ABSTRACT

LEKSRISOMPONG, NIRADA. Effects of Feeder Space and Feeding Programs During Rearing and Laying on Broiler Breeder Reproductive Performance and Livability. (Under the direction of Dr. John T. Brake).

A series of four experiments were conducted in slat-litter pens in order to determine the effects of feeder space, feeding programs during rearing and laying, strain, and length of starter feed on broiler breeder female reproductive performance, uniformity, mortality, and progeny performance.

In Experiments I and IV, there was an increased feeder space between the rearing and laying periods but no change in Experiment III. In Experiment II, an increased, decreased, or no change in feeder space were compared. Irrespective of other treatments, maintaining similar feeder space between rearing and laying periods produced better egg production and generally lower hen mortality during the laying period. Feeder space also did not affect the uniformity of body weight nor livability during rearing.

Line and Sigmoid feeding programs during rearing were compared in Experiments III and IV. In Experiment III, the Sigmoid and Line program hens exhibited similar rates of lay but Sigmoid hens produced greater EHH due to lower female mortality during hot weather while no effect was observed in Experiment IV.

Fast and Slow feeding to peak production programs were compared in Experiments I, II, and III. The Slow feeding to peak program produced lower female mortality in the presence of hot weather early in the laying period and a large increase in feeder space in Experiment I as compared to no change in feeder space and later hot weather in Experiment III.

Additionally, the Slow feeding to peak program produced numerically lower female mortality in Experiment II.

There were no significant effects on hatchability of fertile eggs in Experiment II and IV, but the Ross 708 strain and Sigmoid rearing program hens exhibited improved hatchability of fertile eggs in Experiment I and III, respectively.

An increased feeder space in Experiment I significantly decreased egg weight at 28 and 30 wk of age but had no effect on broiler performance. The Fast feeding to peak approach significantly increased yolk weight, decreased albumen weight, and changed the yolk:albumen ratio in Experiment II. In Experiment III, where there was no change in feeder space, greater egg weight at 28 wk produced by the Slow feeding to peak was observed. This larger egg weight produced male broilers with poorer adjusted feed conversion ratio and greater mortality but this may have been a residual effect due to hotter eggs caused by the lack of proper temperature control during incubation.

In the individually caged hens of Experiment V, an increased albumen height due to the Fast feeding to peak program and the Ross 708 strain was observed. The thicker albumen may have slowed vital gas diffusion during incubation and resulted in smaller broiler progeny that exhibited greater mortality.

It can be concluded that increase or decrease in feeder space at photostimulation can have a detrimental effect on reproductive performance and mortality of broiler breeder females. A Slow feeding to peak program as well as Sigmoid feeding program during rearing improved percentage hen mortality during hot weather. Consumption of a greater quantity of crude protein in early life also produced lower female mortality during the laying period.

Effects of Feeder Space and Feeding Programs During Rearing and Laying
on Broiler Breeder Reproductive Performance and Livability

by
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BIOGRAPHY

Nirada Leksrisompong, the second daughter of Mr. Vinai and Mrs. Phatanee Leksrisompong, was born in Bangkok, Thailand where she was educated until she moved to the United States to attend high school in Kentucky. Nirada continued her undergraduate education at the University of Kentucky, where she received the Bachelor of Science degree in Animal Science in December, 2002. She then enrolled at North Carolina State University and completed her Master of Science in Poultry Science under the supervision of Dr. John Brake. She managed several trials concerning the interaction of incubation and brooding temperatures on broiler chickens and developed an innovative new approach to brooding. Nirada continued to pursue her doctoral study under Dr. Brake where she took on a project dealing with the effects of feeder space and feeding programs during rearing and laying on broiler breeder reproductive performance and livability. While in the Department of Poultry Science, Nirada served as Secretary of the Graduate Student Association. She also presented her research papers at several conferences and won two prizes in the Graduate Student Award of Excellence competition. Nirada is looking forward to using her knowledge and skills to help the poultry industry to improve their production efficiency and eventually contribute her knowledge to her family business, Charoen Pokphand.

