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EFFECTS OF
PHOTOPERIOD AND LIGHT INTENSITY
IN BROILER CHICKENS

BY

RODNEY G. CHARLES

A THESIS SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

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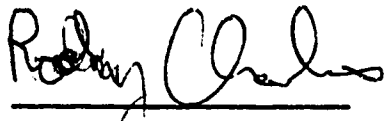

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled **EFFECTS OF PHOTOPERIOD AND LIGHT INTENSITY IN BROILER CHICKENS** submitted by **RODNEY GENE CHARLES** in partial fulfillment of the requirements for the degree of **MASTER OF SCIENCE** in **ANIMAL PRODUCTION.**

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ABSTRACT

Day-old male Hubbard broilers (960) were assigned to one of four treatments (two pens of 120 birds per treatment) to evaluate the effects of increasing (6L:18D increasing 4 h/wk to 23L:1D) versus constant 23 h light (L): 1 h dark (D) photoperiod and high (150 lx) versus low (5 lx) intensity light. The environment of each room was monitored remotely, measuring CO_2 and dust concentrations, over a 24-h period on days 24, 31, 38, and 45. Birds raised under a constant photoperiod were heavier than birds raised under increasing photoperiod from 2 to 5 wk and at 7 wk of age (1.71 % heavier at 7 wk). Low-intensity birds were heavier than high-intensity birds from 2 to 8 wk (3.25 % heavier at 8 wk). High-intensity bird carcasses had lower body fat (7.77 %) and higher body protein (1.77 %) at 8 wk compared with low-intensity bird carcasses. High-intensity birds had smaller (15.46 %) abdominal fat pads at 8 wk compared with low-intensity birds. Birds subjected to an increasing photoperiod had larger (29.36 %) testes at 8 wk compared with birds under the constant photoperiod. Birds treated under increasing photoperiod had higher plasma androgen concentrations at 7 wk compared with birds under constant photoperiod.

Live 8 wk body weight (BW8) was positively correlated with carcass dry matter and fat content (r = .18 and .35, respectively) and negatively with carcass protein and ash content (r = -.33 and -.35, respectively) expressed in absolute amount. BW8 exhibited positive correlation with abdominal fat pad weight and comb weight at 8 wk of age (r = .45 and .24, respectively) while no

correlation existed with 8 wk testes weight. Plasma androgen concentrations correlated positively at 3, 5, and 7 wk of age with values ranging from .72 to .92. Abdominal fat pad weight correlated positively with carcass content of fat ($r = .74$) and negatively with carcass protein content ($r = -.40$).

CO_2 concentrations at 31, 38, and 45 days of age were reduced by 16 to 23 % during dark hours relative to light hours while dust concentrations were reduced 1.8 to 2.9 times lower during dark hours relative to light hours. Mean CO_2 concentrations were increased by 17.5, 10.1, and 10.6 % (at 31, 38, and 45 days of age, respectively) among birds exposed to increasing photoperiod relative to those exposed to constant photoperiod. Dust concentration was elevated among birds exposed to increasing photoperiod at 45 days of age only. High-intensity light resulted in numerically increased CO_2 and dust (significant at 38 days of age) concentrations. These changes in CO_2 and dust concentrations reflect variation in bird activity.

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INTRODUCTION

1.1 PHOTOSTIMULATORY MECHANISMS IN POULTRY

The photo-responsiveness of poultry species is well documented (Moore 1957, Wilson and Follett 1977, Freeman et al. 1981, Siopes et al. 1989). This photo-responsive nature is clearly shown by the stimulation of sexual maturity exhibited when birds are exposed to increasing or long photoperiod length (Farner and Gwinner 1980). It seems probable that photoperiod receptor sites reside not only in the eye, but also in the brain of the bird (Double Photoreceptor Model) (Homma et al. 1980). Photoreceptors located in the brain are referred to as deep photoreceptors while those in the eye are referred to as retinal receptors. It seems likely that both retinal and deep photoreceptors perceive light and then send nervous impulses to the pineal gland. A neural pathway has been demonstrated for light-stimulated impulses to reach the pineal in birds (Hedlund and Nalbandov 1969). The pineal may then affect a response through the release of the hormone melatonin. Melatonin injections into pinealectomized European starlings were shown to synchronize locomotor activity into a circadian pattern (Gwinner and Benzinger 1978). Considerable evidence exists in mammals showing the influence of melatonin and other indole derivatives over pituitary gonadotropins acting directly or indirectly via the hypothalamus (Quay 1963, Reiter 1973).

1.2 PHOTOPERIOD RECEPTOR SITES

1.2.1 THE AVIAN EYE

Like other vertebrates, the eyes of birds have a retina which functions as a visual receptor communicating with higher centres in the brain via the optic nerve (Meyer 1986). Many species of birds have superior vision relative to man (Sturkie, 1986). Vision is most highly developed in raptors which require high resolution over great distances. Colour discrimination has been shown to exist in many species including the chicken (Lashly 1916) and some species are also able to distinguish ultraviolet light (Goldsmith 1980).

The visual receptor cells in the retina are of three types: rods, single cones, and double cones. Rods are involved in dim light vision must be very sensitive to light. Cones are involved in bright light vision, colour discrimination and visual acuity. The chicken retina contains both single and double cones with about twice as many double cones as singles (Meyer and May 1973). Each photoreceptor cell contains a visual pigment (conjugated protein) which absorbs the light entering the retina. The visual pigments associated with the rods absorb maximally at 500-506 nm for most avian species and do not vary with environment or behaviour (Meyer 1986). Thus, the rod cells are probably involved in vision but not in photo-stimulation of behaviour and sexual maturity. The visual pigments associated with the cone cells absorb maximally at 560-575 nm. Cone pigments absorbing light in this range have been found in the chicken (Wald et al. 1955) and also in the turkey (Crescitelli et al. 1964).

1.2.2 DEEP PHOTORECEPTORS

Homma et al. (1980) hypothesized the double receptor model of avian photoperiodism. The double receptor model proposes that photo-receptor cells are located in the brain near the hypothalamus as well as in the retina. The authors found that implantation of radioluminous beads near the hypothalamus of Japanese quail stimulated gonadal development indicating photo-responsive sexual maturation. However, implantation of radioluminous beads in front of the retina did not stimulate sexual maturity. Experiments have been conducted with blinded chickens which indicate the presence of some non-retinal method of light perception (Ralph et al. 1975). Their data supports the hypothesis that photoreceptors might exist in the hypothalamus which may be equally or even more important than those located in the retina.

1.2.3 PINEAL GLAND

Avian pineal organs have both secretory and photoreceptor functions (Sato and Wake 1983). Certain cells within the pineal gland called pinealocytes are believed to be rudimentary photoreceptor cells (Deguchi 1981). Pinealocytes are thought to be photosensitive and transmit impulses to the brain via the pineal tracts (Sato and Wake 1983). The pineal gland also has endocrine functions such as melatonin production which may account for much of the pineal's influence on avian physiology. Deguchi (1980), postulated that the circadian oscillator, photoreceptor, and melatonin synthesizing machinery

are all located in the same cells of the chicken pineal gland. Among its endocrine functions, the pineal gland plays a role in maintenance of body temperature, body weight, and adrenal size (Cogburn and Harrison 1980). The avian pineal appears to have some influence over sexual maturation through gonadal development. Maturation and onset of lay were delayed in pinealectomized Japanese quail (Saylor and Wolfson 1967). Similarly, pinealectomy in the male domestic duck reduced testicular weight and *in vitro* biosynthesis of steroids (Cardinali et al. 1971).

In mammalian and avian species, the pineal gland is the major site of melatonin production (Binkley et al. 1979). However, melatonin has also been shown to arise in the retina of chickens, sparrows, and rats (Binkley et al. 1979). Melatonin is produced in the pinealocytes of these organs ultimately from tryptophan. In mammals, tryptophan is taken up from the blood, hydroxylated to 5-hydroxytryptophan, decarboxylated to serotonin (5HT), acetylated to N-acetylserotonin and then methylated to melatonin (Wight 1971). The biological amines and melatonin present in the avian pineal suggest a similar pathway exists in avian species (Binkley 1980). Binkley et al. (1979) and Deguchi (1980), reported that N-acetyltransferase (NAT), an enzyme involved in the above pathway, is also the key enzyme in melatonin synthesis by the avian pineal. Since NAT is the key enzyme involved in melatonin synthesis, NAT activity has been used by many investigators as a measure of melatonin synthesis.

The general cycle of NAT activity involves high levels during the night and low levels during the daylight period thus controlling the circadian rhythms found in serotonin, N-acetylserotonin, and melatonin. Plasma melatonin levels in chickens follow a similar cycle to that of NAT activity with increasing levels observed at night and decreasing levels observed during the daylight (Pelham 1975, Liou et al. 1987). Liou et al. (1987) postulated that the increase in plasma melatonin during the dark period is essential for regulating the time of oviposition while the duration of the elevated melatonin during the dark phase modifies the time of oviposition in the laying chicken.

1.3 EFFECTS OF MELATONIN

Melatonin is believed to affect a variety of physiological parameters in avian species. In chickens, melatonin has been found to reduce feed intake *in vitro* and also to stimulate drowsiness and sleep at higher doses (Bermudez et al. 1983). The reduced food intake may have resulted from reduced metabolic rate causing a decrease in energy requirement. Such a reduction in metabolic rate during the dark hours has been shown to occur in broiler breeder hens (Macleod et al. 1980). Bermudez et al. (1983) postulated that melatonin acts on the central nervous system perhaps explaining why such high levels of melatonin were required to induce sleep after intraperitoneal injection. Only small amounts of injected melatonin would reach the brain while melatonin released from the pineal gland would need to travel only a short distance and

therefore would still be effective. Melatonin has also been found to reduce testosterone synthesis in the testes of mature White Leghorn cockerels (Usami et al. 1983). The activity of testosterone synthesizing enzymes were reduced during the dark hours probably due to the increased melatonin production known to occur during this time period. Supporting evidence for this theory comes from Sackman (1977) who found that melatonin has a direct inhibitory effect on the metabolism of the testes. The inhibitory effect of melatonin on testes metabolism provides a plausible explanation for the reduced gonadal growth seen following melatonin injection in quail (Homma et al. 1967) and chickens (Singh and Turner 1967).

1.4 EFFECTS OF PHOTOPERIOD MANIPULATION IN POULTRY

Many avian species including poultry are known to be photo-responsive, meaning they respond to daylength (photoperiod) changes. Photoperiod serves as a natural timing device in seasonal breeding species influencing such parameters as moulting, gonadal growth, and migration. These in turn may influence reproductive activity. Extensive reviews have been done indicating the influence of photoperiod on reproductive activity of avian species (Wolfson 1966, Sturkie 1986). Photoperiod is now commonly used to stimulate sexual maturity, maximize egg production, and control body weight in poultry species.

1.4.1 CONSTANT PHOTOPERIOD LENGTH

Exposure of seasonally breeding birds to long photoperiod length stimulates reproductive development (Pittendrigh and Minis 1964). Long photoperiod has direct stimulatory effects on gonadal growth in quail (Gibson et al. 1975) and red grouse (Sharp et al. 1974). Gonadal growth is associated with steroid hormone production which may explain the growth enhancing effects found when birds are exposed to long photoperiod (Beane et al. 1962, Freeman et al. 1981).

Long constant photoperiod length increases growth rate in chickens (Beane et al. 1962, Freeman et al. 1981, Robbins et al. 1984). Increased growth is thought to result primarily from longer periods of access to feed (Freeman et al. 1981). Long photoperiod and the resulting increased growth rate is often accompanied by reduced feed efficiency (Beane et al. 1962, Classen and Riddell 1989). Classen and Riddell (1989) compared a lighting treatment involving 6 hours light and 18 hours dark (6L:18D) increasing to 23L:1D at 21 days of age with one involving constant 23L:1D throughout the six week trial. Birds exposed from 0 to 21 days of age to 6L:18D gained less weight, consumed less feed, and had better feed conversion relative to those exposed to 23L:1D. The reduced feed efficiency recorded for long photoperiods may be explained by the fact that birds are more active when exposed to long photoperiod. High levels of activity require additional energy which would increase maintenance requirements and thus reduce feed

efficiency. Other disadvantages of long photoperiod include increased incidence of leg abnormalities (Robbins et al. 1984) and increased production cost due to higher electrical requirements.

Long constant photoperiod results in larger testes and higher levels of plasma testosterone in 31 week old White Leghorn males (Bachman et al. 1987). Similar long photoperiod programs have been found to improve growth relative to short photoperiod programs (Beane et al. 1962). Testosterone enhances growth in mammalian species (Kilkenny and Sutherland 1970, Powers and Florini 1975), and turkeys (Fennell and Scanes 1987) and it seems likely that the same is true of chickens.

1.4.2 CHANGING PHOTOPERIOD LENGTH

Changing photoperiod length is known to affect sexual maturity in many avian species. Changing from short to long photoperiod stimulates gonadal growth in Japanese quail (Follett and Farner 1966, Follett and Riley 1967), tree sparrows (Wilson and Follett 1974), and chickens (Sharp 1974). Long photoperiod exerts direct stimulating effects (Sharp et al. 1974, Gibson et al. 1975) which appear to increase release of gonadotropin-releasing hormone (Gn-RH) which in turn stimulates release of luteinizing hormone (LH) and follicle stimulating hormone (FSH). These two pituitary hormones then stimulate growth of the gonads. As the gonads are the primary sites of androgen production in the body, increasing photoperiod length enhances androgen

production.

Little research has been done using photoperiod change to stimulate growth in poultry. Studies with turkeys exposed to changing photoperiod have not shown consistent results. Hester et al. (1983) compared a high-intensity step-up (HISU) program with a low-intensity step-down (LISD) program. They found that the HISU program decreased leg abnormalities, had no effect on male growth performance, reduced hen growth performance, increased male plasma androgens and testes weights while reducing length and width of the tarsometatarsi. Hester et al. (1986) compared the same two lighting programs and found that HISU resulted in reduced leg abnormalities, shorter tarsometatarsi, lighter tibias, smaller male body weight after 20 weeks of age, reduced male feed conversions after 14 weeks of age and smaller testes after 20 weeks of age. Hester et al. (1985) compared a low-intensity step-up (LISU) program with the same LISD program and found the LISU program resulted in reduced body weights, poorer feed conversions, no effect on leg abnormalities, higher activity level, and larger testes in one trial but no effect in another. This would seem to suggest that light intensity may have an effect on leg abnormalities as does photoperiod length. In contrast, Siopes et al. (1983) found that light intensities of 1, 11, 110, and 220 lx had no effect on the incidence of leg abnormalities. The combination of these findings suggests that interactions between light intensity and photoperiod length may influence leg abnormalities in turkeys. Changing photoperiod length has been used for

several years to stimulate sexual maturity in laying chickens and also to maximize egg production. On the other hand, photoperiod manipulation in meat producing chickens has been used primarily to maximize feed intake and growth using long constant photoperiods such as 23L:1D or 24L:0D. These programs have been favoured in the past to maximize feed intake with no desire to stimulate sexual maturity. However, recent evidence suggests that other lighting programs, involving more hours of darkness, may have beneficial effects in broiler chickens (Cave 1981, Zakaria 1987, Classen and Riddell 1989, Classen et al. 1991).

A series of experiments have been carried out at the University of Saskatchewan involving several thousand broiler chickens and three different photoperiod programs (Classen and Riddell 1989). The three programs used were: 1) constant photoperiod (23HR) (23L:1D); 2) abruptly increasing photoperiod (6HR) (0-21d, 6L:18D; 21-42d, 23L:1D); and 3) gradually increasing photoperiod (INC) (0-3d, 23L:1D; 3-14d, 6L:18D; 14-21d, 10L:14D; 21-28d, 14L:10D; 28-35d, 18L:6D; 35-42d, 23L:1D). Increasing photoperiod, whether it be gradual or in one step, gives equal or slightly improved growth and feed efficiency while reducing leg abnormalities and mortality, relative to constant long photoperiod. The primary benefit from the increasing photoperiod program was reduced skeletal disease. Comb size was found to increase with exposure to increasing photoperiod which suggests higher androgen production in these birds. Androgens may affect the incidence of leg abnormalities through

their influence on bone development (Pierson et al. 1981).

Classen et al. (1988) used the same 23HR and INC programs as described above along with a decreasing photoperiod program (DEC) (0-3d, 24L:0D; 3-14d, 23L:1D; 14-21d, 18L:6D; 21-28d, 14L:10D; 28-35d, 10L:14d; 35-42d, 6L:18D). The authors found that final body weight was increased by the INC program and reduced by the DEC program relative to the 23HR program. Robinson et al. (1988) found that plasma androstenedione (AND), from broilers in the trial of Classen et al. (1988), followed the same ranking as market body weight (INC>23HR>DEC) but were significantly different only in females at 42 days of age. These results support the hypothesis that androgen production and growth rate are related in juvenile chickens. Similar treatment effects were noted for comb and gonad weights but due to variability among birds did not differ significantly. It cannot be stated conclusively whether or not increasing photoperiod has a significant influence on androgen production by prepubertal broiler chickens. This point requires further investigation for clarification.

