animals have been used to study PRL release (Bourne and Tucker, 1975; Peters and Tucker, 1978; Leining et al., 1979). Leining (1978) demonstrated that a 16L:8D photoperiod of either high (540 Lux) or low (22 Lux) intensity light stimulates PRL secretion in comparison with concentrations observed during prior exposure to 8L:16D.

The effect of continuous low intensity light supplemented with either 16 or 8 h of high intensity light per day has been examined (Rzepkowski, 1981). Eight bull calves were exposed to 6 weeks of 8L:16D and assigned to one of two groups. For an additional 6 weeks, both groups received 24 h of low intensity light which was supplemented with 16 h of high intensity light per day in one group, and 8 h in the other. Prolactin increased about two fold in each treatment relative to that in the initial period of 8L:16D. Because the 8 h of high intensity light induced PRL levels which were not different from the 16 h high intensity group, a legitimate hypothesis would be that the animals cued on a 16 h block of light, irrespective of the relative intensity.

Alternatively, abruptly increasing daily light to the continuous mode stimulated secretion of PRL.

Some researchers have suggested the existence of a photosensitive period in sheep and cattle (Ravault and Ortavant, 1977; Petitclerc et al., 1980). The photosensitive period is an endogenous daily rhythm of sensitivity to photoperiod which if it coincides with exogenous light will initiate a positive physiological response such as release of PRL (Pelletier, 1981). For example, ram lambs exposed to a photoperiod of 7L:9D:1L:7D had elevated PRL concentrations which were similar to those of lambs exposed to 16L:8D (Schanbacher and Crouse, 1981). Both photoperiods were compared to 8L:16D controls. A one hour pulse of light was given 16 h after the beginning of subjective dawn, and apparently was within the range of the photosensitive period. Therefore, a 16-h block of continuous light may not be required to stimulate PRL release. Similar results were obtained in prepubertal bulls. For example, a 6L:8D:2L:8D photoperiod stimulated PRL secretion in calves to concentrations comparable to 16L:8D controls (Petitclerc et al., 1980). A 6L:14D:2L:2D photoperiod was not as effective in stimulating PRL as a 6L:8D:2L:8D photoperiod. Thus, prolactin secretion was greatest when bull calves received light between 14 and 16 h after the beginning of subjective dawn.

Several studies demonstrated that duration, intensity, and wavelength of light can markedly alter the duration of estrus in rats (Fiske, 1941; Singh, 1969; Moore and Rappert, 1971). Ziemann and Kittel (1980) showed that red light (12L:12D) induced numerous

acyclic (prolonged) estrus phases in albino mice, whereas high intensity (180 Lux) white light (12L:12D) induced persistent estrus. Alteration of cyclicity by photoperiod is apparently due to retinal degeneration (Noel et al., 1966). Lambert (1975) showed that continuous red light induced prolonged estrus in the rat, as did continuous cool-white light, however, cool-white caused retinal degeneration whereas red light did not. Because the cyclicity can be altered by different wavelengths of light, some animals can perceive and distinguish the differences in light type. Prolactin in serum of prepubertal bulls can be significantly increased using 16L:8D photoperiods of either red, blue, or cool-white fluorescent light when compared with 8 h of cool-white fluorescent light (Leining et al., 1979). The conclusion is that certain wavelengths of light affect estrous cycles in rodents (the effect on estrus in cattle is unknown) and several spectra of light can stimulate PRL release equally well in cattle (the effect on PRL release in rodents is unknown).

3. Temperature

Wettemann and Tucker (1974) showed a nearly instantaneous cause-effect relationship between temperature and basal concentrations of PRL in serum of cattle. As temperature increased from 21 to 27°C, PRL increased at a rate of 1.7 ng/ml of serum per °C. Conversely, PRL declined with declining temperature (21 to 10°C) at a rate of .88 ng/ml of serum per °C. Smith et al. (1977) detected similar temperature-induced increases in concentration and secretion

rate of PRL in steers. Metabolic clearance rate of PRL was significantly reduced as ambient temperature increased from 10 to 30°C.

In an attempt to separate the temperature and photoperiod effects of season on PRL release in cattle, Petitclerc et al. (1981) conducted an experiment using blind and sighted bull calves. Both groups of animals were housed out of doors, where they were exposed to the annual climatic changes of mid-Michigan. Blinded animals which were shown to be unresponsive to light in terms of PRL secretion, had PRL concentrations that followed the same seasonal pattern as sighted calves. Therefore, temperature is a major factor inducing seasonal PRL changes. Correcting the data for photoperiod and temperature removed 98% of the seasonal variance of PRL concentrations, however, a seasonal rhythm persisted, revealing the presence of an endogenous circannual rhythm.

4. Stress

Evidence suggests that PRL can be influenced by stress. In goats (Johke, 1970), cows (Tucker, 1971; Johnson and Vanjonack, 1975) and rats (Dunn et al., 1972) PRL concentrations are increased by stressful situations such as forceful restraint, venipuncture, or noise. Therefore, acute PRL surges should be critically regarded, for any stress on an animal may cause PRL in serum to soar to levels which may be three to four times greater than under non-stressed conditions. Such observations could be misinterpreted as treatment effects.

C. Seasonal and Photoperiodic-Effects on Milk Production

Milk production is influenced by several environmental components, including season, photoperiod, and temperature. Therefore, seasonal factors should be considered when milk yield data are collected over long periods of time. Lee et al. (1975) showed that milk production of Holstein cattle was depressed during the hot season in Southern climates such as in Louisiana.

The season of the year when a cow calves can also be a factor in the animals' subsequent production record. Milk yield and butterfat percent were increased 17 and 7% respectively in cows which calved in January and February relative to those calving in July and August (Miller et al., 1969; McDowell et al., 1976). Wylie (1925) showed yearly milk and fat production of Jerseys to be highest in cows freshening between October and December. Climatic conditions have a greater influence on lactation during the first 60 days postpartum relative to later stages of lactation. During this period, high temperatures (>35°C) decrease feed intake, whereas lower temperatures (<-15°C) stimulate feed intake, which partially accounts for increased production during cooler months. Peak-calving periods of 2- to 7-year old cattle managed in northern latitudes (Ontario, Canada) occur in the fall and early winter (Erb and Martin, 1980). This observed seasonality is probably due to human intervention rather than cattle being seasonal breeders; however, the fact remains that a large proportion of milking cattle are attaining the peak of lactation in the middle of winter, and this should be acknowledged when designing lactation experiments.

A daily lighting regimen of 16L:8D stimulated milk production 7 to 10% in Holstein cattle when compared with a natural length Michigan winter photoperiod of 9 to 12 h of light per day (Peters et al., 1978, 1981). In sows, milk yields were stimulated 24% using 16L:8D in comparison with an 8L:16D photoperiod (Mabry et al., 1982). An increase in feed intake has been observed with cows during long-duration exposures to light, and this could partially account for milk production increases (Murrill et al., 1969; Peters et al., 1981). Sixteen and 8 h of light per day generally correspond to summer and winter day lengths seen in Northern latitude states. Therefore, most benefits can be realized in these areas when the trials are carried out in the late fall to early spring months when daily light can be supplemented. Work in this area could lead to a relatively simple way of increasing milk production in herds under practical working conditions. Few trials have been performed on commercial dairies, but those which were done have shown that around 16 h of light per day will increase milk yield (Murrill et al., 1969; Peters et al., 1978; Bodurov, 1979). More large scale trials are needed to establish if photoperiod increases yield on the average dairy farm.

D. Environmental Influences on Milk Composition

As described previously, PRL and milk yield are responsive to photoperiodic control (Bourne and Tucker, 1975; Peters et al., 1978). Milk composition may also be affected by photoperiod, either directly or as a consequence of PRL or milk yield changes. This

would have important practical applications, since component pricing of milk is being given serious consideration. Milk producers will not only be interested in volume, but also in the composition of the product, such as fat and protein percentages.

Generally, an inverse relationship exists between milk production and butterfat percent (Rook and Campling, 1965). As lactation advances, milk yield tends to decrease and the per cent of fat in milk tends to increase (Wylie, 1925). Butterfat is one of the most variable components of milk. Butterfat percentage may change appreciably with season, being lowest in the summer and highest in winter (Ragsdale and Turner, 1922). Weaver and Matthews (1928) calculated that for each one degree (°F) increase in atmospheric temperature, butterfat decreases .0017, .0103, .0063, .0066 per cent in Ayrshires, Guernseys, Holsteins, and Jerseys respectively. In another experiment conducted over a 16-year period in Florida, butterfat in Jersey milk declined .31% for each 10°F rise in temperature between 57°-81°F (Becker and Dix Arnold, 1935). Ragsdale and Turner (1922) concluded that the effect of season on butterfat percent was greater than the effect of lactation stage. No apparent change in butterfat was observed in Holstein cattle exposed to a 16L:8D or natural (8L:16D) photoperiod (Peters, 1980; Peters et al., 1978, 1981). Summary of available data implies that the primary seasonal cue affecting butterfat percent in milk is temperature, rather than photoperiod.

MATERIALS AND METHODS

A. Experimental Objectives and Design

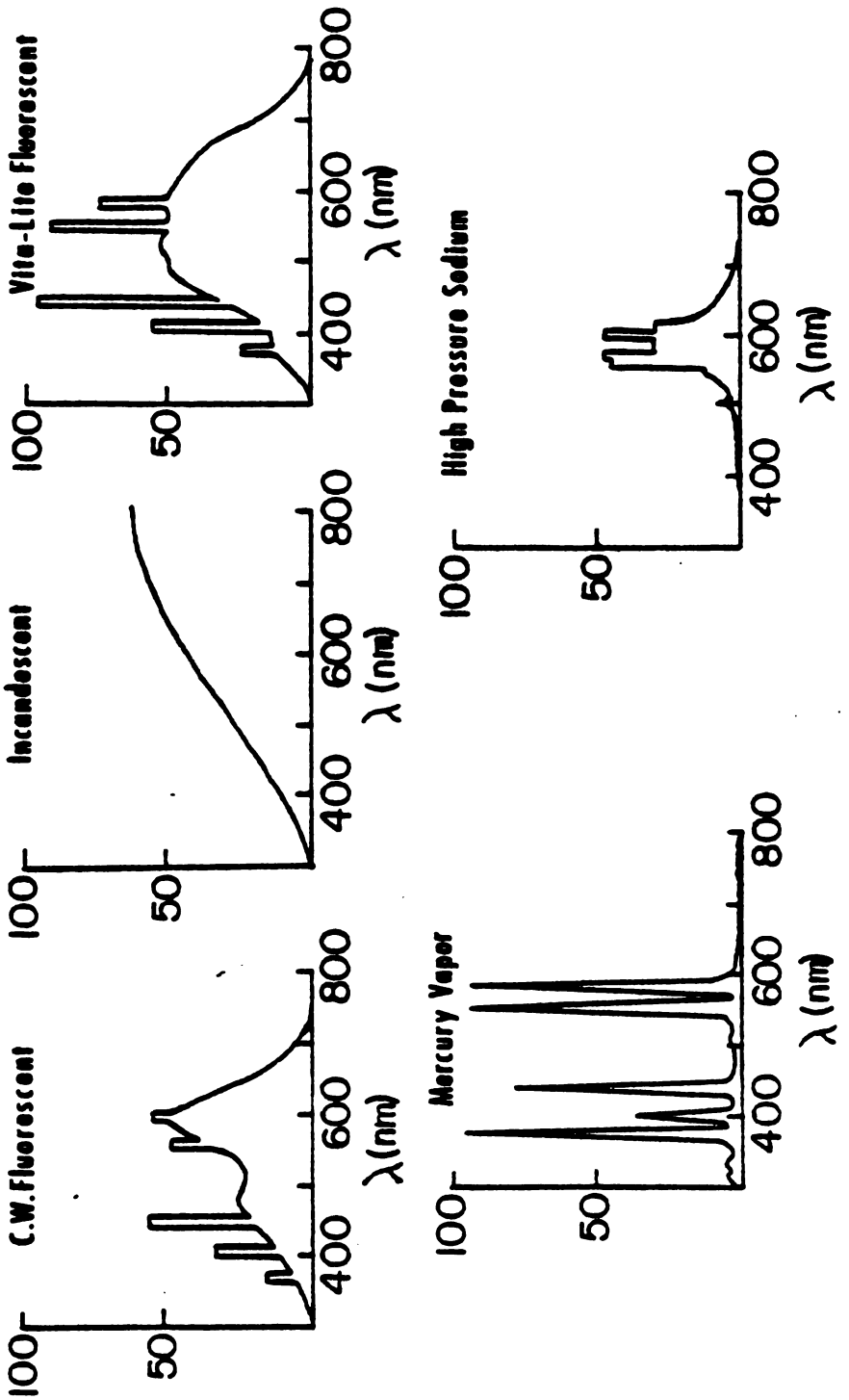
1. Experiment 1a-d

The objective of the first experiment was to observe changes of PRL concentration in serum of prepubertal bulls exposed to a 16L:8D photoperiod using incandescent (General Electric 200A), Vita-Lite fluorescent (Durotest 1157), mercury vapor (General Electric H175A3922) or high pressure sodium (General Electric LU70/BU) light sources in comparison with a 16L:8D photoperiod of cool-white fluorescent light (General Electric F40CW/RS/WM). Spectral characteristics of each lamp are shown in Figure 1. The following design was repeated in four separate trials to test each type of lamp.