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LIST OF ABBREVIATIONS

AdjFCR	Adjusted feed conversion ratio, corrected for mortality
AMH	Anti-Müllerian Hormone
AW	Albumen weight
BW	Body weight
C	Celsius
cm	Centimeter
d	Day
EW	Egg weight
FSH	Follicle Stimulating Hormone
g	Gram
h	Hour
kg	Kilogram
LH	Luteinizing Hormone
SD	Standard deviation
YW	Yolk weight
YW:AW	Yolk:albumen

INTRODUCTION

Historically, the brood-grow-lay housing system where broiler breeders reside for 65 wk in a single facility has been popular internationally while the brood-grow and lay housing system where broiler breeders have been moved from growing quarters to laying quarters at about 21 wk of age has been popular in the USA. One difference between these two systems was the change in feeder space from rearing and laying periods that has generally occurred in the latter housing system. Many of the breeder management guidelines have also suggested an increase or “adequate” feeder space to insure that all birds have access to the feed at the same time to insure uniform feed intake (Anonymous, 2006, 2010a). Also, inadequate feeder space has been generally associated with poor uniformity of flock body weight (BW) (Anonymous, 1997). Robinson et al. (2003) also stated that, under typical conditions of feed restriction, inadequate access to feed has been thought to cause problems with BW uniformity at photostimulation. This has been thought to lead to non-uniform sexual maturation such that the all birds in the flock would not begin to produce eggs at the same time.

Different broiler breeder strains have also been shown to produce eggs with different egg content (Suarez et al., 1997) due to phenotypic and genetic differences amount strains. Two popular strains have been the Ross 308 and Ross 708 females that have been selected to have slightly different characteristics that favored either breeder performance or broiler carcass yield, respectively. The development of modern birds has been somewhat focused on high breast-yielding strains and this has complicated breeder management and feeding programs. The recommendations for the breeder feeding programs had varied for these two strains. Reddish and Lilburn (2004) showed that there were differences in carcass and reproductive characteristics between breeders that were selected for the production of heavy broilers with increased breast yield and a commercial broiler breeder line that had considerably less broiler breast meat yield. They found that birds with greater breast muscle weight also had a smaller oviduct when compared to birds with less extreme breast yield. Since the oviduct has been characterized as a priority tissue for nutrient partitioning during sexual maturation (Joseph et al., 2000), the feeding program before and after photostimulation has to be given high priority. The feeding program during this time period would likely affect reproductive tract development as a fast growth rate could result in overweight broiler breeders that would exhibit poor egg production, fertility, and hatchability (Havenstein et al., 1994; Tona et al., 2004).

Skeletal growth has been known to be increased when the level of dietary protein was increased during the early life of a pullet (Leeson and Summers, 1984). Dietary protein has also been shown to influence body growth and the body composition of domestic fowl. Therefore, feeding a low protein diet to pullets during their early life could cause a disturbance in their growth and development (Kim and McGinnis, 1976; Hussein et al., 1996). There have been many studies concerning early crude protein intake as well as growth and development of pullets (Leeson and Summers, 1984; Brake et al., 1985; Lilburn et al., 1987; Hudson et al., 2000), but none concerning the length of time that starter feed was fed, the long-term effects of early crude protein intake, the combinations of the starter feed on broiler breeder males and females, and the effects with feeding program during rearing and laying periods.

Therefore, the objective of this study was to evaluate a number of factors that could affect broiler breeder performance and performance of the broiler progeny. Factors that were considered to be of potential importance included feeder space, feeding programs during rearing, feeding to peak programs, and amount of starter feed during early rearing.

LITERATURE REVIEW

Genetic Trends

The U.S. population has more than doubled from 151 million in 1950 to over 308 million in 2010 (U.S. Census Bureau, 2010) and the population will continue to increase every year. The demand for poultry meat has also increased over the past decades as compared to red meat. According to the United States Department of Agriculture Economic Research Service (USDA ERS, 2010), broiler meat consumption per capita increased from 10 pounds in 1950 to about 85 pounds in 2010 and will continue to increase through 2020, in contrast to red meat (USDA ERS, 2010). Poultry genetics and production efficiency evolved rapidly to meet this demand. Due largely to genetic selection, the broiler of 2001 was nearly five times as large at 42 and 56 d of age as compared to the 1957 randombred broiler (Havenstein et al., 2003a, b). As genetic selection has progressed, the productivity of domestic livestock and poultry has almost tripled in the past 100 years (Grandin and Deesing, 1998). The three most visible changes in the modern broilers have been rapid growth, improved feed efficiency, and increased breast muscle (BM) (Havenstein et al., 2003a, b). Two popular strains within the United States and internationally have been the Ross 308 and Ross 708. Geneticists have selected these two strains for slightly different purposes. The Ross 308 has been selected to produce a high number of eggs combined with good hatchability, while the Ross 708 has been developed to produce higher breast meat yielding broilers (Anonymous, 2010b). The slight difference in genetic selection pressure at the broiler level also has produced broiler parents (broiler breeders) that differ slightly in their phenotypic expression.