1.4.3 INTERMITTENT LIGHTING PROGRAMS

Intermittent lighting (IL) systems use short alternating periods of light and dark. Several different intermittent lighting programs have been tested for poultry production, primarily with broiler chickens. Definite benefits arise from the use of IL systems in comparison to continuous lighting systems. Experiments to date dealing with IL systems indicate superior growth rate

compared to continuous lighting systems (Hoopaw and Goodman 1976, McDaniel et al. 1977, Zakaria 1987). Zakaria (1987) reported stimulation of testicular growth in birds exposed to IL systems, which may indicate stimulated androgen production and these androgens could be involved in the superior growth noted above. Improved feed efficiency has been associated with IL systems (Malone et al. 1980a,b) along with reduced incidence of leg abnormalities (Buckland et al. 1973, Wilson et al. 1984) and sudden death mortality (Ononiwu et al. 1979).

1.5 EFFECTS OF LIGHT INTENSITY

Light intensity has significant effects on poultry production and extremely high or low-intensity light should be avoided. It has been shown that low-intensity light (<100 lx) stimulates growth performance and improves feed efficiency in broiler chickens (Barott and Pringle 1951, Morris 1967, Deaton et al. 1976). Similarly, light intensity below 5 lx improved growth performance and feed efficiency of turkeys exposed to relatively short daylength (Bacon and Touchburn 1976, Hester et al. 1986). However, contradictory results have been shown for chickens (Deaton et al. 1988) and turkeys exposed to long photoperiods (Proudfoot et al. 1979, Siopes et al. 1983). Deaton et al. (1988) found that under continuous lighting, broiler chickens exhibited similar growth performance and feed conversion when exposed to light intensities of 2 and 52 lx. Similarly, Proudfoot et al. (1979) found that light intensities of .4 and 7 lx

resulted in near equal growth performance and feed efficiency in male and female turkeys exposed to long photoperiod (23L:1D). Siopes et al. (1983) found that light intensity of 1 lx actually inhibited growth performance of male turkeys exposed to long photoperiod (23L:1D) relative to turkeys exposed to 11, 110 and 220 lx.

The improved feed efficiency noted above in association with low-intensity light may be due to reduced maintenance energy requirements. High-intensity light is thought to stimulate activity and metabolic rate in birds (Gwinner 1975, Deaton et al. 1976), thus increasing maintenance energy requirements resulting in reduced feed efficiency. Evidence supporting this explanation includes noticeable increases in "flightiness" of turkeys when exposed to high-intensity light (Siopes et al. 1983, Hester et al. 1983, Hester et al. 1986). High-intensity light significantly enhances testes size in turkeys (Siopes et al. 1983, Hester et al. 1986). The increased testes size may be interpreted as a sign of stimulated sexual maturity. As the testes are the primary sites of androgen production in the male, it seems likely that the high-intensity light was stimulating androgen production. Increased androgen production may explain the reduction in length of long bones observed in tom turkeys (Hester et al. 1983). The reduction in length of long bones may at least partially explain the reduction in leg abnormalities reported by Hester et al. (1983, 1985, 1986) since short bones are stronger than long bones. This same reduction in bone length may also explain the reduced body weights seen when

birds were exposed to high-intensity light (Hester et al. 1983, 1985, 1986) since reduced bone length would ultimately limit the amount of growth possible by these birds.

1.6 EFFECTS OF LIGHT WAVELENGTH

The wavelength of light to which birds are exposed will influence sexual development with birds generally being more sensitive to longer wavelength. Light in the orange or red spectrum stimulates testicular growth in starlings (Burger 1943). Also, red light wavelengths have been shown to increase pituitary weight and gonadotrophin content of cockerels (Foss et al. 1972). Therefore, it is not surprising that birds exposed to red light exhibit increased circulating testosterone levels and testicular weights relative to those exposed to ultraviolet, blue, green, and infrared wavelengths (Osol et al. 1984). Osol et al. (1984) found that white light stimulated increases in circulating testosterone and testes weights of cockerels relative to those exposed ultraviolet, blue, green, and infrared wavelengths. The stimulatory effects of white light probably result from the fact that white light includes red light wavelengths. The authors also found that green light stimulated circulating testosterone levels and growth but did not affect testicle weight. This observation is inconsistent since green light contains much shorter wavelengths than red light and was generally thought to be non-stimulatory (Bissonnette 1932).

1.7 TESTOSTERONE IN POULTRY SPECIES

1.7.1 TESTOSTERONE PRODUCTION

Avian reproductive activity is controlled by the brain in response to physical and psychological external stimuli (Sturkie, 1986). The information derived from these stimuli modifies the release of gonadotropin-releasing hormone (Gn-RH) from the hypothalamus. Gn-RH released from the hypothalamus is transported via the hypophyseal portal circulation to the adenohypophysis. At the adenohypophysis, the Gn-RH regulates production and secretion of luteinizing hormone (LH) and follicle-stimulating hormone (FSH). Luteinizing hormone stimulates testosterone production (Maung and Follett 1977) through differentiation and maturation of gonadal Leydig cells into steroid secreting cells (Brown et al. 1975). Increased levels of circulating LH initially stimulate testosterone secretion, followed by a period of refractoriness due to Leydig cell desensitization. Cigorraga et al. (1980) illustrated this desensitization process *in vitro* with rat testes. In the male domestic fowl, it appears that FSH is specifically bound to testicular tissue (Ishii and Adachi 1977) and stimulates growth, differentiation, and spermatogenic activity of the seminiferous tubules. The degree of FSH binding is controlled by testosterone acting synergistically with FSH (Tsutsui and Ishii 1980). Indirect evidence suggests that LH action depends on similar specific binding to Leydig and interstitial cells (Maung and Follett 1977). The androgenic hormones produced by Leydig cells are involved in a negative feedback control affecting the release

of Gn-RH (Wilson and Follett 1974).

As in mammalian species, the primary sites of steroidogenesis in birds are the interstitial Leydig cells in the male testes and the theca/granulosa cells of the developing preovulatory follicle in the female ovary (Harvey et al. 1986, Sturkie 1986). Testosterone production by embryos is highest in the adrenal glands while after hatching, testosterone production is higher in the testes and ovaries than in the adrenals (Tanabe et al. 1979).

1.7.2 AGE RELATED TESTOSTERONE PRODUCTION PATTERNS

Variable age related testosterone production patterns exist in poultry species. During embryonic life the adrenal glands are more important than the gonads for testosterone production and secretion (Tanabe et al. 1979). However, this situation changes quickly after hatching when the gonads become most important. Plasma testosterone levels in male chickens remain low during early embryonic life (<100 pg/ml) but increase to fairly high levels by one day post-hatching (293 pg/ml). From 1-42 days of age, plasma testosterone levels fluctuated with peaks on days 1 (293 pg/ml), 14 (305 pg/ml), and 35 (772 pg/ml). The plasma testosterone level determined for the mature cockerel (150 days) was 3.2 ng/ml indicating a drastic increase over levels at 6 weeks of age. Desanto et al. (1983) found a similar pattern existed with plasma testosterone levels increasing from day 1 to 56, stabilizing until day 112, and increasing again by day 168. Unfortunately these authors did not

measure plasma hormone levels between days 1 and 56 which is the relevant time period for broiler production. Driot et al. (1979) found somewhat contradictory results, reporting plasma testosterone levels consistently low (.32 ng/ml) from 2-11 weeks, after which levels rose rapidly until 23 weeks where they fluctuated around a mean value of 2.5 ng/ml. Williams and de Reviers (1981) found similar results and values when measuring plasma androstenedione levels in cockerels of comparable age. Knight (1983) found that plasma testosterone levels did not increase from 8-12 weeks but were significantly higher at 16 weeks of age. Sterling et al. (1984) found that plasma androgens did not increase from 3-16 weeks of age but then rose rapidly.

1.7.3 TESTOSTERONE METABOLISM IN BIRDS

Testosterone is metabolized in several locations throughout the avian body. Experiments conducted *in vitro* have indicated that testosterone is metabolized in chicken epididymal tissue to androstenedione (AND), 5α- and 5ß-dihydrotestosterone (DHT), 5α-androstan-3α, 17ß-diol (5α-3α diol) and 5ß-androstan-3ß, 17ß-diol (5ß-3ß diol) (Lofts and Massa 1980). The same metabolites have been found to occur in chicken comb tissue *in vitro* (Gloyna and Wilson 1969). In quail, the cloacal gland has been found to metabolize testosterone to AND, 5α- and 5ß-DHT, 5α- and 5ß-3α diol (Massa et al. 1980). In the quail cloacal gland AND was found to be the major product of testosterone metabolism (Balthazart et al. 1979). However, the AND production

was decreased with long term exposure to stimulatory photoperiods with preferential conversion of testosterone to 5α-DHT (Massa et al. 1980). Lofts and Massa (1980), used these findings to postulate that AND is probably the most important androgen in the development of male secondary sex organs while 5α-DHT is more involved with maintenance of these organs after development. Testosterone is also metabolized in the central nervous system (CNS) of birds producing small amounts of 5α-DHT and larger amounts of 5ß-reduction and 17ß-oxidation products (Massa et al. 1977). Early studies were carried out with starlings but similar 5ß-reduction has been shown to occur in the maturing cockerel (Massa and Sharp 1981). The 5ß-reduction pathway is believed to act as a major route of testosterone inactivation while AND and 5α-reduced metabolites are believed to inhibit LH secretion (Massa 1982). Estrogens such as oestradiol have also been shown to result from androgen metabolism in the CNS. Considerable evidence exists indicating that the avian comb is a site of testosterone metabolism and that a correlation exists between comb weight and plasma testosterone (Balthazart et al. 1979, Guichard and Reyss-Brion 1982). Nakamura and Tanabe (1973) found that AND, 5α-DHT, and testosterone were equally active in inducing comb growth. Comb weights are also increased by testosterone propionate (TP) (Peebles et al. 1987). From this information, there is little doubt that the comb is a site of testosterone metabolism in domestic fowl. The uropygial gland has also been found to be involved in conversion of testosterone and AND to 5α-reduced metabolites

(Gloyna and Wilson 1969).

1.7.4 EFFECTS OF TESTOSTERONE AND IT'S METABOLITES IN BIRDS

Testosterone is known to have significant effects in chickens even as early as the embryonic stage (Puche and Romano 1968). Testosterone acts directly on chick embryo frontal bones to cause increased alkaline phosphatase activity *in vitro*, resulting in increased osteoid (bone) tissue (Puche and Romano 1968). Similarly, Tanabe et al. (1979), found testosterone levels in plasma, gonads, and adrenals to be relatively high in the later embryonic stages when primary growth of frontal bones occurs. Testosterone has been implicated in bone development of older birds as well. Hester et al. (1983) suggested that high testosterone levels in growing turkeys may cause premature closure of long bones resulting in shorter bones and reduced leg abnormalities. This hypothesis may be supported by Pierson et al. (1981) who reported castrated turkeys, which lack testosterone, had a higher incidence of leg abnormalities. Similar results have been reported for White Leghorn cockerels (Johnson and Rendano 1984).

In rats, testosterone has been found to stimulate growth of isolated muscle cells *in vitro* while oestradiol, pregnanediol, dihydrotestosterone, and androstenedione were found to have no significant influence (Powers and Florini 1975). Limited work has been done to elucidate the effects of testosterone and certain metabolites on muscle deposition in chickens.

Estrogens which are produced from testosterone breakdown in the avian CNS (Massa 1982), cause excessive fat deposition *in vitro* in breast and leg muscle (Lorenz 1943) and also in the abdomen (Lorenz 1944) of male chickens. Increased weight gains have been reported for oestrogen treated birds, however, this is primarily due to excessive fat deposition. Oestrogens have also been found to reduce feed efficiency in chickens (Warden et al. 1958). Testosterone has been found to increase moisture content of breast and leg muscles in growing tom turkeys (Ranaweera and Wise 1982). Increased moisture content indicates a higher proportion of muscle tissue as adipose tissue contains very little water. Supporting evidence has been found in turkeys where 19-nor-testosterone (19-NT), 5α-DHT, and testosterone (T) implants resulted in increased growth rate and feed efficiency while reducing abdominal fat (Fennell and Scanes 1987). The order of effectiveness for the three compounds was reported to be 19-NT>5α-DHT>=T. An androstenedione (AND) metabolite, 19-oxo-androstenedione, was found to only weakly stimulate body weight gain in female White Leghorn chicks (Johnston et al. 1980). However, due to its lack of other oestrogenic effects such as excessive fat deposition, 19-oxo-androstenedione may be a useful growth promotant in poultry.

Experiments with quail indicate that testosterone and many of it's derivatives are effective inhibitors of gonadotropin (LH and FSH) secretion (Davies et al. 1980). It was found that implantation of testosterone and six of

it's metabolites reduced plasma LH. In order of potency, testosterone, 5α-dihydrotestosterone, androstenedione, 5α-androstan-3,17-dione, 5α-androstan-3α,17ß-diol, 5α-androstan-3α-ol-17-one and 5α-androstan-3ß-ol-17-one reduced plasma LH levels. The 5ß-metabolites were not effective in reducing plasma LH levels which is in accordance with Massa (1982) who hypothesized that the 5ß-reduction pathway was a method of testosterone inactivation. Testosterone is involved in the development of secondary sexual characteristics of avian species including comb growth, plumage and bill colour, vocalizations and behaviour (Sturkie 1986). Testosterone, 5α-DHT, and AND have been shown to increase comb growth in chickens with equal effectiveness (Nakamura and Tanabe 1973). Supporting evidence for the stimulatory role of testosterone in comb growth is given by Guichard and Reyss-Brion (1982). Testosterone propionate, a derivative of testosterone, has also been shown to increase comb growth in male chickens (Peebles et al. 1987). Therefore, comb growth has been conclusively associated with androgen levels in growing chickens.

1.8 PHOTOPERIOD EFFECTS ON TESTOSTERONE PRODUCTION IN BIRDS

Photoperiod manipulation exerts strong effects on gonadal growth, androgen production, and development of sexual characteristics in birds. Sexual maturity is stimulated upon exposure to long photoperiod in Japanese quail (Follett and Farner 1966), chickens (Sharp 1974), and tree sparrows (Wilson and Follett 1974). On the other hand, transfer of most photoperiodic

species from long to short daylengths results in reduced testes size and activity, regression of androgen-dependent accessory organs and reduced plasma gonadotropin levels (Wilson and Follett 1977).

Stimulation of sexual maturity appears to be caused by increased secretion of hypothalamic gonadotropin-releasing hormone (Gn-RH) due to changes in hypothalamic sensitivity to negative feedback of steroid hormones (Davies et al. 1976, Jallageas et al. 1976, Wilson and Follett 1977) and also due to direct stimulating effects of long photoperiod (Sharp et al. 1974, Gibson et al. 1975). Therefore, it appears that long photoperiod directly and indirectly stimulates release of Gn-RH which causes increased secretion of both luteinizing hormone (LH) and follicle-stimulating hormone (FSH). Close association between plasma luteinizing hormone levels and testosterone (Tanabe et al. 1979) indicates LH stimulation of Leydig cell development and the secretion of androgen hormones, thus giving a positive relationship between long photoperiod and testosterone secretion. Therefore, exposing birds previously accustomed to short photoperiod, to long photoperiod will result in increased production of testosterone. However, it has been shown that testosterone not only plays a large part in the inhibition of pituitary gonadotropin secretion (Wilson and Follett 1974, Davies et al. 1976, Davies and Bicknell 1976; Mattocks et al. 1976, Wilson et al. 1983), but may also be involved in the inhibition of receptors near the basal fundibular nucleus of the hypothalamus (Cusick and Wilson 1972), thus resulting in a photo-refractory phase. Long

photoperiods have been shown to reduce hypothalamic sensitivity to androgen inhibition (Wilson and Follett 1977, Jallageas et al. 1974). This may explain how sustained exposure to long daylengths can maintain LH secretion, testicular maturation, and expression of sex-related behaviour. Another possible explanation for maintenance of gonadal weight is preferential metabolism of testosterone to inactive metabolites, via a beta-reductive system (Harvey et al. 1986). Sturkie (1986) suggests both hypothalamic desensitization and preferential testosterone metabolism are involved in the elimination of photo-refractoriness seen in non-seasonal breeders such as chickens.

The regression of sexual characteristics seen when birds are moved from long to short photoperiod (Wilson and Follett 1977) is a reversal of the photo-stimulatory process outlined above. Robinson et al. (1988) observed that broiler chickens exposed to decreasing photoperiod exhibited reduced plasma androstenedione levels. As androstenedione is a metabolite of testosterone, reduced androstenedione in blood may indicate reduced testosterone production. Past investigation dealing with photoperiod effects on testosterone production has been inconclusive indicating that more research in this area is required.