Eight Holstein bull calves were placed in a light-controlled room at approximately 3 days of age. Within the room, calves were individually penned in a 1.1 m wide x 1.8 m long stall. Cool-white fluorescent lamps (1.2 m) were placed end to end 2 m above heads of the calves, and 1.2 m apart. Mean light intensity was 212 Lux at eye level of the calves. Lights were programmed to turn on at 0700h and turn off at 1500h (8L:16D). My purpose was to raise the calves to weaning in a consistent short-light controlled environment which would establish low baseline concentrations of PRL. After weaning at about 6 weeks of age, the animals were moved into one of two light

Figure 1.--Spectral characteristics of five different lamp types. Panels show the relative power (ordinate) between the spectral range (abscissa) of ultra-violet (300 nm) to infra-red (800 nm).

SOURCES: Henderson, S. T., and A. M. Marsden (eds.), 1972.
Merik, B., 1971.
Wurtman, R. J., and J. Weisel, 1969.


C.W. Fluorescent
Incandescent
Vita-Lite Fluorescent
High Pressure Sodium
Mercury Vapor
100
50
400
600
800
λ (nm)

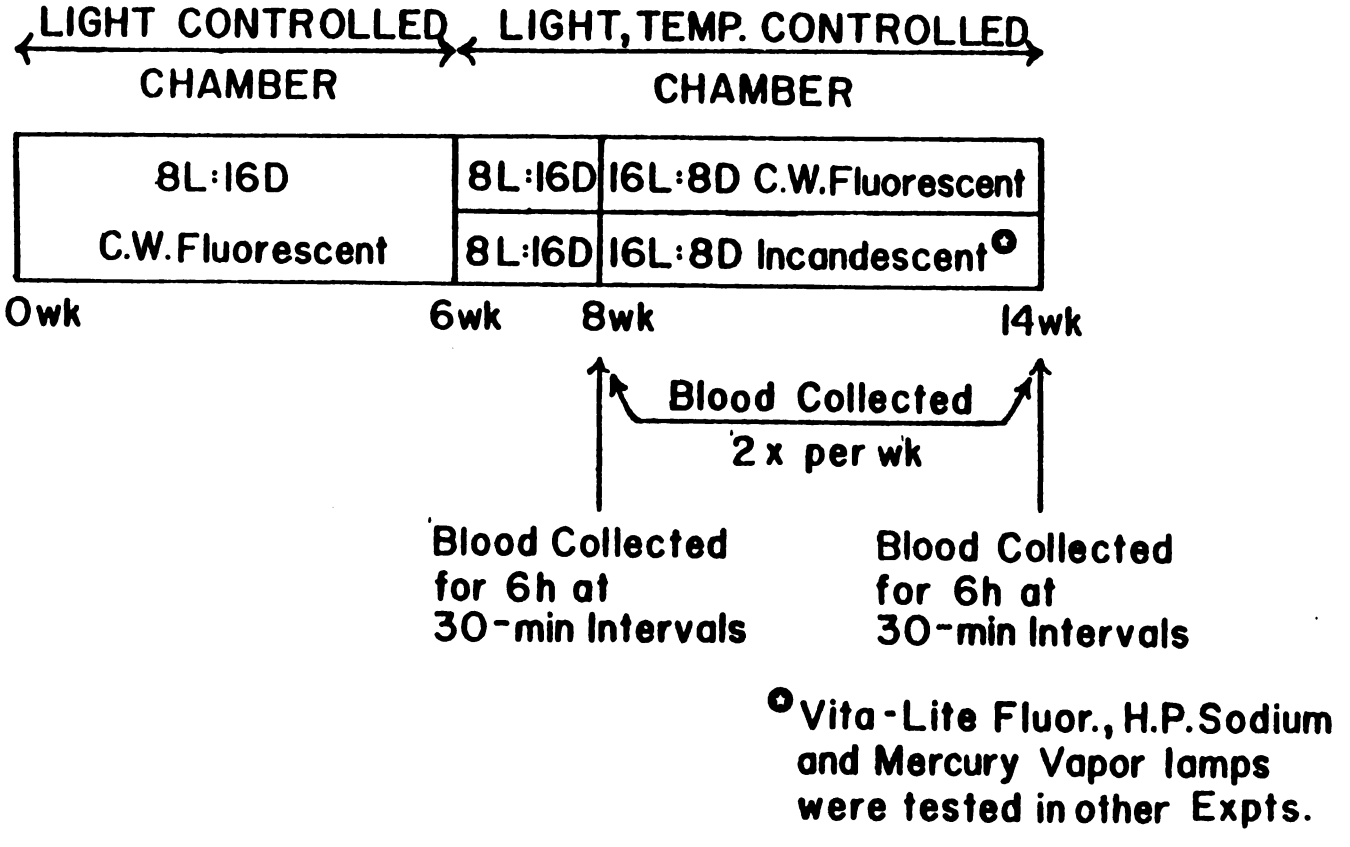
and temperature controlled chambers (Figure 2). The mean weight of the four calves in each chamber were approximately equal (±1.8 kg). Animals were housed unrestrained within each chamber. One chamber was 4.4 m x 2.4 m and the other 3.7 m x 2.4 m. Canadian peat moss (acidic pH) was used as a bedding base to neutralize urinary ammonia. Bedding was covered daily with dry straw. Water and feed were supplied ad libitum. Diet consisted of calf starter (Calf Starter or BIR Milking Chow, Ralston Purina Co., St. Louis, MO) alfalfa hay, and mineral supplement block. Photoperiod was continued at 8L:16D of cool-white fluorescent light.

Approximately 1.5 to 2.5 weeks after being moved to the light-temperature controlled chambers, the calves were fitted with an indwelling jugular cannula (Ico-Rally Corp. SLV 105 18 Clr.) and bled the following day (approximately 8 weeks of age). At 0700h on the day of sampling, the animals were restrained with halters and blood was drawn and discarded at 15-minute intervals for 1 h to accustom the animals to the sampling procedure. After the pre-sampling period, blood was collected for 6 h at 0.5 h intervals. Cannulas were filled with a 3.5% sodium citrate solution between sampling to prevent coagulation. Blood samples were allowed to clot for 6 to 8 h at room temperature and stored for 24 h at 5°C, then centrifuged at 991 x g for 20 minutes. Serum was decanted and frozen at -20°C until assayed for PRL (Koprowski and Tucker, 1971).

After initial blood samples were collected, the daily length of light was increased to 16L:8D (0300-1900h) for an additional 6 weeks. The four calves in one chamber were exposed to incandescent,

Figure 2.--Experimental design schematic. Eight newborn bulls were placed in light-controlled chamber at 0 wk. At 6 wk, the animals were moved into one of two light and temperature controlled chambers (4 bulls per chamber).

EXPERIMENTAL DESIGN



Vita-Lite fluorescent, mercury vapor, or high pressure sodium light sources in separate trials. A 16L:8D photoperiod of cool-white fluorescent light was used as the control treatment for the second group of four calves in each trial. Light intensities were equalized between chambers during each trial. The following are intensities (Lux) for each lamp type and its cool-white fluorescent control: incandescent (367, 365), Vita-Lite® (554, 622), mercury vapor (232, 236), high pressure sodium (151, 121). Venipuncture samples were collected twice weekly during the 6 weeks of 16L:8D. At the end of the 6 weeks exposure to 16L:8D from each light source, calves were cannulated and blood was collected for 6 h at 0.5 h intervals (approximately 14 weeks of age). Ambient temperatures were recorded in each chamber at the time each blood sample was collected throughout the experiment. Prolactin was quantified in sera of all samples. Feed and water were available during sampling periods.

2. Experiment 2

The objective was to determine if PRL concentrations would increase in serum of prepubertal bulls exposed to continuous low (lo) intensity light supplemented with an 8 h period of high (hi) intensity light (8-hiL:16-loL) when compared with calves receiving only 24 h of low intensity light (24-loL:0D). Cool-white fluorescent light sources were used throughout the experiment.

Beginning at approximately 3 days of age, eight Holstein bulls were housed in the light-controlled room for 6 weeks under an 8L:16D photoperiod as previously described for Experiment 1.

Subsequently, calves were moved into the light- and temperature-controlled environmental chambers. At approximately 8 weeks of age, animals were cannulated, and blood was collected at 0.5 h intervals for 6 h as previously described. Photoperiod was then switched to 24-loL:0D in one chamber, where mean light intensity was 16.1 Lux. Photoperiod was shifted in the second chamber to an 8-hiL;16-loL regimen. Mean intensity during the high intensity period was 618 Lux, and low intensity light averaged 14 Lux. Over the following 6 weeks, blood was collected by venipuncture twice weekly. After 6 weeks, animals were cannulated and bled for 6 h at 0.5 h intervals. Prolactin was quantified in sera of all samples.

3. Experiment 3

The objective was to determine if 16 h of high intensity light would alter production and composition of milk of lactating Holstein cattle supplemented with 24 h of low intensity light plus sunlight. A control group of cows received 24 h of low intensity light, plus sunlight, which ranged from 9 to 12 h per day over the time course of the experiment.

Forty Holstein cows in the Michigan State University dairy herd were paired based on daily milk production over a 2-week period preceding the start of the experiment (details below). One animal of each pair was assigned to one of two stanchion barns. These same animals were concurrently part of a nutrition trial in which they were fed one of five completely mixed rations ad libitum, twice daily. Rations consisted of 50% concentrate, 25% haylage and one of the following:

1. 25% corn silage - 9.5% Crude Protein (CP)
2. 25% untreated corn stalkage - 5.4% CP
3. 2% anhydrous ammonia corn stalkage - 18.6% CP
4. 25% ammonia-mineral-molasses corn stalkage - 14% CP
5. 25% ammonia-mineral-molasses corn stalkage - 16.8% CP

Nutrition treatment was accounted for in the experimental model as an independent variable in the first section of a triple split-plot analysis (see statistical methods).

Cows were moved to their respective stanchions on November 26, 1979. Milk production for each cow was recorded daily between December 3, and March 19. All cattle were fed ad libitum twice daily. Oats were weighed daily for each cow to calculate feed intakes. Beginning on December 13, and for every 2-weeks thereafter, a milk sample was collected from each animal to determine fat, crude protein and total solids-not-fat as described in the Milk Sampling and Composition Analysis section. Breeding group (high, medium, or low genetic potential), parity (lactations), and pre-experiment milk weights of each animal were used as covariates in the analysis of data.

Photoperiod in one barn (barn 1) was 16-hiL:8-loL plus natural duration sunlight; whereas, the photoperiod in the second barn (barn 2) was 24-loL plus natural duration sunlight. In barn 1, cool-white fluorescent light fixtures were located above the cows' heads and came on at 0300h and went off at 1900h. In addition, continuous light was supplied from incandescent light fixtures mounted on the ceiling directly behind the cows. Sunlight entered

through windows in each barn. Median light intensity during mid-morning with lights on was 280 Lux at eye level of the animals. The median light intensity from the incandescent lamps alone at eye level of the cows was 5 Lux.

In barn 2, the control group of cows received continuous light from incandescent fixtures located behind them. Median intensity of these lamps alone was 11 Lux. Sunlight was allowed to enter through windows, and mid-morning light intensity at eye level of the cows was 45 Lux.

4. Experiment 4

The objective of the fourth experiment was to determine if a 16L:8D photoperiod was effective in increasing milk production when compared with natural winter photoperiods under practical farming conditions in Michigan. Thirteen dairy herds were selected. Milk production records of cows receiving supplemental light (16L:8D) were compared with those of animals receiving natural photoperiods plus minimal supplemental light. Minimal supplemental light consisted of lighting used for milking, feeding, and routine chores, and did not exceed 12 h duration per day. Herd production ranged from 4220 to 9595 kg of milk per lactation. All of the cows used in the trial were Holsteins, except for one herd of Jerseys and one of Brown Swiss. General herd characteristics are shown in Table 1.

Farmers were informed of this study through the County Agent of their area. Those farmers that were interested were then visited to determine the adaptability of their facilities to this trial.

TABLE 1.--General Characteristics of Dairy Herds Participating in a Cooperative Photoperiod Field Study.

Herd/ Start Date	Lamp Type	Cows/ Trt	Light Schedule	Light Inten.	Milking Times	Times of Feeding	Diet	Mean Daily Milk	Adj. Daily Milk	Feed: Milk
				(Lux)				(kg)	(kg)	
1	Vita-Lite	10	0445-2100	447.3	0445-0545	0530 0900	Grain,Hay Silage,Hay	20.1	19.9	1:2.5
11/14	Natural	9		21.4	1645-1745	1630 1800	Grain,Hay Hay	21.7	21.1	
2	C.W. Fluor.	16	0500-2100	547.8	0600-0730	0500 1700	Grain,Silage Grain,Silage	23.8	25.4	1:3
11/14	Natural	17		5.4	1800-1930		Hay ad libitum	25.0	24.8	
3	C.W. Fluor.	11	0500-2100	838.9	0600-0720	0530 0600	Grain Hay	24.0	22.8	1:2.5
11/5	Natural	18		42.8	1730-1850	0900 1800	Silage Hay	23.5	23.2	
4	C.W. Fluor.	16	0500-2100	578.9	0600-0730	0730 1200	Hay Hay	21.1	23.2	1:3
12/2	Natural	13		0.0	1700-1830	1630 1830	Grain Silage	22.1	21.6	
5	Vita-Lite	10	0430-2030	341.3	0500-0600	0600	H.M.Corn,Haylage Silage,Hay	21.0	20.9	1:2.5
12/9	Natural	20		63.1	1700-1800	1800	H.M.Corn,Haylage Silage,Hay	20.9	21.9	
6	Vita-Lite	24	0500-2100	397.0	0600-0800	0830	Haylage,Sh.Corn, Soy	19.5	19.6	1:3
11/10	Natural	27		0.0	1730-1930	1800	Haylage,Sh.Corn, Soy	18.5	18.6	
7	Vita-Lite	11	0500-2100	316.7	0645-0745	0700 1000	Silage,Grain Hay	24.7	23.9	1:3
11/10	Natural	14		36.4	1745-1845	1730 1900	Silage,Grain Hay	21.8	23.0	
8	Vita-Lite	13	0515-2130	1431.7	0530-0700	0515 1000	Silage,Grain Silage,Grain	24.9	23.9	1:3
11/4	Natural	12		126.3	1730-1900	1200 1300 1630 1900	Grain Hay Silage,Grain Hay	24.2	24.9	

TABLE 1.--Continued.