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2

GROWTH, BODY COMPOSITION AND PLASMA ANDROGEN CONCENTRATIONS OF MALE BROILER CHICKENS SUBJECTED TO DIFFERENT REGIMENS OF PHOTOPERIOD AND LIGHT INTENSITY

2.1 INTRODUCTION

Modern broiler chickens are capable of rapid and efficient growth in terms of feed utilization, but concomitantly they exhibit a high incidence of metabolic and skeletal problems. One approach to control such problems is through feed restriction, imposed by either quantitative or qualitative methods, beginning at a young age. Robinson et al. (1991) showed a reduction in skeletal disease resulting from either qualitative (diet dilution) or quantitative (limited daily and skip-a-day) feed restriction. Although early growth rate (prior to 2 wk) is reduced, skeletal development continues, and thus the bird is physiologically more capable of sustaining the stress of rapid growth for which broiler chickens have come to be known.

Photoperiod manipulation has been investigated as a method of reducing the incidence of metabolic and skeletal disease. Traditional photoperiod programs have attempted to maximize growth through promoting continuous 24 h light (L): 0 h dark (D) or near continuous (23L:1D) feed access. Improvements have been noted with short (1L:2D, 1L:3D) periods of darkness including reduced leg abnormalities (Simmons 1982, Robbins et al. 1984, Wilson et al. 1984, Renden et al. 1991) and improved livability (Buckland et al. 1971, Ononiwu et al. 1979). However, growth and feed conversion remain unaffected (Buckland et al. 1976) or exhibit slight improvement (Malone et al. 1980).

More recently, Classen and coworkers (Classen et al. 1988, 1991,

Classen and Riddell 1989) investigated increasing photoperiod programs for broiler chickens. When compared with near continuous day length, gradual or abrupt increases in day length resulted in improvements in metabolic and skeletal disease but performance characteristics remained equal or only slightly improved. While improving bird health, increasing day length may result in excessive body fat deposition (Newcombe et al. 1991). Classen and Riddell (1989) suggested that any potential health benefit associated with increasing photoperiod may result from reduced early growth rate, increased activity, increased androgen hormone production, changes in metabolism, or combinations of these. The reduction in early (prior to 2 wk) growth rate observed under conditions of reduced day length, as seen among birds exposed to increasing photoperiod, is very similar to the results of early feed restriction (Pokniak and Cornejo 1982, Pokniak et al. 1984, Robinson et al. 1991). It is likely that the improvements in bird health observed under increasing photoperiod are at least partially due to a mild feed restriction effect of reduced day length. Classen and Riddell (1990), concluded that improved bird health under increasing photoperiod was primarily due to reduced early growth and to a lesser extent due to the lighting program itself. Increased bird activity has been implicated previously in reducing the incidence of skeletal disease (Simmons 1982, Wilson et al. 1984).

Involvement of androgen hormones in reducing the incidence of skeletal disease has been reported for juvenile turkeys (Pierson et al. 1981, Hester et

al. 1983). Although androgen hormone levels were not determined, observation of increased comb size among birds exposed to increasing photoperiod led Classen and Riddell (1989) to suggest involvement of androgen hormones in reducing the incidence of skeletal disease in broiler chickens. Charles et al. (1989) showed that increasing photoperiod stimulates broiler testes and comb development similar to the increased comb size noted by Classen and Riddell (1989). Although Charles et al. (1989) did not detect an elevation of plasma androstenedione concentration under increasing photoperiod, a different steroid such as testosterone may have been affected. Hester et al. (1983) compared a high-intensity, step-up (increasing photoperiod) (HISU) and a low-intensity, step-down (LISD) program in turkeys. The HISU program was found to reduce the incidence of skeletal disease while stimulating higher plasma androgen levels and increased testes weights. However, a comparison of increasing and decreasing photoperiod under low-intensity light failed to give similar results and Hester et al. (1985) concluded that light intensity was partially responsible for the effects of the HISU program.

Past investigations of light intensity effects on broiler chickens have given inconsistent results. High-intensity light may have no effect (Newberry et al. 1986) or a significant positive effect (Newberry et al. 1988) upon the incidence of leg disorders. Similarly, high-intensity light may reduce mortality (Newberry et al. 1988) or have no effect (Deaton et al. 1988).

The objectives of this study were to determine the effects of increasing

versus constant photoperiod in combination with high- versus low-intensity light on broiler chicken growth rate, feed efficiency, carcass composition, organ weights, shank length, plasma androgen concentrations, and the incidence of metabolic and skeletal disease.

2.2 MATERIALS AND METHODS

A total of 960 day-old male Hubbard broiler chicks were obtained from a commercial hatchery[1] for use in two trials and were grown to 8 wk of age. Within each treatment chicks were wing-banded, weighed, and randomly assigned to one of four floor pens (120 birds per pen) each measuring 3.4 m^2 and having straw litter. Room temperature was 32 C on Day 1, reduced gradually to 21 C on Day 28, and maintained to Day 56.

Two levels of light intensity (low versus high) and two photoperiod programs (constant versus increasing) (Table 2.2) (Figure 2.1) were compared simultaneously. The four treatment groups were: low-intensity light (5 lx) and constant photoperiod (LC), low-intensity light and increasing photoperiod (LI), high-intensity light (150 lx) and constant photoperiod (HC); and high-intensity light and increasing photoperiod (HI).

Birds were allowed *ad libitum* access to feed and water from 0 to 8 wk with a typical commercial four-diet program being used. The four diets used

[1]Co-op Hatchery, Edmonton, AL, T5C 1R9, Canada.

(Table 2.1) were: 23% CP, 3,200 kcal ME/kg broiler starter (0 to 21 days of age); 20% CP, 3,220 kcal ME/kg broiler grower (21 to 30 days of age); 18% CP, 3,245 kcal ME/kg roaster grower (30 to 42 days of age); and 16% CP, 3,325 kcal ME/kg roaster finisher (42 to 56 days of age). Incandescent light was provided in two rooms at 5 lx and in the other two rooms at 150 lx. Average light intensity was determined weekly based upon measurements in the centre and four corners of each room at bird height using a light intensity meter.[2] The experimental protocol was approved by the University of Alberta Animal Policy and Welfare Committee.

Weekly individual body weights and pen average feed intakes were measured and feed efficiency was calculated. Birds that failed to gain weight in 2 consecutive wks were defined as culls and were killed via cervical dislocation. All mortality and culls were subjected to post-mortem examination to determine the cause of death or illness.

At 3 wk of age, 40 birds from each pen were weighed and blood sampled (3 mL) via brachial venipuncture for plasma androgen quantification, and measured for right shank length. These same parameters were again measured on the same birds at 5 and 7 wk of age. Blood samples were collected into heparinized vacutainers and then centrifuged at 1,400 X *g* for 15 min to separate plasma.

Duplicate aliquots of plasma for each bird at each age were analyzed via

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[2]Gossen, Panlux Electronic 2, Erlangen, Germany.

radioimmunoassay (RIA) procedures for androstenedione and testosterone content. Birds missing one or more samples (due to death loss or sample contamination) were excluded from the data set. Total plasma testosterone concentration was determined in a solid phase assay[3] involving no extraction procedure. Parallelism was determined by measuring the testosterone in different volumes of a sample of pooled broiler plasma. The concentration of testosterone was 45.9 ± 4.0, 87.0 ± 8.5, and 202.3 ± 20.7 pg/mL respectively for 100, 200, and 400 µL of pooled plasma. The interassay and intraassay coefficients of variation were 10.7 and 3.2%, respectively and the sensitivity of the assay was 26 pg/mL (as measured by two standard deviations subtracted from mean maximum binding of eight assays). The cross-reactivity of the antiserum (reported by the manufacturer) was 20.0% with 19-nortestosterone, 16.0% with 11-ketotestosterone, 3.4% with 5α-dihydrotestosterone, 2.0% with 19-hydroxyandrostenedione, 1.7% with methyltestosterone, 1.2% with 11β-hydroxytestosterone, and less than 1% with each of eight other steroids.

Androstenedione concentration was determined in an aqueous phase assay, in which plasma recovery was found to be 83%. Plasma samples were extracted by adding 3 mL of hexane and vortexing for 5 min. The samples were then frozen using a liquid nitrogen bath and the liquid portion (solvent) was decanted and dried down under vacuum leaving the steroid to be

[3]Diagnostic Products Corporation, Los Angeles, CA 90045.

measured dried within the glass tube. The major cross-reactions of the androstenedione antisera[4] have been reported (Cook et al. 1982). The interassay and intraassay coefficients of variation were 9.2 and 5.7%, respectively and the sensitivity of the assay was 1 pg/mL (as measured by two standard deviations subtracted from mean maximum binding of five assays).

At 8 wk of age, 25 birds per pen were selected from among the 40 blood sampled birds per pen. The birds were fasted for 24 h, prior to being killed by cervical dislocation, and then weighed. Weights of carcass, heart, liver, testes, comb, and abdominal fat pad (including fat adhering to the gizzard and proventriculus) were recorded. These organs were returned to the individual carcasses for chemical analysis of moisture content, total protein, total lipid, and total ash. For a detailed procedure description see Pawlina (1991). Briefly, feathered carcasses were autoclaved for 8 h and homogenized with an industrial blender. Subsamples were taken, weighed, freeze-dried for 6 days, and weighed again. Total dry matter, total protein, total lipid, and total ash were analyzed using standard procedures (Association of Official Analytical Chemists 1980).

Data were analyzed by multi-way analysis of variance to determine main effects using SAS® software for personal computers (Joyner et al. 1985). Identified sources of variation were: trials (t=2), light intensity (i=2), photoperiod

[4]N. C. Rawlings, Western College of Veterinary Medicine, University of Saskatchewan, Saskatoon, SK, S7N 0W0, Canada.

(p=2), light intensity by photoperiod, and trial by light intensity by photoperiod. Individual bird variation was included in the error statement for testing main effects. A literature search relating to similar research indicated that individual birds are often used as the experimental units (Hocking 1988, Pinchasov and Jensen 1989, Ballay et al. 1992). Main effects were constant versus increasing photoperiod and high versus low-intensity light. Student's *t* test was used for separating least squares means for individual treatment effects only when main effect interactions occurred. In all analyses significance was assessed at $p<.05$.

2.3 RESULTS

When compared with constant photoperiod, birds exposed to increasing photoperiod were 10.0% smaller at 3 wk but not different at 6 and 8 wk of age (Table 2.3). A significant interaction of photoperiod and light intensity was seen for 3 wk body weight (Figure 2.2) and the 3 wk ratio of shank length to body weight (Figure 2.3) but for no other parameters. Birds exposed to high-intensity light were smaller (2.2, 3.5, and 3.1%, respectively) at 3, 6, and 8 wk of age relative to birds exposed to low-intensity light (Table 2.3). Increasing photoperiod resulted in improved feed efficiency to 6 wk of age (4.6% lower than constant photoperiod) but high-intensity light was found to reduce 3 to 6 wk feed efficiency (4.7%) relative to low-intensity light (Table 2.3).

Photoperiod and light intensity effects were observed for body weights of

birds measured for shank length (Table 2.4). Birds under increasing photoperiod were smaller (8.3%) and had shorter shank length (2.5%) at 3 wk of age relative to birds under constant photoperiod. However, the ratio of shank length to body weight was increased among birds under increasing photoperiod (6.2%). Similarly, body weight and shank length at 5 wk of age were smaller (2.5 and 1.6%, respectively) among birds under increasing photoperiod relative to those under constant photoperiod. The ratio of shank length to body weight at 5 wk of age was unaffected by photoperiod. Photoperiod had no effect upon 7-wk body weight, shank length, or ratio of shank length to body weight. High-intensity light resulted in reduced body weight (1.8, 3.4, and 3.6%) and shank length (1.0, 1.3, and 1.0%) at 3, 5, and 7 wk of age, respectively, and increased ratio of shank length to body weight at 5 and 7 wk of age (2.2 and 2.8%, respectively) relative to birds exposed to low-intensity light.

Although photoperiod had no effect upon 8-wk body composition (Table 2.5), high-intensity light was found to increase carcass protein (1.0%) and reduce carcass fat (10.3%) relative to low-intensity light. Birds exposed to low-intensity light were on average 90 g heavier and contained 52 g more fat relative to those exposed to high-intensity light. Photoperiod program had no effect upon abdominal fat pad size (Table 2.5) but high-intensity light resulted in reduced abdominal fat pad size (14.4%) relative to low-intensity light. Increasing photoperiod resulted in increased testes size (25.4%) at 8 wk of age

relative to constant photoperiod but light intensity treatment had no effect upon testes size. Heart, liver, and comb size at 8 wk of age were unaffected by photoperiod or light intensity treatment (Table 2.5).

Birds raised under increasing photoperiod exhibited elevated levels of plasma androstenedione and testosterone (22.6 and 31.2%, respectively) relative to birds reared under constant photoperiod at 7 wk of age (Table 2.3). Light intensity treatment had no effect upon plasma androgen levels at 3, 5, or 7 wk of age.

Increasing photoperiod treatment resulted in reduced mortality to 8 wk of age (31.6%) (Table 2.3) relative to constant photoperiod but light intensity treatment had no effect upon mortality for this period. Incidence of cull birds was not affected by photoperiod or light intensity treatments.

2.4 DISCUSSION

The results of this research suggest that a lighting program beginning with an extended dark period and gradually increasing the day length results in reduced early growth rate, improved feed efficiency, compensatory growth, and improved bird livability when compared with birds exposed to a near continuous constant photoperiod program. Similar results have been reported by Classen and Riddell (1989) and Classen et al. (1991). The reduction in early growth rate in the present research is due primarily to limited access to feed during dark hours acting as a mild form of quantitative feed restriction. The qualifier

"mild" is used here because 3 wk body weight was depressed by only 10%. The growth depression effect disappeared completely by 6 wk of age, thus indicating the existence of compensatory growth (defined as the rate of growth exceeding that normally observed in the same breed of chicken at the same age; Yu et al. 1990). In the present research, compensatory growth accompanied by reduced feed intake resulted in improved feed efficiency among birds exposed to the increasing photoperiod program. Conditions of more severe feed restriction have also resulted in compensatory growth and improved feed efficiency in chickens (Plavnik and Hurwitz 1985, 1988, 1991). However, broiler chickens are often unable to compensate for severe early feed restriction, resulting in reduced 6 wk and later body weight even though feed efficiency may be improved or remain unchanged (Pokniak et al. 1984, Pinchasov and Jensen 1989, Yu et al. 1990, Robinson et al. 1991). A significant photoperiod by light intensity interaction was observed for 3-wk body weight. This interaction is due primarily to the weight depression effect of high-intensity light on birds exposed to constant photoperiod.

The weight depression effect of high-intensity light observed at 3, 5, and 7 wk of age in the present research is likely due to increased bird activity levels relative to birds exposed to low-intensity light. Bird activity levels were not measured in the present research, however, intermittent lighting programs (Simmons 1982, Wilson et al. 1984) and high-intensity light (Newberry et al. 1988) have been shown to increase bird activity . Increased bird activity would

increase energy expenditure, and without increased feed intake, reduce overall growth. This statement is supported by the fact that no significant increase in feed intake to 8 wk of age was noted in the present research. Increased 3 to 6 wk feed to gain ratio in the present research under high-intensity light resulted from reduced growth rate observed without a similar reduction in feed intake. The adverse effects of high-intensity light observed in the present research agree with earlier findings (Barott and Pringle 1951, Cherry and Barwick 1962, Skoglund and Palmer 1962) but not with more recent results (Deaton et al. 1981, 1988, Newberry et al. 1986, 1988). Without measured activity levels in the present research it is difficult to explain the inconsistent light intensity effects upon the growth parameters measured. Also, it is difficult to assess the relevance of 30-yr-old literature when birds have changed so much genetically. Although no consistent interactions were observed in the present research, light intensity and photoperiod may act together and adversely affect growth parameters.

Shank lengths in the present research were expressed as a ratio of shank length to body weight to eliminate the effects of differing body weights among birds measured for shank length. During the period of reduced feed intake (extended dark period), bone development continues and protein and fat deposition are reduced (Yu et al. 1990), thus explaining the increased ratio of shank length to body weight observed among birds exposed to increasing photoperiod at 3 wk of age. Similar results were not observed at 5 and 7 wk of

age because, during the period following feed restriction, tissue deposition is more rapid in relation to bone development. Data has been published concerning the effects of photoperiod on bone development in turkeys (Hester et al. 1983, 1985, 1986). Hester et al. (1983, 1986) compared the effects of a high-intensity, step-up (HISU) program and low-intensity, step-down (LISD) program. The HISU program was found to reduce both the length of the tarsometatarsal bone and the incidence of leg abnormalities. However, similar results were not observed when comparing a step-up with a step-down program both at low-intensity light (Hester et al. 1985). These inconsistent results led to the conclusion that light intensity may influence bone development and thus leg abnormalities in turkeys. Contradictory results by Siopes et al. (1983) found that high-intensity light resulted in increased testes size but had no effect on leg abnormalities in male turkeys. In the present research, high-intensity light did not affect the incidence of leg abnormalities but resulted in birds with greater relative shank length compared with birds exposed to low-intensity light. It remains unclear by what mode of action light intensity affects bone development. However, it has been suggested that light stimulation of androgen production may result in premature closure of the epiphyseal plates of the long bones and thus cause stunting (Hester et al. 1983). Hormonal involvement in the process of bone development is indicated by the increase in leg abnormalities noted following caponization of turkey males and subsequent reduction in leg abnormalities following dietary inclusion of 17α-

methyltestosterone (Pierson et al. 1981). The present research showed an increase in plasma androgens among birds exposed to increasing photoperiod but a corresponding significant reduction in leg abnormalities was not seen. As androgen levels were not affected until after most leg problems develop, androgens may not be as important for bone development as previously suggested. The increase in plasma androgen concentration, noted in the present research, for birds exposed to increasing photoperiod has not been seen previously in male broilers but similar results have been documented in female broilers (Robinson et al. 1988) and juvenile turkeys (Hester et al. 1983). The photoperiod-induced increase in plasma androgen concentration may indicate stimulation of sexual maturity in broiler chickens as early as 7 wk of age. The stimulation in testes size at 8 wk of age noted among birds exposed to increasing photoperiod in the present research supports the idea that the onset of sexual maturity has been stimulated. Hester et al. (1983) noted a similar stimulation of testicular growth among juvenile male turkeys exposed to increasing photoperiod.

Abdominal fat pad and total body fat at 8 wk of age were reduced among birds exposed to high-intensity light probably due to stimulation of bird activity (Newberry et al. 1988) requiring more energy and muscular development. Therefore, the corresponding increase in carcass protein was not surprising. In contrast, Deaton et al. (1988) noted no difference in carcass composition for light intensities of 2 or 52 lx. Perhaps 52 lx was not sufficient to stimulate bird

activity to the degree resulting from 150 lx in the present research. Acting as a mild form of feed restriction, increasing photoperiod did not affect abdominal fat and total body fat. Pokniak and Cornejo (1982) and Pokniak et al. (1984) reported no change in 8-wk body fat among birds restricted to 45% of control intake from 8 to 23 days of age. More severe feed restriction programs have resulted in reduced body fat (Plavnik and Hurwitz 1985, 1991).

The present research supports the statement that increasing photoperiod stimulates sexual maturity as early as 7 wk of age whereas light intensity has no effect. High-intensity light reduces body fat while photoperiod has no effect. Further, increasing photoperiod improves feed efficiency and bird livability, probably due to the early feed restriction affect of reduced day length.

TABLE 2.1 Broiler feed formulation and calculated analysis

Ingredients and analysis	Broiler			
	Starter 0 to 21 days	Grower 21 to 30 days	Finisher 31 to 42 days	Roaster finisher 43 to 56 days
	(g/kg)			
Wheat	626.35	699.65	732.45	501.90
Soybean meal (46.5% CP)	150.00	87.50	55.00	37.50
Canola meal	50.00	50.00	50.00	50.00
Meat meal	70.00	72.50	72.50	72.50
Feather meal	25.00	20.00	20.00	20.00
Tallow	40.00	39.00	39.00	39.00
Corn	5.00	.00	.00	250.00
Dicalcium phosphate	.00	.50	1.00	.00
Calcium carbonate	2.00	2.00	2.00	.00
Salt	1.00	1.00	1.00	1.40
Methionine (98%)	.70	.50	.30	.50
Lysine (98%)	.90	1.10	.50	.70
Monensin 132	.75	.75	.75	.00
Coxistac (6%)	.00	.00	.00	1.00
Stafac 22	.50	.50	.50	.50
Mold curb	.50	.00	.00	.00
Broiler premix[1]	25.00	25.00	25.00	25.00
TOTAL	1000.00	1000.00	1000.00	1000.00
Calculated analysis				
Protein, %	22.75	20.36	19.14	17.86
ME, kcal/kg feed	2976	3026	3056	3135
Calcium, %	.77	.79	.79	.68
Phosphorus, %	.67	.67	.67	.63
Lysine, %	1.10	.96	.82	.77
Methionine, %	.36	.31	.27	.30
Cystine, %	.42	.37	.35	.33
Methionine + cystine, %	.78	.68	.63	.63

[1]Contains per kilogram of diet: vitamin A, 10,500 IU, vitamin D, 3,000 IU, vitamin E, 15 IU, vitamin K, 2.2 mg, niacin, 40.3 mg, pantothenic acid, 10.0 mg, pyridoxine, 1.5 mg, thiamine, 1.5 mg, choline, 351 mg, riboflavin, 5.4 mg, biotin, .8 mg, folic acid, .6 mg, vitamin B_{12}, .009 mg, Cu, 125 mg, Mn, 75 mg, Zn, 65 mg, Fe, .3 mg, Se, .3 mg, and I, .7 mg.

TABLE 2.2 Experimental photoperiod programs

Age	Treatment group		Clock schedule (Lights on or off)			
	CON[1]	INC[2]	CON[1]		INC[2]	
			ON	OFF	ON	OFF
(days)	— (h light:h dark) —		(h)			
0 to 3	23L:1D	23L:1D	0100	2400	0100	2400
3 to 7	23L:1D	18L:6D	0100	2400	0300	2100
7 to 14	23L:1D	6L:18D	0100	2400	0900	1500
14 to 21	23L:1D	10L:14D	0100	2400	0700	1700
21 to 28	23L:1D	14L:10D	0100	2400	0500	1900
28 to 32	23L:1D	18L:6D	0100	2400	0300	2100
32 to 35	23L:1D	21L:3D	0100	2400	0200	2300
35 to 56	23L:1D	23L:1D	0100	2400	0100	2400

[1]CON = Constant 23 h light:1 h dark photoperiod program

[2]INC = Increasing photoperiod program

TABLE 2.3 Broiler body weight, feed conversion efficiency, plasma androgen concentrations, mortality, and culls

	Photoperiod[1]					Light intensity[2]				
Variable	CON	n	INC	n	SEM[3]	HI	n	LOW	n	SEM
Mean body weight, kg										
0 wk	.043	480	.043	480	.000	.043	480	.043	480	.000
3 wk	.728[a]	478	.655[b]	471	.003	.683[y]	471	.699[z]	478	.003
6 wk	2.179	422	2.195	443	.010	2.148[y]	416	2.227[z]	449	.010
8 wk	3.129	391	3.173	421	.016	3.101[y]	388	3.201[z]	424	.016
Feed conversion efficiency, kg feed:kg gain										
0 to 3 wk	1.529[a]	4	1.454[b]	4	.022	1.522	4	1.481	4	.030
3 to 6 wk	2.124[a]	4	1.977[b]	4	.047	2.182[z]	4	2.081[y]	4	.036
0 to 6 wk	1.934[a]	4	1.846[b]	4	.041	1.938	4	1.857	4	.043
6 to 8 wk	2.962	4	2.891	4	.068	2.993	4	2.905	4	.061
0 to 8 wk	2.253	4	2.211	4	.072	2.242	4	2.208	4	.067
Plasma androstenedione concentration, ng/mL										
3 wk	.363	134	.352	143	.024	.352	131	.362	146	.024
5 wk	.552	134	.570	143	.040	.595	131	.528	146	.040
7 wk	.493[b]	134	.637[a]	143	.037	.586	131	.544	146	.037
Plasma testosterone concentration, ng/mL										
3 wk	.055	134	.055	143	.004	.054	131	.056	146	.004
5 wk	.132	134	.129	143	.011	.135	131	.126	146	.011
7 wk	.187[b]	134	.272[a]	143	.018	.240	131	.220	146	.018
Mortality and culls from 0 to 6 wk of age, incidence										
Mortality	7.00	4	3.75	4	1.20	5.25	4	5.50	4	1.20
Culls	2.75	4	2.75	4	1.04	3.50	4	2.00	4	1.04
Total	9.75	4	6.50	4	2.22	8.75	4	7.50	4	2.22
Mortality and culls from 0 to 8 wk of age, incidence										
Mortality	14.25[a]	4	9.75[b]	4	.84	12.25	4	11.75	4	.84
Culls	5.25	4	4.25	4	1.01	5.25	4	4.25	4	1.01
Total	19.50	4	14.00	4	1.73	5.25	4	4.25	4	1.73

[a,b]Photoperiod means within a row with no common superscripts differ significantly ($P < .05$).

[z,y]Light intensity means within a row with no common superscripts differ significantly ($P < .05$).

[1]CON = constant 23 h light:1 h dark from Day 0 to 56; INC = increasing photoperiod program.

[2]HI = high (150 lx) intensity light; LOW = low (5 lx) intensity light

[3]SEM's for unequal n are rounded.

TABLE 2.4 Broiler body weight, shank length and ratio of shank length to body weight

Variable	Photoperiod[1]					Light intensity[2]				
	CON	n	INC	n	SEM[3]	HI	n	LOW	n	SEM
Broiler body weight, kg										
3 wk	.843[a]	135	.773[b]	147	.005	.801[y]	135	.816[x]	147	.005
5 wk	1.845[a]	135	1.799[b]	147	.010	1.791[y]	135	1.853[x]	147	.010
7 wk	2.862	135	2.866	147	.018	2.812[y]	135	2.916[x]	147	.018
Broiler shank length, cm										
3 wk	7.54[a]	135	7.35[b]	147	.23	7.42[y]	135	7.48[x]	147	.23
5 wk	10.06[a]	135	9.90[b]	147	.28	9.92[y]	135	10.05[x]	147	.28
7 wk	12.19	135	12.19	135	.37	12.12[y]	135	12.23[x]	147	.37
Ratio of shank length to body weight, cm/kg										
3 wk	8.98[b]	135	9.57[a]	147	.004	9.32	135	9.23	147	.004
5 wk	5.47	135	5.52	147	.004	5.56[x]	135	5.44[y]	147	.003
7 wk	4.28	135	4.27	147	.003	4.34[x]	135	4.22[y]	147	.003

[a,b]Photoperiod means within a row with no common superscripts differ significantly ($P < .05$).

[x,y]Light Intensity means within a row with no common superscripts differ significantly ($P < .05$).

[1]CON = constant 23 h light:1 h dark from Day 0 to 56; INC = increasing photoperiod program.

[2]Hi = high (150 lx) intensity light; LOW = low (5 lx) intensity light.

[3]SEM's for unequal n are rounded.

TABLE 2.5 Broiler body composition on a dry matter and whole carcass basis and organ weights expressed in grams and as a percentage of body weight (n = 100)

Variable	Photoperiod[1]			Light intensity[2]		
	CON	INC	SEM[3]	HI	LOW	SEM
Body composition, % DM						
Ash	7.5	7.5	.1	7.6	7.4	.1
Fat	41.6	42.4	.3	40.9[y]	43.1[x]	.3
Protein	51.6	50.9	.3	52.3[x]	50.2[y]	.3
Body composition, kg						
DM	1.135	1.145	.008	1.110	1.170	.008
Ash	.085	.085	.001	.084	.086	.001
Fat	.475	.488	.006	.455[y]	.507[x]	.006
Protein	.584	.581	.003	.579[y]	.585[x]	.003
BW	3.031	3.041	.016	2.991[y]	3.081[x]	.016
Organ weights, g						
Heart	19.47	19.86	.28	19.47	19.87	.28
Liver	52.10	53.84	.77	52.32	53.61	.77
Comb	3.26	3.58	.13	2.39	3.54	.13
Testes	1.54[b]	2.07[a]	.16	1.75	1.86	.16
Fat Pad	68.76	72.49	1.77	65.15[y]	76.09[x]	1.77
Organ weights, % BW						
Heart	.637	.650	.009	.647	.640	.009
Liver	1.707	1.759	.024	.740	.726	.024
Comb	.106	.117	.004	.109	.114	.004
Testes	.050[b]	.068[a]	.005	.058	.060	.005
Fat Pad	2.238	2.362	.054	2.162[y]	2.438[x]	.054

[a,b]Photoperiod means within a row with no common superscripts differ significantly (P <.05).

[x,y]Light intensity means within a row with no common superscripts differ significantly (P <.05).

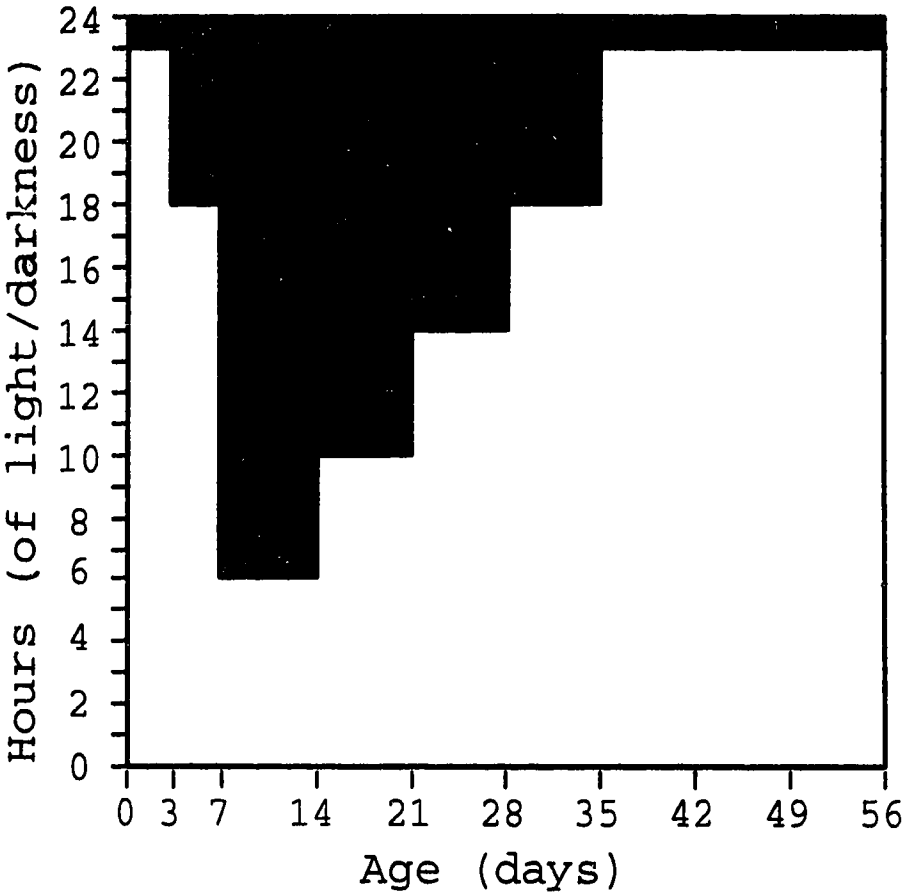
[1]CON = constant 23 h light:1 h dark from Day 0 to 56; INC = increasing photoperiod program.

[2]HI = high (150 lx) intensity light; LOW = low (5 lx) intensity light.

[3]SEM's for unequal n are rounded.

FIGURE 2.1

INCREASING PHOTOPERIOD PROGRAM



Light hours indicated as white.
Dark hours indicated as black.