Herd/ Start Date	Lamp Type	Cows/ Trt	Light Schedule	Light Inten.	Milking Times	Times of Feeding	Diet	Mean Daily Milk	Adj. Daily Milk	Feed: Milk
				(Lux)				(kg)	(kg)	
9	Vita-Lite	27	0430-2030	421.6	0430-0600	0700	Grain,Sh.Corn	18.8	20.2	
						1000	Hay			1:2.5
11/5	Natural	34		267.5	1630-1800	1800	Haylage,Grain	19.8	20.0	
						2000	Hay			
10	C.W. Fluor.	25	0500-2100	718.0	0600-0715	0545	Grain,H.M.Corn	11.4	12.5	
						1100	Hay			1:2
10/21	Natural	24		248.2	1730-1845	1845	Haylage	13.7	14.4	
11	C.W. Fluor.	15	0400-2000	866.7	0500-0630	0430	Hay,Silage,Grain	22.1	22.2	
							Hay ad libitum			1:2.3
11/4	Natural	19		250.4	1600-1730	1630	Hay,Silage,Grain	19.6	20.3	
							Sh.Corn			
12	C.W. Fluor.	16	0500-2100	339.2	0630-0800	0600	Hay,Corn,Conc.	10.8	10.6	
						1630	Hay,Corn,Conc.			
11/10	Natural	12		48.2	1700-1830			9.1	9.6	
13	Vita-Lite	22	0500-2100	330.6	0530-0645	0530	H.M.Corn,Hay	24.4	24.0	
						0800	Haylage			1:2.7
11/21	Natural	21		3.2	1700-1815	1100	Silage	22.3	23.1	
						1630	H.M.Corn			
						1900	Hay			

Abbreviations:

H.M. Corn ---------- High Moisture corn
Sh. Corn ---------- Shelled corn
Conc. ---------- Grain concentrate

[a]Milk yields were adjusted for stage of lactation, lactation number, mature equivalent prediction, pre-trial production.

[b]Information unavailable.

The basic requirements were the following: 1) herds must be on DHI test; 2) cows must be housed in a tiestall or stanchion barn; 3) all cows must be randomly distributed in terms of milk production within each barn, but a given cow was assigned to a specific stall throughout the experiment; 4) all cattle must remain indoors for the duration of the study with the exception of short-duration exposure outdoors for normal activities such as detection of estrus and exercise; 5) the farm owner would allow the installation of lights and time clock, and agree not to alter their settings during the experiment; 6) barns should be designed such that spillover of light from fluorescent lamps was less than 5 Lux as detected by a Spectra, LD-300 light meter (Photo Research Corp., Burbank, CA) at eye level of control cows receiving natural light; 7) the owner signed a written release form to allow examination of his DHIA records (Appendix 1). Thirteen farms were selected which met these requirements.

The experimental design was as follows. The trial was to start at the time each herd was brought indoors for the winter. Starting times varied between October 21 and December 9. Prior to the start of the experiment, fluorescent light fixtures were installed on one side of each barn such that approximately half of the cows in a herd received supplemental light. For every four animals standing side by side, one 2.4 m (or equivalent number of 1.2 m) light fixture was installed over their heads. Lights were set to come on automatically by time clock, and remained on for 16 h. Cool-white fluorescent was the light source on six of the farms.

Vita-Lite fluorescent (Durotest 1157) was used on the other seven. In the event that an animal had to be moved from one light treatment to the other, that animal was deleted from the trial.

Light intensities varied greatly among herds (Table 1). At mid-morning cows receiving supplemental light were exposed to an intensity which was two to ten times greater at eye level than intensities at eye level of cows exposed to natural duration light.

Milk and fat production records of all animals were obtained through the DHIA office in East Lansing, Michigan, and were recorded on a monthly basis.

B. Hormone Assay

Concentrations of PRL in serum were quantified by double antibody radioimmunoassay (RIA) as previously described (Koprowski and Tucker, 1971).

C. Milk Sampling and Composition Analysis

For experiment 3, milk samples were collected from each animal at 2-week intervals. During usual milking times (0400 and 1530h), samples were collected from the milk weigh jars and a daily composite sample was made from each cow. Fat and crude protein percentages were determined for each sample by a composition analyser (Berwind Instrument Corp., Multispec, N.Y.) at the DHIA laboratory in East Lansing, MI. Total milk solids were calculated (in 2 replicates) on a percentage basis by the following procedure. Aluminum weighing pans (Scientific Products, McGraw Park, IL) were

oven dried (1 h, 60°C) to eliminate environmental condensation and tared to the nearest ten-thousandth gram on a Mettler balance (Mettler Instr. Corp., Box 100, Princeton, N.J.). A 2-ml sample of milk was pipetted into the dried pan and weighed, then placed into an oven for 24 h at 60°C. The pan and dried sample were cooled in desiccant (W.A. Hammond Drierette Co., Xenia, OH) and weighed. Total milk solids were calculated for each sample using the following equation:

$$\frac{\text{(Dry Milk Wt + Pan) - Dry Pan Wt.}}{\text{(Wet Milk Wt + Pan) - Dry Pan Wt.}} \times 100\%$$

D. Statistical Methods

Experiment 1

Data from trials in experiment 1 were analyzed using a split-plot analysis of variance to test for PRL differences between bleeding periods. A mean PRL value was calculated for each animal at the 6 h bleeding times at weeks 8 and 14. The following model was used:

$$y_{ijk} = u + T_i + Ea_{ij} + t_k + Tt_{jk} + Eb_{ijk}$$

u = Grand mean
T_i = Lamp type treatment
Ea_{ij} = Animals within treatment
t_k = Bleeding (6 wk time interval)
Tt_{jk} = Treatment by bleed interaction
Eb_{ijk} = Residual error

In addition to the model analysis, mean values of bleedings within each treatment were compared using Students t test, where the

first bleeding mean was compared with the last bleeding mean of each trial.

An identical model was used to test for differences of samples which were collected by venipuncture at 3-day intervals throughout the trials. The time value t_k was then defined as a 3-day interval between samples.

Experiment 2

Identical statistical methods were used as in experiment 1, however, because of small temperature fluctuations in the environmental chambers, temperature was used as a covariate to adjust PRL values.

Experiment 3

Milk yield and feed intake for each cow were recorded daily. The number of observations had to be reduced so that the design matrix could be analyzed. Therefore, yield and intake were condensed by averaging successive 2-week periods. Triple split-plot analysis of variance with repeat measurement over time was used to test for milk yield, per cent butterfat or feed intake differences. The following model was used:

$$Y_{ijkl} = u + N_i + b_1(\text{Lact no}_{ij}) + b_2(\text{Pre-t}_{ij}) + b_3(BG_{ij}) + Ea_{ij} + L_k + NL_{ik} + Eb_{ijk} + t_l + Nt_{il} + Ec_{ijl} + Lt_{kl} + NLt_{ikl} + Ed_{ijkl}$$

u = Grand mean

N_i = Diet

$b_1(\text{Lact no}_{ij})$ = Lactation number covariate

$b_2(\text{Pre-}t_{ij})$ = Pre-trial milk yield average covariate

$b_3(BG_{ij})$ = Genetic breeding group covariate

Ea_{ij} = Animal pair from light and control groups within diet treatment

L_k = Light treatment

NL_{ik} = Diet by light (interaction)

Eb_{ijk} = Animal pair within diet by light treatment (interaction)

t_l = time

Nt_{il} = Diet by time (interaction)

Ec_{ijl} = Animal pair within diet by time (interaction)

Lt_{ikl} = Light by time (interaction)

NLt_{ikl} = Diet by light by time (interaction)

Ed_{ijkl} = Animal pair within diet by light by time (interaction)

The same model was used to test for differences in milk composition, however, composition analysis was recorded biweekly. Therefore, time represented a 2-week interval.

Experiment 4

A split-plot analysis of variance with repeat measurement over time was used to test effects of photoperiod on a within-herd basis. In addition, data were pooled from all herds and analyzed (split-plot) using the following model:

$$Y_{ijkl} = u + H_i + T_j + HT_{ij} + b_i(Stage_{ijk}) + b_2(Lact\ no_{ijk}) + b_3(ME_{ijk}) + b_4(\text{Pre-}t_{ijk}) + Ea_{ijk} + t_l + Ht_{il} + Tt_{jl} + HTt_{ijl} + Eb_{ijkl}$$

u = Grand mean

H_i = Herds

T_j = Light treatment

HT_{ij} = Herd by treatment (interaction)

$b_1(\text{Stage}_{ijk})$ = Stage of lactation at start of experiment (covariate)

$b_2(\text{Lact no}_{ijb})$ = Lactation number covariate

$b_3(ME_{ijk})$ = Mature equivalent milk production covariate

$b_4(\text{Pre-t}_{ijk})$ = Pre-trial milk average covariate

Ea_{ijk} = Cows within herd by treatment (interaction)

t_l = Time

Ht_{il} = Herd by time (interaction)

Tt_{jl} = Light treatment by time (interaction)

HTt_{ijl} = Herd by treatment by time (interaction)

Eb_{ijkl} = Residual error

The same model as above was used to test for treatment effects on per cent butterfat in milk. Pre-trial milk yield average was replaced by pre-trial fat percentage as a covariate in the analysis.

A Pearson correlation was used to test the correlation between milk yield and butterfat per cent.

RESULTS

Experiment 1a

After 8 weeks exposure to 8 h of cool-white fluorescent light per day, two groups of bull calves were bled at 30-min intervals for 6 h. Prolactin averaged 32.7 and 35.6 (± 4.7) ng/ml ($P>.05$) of serum for each group of four animals (Figure 3). For an additional 6 weeks, calves were exposed to 16 h of daily light from cool-white and Vita-Lite fluorescent lamps. Based on samples collected at 30-min intervals for 6 h at the end of 6 weeks, PRL increased ($P<.01$) to 66.8 and 53.2 (± 6.1) ng/ml after 16 L from cool-white and Vita-Lite fluorescent lamps respectively (Figure 3). The PRL response to light source treatment did not differ ($P>.05$). However, there was an interaction ($P<.01$) between light source and time.

Subsequent to switching daily light exposure from 8 to 16 h, single samples were collected by jugular venipuncture twice weekly. A linear increase ($P<.05$) in PRL was observed over time in both groups after the 16L:8D photoperiod was begun; however, PRL release in response to light source was not different ($P>.05$; Figure 4). Within comparable time frames, PRL concentrations tended to be higher in serum of samples collected by venipuncture versus those collected by cannulation.

Figure 3.--Six hour profiles of the effect of 8 h of light per day (cool-white fluorescent) of 16 h of light per day (cool-white fluorescent or Vita-Lite fluorescent) on concentrations of prolactin in serum of prepubertal bulls. Samples were collected by jugular cannula. There were 4 bulls per observation.

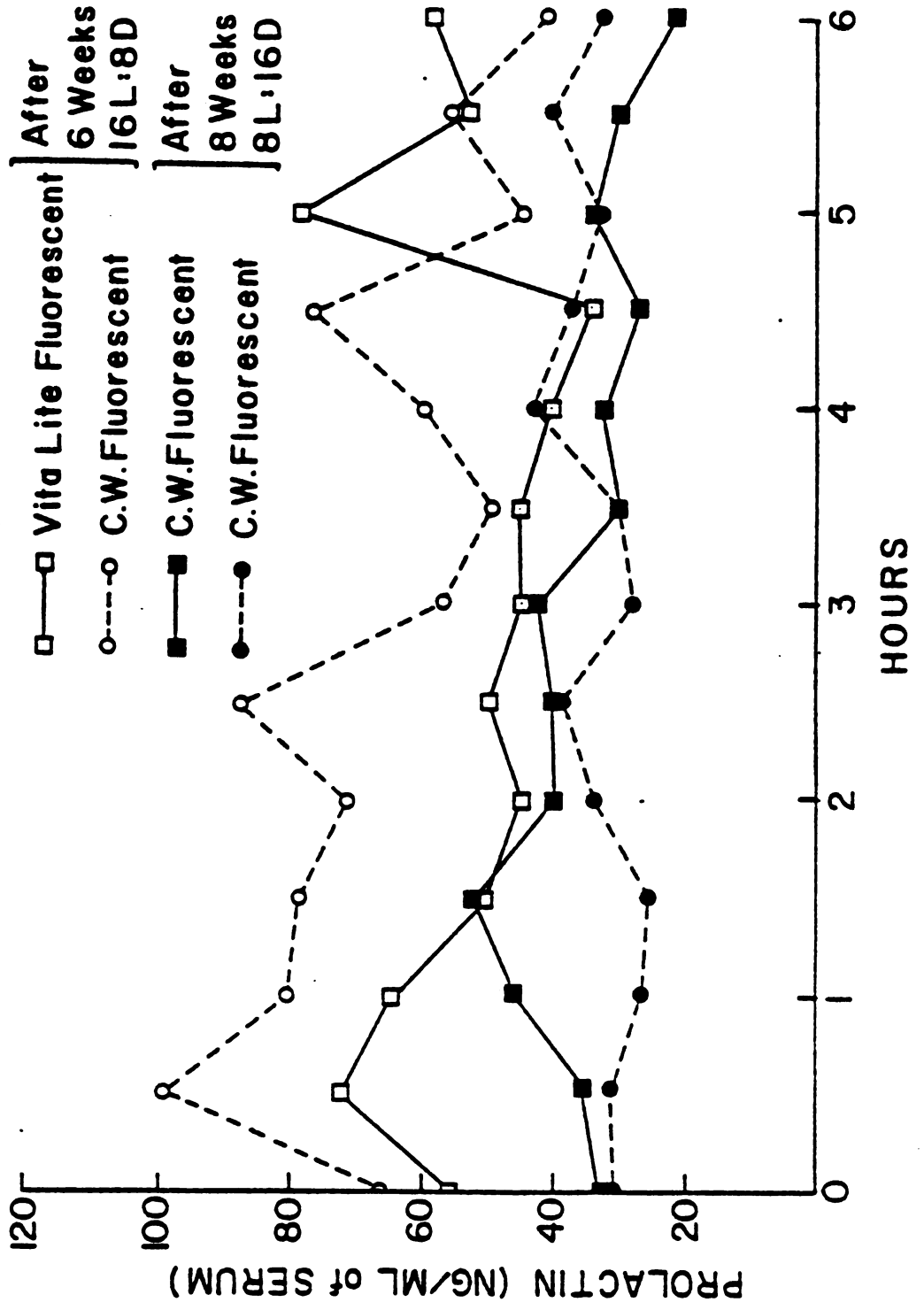
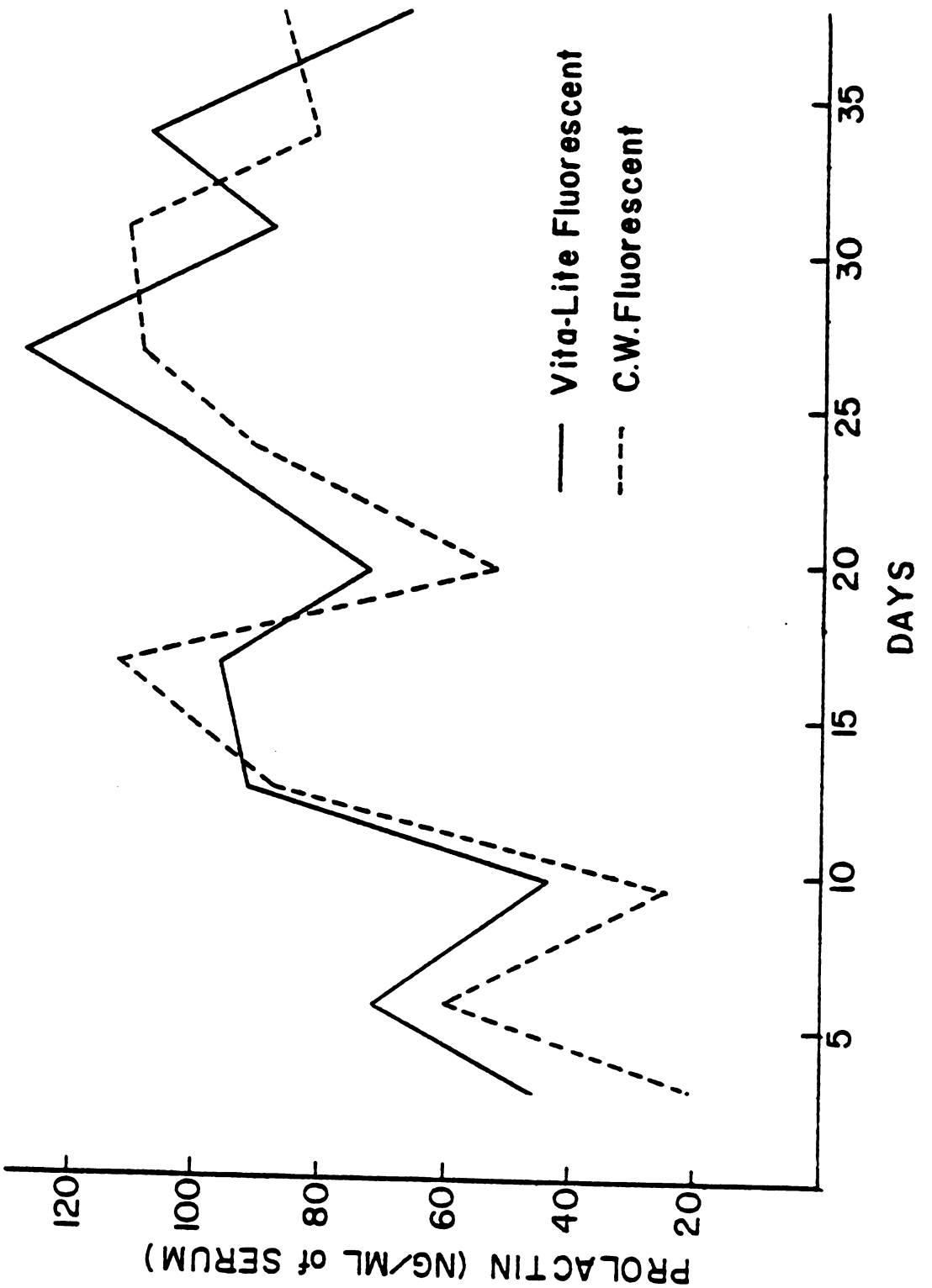

Vita Lite Fluorescent
C.W.Fluorescent
C.W.Fluorescent
C.W.Fluorescent
After 6 Weeks 16L:8D
After 8 Weeks 8L:16D
PROLACTIN (NG/ML of SERUM)
120
100
80
60
40
20
0
1
2
3
4
5
6
HOURS

Figure 4.--Prolactin in serum from prepubertal bulls after switching from 8 h per day of cool-white fluorescent to 16 h per day of cool-white fluorescent or Vita-Lite fluorescent lamps at day 0. Samples were collected via jugular venipuncture. There were 4 bulls per observation.


PROLACTIN (NG/ML of SERUM)
120
100
80
60
40
20
5
10
15
20
25
30
35
DAYS
Vita-Lite Fluorescent
C.W. Fluorescent

Experiment 1b

Two groups of animals were exposed to 8 h of cool-white fluorescent light per day for 8 weeks. At week 8, blood was collected at 30-min intervals for 6 h and PRL concentrations in serum averaged 10.6 and 9.5 (± 1.9) ng/ml ($P>.05$; Figure 5). Photoperiod was shifted from 8L:16D (cool-white fluorescent light source) to 16L:8D from cool-white fluorescent or incandescent lamps. After 6 weeks exposure to 16 h of light per day, calves were bled for 6 h at 30-min intervals and PRL averaged 71.0 and 85.4 (15.1) ng/ml (Figure 5). Thus, PRL concentrations were markedly increased ($P<.01$) after daily light exposure was increased from 8 to 16 hours. The incandescent light source did not differ ($P>.05$) from cool-white fluorescent light in terms of capacity to affect PRL concentrations in the bulls. Concentration of PRL decreased ($P<.01$) in both incandescent and cool-white fluorescent groups over the 6-h period.

In samples collected twice weekly throughout the 6 weeks of 16L:8D, PRL concentrations increased ($P<.01$) linearly over time (Figure 6). Prolactin responses to the cool-white fluorescent and incandescent light sources were not different ($P>.05$). PRL concentrations were generally elevated in samples collected by venipuncture as compared with cannula.

Experiment 1c

In a third experiment of this series, two groups of newborn calves were exposed to 8 h of cool-white fluorescent light per day for 8 weeks. At week 8, PRL averaged 9.7 and 10.1 (± 1.4) ng/ml of serum ($P>.05$) during 6 h of blood collection (Figure 7). Six weeks

Figure 5.--Six hour profiles of the effect of 8 h of light per day (cool-white fluorescent) or 16 h of light per day (cool-white fluorescent or incandescent) on concentrations of prolactin in serum of prepubertal bulls. Samples were collected by jugular cannula. There were 4 bulls per observation.

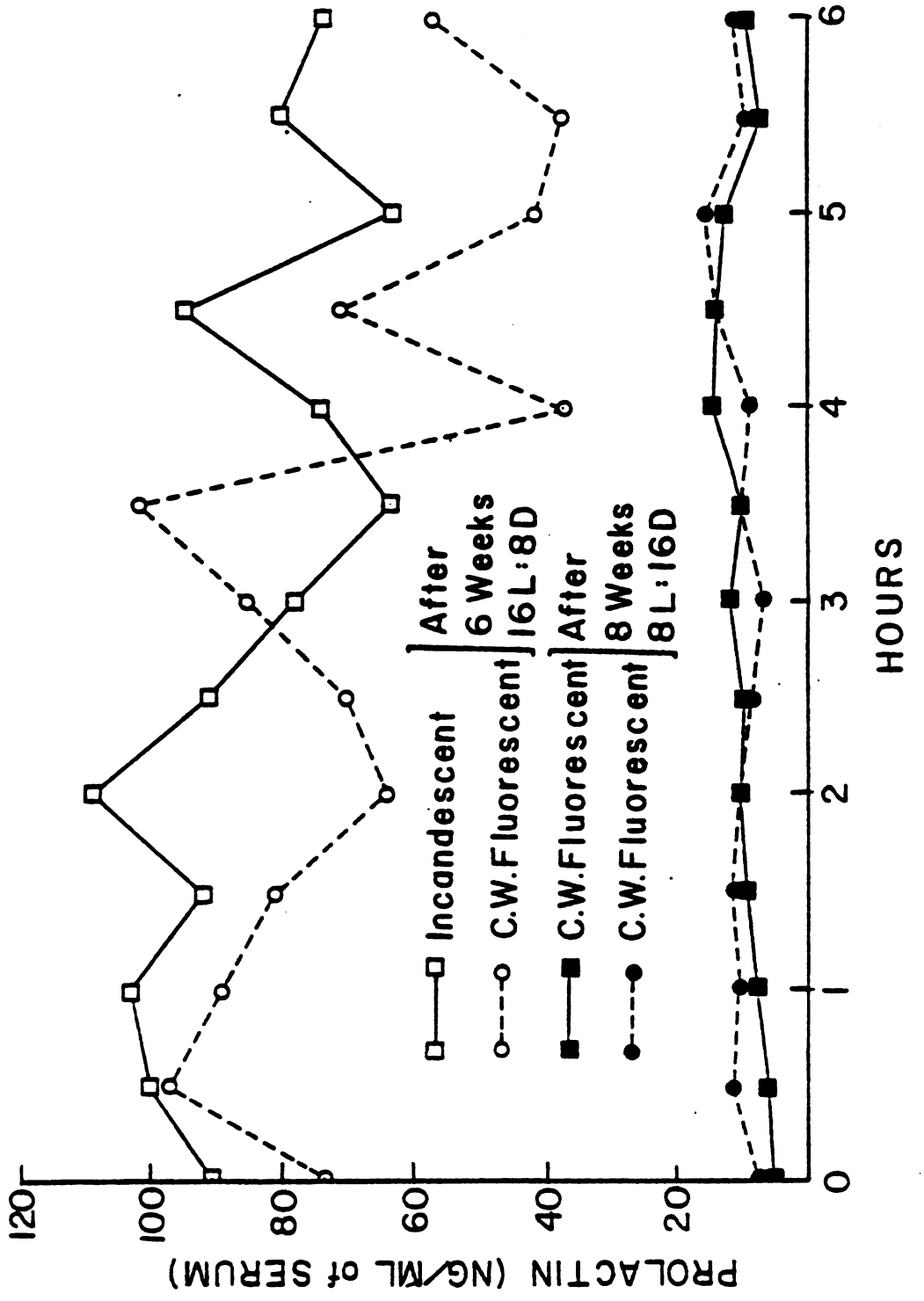

PROLACTIN (NG/ML of SERUM)
120
100
80
60
40
20
0
1
2
3
4
5
6
HOURS
Incandescent
C.W.Fluorescent
After 6 Weeks 16L:8D
C.W.Fluorescent
C.W.Fluorescent
After 8 Weeks 8L:16D

Figure 6.--Prolactin in serum from prepubertal bulls after switching from 8 h per day of cool-white fluorescent to 16 h per day of cool-white fluorescent or incandescent lamps at day 0. Samples were collected via jugular venipuncture. There were 4 bulls per observation.