FIGURE 2.2

Interaction Of Photoperiod And Light Intensity On 3 Week Body Weight

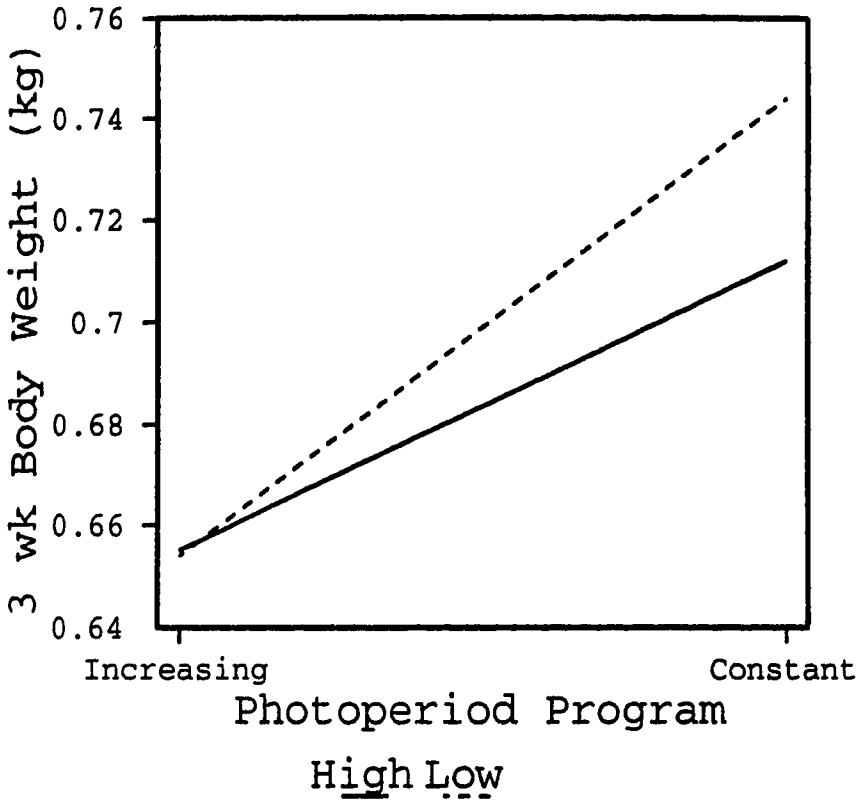
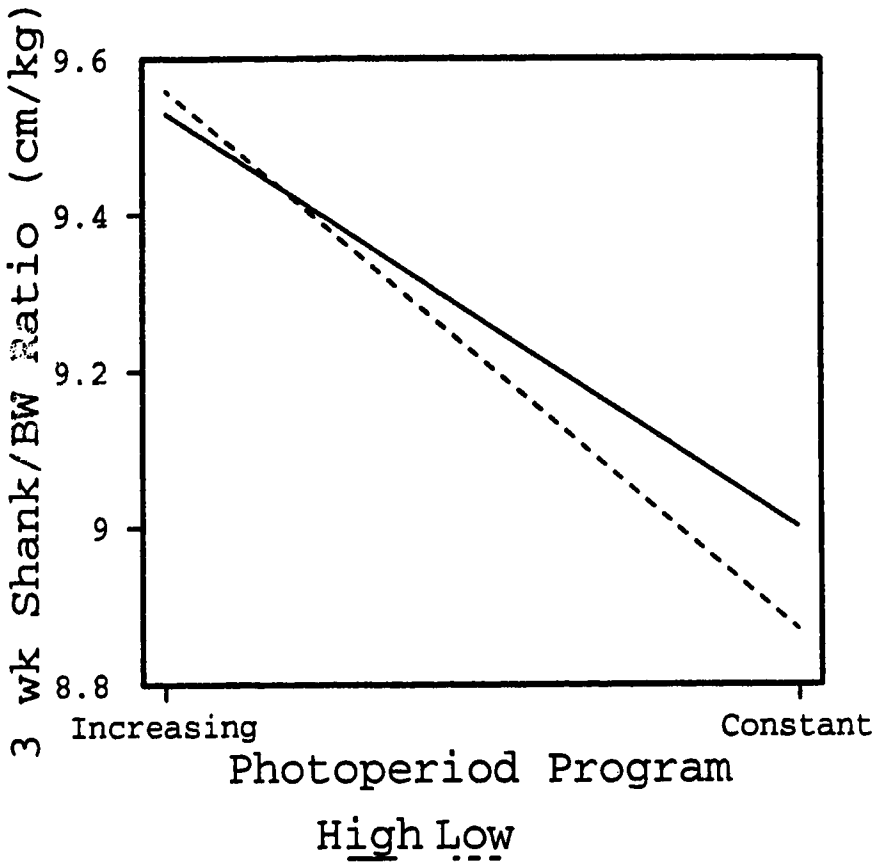

0.76
0.74
0.72
0.7
0.68
0.66
0.64
3 wk Body Weight (kg)
Increasing
Constant
Photoperiod Program
High Low

FIGURE 2.3

Interaction Of Photoperiod And Light Intensity On 3 Week Ratio Of Shank Length To Body Weight


3 wk Shank/BW Ratio (cm/kg)
9.6
9.4
9.2
9
8.8
Increasing
Constant
Photoperiod Program
High Low

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3

RELATIONSHIPS AMONG LIVE BODY WEIGHT, BODY COMPOSITION, ORGAN WEIGHTS, PLASMA ANDROGEN CONCENTRATION, AND SHANK LENGTH IN MALE BROILER CHICKENS

3.1 INTRODUCTION

Past investigations have established strong positive correlations in broiler chickens between live BW and percent abdominal fat (Becker et al. 1979, 1981, Leenstra et al. 1986), abdominal fat pad weight (Pym and Thompson 1980), carcass fat content (Becker et al. 1979, 1981, Pym and Solvyns 1979, Chambers and Fortin 1984, Leenstra et al. 1986), as well as carcass content of dry matter, protein, and ash (Chambers and Fortin 1984, Wolynetz and Sibbald 1986a,b, 1987). Positive relationships existing in broiler chickens between body water and body protein have been demonstrated (Pym and Solvyns 1979, Chambers and Fortin 1984). Negative relationships have been demonstrated between body water and body fat content (Pym and Solvyns 1979; Chambers and Fortin 1984). Similar relationships have been published for large-bodied turkey lines (Bacon et al. 1986, 1989). Live BW has also been found to be highly correlated with shank length in broilers (Verma et al. 1979, Mishra et al. 1984, Singh et al. 1985, Abasiekong 1986). In turkeys, studies have shown strong correlations between live BW and abdominal fat deposition (Bacon et al. 1986, 1989). A moderate positive correlation has been found in Japanese quail between live BW and testes size and between testes size and abdominal fat content (Marks 1990). However, this relationship has not been investigated in broiler chickens to date. Such a relationship, if shown to exist, may indicate involvement of androgen hormones in fat deposition and growth.

Research studies have shown strong evidence of relationships between

avian testicular development, androgen hormone production, growth, carcass composition, comb development and bone growth. Production of testosterone is highest in the adrenal glands prior to hatch but is highest in the gonads post hatch (Tanabe et al. 1979). In turkeys, testosterone administration via subcutaneous implants has resulted in increased growth rate (Fennel and Scanes 1987, 1992) and increased water content of leg and breast muscle, which is indicative of increased muscle tissue (Ranaweera and Wise 1982). Estrogens produced from testosterone aromatization in the central nervous system (Massa 1982), cause fat deposition in leg and breast muscle of cockerels (Lorenz 1943) and in the abdomen of male turkeys (Lorenz 1944). Comb development is stimulated via oral administration of methyl testosterone (Snedecor and Camyre 1966), administration of a silastic testosterone implant (Nakamura and Tanabe 1973, Gause and Marsh 1987) or either of two metabolites, androstenedione and 5α-dihydrotestosterone (Nakamura and Tanabe 1973). A subcutaneous silastic implant containing testosterone propionate, a derivative of testosterone, has also been shown to stimulate comb growth in male chickens (Peebles et al. 1987). Puche and Romano (1968) found that testosterone acts directly on chick embryo frontal bones to stimulate alkaline phosphatase activity *in vitro*, resulting in increased osteoid tissue. It has been suggested that androgen hormone involvement in bone growth may influence the incidence of skeletal disease in turkeys (Hester et al. 1985).

Involvement of androgen hormones in reducing the incidence of skeletal

disease has been suggested for juvenile turkeys (Pierson et al. 1981, Hester et al. 1983). Increased levels of androgen hormones may result in premature closure of the epiphyseal growth plates and shortening of the long bones in the leg and thus reduce leg abnormalities (Hester et al. 1983). Pines and Hurwitz (1991) have suggested that gonadal hormones play a key role in closure of the epiphyseal growth plates. However, correlation coefficients are not available relating plasma androgen concentrations with rates of bone growth.

The objectives of this study were to estimate correlation coefficients and further define relationships existing among live BW, growth, body composition, selected organ weights, plasma androgen hormones, and shank length for male broiler chickens subjected to different regimens of photoperiod and light intensity.

3.2 MATERIALS AND METHODS

A total of 960 day-old male Hubbard broiler chicks were obtained from a commercial hatchery[1] for use in two trials and were grown to 8 wk of age, as outlined previously in chapter 2. Incandescent light provided two levels of light intensity (low versus high) and two photoperiod programs (constant versus increasing) simultaneously. Constant photoperiod consisted of 23 h light and 1 h dark while daily light increased 4 h per week from 6 h on day 7 to 23 h on

[1]Co-op Hatchery, Edmonton, AL, T5C 1R9, Canada.

day 35 for the increasing photoperiod program. The four treatment groups were: low-intensity light (5 lx) and constant photoperiod (LC), low-intensity light and increasing photoperiod (LI), high-intensity light (150 lx) and constant photoperiod (HC); and high-intensity light and increasing photoperiod (HI).

Weekly individual BW and average feed intakes per pen were measured and feed efficiency was calculated. At 3, 5, and 7 wk of age, the same 40 birds from each pen were weighed, measured for right shank length, and 3 mL of blood was collected via brachial venipuncture into heparinized vacutainers. Blood samples were later analyzed for plasma androgen (androstenedione and testosterone) quantification. At 8 wk of age, 25 birds per pen were selected from among the 40 blood sampled birds per pen. The birds were fasted for 24 h, killed by cervical dislocation, and then individually weighed. Weights of carcass, testes, comb, and abdominal fat pad (including fat adhering to the gizzard and proventriculus) were recorded. These organs were returned to the individual carcasses for chemical analysis of moisture content, total protein, total lipid, and total ash. For a detailed procedure description see Pawlina (1991).

Data were analyzed to obtain Pearson correlation coefficients using SAS® software for personal computers (Joyner et al. 1985). Correlation coefficients were determined for the complete data set accross all treatments. In all analyses significance was assessed at $p<.05$.

3.3 RESULTS AND DISCUSSION

Whole body DM (BDDM) content was positively correlated (r = .18) with live BW at 8 wk of age (BW8) (Table 3.1). BW8 showed a positive correlation with carcass fat content on a whole body basis (BDFAT) (r = .37) and also when carcass fat content was expressed on a DM basis (DMFAT) (r = .44). Pym and Solvyns (1979) reported a correlation of .31 between 9 wk BW and carcass fat content expressed on a wet basis. Chambers and Fortin (1984) reported a correlation of .53 between live BW at 61 days of age and carcass fat content expressed as a percentage of dry matter. Variation from previously reported values may be due to differences in age and BW of birds being measured. Broilers become proportionally fatter as they grow (Leeson and Summers, 1980). Therefore, a positive correlation should exist between BW and body fat and also between BW and body DM since fat contains little water. It is not surprising that significant positive correlations were observed between BDDM and BW gain from 5 to 7 (GAIN57) and 0 to 7 (GAIN07) wk of age (.23 and .18, respectively) (Table 3.1). Similarly, significant positive correlations were noted between BDFAT and GAIN57 and GAIN07 (.32 and .26, respectively). Positive correlations were also found between DMFAT and GAIN57 and GAIN07 (.34 and .28, respectively). The stronger correlation between body fat content and GAIN57 relative to GAIN07 may indicate that proportionally more of the weight gained from 5 to 7 wk of age was fat.

Negative correlations were found to exist between BW8 and carcass protein

content (Table 3.1) expressed on a whole body basis (BDPROT) (-.35) or DM basis (DMPROT) (-.36). Negative correlations were found between BDPROT and GAIN57 and GAIN07 (-.21 and -.14, respectively), also between DMPROT and GAIN57 and GAIN07 (-.26 and -.25, respectively). The negative relationship between body protein and BW gain further supports the concept of additional fat deposition at the expense of protein in growing birds. A strong negative correlation, observed in the present research between DMFAT and DMPROT (-.87), supports the idea that as BW increases the proportion of fat increases primarily at the expense of protein resulting in a negative correlation between BW and body protein content. The value -.87 is only slightly lower than that of -.94 reported by Wolynetz and Sibbald (1986a) but is larger than that of -.70 reported by Chambers and Fortin (1984). However, the value reported by Chambers and Fortin (1984) was expressed on a wet basis.

Negative correlations were found between BW8 and carcass ash content (Table 3.1) expressed on whole body (BDASH) (-.34) or DM basis (DMASH) (-.37). Negative correlations were observed between BDASH and GAIN57 and GAIN07 (-.31 and -.29, respectively), also between DMASH and GAIN57 and GAIN07 (-.36 and -.33, respectively). This negative relationship indicates that as the bird grows proportionally less bone growth occurs relative to other body components. A correlation value of -.75 was found in the present research between DMFAT and DMASH supporting the idea that as the bird grows, the proportion of fat increases, partially at the expense of ash resulting in a negative correlation between BW and

body ash content. Chambers and Fortin (1984) reported a lower value of -.46 when percentages were expressed on a wet basis while Wolynetz and Sibbald (1986a) reported a similar value of -.79 when based on proportions of DM.

Abdominal fat pad (FATPAD8) and comb (COMB8) weights at 8 wk of age were positively correlated with BW8 (.45 and .24, respectively) while 8 wk testes weight (TESTES8) exhibited no significant correlation with BW8 (Table 3.1). GAIN57 and GAIN07 also failed to exhibit any significant correlation with TESTES8. The greater variability observed for testes weights relative to comb and fat pad weights may explain the lack of correlation between BW8 and TESTES8. Published data correlating BW to testes weight in broilers are very limited. However, Marks (1990) reported positive correlation values ranging from .37 to .47 between 21 and 42 days of age for Japanese quail. The onset of sexual maturity occurring at a younger age in Japanese quail relative to broiler chickens may explain the observed differences.

COMB8 exhibited positive correlation with GAIN57 and GAIN07 (.20 and .22, respectively). A positive relationship between COMB8 and BDWT8, GAIN57, and GAIN07 appears to indicate involvement of androgen hormones in growth of the bird. However, the lack of correlation between BW8, GAIN57, and GAIN07 with TESTES8 confuses the relationship between BW8 and COMB8 and seemingly contradicts the involvement of androgen hormones in broiler growth. With the testes being the primary source of androgens post-hatch (Tanabe et al. 1979) and the comb being a site of testosterone metabolism (Balthazart et al. 1979), a

positive relationship was expected to exist between the two sites. Such a relationship was found to exist in the present research (r= .40).

FATPAD8 exhibited a positive correlation with GAIN57 and GAIN07 (.26 and .22, respectively), in agreement with the findings of previous researchers. Pym and Thompson (1980) reported a correlation of .46 between fat pad weight and BW for male broilers at 63 days of age. Becker et al. (1981) reported a correlation value of .49 occurring between abdominal fat pad weight and BW for male broilers at 54 days of age. Leenstra et al. (1986) reported a correlation value of .48 between percent abdominal fat and BW for male broilers at 55 days of age.

A positive correlation value of .67 was observed between FATPAD8 and BDDM (Table 3.2). This positive correlation was to be expected since fat contains little water. Becker et al. (1981) reported a negative correlation (-.56) between abdominal fat pad weight and percent carcass moisture representing the reciprocal to a dry matter comparison.

A strong positive correlation resulted between FATPAD8 and BDFAT (.74), and also between FATPAD8 and DMFAT (.72) (Table 3.2), in agreement with the values previously reported. Becker et al. (1979) and Leenstra et al. (1986) reported correlation values of .76 and .88, respectively between percent carcass fat and percent abdominal fat for male broilers at 59 and 55 days of age. Also, Becker et al. (1981) reported a correlation value of .51 between percent carcass fat and percent abdominal fat for male broilers at 55 days of age. These results indicate that fat pad weight expressed in either absolute amount or as a

percentage of BW could be used as a predictor of total carcass fat. A negative correlation was observed between FATPAD8 and BDPROT (-.40) (Table 3.2) with a stronger correlation occurring between FATPAD8 and DMPROT (-.72). The negative correlations noted here further support the inverse relationship reported between fat and protein in the broiler chicken.

Live BW at 3 (BW3), 5 (BW5), and 7 (BW7) wk of age were positively correlated with shank length at the same ages (SHK3, SHK5, and SHK7, respectively) (Table 3.3). The positive correlations observed between BW and shank length in the present research are lower than those reported previously (Singh et al. 1985, Abasiekong 1986) (.69 and .79, respectively). The reasons for these differences are unclear but may be related to the growth restricting effects of reduced daylength in the present research.

Positive correlations were observed between plasma concentrations of androstenedione and testosterone at 3, 5, and 7 wk of age (AND3, AND5, AND7, TEST3, TEST5, and TEST7) (Table 3.4). Correlation values ranged from .76 to .86 with slightly lower values occurring at week 3. The close relationship existing between these two hormones in birds is understandable since androstenedione is both a precursor of testosterone production (Nakamura and Tanabe 1972) and a product of testosterone metabolism (Balthazart et al. 1983). The present research indicates that quantification of androstenedione is preferable due to greater plasma concentrations (650%, 430%, and 247% at 3, 5, and 7 wk of age, respectively) relative to testosterone.

Several expected correlations failed to materialize out of the present research and some of these should be noted (data not shown). No correlation was found between plasma concentration of either testosterone or androstenedione and BW at 3, 5, and 7 wk of age. Similarly, no consistent correlation was found between GAIN57 or GAIN07 and plasma concentration of either hormone at 3, 5, and 7 wk of age. Increasing photoperiod has been shown to increase the size of the testes at 8 wk of age (Charles et al. 1989), perhaps indicating the onset of sexual maturity. However, the above mentioned lack of correlation between plasma androgen concentration and BW does not support the suggestion that endogenous plasma androgens influence growth in immature birds. Contradictory results have also been reported previously for turkeys. Hester et al. (1983) noted a stimulation of testicular growth and plasma androgen concentration in juvenile male turkeys exposed to increasing photoperiod. Fennell and Scanes (1987) reported that testosterone administration via subcutaneous implants increased growth rate of immature large white turkeys. However, Fennell and Scanes (1992) suggest that endogenous testicular androgens have little influence on growth rate of large white turkeys prior to 9 wk of age.

Even though a positive correlation was noted between COMB8 and TESTES8, the present research found no consistent correlation between concentration of either hormone and TESTES8 or COMB8 (data not shown). This lack of correlation may indicate that size of the testes and comb does not necessarily indicate their functionality. These data do not support the suggestion

that larger testes produce a greater amount of androgen, resulting in greater BW gain.

No correlation was found between plasma concentration of either hormone and FATPAD8 (data not shown). Similarly, no correlation resulted between plasma hormone concentration and body fat content (BDFAT or DMFAT). These results agree with those of Rozenboim et al. (1990) who reported no effect of intramuscular injection of testosterone propionate on broiler adiposity. No correlation was found in the current research between plasma androgen concentration and body protein content (BDPROT or DMPROT). Contradictory results have been reported by Ranaweera and Wise (1982) who observed increased muscle moisture content, indicative of increased muscle tissue, in turkeys treated with subcutaneous testosterone implants. Despite the results observed in turkeys, the present research suggests no growth-enhancing benefit resulting from elevated plasma hormone concentrations in immature broiler chickens.

Plasma hormone concentrations exhibited no consistent correlation with shank length at 3, 5, and 7 wk of age (data not shown). It has been reported that testosterone is necessary for normal bone growth in chickens (Johnson and Rendano 1984) and turkeys (Pierson et al. 1981). Therefore, a positive relationship was expected between plasma hormone concentration and bone growth. The above results seemingly contradict the suggested involvement of plasma androgens in reduced leg abnormalities through shortening of the long

bones in turkeys (Pierson et al. 1981, Hester et al. 1983). However, the relationship between shank length, plasma androgen concentration, and the incidence of leg abnormalities in broiler chickens requires further investigation.

TABLE 3.1 Correlation coefficients (probability values below) between body weight and carcass composition traits and selected organ weights at 8 wk of age

Comparisons[1]	
N	195
BW8:BDDM	.18 .0109
BW8:BDFAT	.37 .0001
BW8:BDPROT	-.35 .0001
BW8:BDASH	-.34 .0001
BW8:DMFAT	.44 .0001
BW8:DMPROT	-.36 .0001
BW8:DMASH	-.37 .0001
BW8:TESTES8	.07 NS[2]
BW8:COMB8	.24 .0009
BW8:FATPAD8	.45 .0001

[1]BW8 = 8 wk live body weight; BDDM = 8 wk carcass dry matter content BDFAT, BDPROT, and BDASH = 8 wk carcass content of fat, protein, and ash expressed in absolute amount. DMFAT, DMPROT, and DMASH = carcass content of fat, protein and ash expressed as a percentage of dry mat TESTES8, COMB8, and FATPAD8 - 8 wk testes, comb, and abdominal fat pad weight.

[2]NS = not significant at $p < .05$.

TABLE 3.2 Correlation coefficients (probability values below) between body weight and shank length at 3, 5 and 7 wk of age

Comparisons[1]	
N	195
BW3:SHK3	.50 .0001
BW5:SHK5	.47 .0001
BW7:SHK7	.41 .0001

[1]BW3, BW5, and BW7 = live body weight at 3, 5, and 7 wk of age. SHK3, SHK5, and SHK7 = right shank length at 3, 5, and 7 wk of age.

TABLE 3.3 Correlation coefficients (probability values below) between fat pad weight and carcass composition traits at 8 wk of age

Comparisons[1]	
N	195
FATPAD8:BDDM	.67 .0001
FATPAD8:BDFAT	.74 .0001
FATPAD8:BDPROT	-.40 .0001
FATPAD8:DMFAT	.72 .0001
FATPAD8:DMPROT	-.72 .0001

[1] FATPAD8 = 8 wk abdominal fat pad weight; BDDM = 8 wk carcass dry matter content; BDFAT, BDPROT, and BDASH = 8 wk carcass content of fat, protein, and ash expressed in absolute amount. DMFAT and DMPROT = carcass content of fat and protein expressed as a percentage of dry matter.

TABLE 3.4 Correlation coefficients (probability values below) between plasma concentrations of androstenedione and testosterone at 3, 5 and 7 wk of age

Comparisons[1]	
N	195
AND3:TEST3	.76 .0001
AND5:TEST5	.86 .0001
AND7:TEST7	.86 .0001

[1]AND3, AND5, and AND7 = plasma concentration of androstenedione at 3, 5 and 7 wk of age; TEST 3, TEST5 and TEST7 = plasma concentration of testosterone at 3, 5 and 7 wk of age.

3.4 LITERATURE CITED

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4

CONCENTRATIONS OF CARBON DIOXIDE AND DUST AMONG MALE BROILER CHICKENS SUBJECTED TO DIFFERENT REGIMENS OF PHOTOPERIOD AND LIGHT INTENSITY

4.1 INTRODUCTION

Photoperiod and light intensity have been related to bird activity in past investigations. Simmons (1982) reported increased broiler chicken activity, measured by radar waves, among birds exposed to intermittent light relative to continuous light. Wilson et al. (1984) stated that "birds given intermittent light were much more active when the lights were on" relative to broiler chickens that were provided continuous light which were very docile. Unfortunately, quantitative data on activity levels were not provided to support this statement. Hester et al. (1985) reported increased activity levels among male turkeys exposed to a low intensity step-up lighting program relative to a low intensity step-down lighting program. Hester et al. (1986) reported increased activity levels among male turkeys exposed to a high intensity step-up lighting program relative to a low intensity step-down lighting program. Classen and Riddell (1989) stated that "birds exposed to increasing photoperiod appeared more active" relative to broiler chickens provided continuous light. However, activity was judged subjectively without quantitative data. Past investigations relating light intensity to broiler chicken activity have yielded contradictory results. High-intensity light has been shown to increase broiler chicken activity relative to low-intensity light (Deaton et al. 1976, Newberry et al. 1988). In contrast, Newberry et al. (1986) reported higher activity levels among birds exposed to low versus high-intensity light. However, the authors admit that observer presence may have altered activity responses. Investigations using

male turkeys have shown increased activity associated with high-intensity versus low-intensity light (Siopes et al. 1983, 1984).

CO_2 in the animal environment is produced primarily via the animals' respiration and is influenced by the animals' metabolic activity (Scott et al. 1984). Metabolic and respiration rates increase with animal activity and thus production of CO_2 increases. Similarly, dust particles are dislodged into the air when animals move. Increased activity results in increased numbers of air-borne dust particles (Yoder and Van Wicklen 1988).

The objectives of this study were to determine the effects of increasing versus constant photoperiod in combination with high versus low-intensity light on broiler chicken activity levels. It was thought that measured differences in CO_2 and dust concentrations would indicate variation in activity levels.

4.2 MATERIALS AND METHODS

A total of 960 day-old male Hubbard broiler chicks were obtained from a commercial hatchery[1] for use in two trials and were grown to 8 wk of age. Chicks were wing-banded, weighed, and randomly assigned to one of four floor pens (120 birds per pen) having straw litter. Each sealed room measured 3.4x3.4x2.4 m and contained one 25 cm 2-speed and one 35 cm variable speed exhaust fan (Figure 4.1). Complete mixing of incoming and resident air

[1]Co-op Hatchery, Edmonton, AB, T5C 1R9, Canada.

inlet. Ventilation rates varied with age of bird but did not vary between rooms. Room temperature was 32 C on Day 1, reduced gradually to 21 C on Day 28, and maintained to Day 56.

Incandescent light was provided in two rooms at 5 lx and two other rooms at 150 lx. Two levels of light intensity (low versus high) and two photoperiod programs (constant versus increasing) were compared simultaneously. Constant photoperiod consisted of 23 h light and 1 h dark while daily light increased 4 h per week from 6 h on day 7 to 23 h on day 35 for the increasing photoperiod program. The four treatment groups were: low-intensity light (5 lx) and constant photoperiod (LC), low-intensity light and increasing photoperiod (LI), high-intensity light (150 lx) and constant photoperiod (HC); and high-intensity light and increasing photoperiod (HI).

Birds were allowed *ad libitum* access to feed and water from 0 to 8 wk with a typical commercial four-diet program being used. The four diets used were: 23% CP, 3200 kcal ME/kg broiler starter (0 to 21 days of age); 20% CP, 3220 kcal ME/kg broiler grower (21 to 30 days of age); 18% CP, 3245 kcal ME/kg roaster grower (30 to 42 days of age); 16% CP, 3325 kcal ME/kg roaster finisher (42 to 56 days of age).

The environment of each room was monitored remotely over a 24-h period on days 24, 31, 38, and 45. Parameters measured included CO_2 and dust concentrations. A plenum located directly above the rooms provided incoming fresh air. A room located within the plenum provided space for all

incoming fresh air. A room located within the plenum provided space for all equipment required for air analysis and data recording. Incoming and exhaust air from each room were measured for CO_2 concentration while dust measurements were obtained by drawing air from a position 1 m above the floor in the centre of each room. CO_2 concentrations were measured once per hour for each room and the plenum using a non-dispersive infrared analyzer[2] zeroed with nitrogen gas and spanned with a certified gas of 1510 ppm CO_2 gas. Air samples were drawn to the analyzer through sample tubes connected to solenoid activated valves controlled by a datalogger. A vacuum pump located downstream from the valves provided air to the analyzer at prescribed rates controlled by flowmeters. An IBM-PC connected to the datalogger recorded the CO_2 concentrations. A particle sizer[3] and counter was used to measure dust concentrations in two categories; <5 microns and >5 microns. Sample tubes from each room and the plenum were connected to a ball valve assembly which was controlled by an I/O board connected to an IBM-PC. Each room and the plenum were sampled for a period of 4 min/h.

Data were analyzed by multi-way analysis of variance using SAS® software for personal computers (Joyner et al. 1985). Identified sources of variation of main effects were trials (t=2), light intensity (i=2), photoperiod (p=2), period of day (x=2) and appropriate interactions. Individual hourly

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[2]Model 870, Beckman Industrial, La Habra, CA.

[3]Climet, Redlands, CA.

Main effects were constant versus increasing photoperiod and high versus low light intensity. In all analyses significance was assessed at $p<.05$.

4.3 RESULTS AND DISCUSSION

CO_2 concentrations at 31, 38 and 45 days of age were reduced by 16 to 23 % during dark hours relative to light hours (Table 4.1). While CO_2 concentrations fluctuated through daylight hours, a distinct decrease occurred during darkness and is illustrated in Figures 4.2, 4.3, and 4.4. The reduction was noted regardless of main effect (constant versus increasing photoperiod or high versus low-intensity light). The reduced CO_2 concentration during dark hours noted in the present research agrees with previous reports of reduced CO_2 production at night (McQuitty et al. 1985, O'Connor et al. 1988). McQuitty et al. (1985) reported CO_2 production in commercial laying barns to be 50 % greater during light periods relative to dark periods. O'Connor et al. (1988), investigating commercial broiler breeder barns, reported 26-28 % reductions in CO_2 production during dark periods relative to light periods. These results support the idea that activity levels among chickens are reduced during periods of darkness (Foshee et al. 1970).

Mean CO_2 concentrations were found to be higher among birds exposed to increasing photoperiod relative to those exposed to constant photoperiod (Table 4.1). Overall mean CO_2 concentrations were increased by 17.5, 10.1, and 10.6 % (at 31, 38, and 45 days of age, respectively) among birds exposed

to increasing photoperiod relative to those exposed to constant photoperiod. It seems likely that the above increase in CO_2 concentration among birds exposed to increasing photoperiod indicates a stimulation of bird activity. Hester et al. (1985, 1986) reported increased activity levels among male turkeys exposed to either low or high-intensity step-up lighting programs. It remains unclear whether or not the increase in bird activity levels are stimulated by increasing photoperiod as suggested previously (Classen and Riddell 1989). Perhaps the reduced incidence of leg abnormalities noted among birds exposed to increasing photoperiod (Classen and Riddell 1989, Classen et al. 1991, Hester et al. 1983, 1986) is related to greater mobility and hence greater activity levels in such birds compared to constant photoperiod birds.

CO_2 concentrations were numerically higher for birds exposed to high versus low-intensity light (Table 4.1). Mean CO_2 concentrations measured over the full 24 h period showed a slight numerical increase among birds exposed to high-intensity light relative to those exposed to low-intensity light. The trend towards higher CO_2 concentrations may indicate a slight stimulation of bird activity in response to high-intensity light. Increased activity levels associated with high-intensity light have been reported (Deaton et al. 1976, Newberry et al. 1986, 1988). Newberry et al. (1986) reported stimulated bird activity in response to high-intensity light but did not observe any reduction in leg disorders. Similarly, results of the present research showed no reduction in leg disorders while increased activity was indicated by elevated dust concentration

among birds exposed to high relative to low-intensity light. In contrast, Newberry et al (1988) reported both increased bird activity and reduced incidence of leg disorders in association with high-intensity light.

Air-borne dust concentrations (particles < 5 microns) at 24, 38, and 45 days of age were significantly reduced by 38 to 66 % during dark hours relative to light hours (Table 4.2). Fluctuating dust concentrations were noted during light hours regardless of main effects (constant versus increasing photoperiod or high versus low-intensity light) (Figures 4.5, 4.6, and 4.7). The reduced concentrations of dust noted during dark hours is in agreement with previous reports (Van Wicklen and Mitchell 1987, Yoder and Van Wicklen 1988). Van Wicklen and Mitchell (1987) reported respirable dust concentrations up to five times greater during light versus dark periods among broiler breeder chickens housed on the floor. Yoder and Van Wicklen (1988) reported respirable dust concentrations to be 1.8 to 2.9 times greater during light periods relative to dark periods in floor-reared broiler chickens. The above results support speculation that higher day-time dust concentrations result from increased bird activity (Van Wicklen and Mitchell 1987). It is interesting to note that in the present research the smallest darkness reduction (38 %) of dust concentration occurred among birds exposed to increasing photoperiod at 24 days of age. A possible explanation for the smaller reduction may be the fact that reduced daylength (14L:10D) forced birds to eat during dark hours requiring movement to and from feeders and hence, increasing dust concentrations.

Mean overall dust concentrations were slightly increased among birds exposed to high-intensity light (significant at 38 days of age only) (Table 4.2). A high degree of variability in the data set likely contributed to the observed lack of significance. Increased dust concentrations may indicate stimulation of bird activity in response to high-intensity light. Increased dust and CO_2 concentrations observed in the present research, provide evidence supporting the activity stimulating effects of high-intensity light.

Mean overall dust concentrations were increased significantly among birds exposed to increasing photoperiod relative to those exposed to constant photoperiod at 45 days of age (Table 4.2). Similar but not significant results were observed at 24 and 38 days of age. The apparent stimulation of dust concentration resulting from increasing photoperiod likely indicates photoperiod stimulation of bird activity similar to that indicated by increased CO_2 concentration noted above. The present research supports the statement that bird activity can be stimulated via increasing photoperiod or high-intensity light. Further, bird activity is reduced by up to 68 % during periods of darkness.

TABLE 4.1 Mean carbon dioxide concentrations (ppm) at 31, 38, and 45 days of age

Age		Photoperiod[1]				Light intensity[2]			
(days)	Period[3]	CON	n	INC	n	HI	n	LOW	n
31	Light	1104	92	1407	72	1411	82	1401	82
	Dark	883	4	1173	24	1149	14	1107	14
	Overall	1090[b]	96	1398[a]	96	1400	96	1388	96
38	Light	1314	92	1447	92	1421	92	1407	92
	Dark	1104	4	1142	4	1157	4	1115	4
	Overall	1303[b]	96	1435[a]	96	1414	96	1393	96
45	Light	1620	92	1768	92	1745	92	1702	92
	Dark	1390	4	1457	4	1414	4	1433	4
	Overall	1587[b]	96	1756[a]	96	1731	96	1691	96

[a,b]Photoperiod means within a row with no common superscripts differ significantly.

[1]CON = constant 23L:1D from day 0 to day 56; INC = increasing photoperiod program.

[2]HI = high (150 lx) intensity light; LOW = low (5 lx) intensity light.

[3]Carbon dioxide concentrations are significantly different ($p < .05$) between light and dark periods for each main effect and age.

TABLE 4.2 Mean dust concentrations (particles/mL) at 24, 38, and 45 days of age (Particle size < 5 microns).