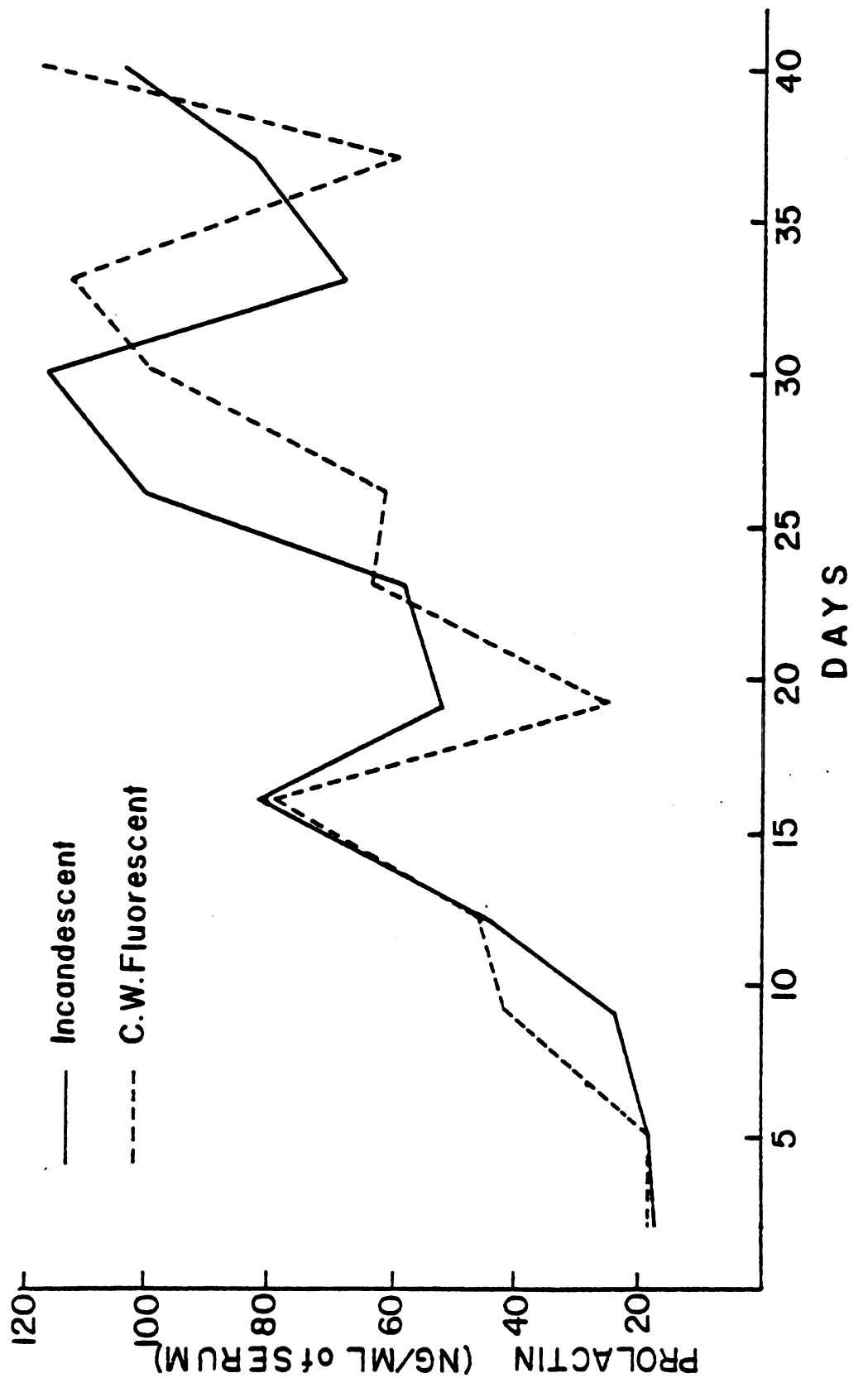
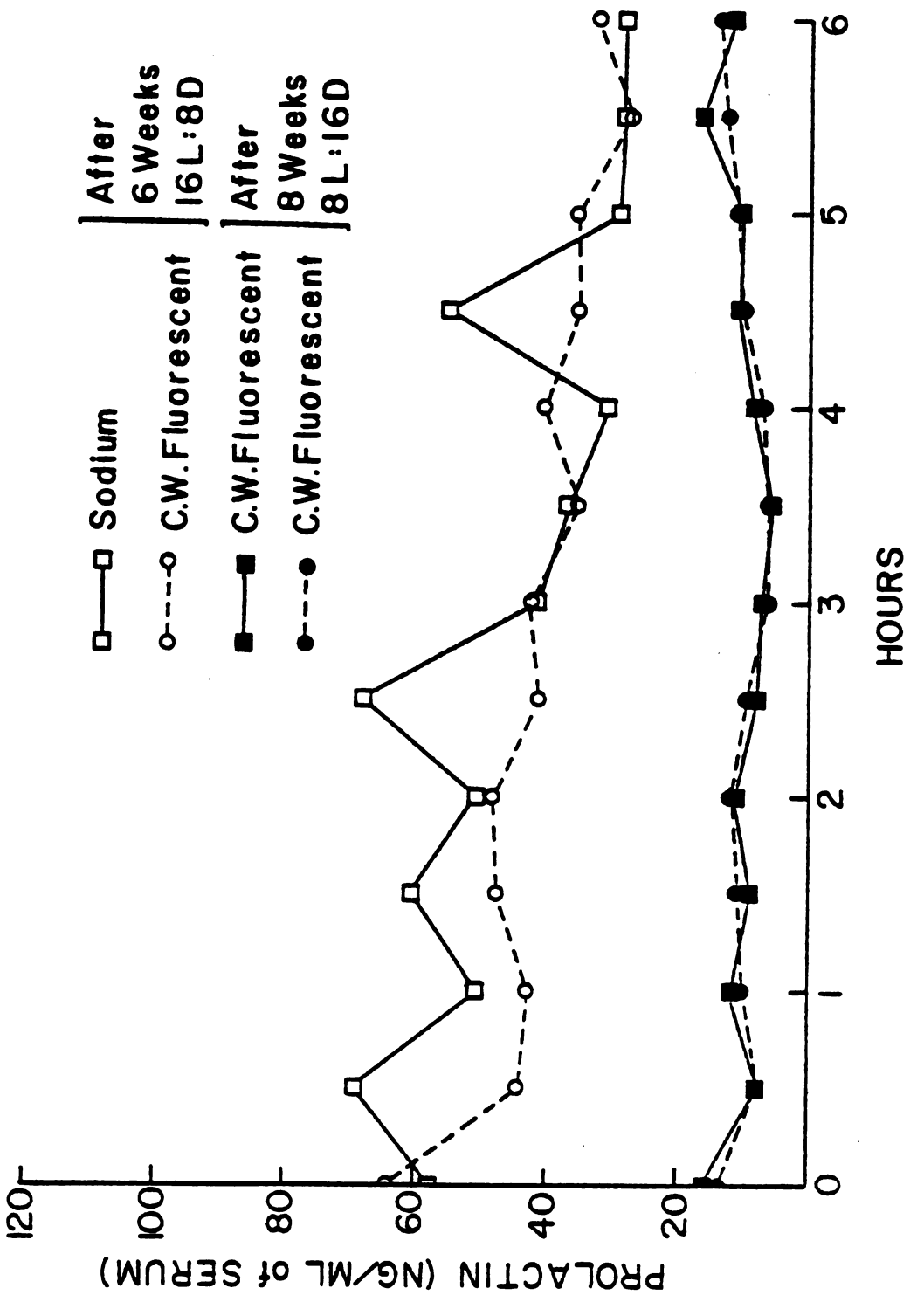

Incandescent
C.W.Fluorescent
PROLACTIN (NG/ML of SERUM)
120
100
80
60
40
20
5
10
15
20
25
30
35
40
DAYS

Figure 7.--Six hour profiles of the effect of 8 h of light per day (cool-white fluorescent) or 16 h of light per day (cool-white fluorescent or high pressure sodium) on concentrations of prolactin in serum of prepubertal bulls. Samples were collected by jugular cannula. There were 4 bulls per observation.


Sodium
C.W.Fluorescent
C.W.Fluorescent
C.W.Fluorescent
After 6 Weeks 16L:8D
After 8 Weeks 8L:16D
PROLACTIN (NG/ML of SERUM)
120
100
80
60
40
20
0
1
2
3
4
5
6
HOURS

later, PRL concentrations increased ($P<.01$) to 41.4 and 46.7 (± 5.2) ng/ml after 16 h per day exposure to light from cool-white fluorescent and sodium lamps, respectively (Figure 7). Source of light did not affect the PRL response ($P>.05$). Average PRL concentrations declined ($P<.01$) over the 6-h interval in each group of calves given 16L:8D.

Twice weekly samples collected after week 8 showed a linear increase ($P<.01$) of PRL concentrations in each group over time (Figure 8). Effectiveness of cool-white fluorescent and sodium lamps on PRL release was not different ($P>.05$). Concentrations of PRL were commonly greater in venipuncture samples than in samples collected by cannula.

Experiment 1d

In the final experiment of this series, 8 weeks of 8 h daily light resulted in PRL concentrations of 21.2 and 26.3 (± 3.8) ng/ml of serum ($P>.05$) in each group of bulls (Figure 9). An additional 6-h bleeding period conducted after 6 weeks exposure to 16 h per day of cool-white fluorescent and mercury vapor lamps increased ($P<.05$) to 52.9 and 53.8 (± 6.3) ng/ml of serum in each group respectively (Figure 9). Prolactin concentration declined ($P<.01$) in each group of calves over the 6 h bleeding time after 6 weeks of 16L:8D. Prolactin concentrations of calves exposed to mercury vapor lamps did not differ ($P>.05$) from calves exposed to cool-white fluorescent. After an abrupt shift of photoperiod from 8L:16D to 16L:8D, twice weekly blood samples showed a linear increase ($P<.01$) of PRL concentrations in each group (Figure 10). Both light sources stimulated PRL release equally well ($P>.05$).

Figure 8.--Prolactin in serum from prepubertal bulls after switching from 8 h per day of cool-white fluorescent to 16 h per day of cool-white fluorescent or high pressure sodium lamps at day 0. Samples were collected via jugular venipuncture. There were 4 bulls per observation.

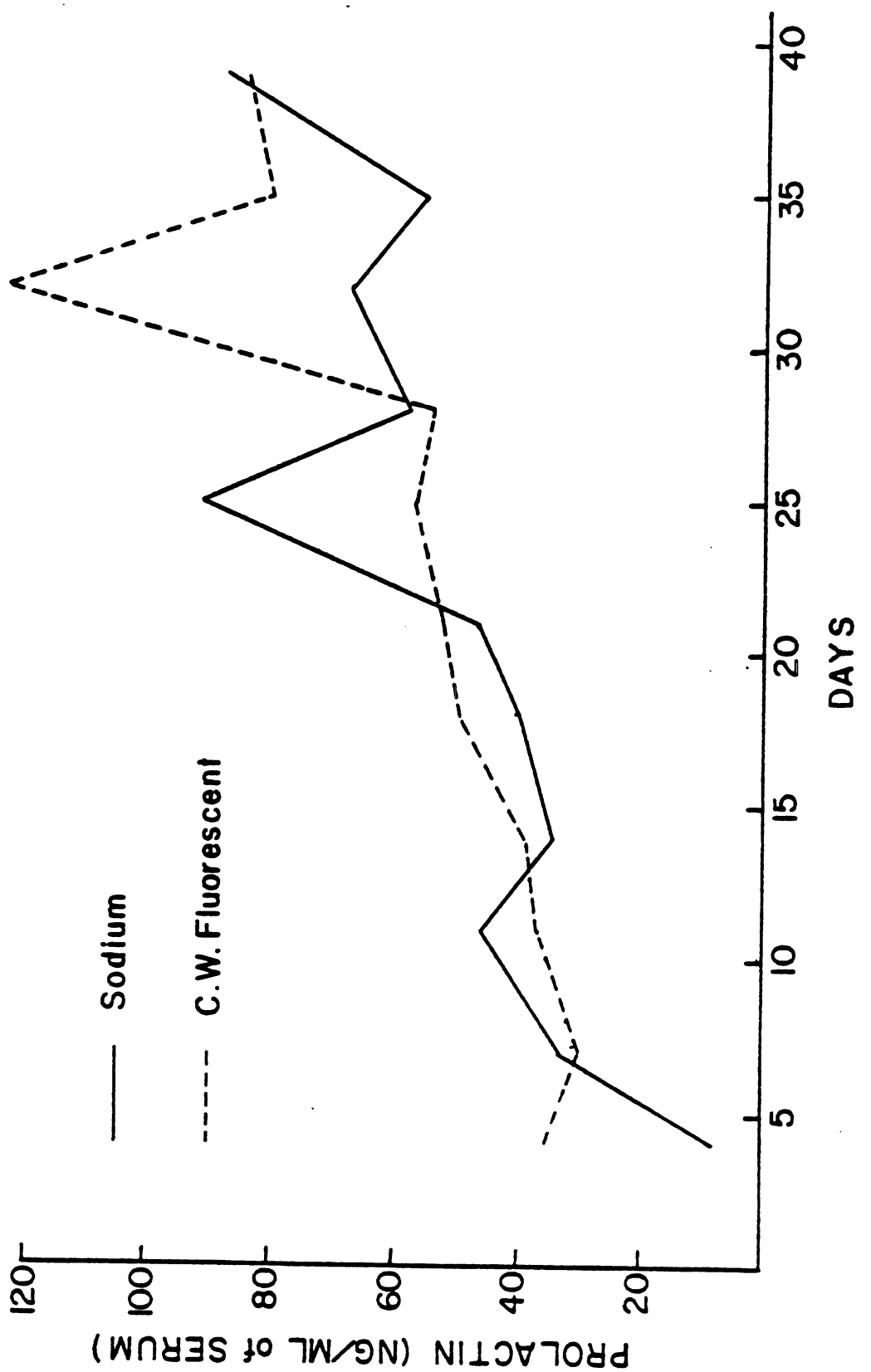

PROLACTIN (NG/ML of SERUM)
120
100
80
60
40
20
5
10
15
20
25
30
35
40
DAYS
Sodium
C.W. Fluorescent

Figure 9.--Six hour profiles of the effect of 8 h of light per day (cool-white fluorescent) or 16 h of light per day (cool-white fluorescent or mercury vapor) on concentrations of prolactin in serum of prepubertal bulls. Samples were collected by jugular cannula. There were 4 bulls per observation.