Age		Photoperiod[1]				Light intensity[2]			
(days)	Period[3]	CON	n	INC	n	HI	n	LOW	n
24	Light	48	44	51	28	51	36	47	36
	Dark	23	4	34	20	35	12	35	12
	Overall	47	48	46	48	47	48	45	48
38	Light	96	44	100	44	101	44	96	44
	Dark	46	4	48	4	49	4	47	4
	Overall	95	48	99	48	101[x]	48	95[y]	48
45	Light	88	44	94	44	95	44	91	44
	Dark	39	4	41	4	44	4	37	4
	Overall	86[b]	48	92[a]	48	94	48	90	48

[a,b]Photoperiod means within a row with no common superscripts differ significantly.

[x,y]Light intensity means within a row with no common superscripts differ significantly.

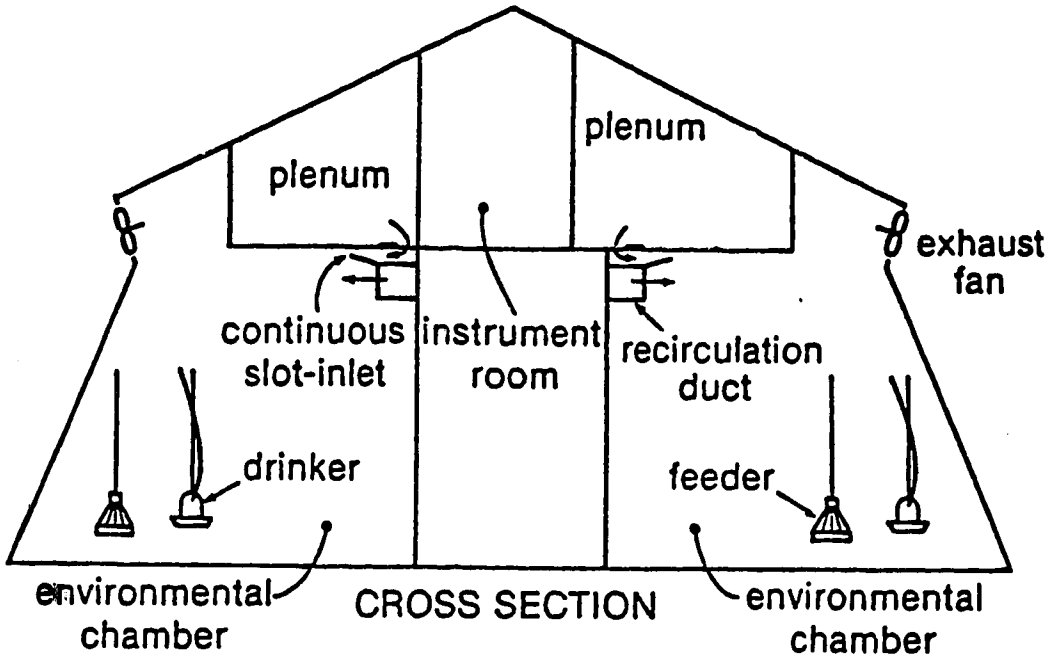
[1]CON = constant 23L:1D from day 0 to day 56; INC = increasing photoperiod program.

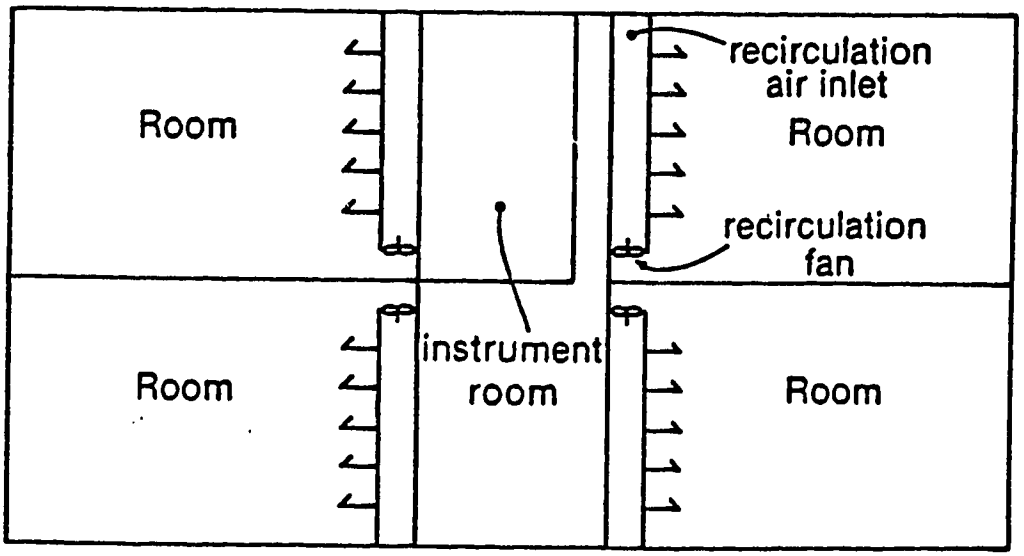
[2]HI = high (150 1x) intensity light; LOW = low (5 1x) intensity light.

[3]Dust concentrations are significantly different ($p < .05$) between light and dark periods for each main effect and age.

FIGURE 4.1

Experimental Facility

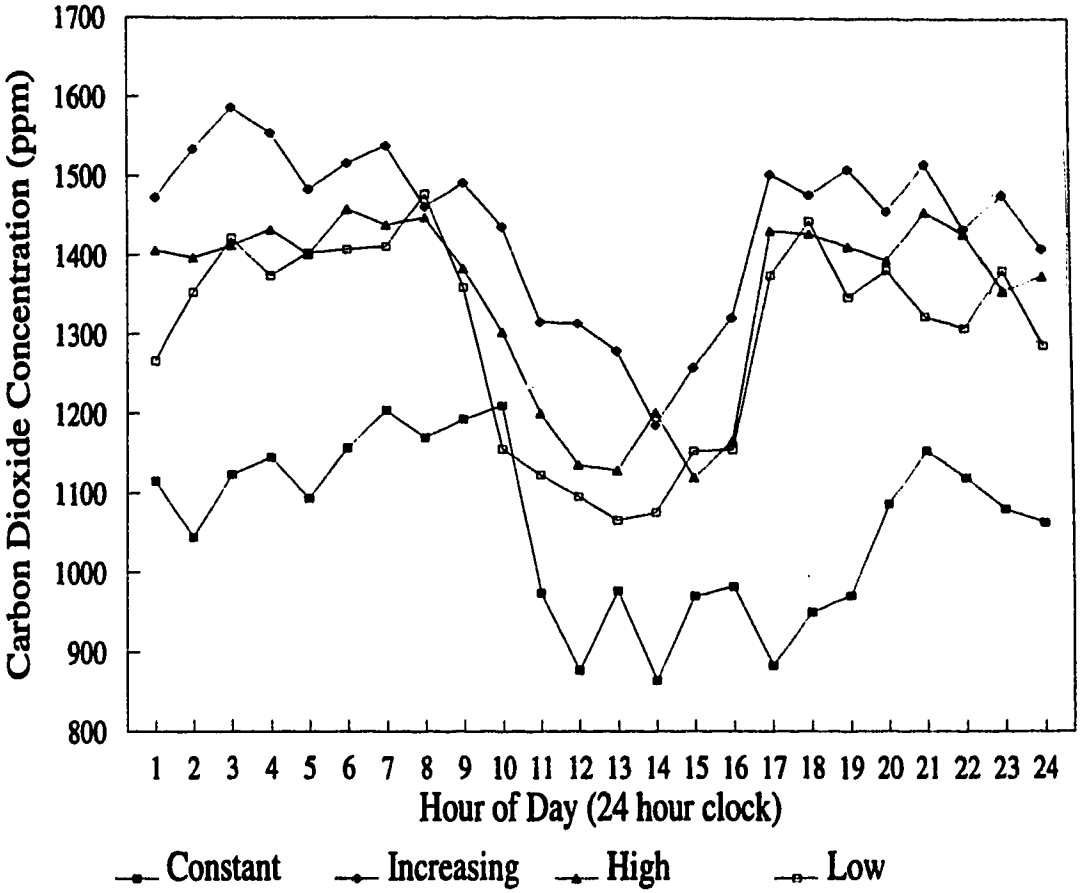

plenum
plenum
exhaust fan
continuous slot-inlet
instrument room
recirculation duct
drinker
feeder
environmental chamber
CROSS SECTION
environmental chamber


Room
recirculation air inlet
Room
recirculation fan
Room
instrument room
Room

PLAN VIEW

FIGURE 4.2

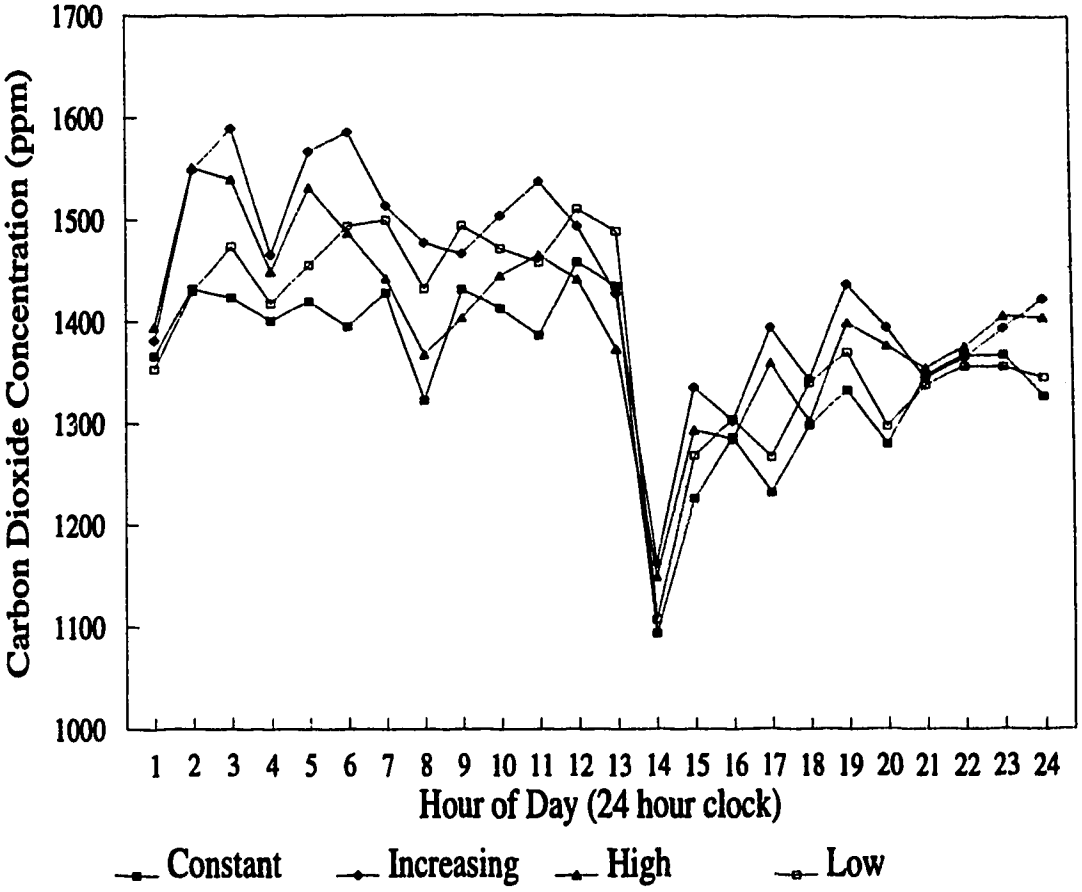
Carbon Dioxide Concentrations (ppm) On Day 31



Constant photoperiod (hour 14 dark).
Increasing photoperiod (hours 11 to 16 dark).

FIGURE 4.3

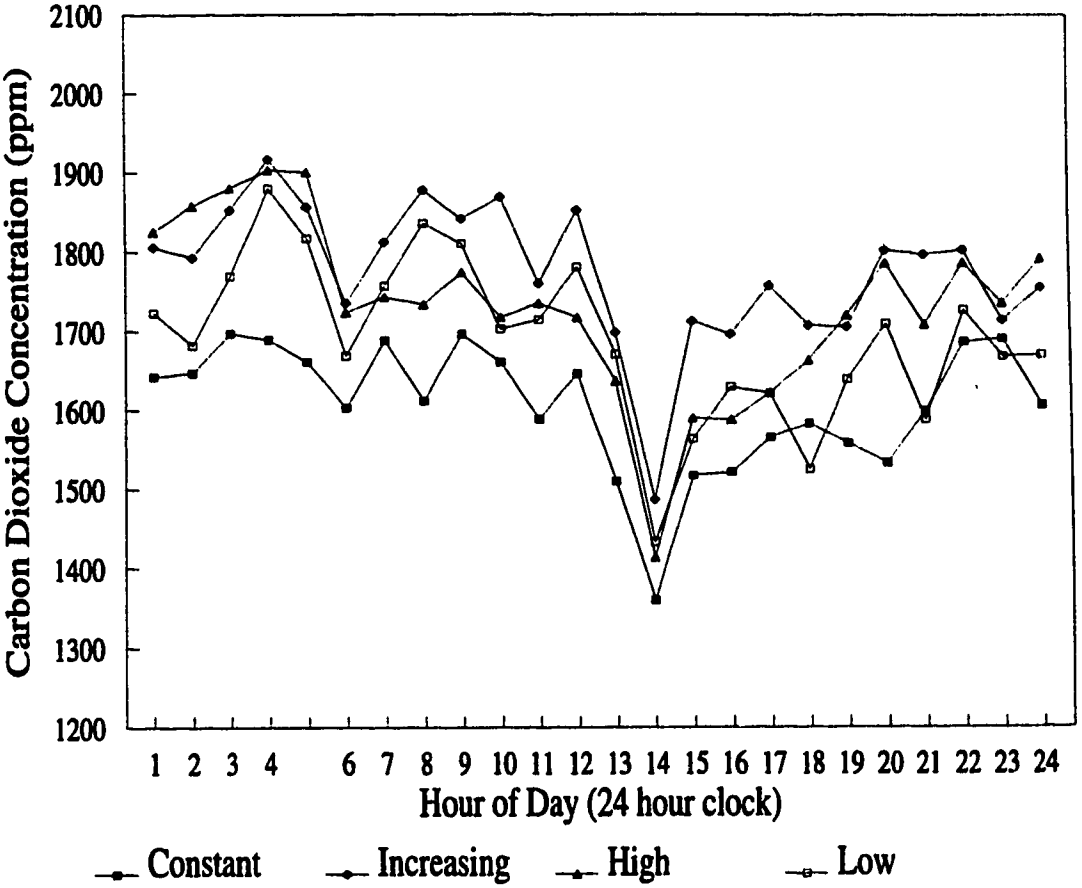
Carbon Dioxide Concentrations (ppm) On Day 38



Constant photoperiod (hour 14 dark).
Increasing photoperiod (hour 14 dark).

FIGURE 4.4

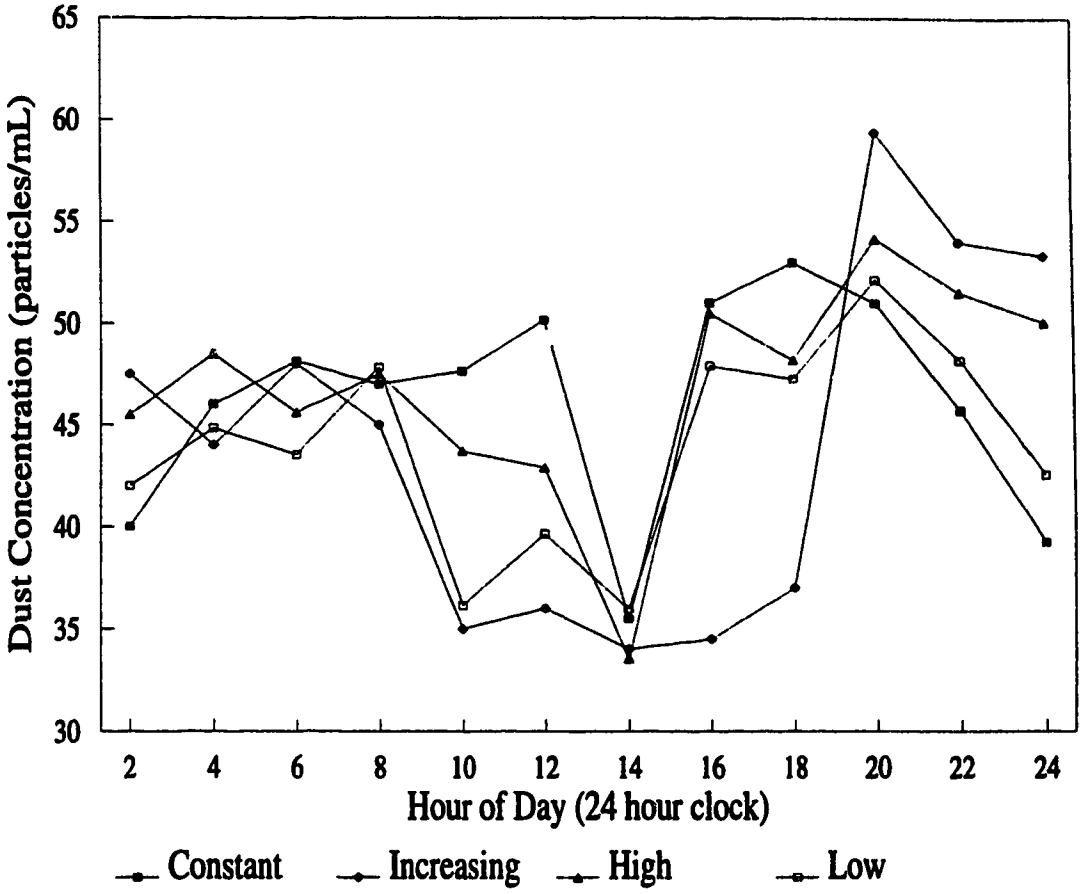
Carbon Dioxide Concentrations (ppm) On Day 45



Constant photoperiod (hour 14 dark).
Increasing photoperiod (hour 14 dark).