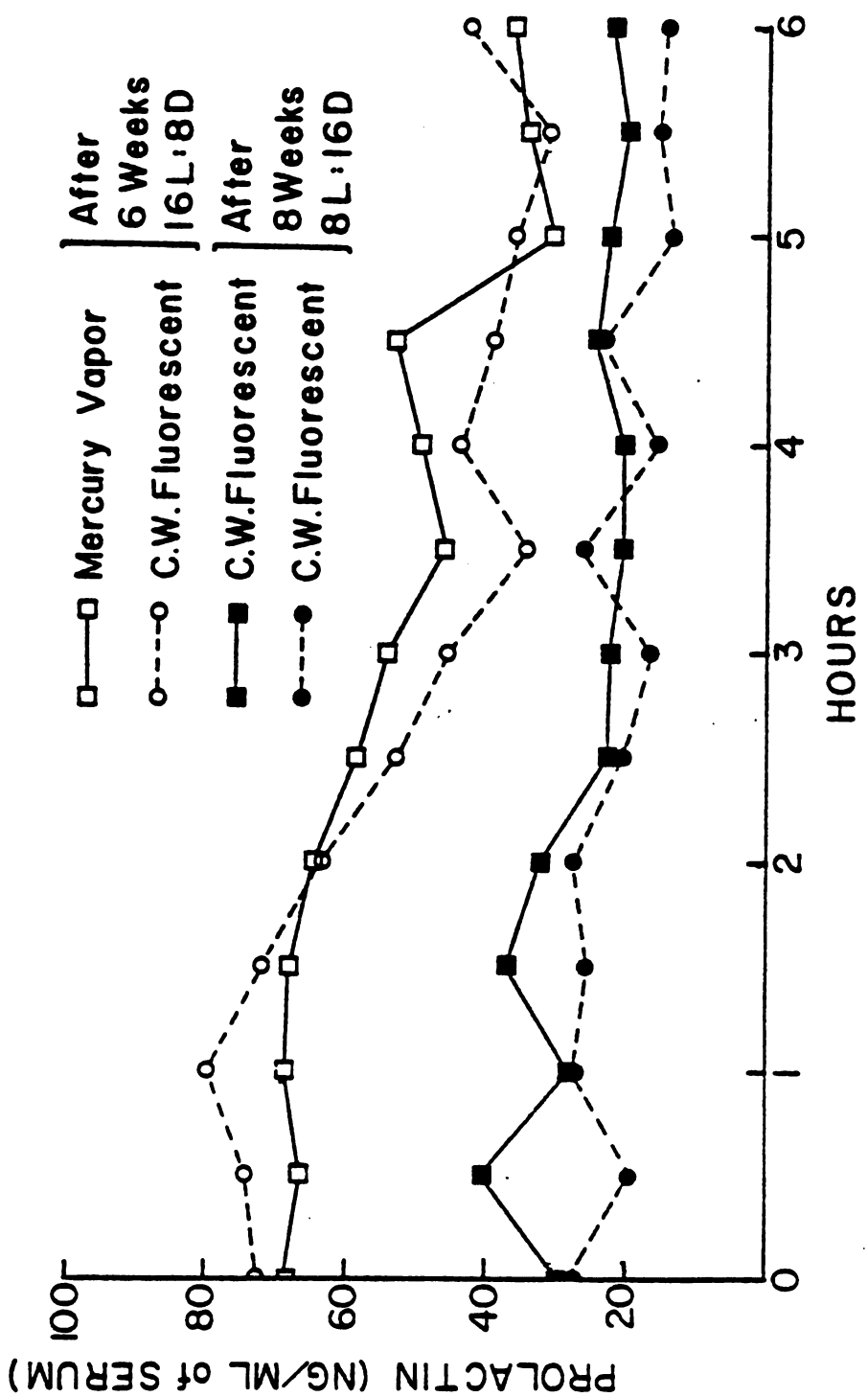

Mercury Vapor
C.W.Fluorescent
C.W.Fluorescent
C.W.Fluorescent
After 6 Weeks 16L:8D
After 8Weeks 8L:16D
PROLACTIN (NG/ML of SERUM)
100
80
60
40
20
0
1
2
3
4
5
6
HOURS

Figure 10.--Prolactin in serum from prepubertal bulls after switching from 8 h per day of cool-white fluorescent to 16 h per day of cool-white fluorescent or mercury vapor lamps at day 0. Samples were collected via jugular venipuncture. There were 4 bulls per observation.

Summarizing Experiment 1, average concentrations of PRL over the 6-h bleeding periods were increased 2 to 7 fold among all treatment groups, when daily light exposure was increased from 8 to 16 h (Figure 11). Thus all light sources tested influenced PRL concentrations as effectively as cool-white fluorescent. Experiments starting during cooler months tended to have increased initial (8L:16D) PRL concentrations when compared with experiments starting during warmer times.

Experiment 2

In a second experiment, PRL values averaged 21.6 and 17.9 (± 3.0) ng/ml of serum over a 6-h period in two groups of calves exposed to 8 weeks of an 8L:16D photoperiod ($P>.05$; Figure 12). Photoperiod was then shifted to 24-lo :0D in one group, and 8-hi 1:16-lo L in the other for an additional 6 weeks. Based on successive samples collected at 30-min intervals 6 weeks after the photoperiod switched from 8L:16D, prolactin in serum increased ($P<.05$) to 36.2 and 37.2 (± 7.1) ng/ml in calves exposed to 24-lo L:0D and 8-hi L:16-lo L, respectively. These means were not different ($P>.05$) from each other at that time (Figure 12).

In contrast, PRL in samples collected twice weekly by venipuncture throughout the 6-week period of 24-lo L:0D or 8-hi L:16-lo L, did not change over time (Figure 13; $P>.05$).

Experiment 3

Cows exposed to 16-hi L:8-lo L produced an average of 23.7 kg per day of milk over a 14-week period of time, while cows under

Figure 11.--Mean concentrations of prolactin in serum of prepubertal bulls after 8 weeks of 8L:16D (8L) or 6 weeks of 16L:8D (16L) from cool-white fluorescent or other light sources. There were 4 bulls per observation.


Cool-White Fluorescent Controls
Other Lamps
PROLACTIN (NG/ML of SERUM)
0
20
40
60
80
100
120
VITA-LITE
INCANDESCENT
SODIUM
MERCURY VAPOR
8L
16L
Expt. Ia
Expt. Ib
(Aug)
Expt. Ic
(Nov)
Expt. Id
(Feb)
Starting Month: (Feb)

Figure 12.--Six hour profiles of the effects of 8 h of light per day (cool-white fluorescent), 24-lo L:0D, or 8-hi L:16-lo L photoperiods on concentrations of prolactin in serum of prepubertal bulls. Samples were collected by jugular cannula. There were 4 bulls per observation.

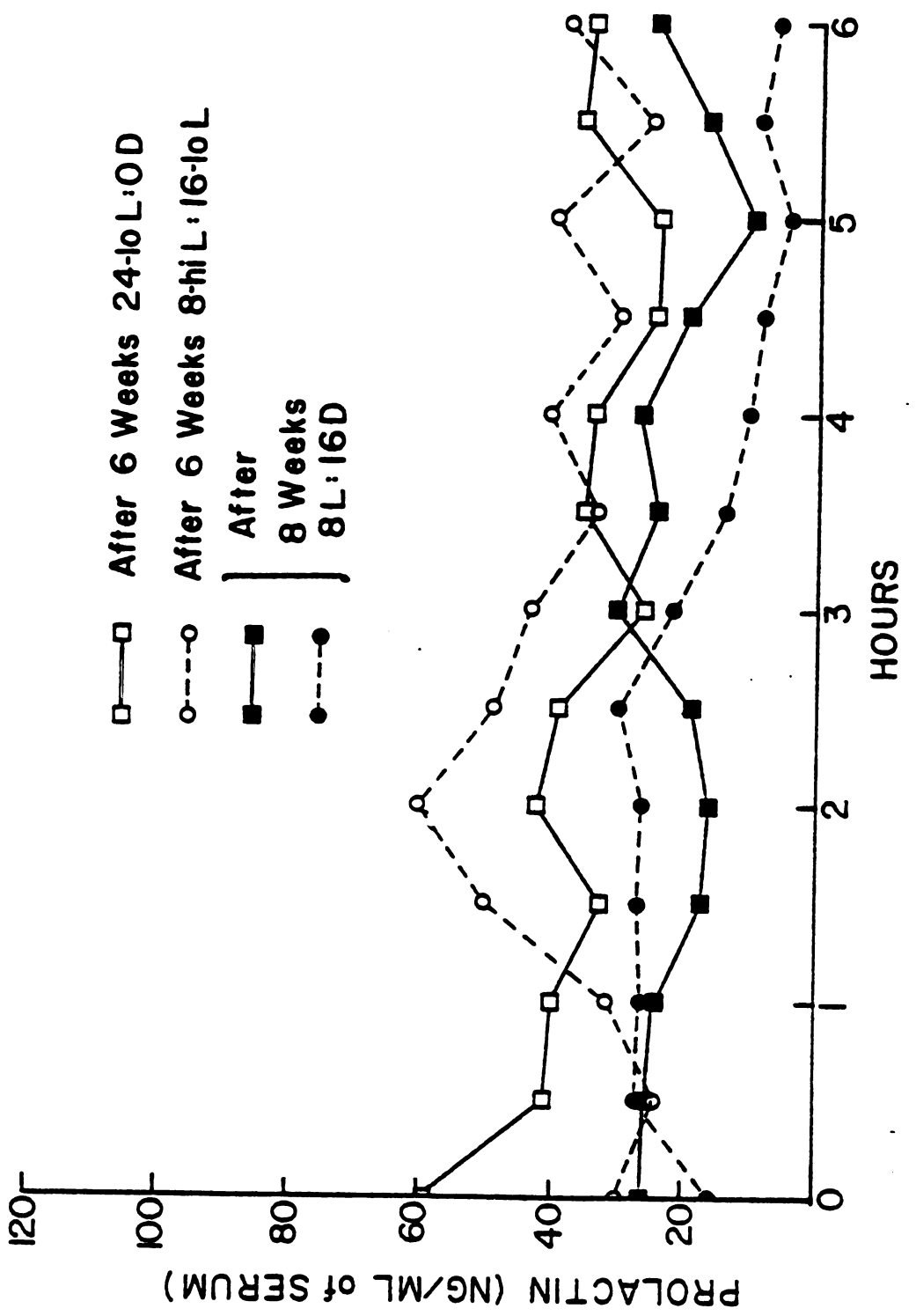
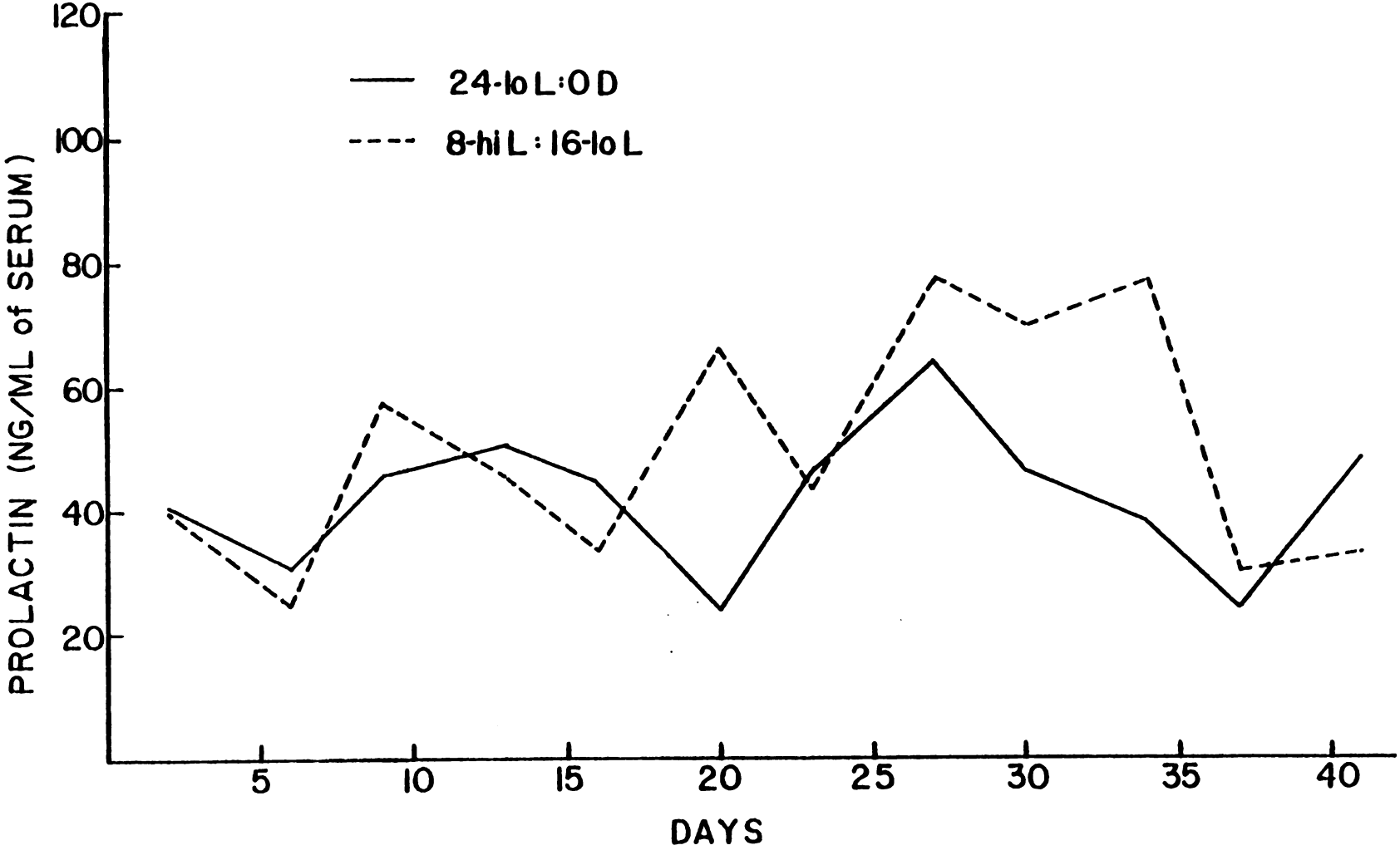

After 6 Weeks 24-lo L:0 D
After 6 Weeks 8-hi L: 16-lo L
After 8 Weeks 8L:16D
PROLACTIN (NG/ML of SERUM)
120
100
80
60
40
20
0
1
2
3
4
5
6
HOURS

Figure 13.--Prolactin in serum from prepubertal bulls after switching from 8 h per day of cool-white fluorescent to 24-lo L:0D or 8-hi L:16-lo L from fluorescent light sources. Samples were collected via jugular venipuncture. There were 4 bulls per observation.


120
100
80
60
40
20
PROLACTIN (NG/ML of SERUM)
24-lo L:0 D
8-hi L : 16-lo L
5
10
15
20
25
30
35
40
DAYS

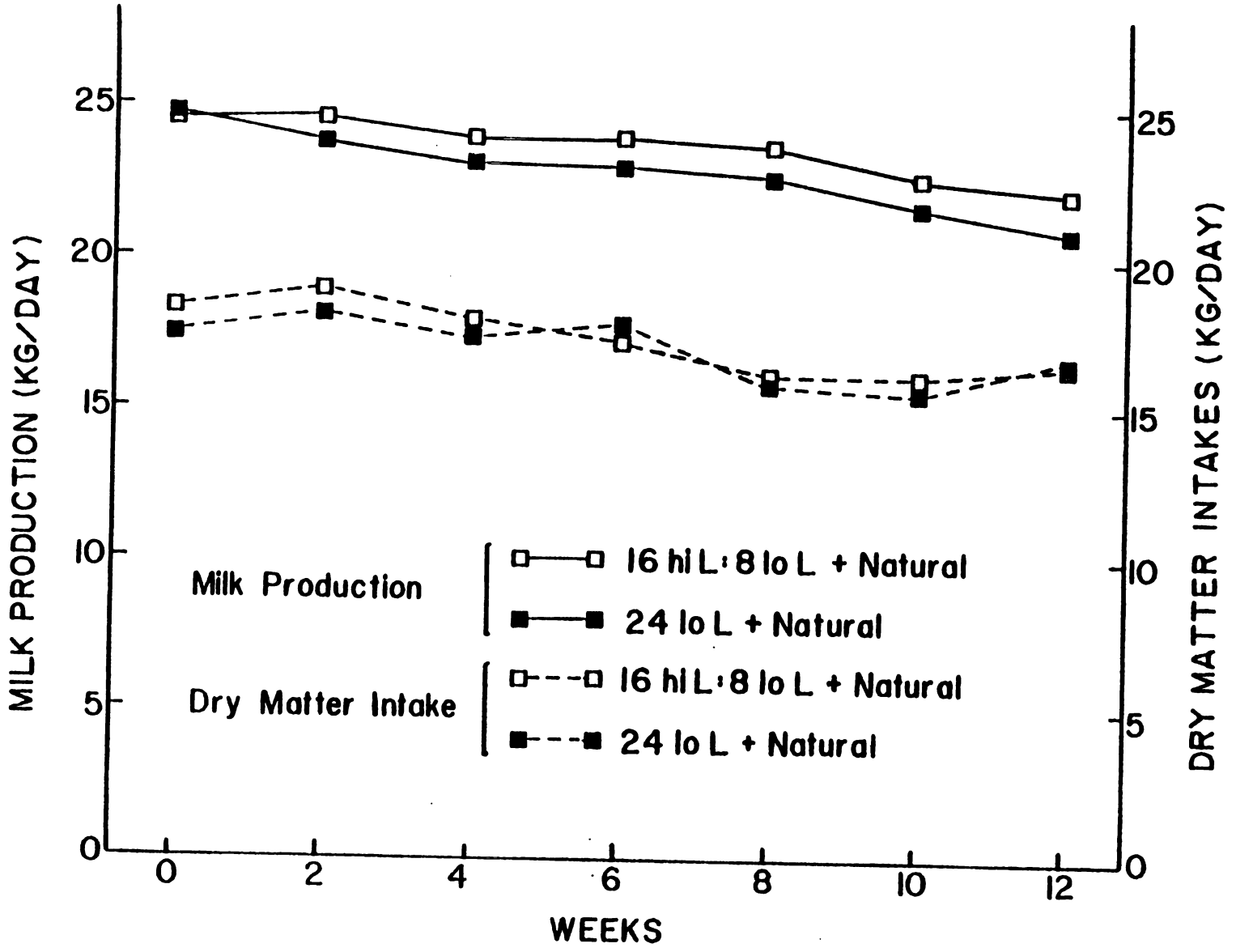
continuous low intensity light plus natural light produced an average of 22.9 kg per day (Figure 13). Milk production levels were not different ($P>.05$) between light groups. The light treatments used had no effect ($P>.05$) on milk composition. Fat percentages were 3.7 and 3.6% for the 16-hi L:8-lo L and 24-lo L:0D groups respectively. Crude protein was 3.3% in both groups and total solids averaged 12.4 and 12.3% throughout the experiment.

It was also found that the five rations fed had no effect ($P>.05$) on production. Animals receiving 16-h of fluorescent light per day ate an average of 17.3 kg of dry matter per day over the 14-week period; whereas, cows under 24-lo L:0D plus natural light ate 16.9 kg of dry matter per day (Figure 13). Dry matter intakes between the two light treatments did not differ ($P>.05$), however, ration (see Materials and Methods) had a marked effect ($P<.01$) on feed intakes.

Experiment 4

When milk production data were pooled from 13 herds (2602 observations), it was found that cattle receiving supplemental light produced an average of 2.17 kg more ($P<.05$) per day than controls during the 6-month trial (Figure 14). Unadjusted data showed that cows which produced 21.8 kg/day at the start of the experiment produced 18.9 kg/day after 6 months of supplemental light. On the other hand, control cows which initially produced 22.3 kg/day produced 17.6 kg/day 6 months later. Milk production decreased throughout the experiment in both groups of cattle as lactation advanced (Figure 14).

Figure 14.--Daily milk production and dry matter intakes of cattle exposed to 16 h of high intensity plus 8 h of low intensity light per day supplemented with sunlight or 24 h of low intensity light supplemented with sunlight. There were 20 cows per observation.

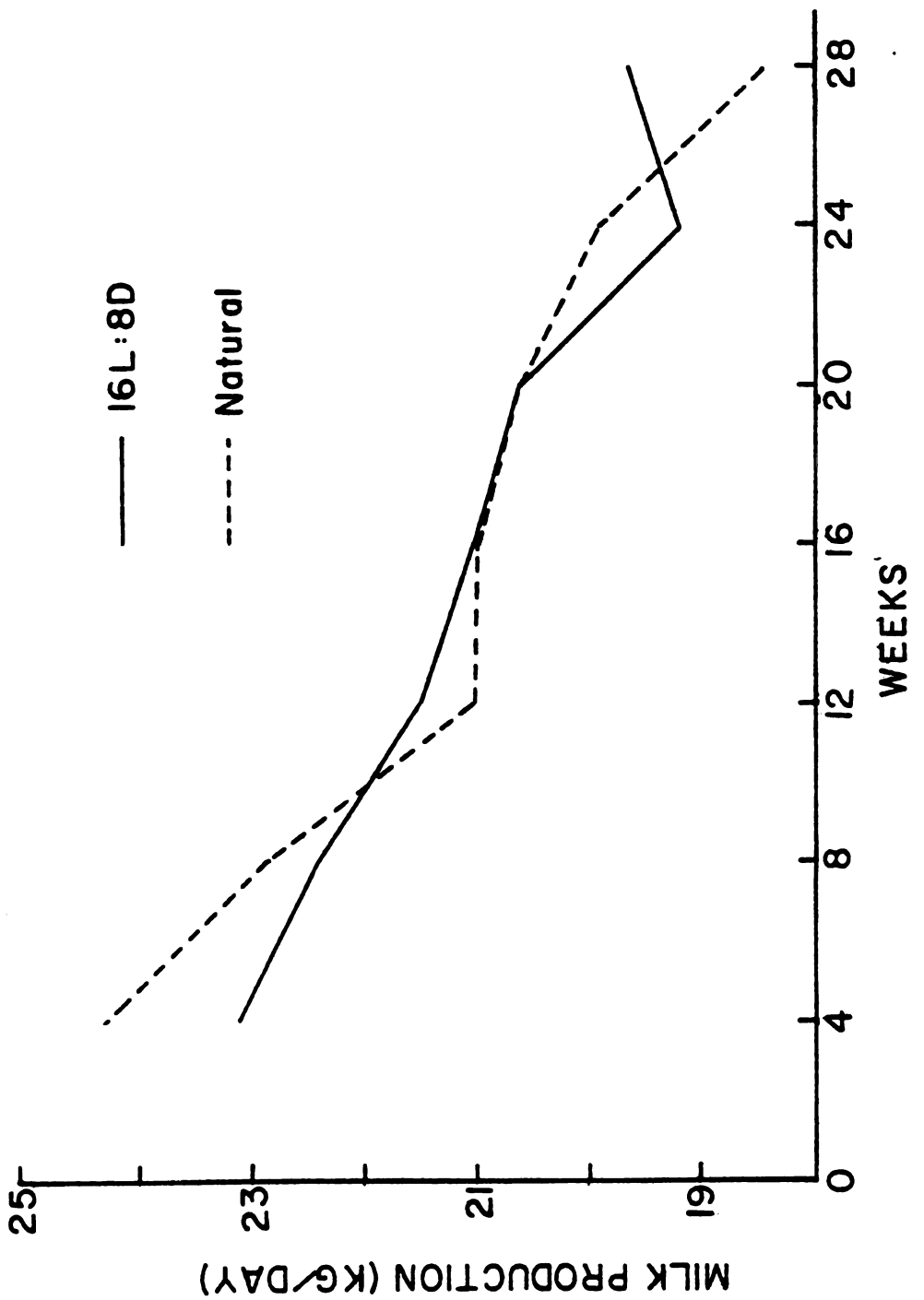

MILK PRODUCTION (KG/DAY)
DRY MATTER INTAKES (KG/DAY)
WEEKS
0
2
4
6
8
10
12
0
5
10
15
20
25
Milk Production
16 hi L:8 lo L + Natural
24 lo L + Natural
Dry Matter Intake
16 hi L:8 lo L + Natural
24 lo L + Natural

Cows exposed to supplemental light had an average of 0.164% less ($P<.01$) butterfat in milk than controls.

When data were examined on a within-herd basis for milk production, only two of the 13 herds had a detectable ($P<.05$) treatment effect due to additional lighting. Similar analysis of butterfat percent showed again that only two herds had detectable treatment effects. However, herds with increased fat percent were not the same herds which had significant differences in milk yield.

Pooled data from all cows showed a significant ($P<.01$) negative correlation of -.38 when comparing total milk production with percent butterfat. Selecting only cows which were under supplemental lighting resulted in a correlation of -.45. The correlation of milk with butterfat percent in control cows was -.32.

Figure 15.--Average daily milk yield of Holstein cattle exposed to natural Michigan winter daylengths or supplemented with fluorescent light for 16 h per day. Initially there were 209 cows exposed to natural and 192 cows exposed to 16L:8D. By week 14 the number of cows was reduced to 92 and 78 respectively.


16L:8D
Natural
MILK PRODUCTION (KG/DAY)
25
23
21
19
0
4
8
12
16
20
24
28
WEEKS'

Document 1.--Copy of agreement signed by herd owners to allow inspection of DHIA production records.

AGREEMENT

The undersigned does hereby warrant ownership and control of a certain herd of dairy cattle, and gives permission to the Dairy Herd Improvement Association (DHIA) to allow Edward Stanisiewski, H. Allen Tucker, and Roger Mellenberger of Michigan State University, Department of Dairy Science to examine the herd's production records with the provision the records will remain confidential between the Dairy Herd Improvement Association and Edward Stanisiewski, H. Allen Tucker, and Roger Mellenberger and no reference by either name or herd number will be permitted, published, or otherwise released to the general public at any time. However, the material referred to may be used and otherwise utilized for scientific purposes, including publication, provided said herd's identity is protected from public disclosure.

_____ _____

Date

DISCUSSION

Previous studies in cattle (Bourne and Tucker, 1975; Peters and Tucker, 1978; Leining et al., 1979) and sheep (Pelletier, 1973; Lincoln et al., 1978; Sanford et al., 1978) showed that 16 h of fluorescent light per day increased PRL concentrations in serum when compared with concentrations in control animals exposed to only 8 h of light per day. This finding could have important applications to the cattle industry since PRL has been implicated in several physiological functions of mammals including lactogenesis, lactation, and growth (Lyons, 1958; Cowie et al., 1964a; Peters et al., 1980). Leining et al. (1979) increased PRL in serum of bull calves using 8 h of cool-white fluorescent plus 8 h of red (550-750 nm) or blue (300-425 nm) light (16 h daily total) in comparison with 8 h of cool-white fluorescent light per day.