FIGURE 4.5

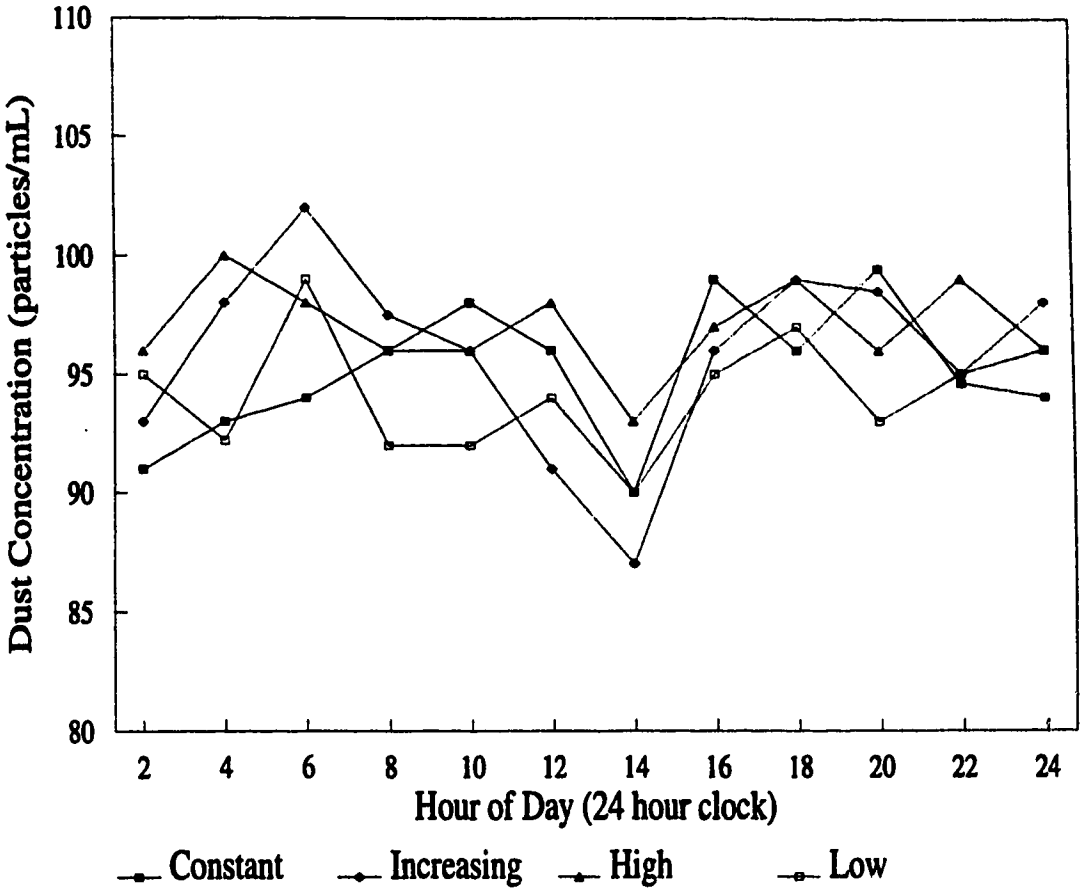
Dust Particle (< 5 microns) Concentrations (particles/mL) On Day 24



Constant photoperiod (hour 14 dark).
Increasing photoperiod (hours 9 to 18 dark).

FIGURE 4.6

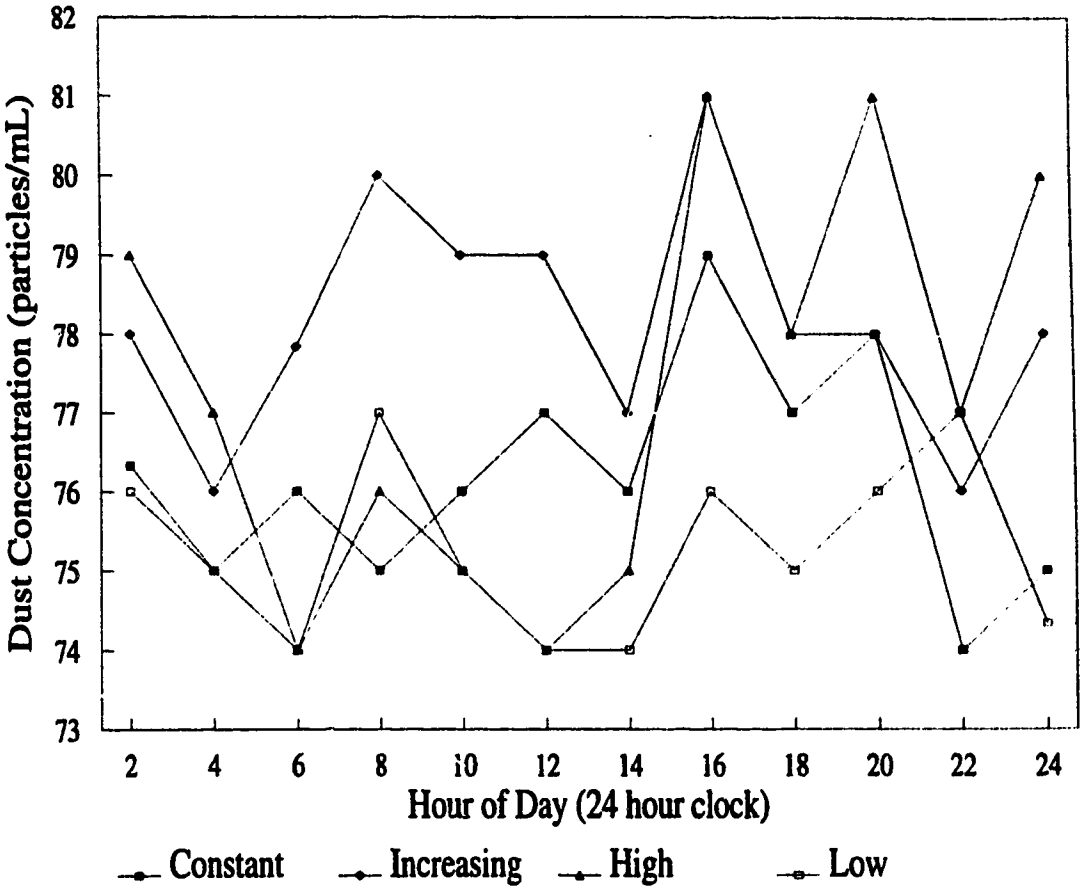
Dust Particle (< 5 microns) Concentrations (particles/mL) On Day 38



Constant photoperiod (hour 14 dark).
Increasing photoperiod (hour 14 dark).

FIGURE 4.7

Dust Particle (< 5 microns) Concentrations (particles/mL) On Day 45



Constant photoperiod (hour 14 dark).
Increasing photoperiod (hour 14 dark).

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GENERAL DISCUSSION

The present research indicates that a lighting program beginning with an extended dark period and gradually increasing day length results in reduced early growth rate, subsequent compensatory growth, improved feed efficiency, improved bird livability, increased bird activity, and stimulated sexual maturity compared with birds exposed to a near continuous constant photoperiod program. High-intensity light results in reduced growth, feed efficiency, body fat, and abdominal fat pad along with increased ratio of shank length to BW relative to birds exposed to low-intensity light.

Limited access to feed during extended dark periods, early in the increasing photoperiod program, acted as a mild form of quantitative feed restriction and resulted in reduced early growth rate. The growth depression effect disappeared completely by 6 wk of age, thus indicating the existence of compensatory growth (defined as the rate of growth exceeding that normally observed in the same breed of chicken at the same age; Yu et al. 1990). Reduced feed intake accompanied by compensatory growth resulted in improved feed efficiency among birds exposed to the increasing photoperiod program. Feed efficiency was improved despite increased activity levels indicated by elevated CO_2 and dust concentrations among birds exposed to increasing photoperiod. The increased activity levels did not increase feed intake and therefore, did not affect feed efficiency significantly. Conditions of more severe feed restriction have also resulted in compensatory growth and improved feed efficiency in chickens (Plavnik and Hurwitz 1985, 1988, 1991).

It has been suggested that although improving bird health, increasing day length may result in excessive body fat deposition (Newcombe et al. 1991). Acting as a mild form of feed restriction, increasing photoperiod in the present research did not affect abdominal fat pad size and total body fat content. Similarly, Pokniak and Cornejo (1982) and Pokniak et al. (1984) reported no change in 8-wk body fat among birds restricted to 45% of control intake from 8 to 23 days of age. More severe feed restriction programs have resulted in reduced body fat (Plavnik and Hurwitz 1985, 1991).

During the period of reduced feed intake and reduced early growth (extended dark period), bone development continued and protein and fat deposition were reduced (Yu et al. 1990), thus explaining the increased ratio of shank length to body weight observed among birds exposed to increasing photoperiod at 3 wk of age. A similar photoperiod treatment effect was not observed at 5 and 7 wk of age because tissue deposition was more rapid in relation to bone development during the period following feed restriction. Negative correlations found in the present research between DMASH and BW8, GAIN57 or GAIN07 indicate that as the bird grows, proportionally less bone growth occurs relative to other body components. This statement was further supported by the strong negative correlation noted in the present research between DMFAT and DMASH. Positive correlations between BW and shank length at 3, 5, and 7 wk of age may at first appear to contradict the above reasoning. However, the degree of correlation decreased (numerically) as the

bird aged, again indicating that bone growth after 3 wk of age occurred at a slower rate than that of the remaining body components.

Reduced bone growth has been associated with increasing photoperiod in the past (Hester et al. 1983, 1986). Hester et al. (1983, 1986), using juvenile turkeys, compared the effects of a high-intensity, step-up (HISU) program (increasing photoperiod) and low-intensity, step-down (LISD) program. The HISU program was found to reduce both the length of the tarsometatarsal bone and the incidence of leg abnormalities. Although bone growth was not measured, reduced incidence of leg abnormalities among broiler chickens exposed to increasing photoperiod has been reported (Classen and Riddell 1989, Classen et al. 1991). Improved bird livability has also been associated with increasing photoperiod (Classen et al. 1991). In the present research, increasing photoperiod had no effect upon the ratio of shank length to BW beyond 3 wk of age or the incidence of leg abnormalities but did improve bird livability to 8 wk of age. Classen and Riddell (1989) suggest that potential health benefits associated with increasing photoperiod may result from reduced early growth rate, increased activity, increased androgen hormone production, changes in metabolism, or combinations of these. Results of the present research support the involvement of reduced early growth rate and/or increased bird activity levels in improved bird livability under conditions of increasing photoperiod. However, it is difficult at this time to state conclusively the relative importance of these two factors. Further, it is not yet clear the importance of

reduced early growth in allowing for increased bird activity.

The photoperiod-induced increase in plasma androgen concentration noted in the present research may indicate stimulation of sexual maturity in broiler chickens as early as 7 wk of age. The stimulation in testes size at 8 wk of age noted among birds exposed to increasing photoperiod in the present research supports the idea that the onset of sexual maturity has begun. Even though both plasma androgen concentration and testes size were stimulated by increasing photoperiod, the present research found no consistent correlation between these two parameters. This lack of correlation may indicate that the size of the testes does not necessarily reflect steroidogenic output *in vivo*. Hester et al. (1983) noted a stimulation of testicular growth and plasma androgen concentration among juvenile male turkeys exposed to increasing photoperiod. Robinson et al. (1988) observed increased plasma androgen concentration in female broiler chickens exposed to increasing photoperiod. Involvement of androgen hormones in growth (Fennell and Scanes, 1987) and bone development (Pierson et al. 1981, Hester et al. 1983) of male turkeys have been reported. Furthermore, it has been reported that testosterone is necessary for normal bone growth in chickens (Johnson and Rendano 1984). The present research did not show any consistent correlation values between plasma androgen concentrations and bird growth or shank length. The present research showed an increase in plasma androgen concentration at 7 wk of age among birds exposed to increasing photoperiod but a corresponding significant

reduction in leg abnormalities was not seen. As androgen levels were not affected until after most leg problems have developed, this indicates androgens may not be as important for bone development as previously suggested. Also, it would seem that light stimulated endogenous androgen production at 7 wk of age has little to do with the compensatory growth from 3 to 6 wk of age noted among birds exposed to increasing photoperiod.

The weight depressing effect of high-intensity light observed at 3, 5, and 7 wk of age in the present research is likely due to increased bird activity levels relative to birds exposed to low-intensity light. Bird activity levels, indicated by CO_2 and dust concentrations, were increased under conditions of high-intensity light. In past investigations, intermittent lighting programs (Simmons 1982; Wilson et al. 1984) and high-intensity light (Newberry et al. 1988) have been shown to increase bird activity . Increased bird activity would increase energy expenditure, and without increased feed intake, reduce overall growth. This statement is supported by the fact that no significant increase in feed intake to 8 wk of age was noted in the present research. Increased feed to gain ratio from 3 to 6 wk in the present research under high-intensity light resulted from reduced growth rate observed without a similar reduction in feed intake. The adverse effects of high-intensity light observed in the present research agree with earlier findings (Barott and Pringle 1951, Cherry and Barwick 1962, Skoglund and Palmer 1962) but not with more recent results (Deaton et al. 1981, 1988, Newberry et al. 1986, 1988). It is difficult to explain the

inconsistent light intensity effects upon the growth parameters measured. Also, it is difficult to assess the relevance of 30-yr-old literature when birds have changed so much genetically. Although no consistent interactions were observed in the present research, light intensity and photoperiod may act together and adversely affect growth parameters.

Inconsistent results found when comparing a step-up with a step-down program in conjunction with high (Hester et al. 1983) and low-intensity light (Hester et al. 1985) led to the conclusion that light intensity may influence bone development and thus leg abnormalities in turkeys. Contradictory results reported by Siopes et al. (1983) found that high-intensity light resulted in increased testes size but had no effect on leg abnormalities in male turkeys. In the present research, high-intensity light did not affect the incidence of leg abnormalities or mortality but resulted in birds with greater relative shank length at 5 and 7 wk of age compared with birds exposed to low-intensity light. It seems likely that increased broiler activity allowed normal bone growth to continue while reducing the deposition of other body components, primarily fat. Stimulated bird activity has been suggested as a reason for improved broiler health (Classen and Riddell 1989). In the present research, broiler activity indicated by CO_2 and dust concentrations was increased under high-intensity light but no associated improvement in bird health was noted. Due to a small sample size it was difficult to show significant differences. It remains unclear by what mode of action light intensity affects bone development but light intensity

appears to have little influence on broiler health.

Abdominal fat pad size and total body fat at 8 wk of age were reduced among birds exposed to high-intensity light probably due to stimulation of bird activity (Newberry et al. 1988) requiring more energy and muscular development. Increased bird activity, indicated by elevated CO_2 and dust concentrations, was noted in the present research among birds exposed to high-intensity light. The positive relationship existing between abdominal fat pad size and carcass fat content was shown via a strong positive correlation existing between these two parameters. The observation of increased carcass protein corresponding to reduced carcass fat was not surprising. The negative relationship existing between these two components is indicated by the strong negative correlation observed between DMFAT and DMPROT. Deaton et al. (1988) noted no difference in carcass composition for light intensities of 2 or 52 lx. However, 52 lx may not be sufficient to stimulate bird activity to the degree resulting from 150 lx in the present research.

The present research supports the statement that increasing photoperiod stimulates sexual maturity as early as 7 wk of age whereas light intensity has no effect. Also, high-intensity light reduces body fat but photoperiod has no effect. Further, increasing photoperiod improves feed efficiency and bird livability, probably due to the early feed restriction affect of reduced day length. It appears that both increasing photoperiod and high-intensity light can stimulate bird activity.

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