The major purpose of my experiments was to test lamps which may differ in their economical or physiological effects. Efficiencies of the lamps used in these experiments ranged from 20 lumens per watt (lpw) for incandescent to 75 lpw for high pressure sodium lamps. My results showed that 16 h of light from sources with several different spectral properties within the visible range (Figure 1) will stimulate PRL secretion. Since an efficient light source (e.g. high pressure sodium or mercury vapor) supplied for a sufficient period of time, can be used to stimulate PRL release, then it may

be possible to promote growth rates and lactation. The benefits of operating lights for 16 h per day (or longer) will be more cost effective with the more efficient light sources.

Each light source has a characteristic spectral intensity pattern. Mercury vapor and high pressure sodium lamps have distinct power outputs which are concentrated within small portions of the visible color range. On the other hand, cool-white fluorescent, incandescent, and Vita-Lite fluorescent are considered to be broad spectrum lamps. Intensity outputs of broad spectrum lamps encompass the entire range of visible light. Sunlight is a broad spectrum light source under which most animals evolved to their present physiological state. Vita-Lite fluorescent lamps have spectral powers and wavelengths which resemble the spectrum of sunlight. Had the effects of Vita-Lite been different from other lamp sources, Vita-Lite lamps could possibly be regarded as the standard by which to make light source comparisons. However, this was not the case since all light sources tested affected PRL secretion similarly to cool-white fluorescent. In terms of the observed PRL release, it appears that calves are responsive to several different wavelengths or combinations of wavelengths.

The PRL response to an abrupt photoperiod change (from 8L:16D to 16L:8D) with cool-white fluorescent light is sluggish, it may take a week or more to detect, and requires several weeks to attain a maximum (Bourne and Tucker, 1975; Peters and Tucker, 1978). This slow response was confirmed in my studies with cool-white fluorescent lights. Moreover, this same pattern of response was seen using

Vita-Lite fluorescent, incandescent, high pressure sodium and mercury vapor lamps (Figures 3, 5, 7, 9). One could therefore postulate that the mechanism by which photoperiod modulates serum PRL is similar for each lamp type. The specific mechanism by which photoperiod regulates PRL serum concentration is unknown; however, Lincoln et al. (1982) have postulated that the response is mediated by an interaction between pineal gland hormones and endogenous rhythms of the hypothalamus. Melatonin and serotonin are two pineal hormones which when injected into the third ventricle of rats will stimulate the release of PRL (Kamberi et al., 1971).

Within a given trial, it was noted that when photoperiod from cool-white lamps was increased from 8L:16D to 16L:8D, PRL always increased. However, this increase ranged from 2 to 7 fold depending upon the trial, even though the same breed, age, ambient temperatures, photoperiod, pens and cool-white light sources were used. Vines et al. (1977) observed in dairy cattle that the quantity of TRH-induced PRL release was 3 to 16 times greater in summer than in winter. Examination of my data (Figure 10) shows that experiments which started in February (Experiments 1a and 1d) had the least increase in PRL over the 6-week period, whereas the experiment starting in August had the greatest. One experiment starting in November showed an intermediate increase when daily light exposure increased from 8 to 16 hours. Therefore, these results agree with the seasonal release patterns reported by Vines et al. (1977). It appears from these data that a seasonal pattern of PRL release to light may exist.

Other workers have demonstrated in cattle (Schams, 1972; Peters, 1980; Tucker, 1982), goats (Buttle, 1974; Muduuli et al., 1979) and sheep (Munro et al., 1980; Kennaway et al., 1981) that basal secretion of PRL is generally elevated during summer months as compared with winter. The primary causes of this pattern are temperature (Wettemann and Tucker, 1974) and light (Bourne and Tucker, 1975). Petitclerc et al. (1983) showed in blind bulls housed out of doors that the seasonal pattern of basal PRL secretion is retained, even when adjusted for temperature. Data were pooled in the present study across light source, within groups exposed to 16L:8D, and within each of the four experiments testing different light sources. A seasonal pattern of PRL secretion existed which agrees with the seasonal pattern reported previously (Schams, 1972; Peters, 1980; Tucker, 1982).

Mean concentrations of PRL in serum of calves attained a maximum (80 ng/ml) in August, whereas calves exposed to identical photoperiods (16L:8D) and temperatures (21.0±3°C) averaged about 55 ng/ml of serum during fall (November) and winter months (February). In contrast, calves exposed to 8 wk of an 8L:16D photoperiod show a pattern of basal PRL secretion which is high in winter and low in summer (Figure 10). These results are opposite those normally expected, and opposite those obtained in calves given 16L:8D in the present study. This may be an exhibition of an annual rhythm demonstrable only under short-day photoperiods and controlled (21.0±3°C) temperature conditions. Such a phenomenon may be associated with season of birth or maternal influence. For example,

in rats and monkeys, fetuses in utero are exposed to changing nutrient and hormone concentrations which reflect the mother's circadian rhythmicity (Deguchi, 1975; Reppert et al., 1979). This rhythmical pattern may be entrained into the offspring for some portion of its' newborn life. Another possible explanation for increased basal concentrations of PRL in the winter is that it may be an "over-compensation" of PRL release in response to moving the calves from uncontrolled to controlled temperature conditions.

Others have shown that PRL concentrations in cattle are highly influenced by stress (Tucker, 1971; Johnson and Vanjonack, 1975). Within similar time frames, we found that PRL concentrations were generally higher in samples collected by jugular venipuncture than in those collected by cannula. These results are likely due to the stress of capture, holding and venipuncture of the calves. This confirms the findings of Leining et al. (1979).

In each of the experiments which tested light sources, PRL concentrations declined over the 6 h bleeding time after 6 weeks exposure to 16L:8D. This phenomenon was observed previously (Tucker, 1971), and may be due to habituation of the animals to the sampling procedure. In contrast, PRL concentrations did not decline over a 6 h bleeding period after 8 h of daily light exposure. Based on the data collected here, the occurrence of a declining baseline seems to be related to the absolute concentration of PRL; that is, PRL in serum remains more stable when concentrations are below 20 ng/ml.

It was previously shown that shifting photoperiod from 8-hi L:16D to 8-hi L:16-lo L causes an increase in PRL concentrations in calves (Rzepkowski, 1981). In addition, calves exposed to continuous light (of constant intensity) had PRL concentrations which were lower than those in calves exposed to 16 h of light per day (Leining et al., 1979). Our finding that bulls exposed to 6 wk of 8-hi L:16-lo L have higher PRL concentrations in serum than when previously exposed to 7 wk of 8-hi L:16D is in agreement with previous work (Rzepkowski, 1981). However, our determination that increasing daily light exposure from 8 to 24 h stimulates PRL concentrations conflicts with the results of Leining et al. (1979). One major difference between the designs of this and Leining's trial, was that after 8 weeks exposure to 8L:16D, continuous light was attained by increasing light at .38 h daily intervals. Whereas in my experiment, continuous light was attained abruptly. One explanation of our results is that the change in PRL may, in part, be a response to a shift in duration of photoperiod and therefore is not wholly dependent on maintenance of the absolute duration of light (or dark) exposure.

But other alternative explanations are possible. For example, previous studies showed that a photosensitive period exists between 16 and 18 hours after subjective dawn in cattle (Petitclerc et al., 1980) and sheep (Ravault and Ortavant, 1977; Schanbacher and Crouse, 1981). The presence of a photosensitive period leads to two possible interpretations of my data. The first is that an 8-hi L:16-lo L photoperiod is seen by the calves as 16L:8D, where 16 h of light is

provided by the low intensity light (16-lo L) which overlaps the photosensitive range. The other possibility is that the 8-hi L:16-lo L photoperiod is interpreted as continuous light, which again, overlaps the photosensitive range. This means that the intensity of light a calf receives does not matter once it is above a certain threshold of perception, it is only important that light is present during a critical phase in the animals' endogenous circadian rhythm.

When compared with natural daylight, 16 h of light per day stimulated milk production during winter months (Peters et al., 1978; Bodurov, 1979; Peters et al., 1981). In each of these previous lactation trials, cows received 8 h of darkness daily. Many commercial dairy herds could benefit from a photoperiod in which light was provided continuously for the purpose of estrous detection, security, or in other emergency situations. We examined the possibility of increasing milk yield by coupling 16 h of high intensity daily light with continuous low intensity light exposure. Cows which were exposed to 16 h of light per day plus continuous light, produced an average of 0.8 kg more milk per day than cows exposed to natural daylight plus continuous light. However, this production difference was not significant. Failure to detect a difference may not be due to the incapacity of the photoperiods to stimulate milk yields, but rather, it may be due to several complications in the experimental design. Peters et al. (1978) used 46 cows per treatment to detect a photoperiod treatment difference of 3.1 kg. In my experiment, only 20 cows were used per treatment. Figures provided by Gill (1969) show there is approximately an 80% chance of detecting a

3 kg per day difference using 25 animals per group. Therefore, the numbers used in my experiment were perhaps below the threshold of sensitivity for detecting the expected yield difference of 3 kg/day. Confounding the results further was the fact that light treatments were broken down into five groups fed different diets. This led to a reduction of the degrees of freedom in the experimental model.

Because a photosensitive phase has been established as a key to PRL release (Schanbacher and Crouse, 1981), it is conceivable that a similar phase may occur which stimulates milk production. Therefore, milk yields could have been stimulated equally well in each group (16-hi L:8-lo L or 24-lo L:0D) due to the presence of continuous light overlapping a photosensitive phase. This experiment needed a negative control (such as 8L:16D) in which light was not available during a critical phase.

Previous studies under controlled conditions showed that a 16L:8D photoperiod will stimulate milk yield 2-3 kg/day (Peters et al., 1978, 1981). Results of the fourth experiment showed that 16L:8D stimulated production 2.2 kg/day over natural light controls when data were amalgamated from 13 commercial dairy herds. However, within herd comparisons failed to show any light treatment differences. Most herds had less than 15 cows per treatment, which means there was less than a 50% chance of detecting a difference of 2 or 3 kg/day (Gill, 1969). As expected (Bath et al., 1978, p. 356), there was a negative correlation (-.38) between milk yield and butterfat percentage. The negative correlation was greater when comparing cows receiving supplemental light versus those under natural light

(-.45 vs. -.32). The correlation of the light-supplemented cows may be further indication that they produced more milk and less butterfat than the control cows.

I concluded that 16 hours of light per day stimulated milk yield in comparison with natural daylength under commercial farm conditions.

SUMMARY AND CONCLUSIONS

Experiments were designed to examine the PRL response in calves exposed to 16L:8D from lamps with different spectral characteristics. Other experiments examined the effects of photoperiods supplemented with continuous low intensity light on PRL release and milk production. A final experiment tested the effectiveness of increasing milk production through supplemental lighting on commercial dairy herds.

In each of the first series of experiments, eight 3-day old bull calves were exposed to 8L:16D for 8 weeks. After which time, four bulls received 16L:8D from cool-white fluorescent light whereas the other four bulls received 16L:8D from either Vita-Lite fluorescent, incandescent, high pressure sodium or mercury vapor lamps. Blood was collected from each calf for 6-hours at half-hour intervals at week 8 (after 8L:16D) and at week 14 (after 16L:8D). In addition, twice weekly venipuncture samples were collected throughout the 6-week period of 16L:8D. Prolactin in serum increased ($P<.05$) 2 to 7 fold between week 8 and week 14, and the increase appeared to be linear. Each lamp tested was as effective as cool-white fluorescent controls in stimulating PRL release.

In another experiment, eight 3-day old bull calves were exposed to 8L:16D for 8 weeks, then, for an additional 6 weeks, four calves received an 8-hi L:16-lo L photoperiod while the other

four calves received continuous low intensity light (24-lo:0D). Prolactin initially averaged 21.6 and 17.9 ng/ml of serum ($P>.05$) at week 8 in the two groups of calves and increased ($P<.05$) to 37.2 and 36.2 ng/ml of serum after 6 weeks of 8-hi L:16-lo L and 24-lo:0D. Prolactin concentrations were not different ($P>.05$) at this time.

Forty Holstein cows were exposed to natural lighting conditions for 14 weeks. Twenty of those cows were supplemented with 16-hi L:8-lo L while the other twenty received continuous low intensity light. An average increase of .8 kg/day in favor of the 16-hi L:8-lo L group was not different ($P>.05$) from the other lighting regimen. In addition, milk composition (fat, crude protein), and dry matter intakes were not different ($P>.05$) between photoperiod treatment.

In a final experiment, 456 cows on 13 commercial dairy herds were exposed to either natural daylight or daylight supplemented with 16 h of fluorescent light daily. Milk production was increased 2.2 kg/day ($P<.05$) in cattle exposed to supplemental light.

In conclusion, sixteen hours of light per day stimulates PRL concentrations in serum of bull calves relative to 8 h of light per day. Bull calves are responsive in terms of PRL secretion to several different spectral characteristics of light. Daily light periods of greater than 16 hours can have a stimulatory effect on PRL release, even if that period consists in whole or in part of relatively low intensity light. However, milk yields were not detectably different in cows exposed to continuous light photoperiods supplemented with

either 16 h of light or natural winter daylight. In the absence of continuous light, milk yields can be increased in cattle using 16 h of light relative to natural daylight.

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