Anatomy Of the Female Reproductive System

General. Embryologically, there are two Mullerian ducts in the hen but only the left duct has been found to normally develop and become fully functional. This could be an adaptation to reduce weight for flight. The right ovary and oviduct have been found to be present during early embryonic stages but development has been reported to become asymmetrical by day 4 of incubation and by day 10, regression of the right oviduct has been reported to have begun (Sturkie, 1986). Anti-Mullerian hormone (AMH or Mullerian inhibiting substance) has been shown to contribute to the regression of the Mullerian duct system in male mammals, but no prenatal function in female mammals has been reported (Johnson et al., 2009). However, immunoreactive AMH has been detected in postnatal female mammals (Ueno et al., 1989 a,b). While in birds, AMH has been shown to have a role in regression of the two Mullerian ducts in males and of the right Mullerian duct in females (Teng, 1987). Female birds have also been reported to have AMH present in both embryonic ovaries (Teng, 1987), but Teng (2000, 2001) reported that ovarian estrogen released from the left ovary protected the left Mullerian duct from the influence of AMH and permitted the development of the left oviduct.

The chicken oviduct has been reported to be comprised of five different functional sections: infundibulum, magnum, isthmus, shell gland (uterus), and vagina. Egg shell formation, which occurs in the uterus, has been characterized as probably the most critical and certainly the most time consuming step of the egg formation process. According to Robinson et al. (2003), shell defects could be indicative of problems caused by aggressive feeding that could lead to excessive follicle formation and ovulation rates. Problems with egg shell quality and egg size have been linked to feed ingredients issues as well as feeding levels (Robinson et al., 2003).

Ovulation and Egg formation. Ovulation has been described as the process whereby a mature follicle may be released from the ovary. This process has been reported to involve the brain, anterior pituitary (adenohypophysis), and ovary (Robinson et al., 2003). Once a large yellow follicle (F1) has matured, the steroid hormone progesterone would be released into the blood stream. The release of progesterone would stimulate the release of gonadotropin releasing hormones (factors) from the hypothalamus, which would cause a luteinizing hormone (LH) surge (release) from the anterior pituitary (adenohypophysis) that has been reported to stimulate sex steroid production in the follicles of the ovary (Robinson et al., 2003). Ovulation typically has been found to follow 4 to 6 hours after the culmination of the hormonal cascade that led to the LH surge. Ovulation would occur when the F1 follicle has ruptured along the stigma, a linear avascular area on each follicle, with the ovum released from the ovary to enter the uppermost section of the oviduct (infundibulum). The F1 follicle has been shown to grow to about 30 mm in diameter prior to its release, although this has been found to depend upon the age of the hen (Robinson et al., 2003). Follicle stimulating hormone (FSH) has also been reported to be released from the anterior pituitary and to be involved in the development of many tiny follicles days or weeks before they become competent to ovulate (Robinson et al., 2003).

Blastodisc (Germinal Disc). The germinal disc can be observed as a small white dot on the surface of the yellow egg yolk, located where spermatozoa must penetrate and fertilization occur. Once fertilized, the blastodisc would normally begin to divide to become the blastoderm (early embryo) once it has reached the 64-cell stage. Only this small group of surface cells has been found to divide and develop. The larger mass of yolk upon which the embryo (blastoderm) sits does not divide and only serves to provide nutrients to the embryo (Robinson et al., 2003).

Yolk. The ovary has several thousand potential ova (egg yolks) that have an appearance similar to a bunch of grapes. As the ova grow to around 1 mm in diameter, they normally would become white in color. Committed yolks would continue to grow and become mature large (35 mm) yellow yolks over a period of about 19 d. As a percentage of its weight, yolk has been found to be made up of mostly water, fat (lipids), and proteins (Burley and Vadehra, 1989). A small white circle of material located in the center of the yellow yolk has been found to provide the first nutrients required for the early embryo to grow and develop.

Infundibulum. After the egg yolk has matured and been ovulated, it should be captured by the infundibulum within about 20 minutes. Engulfment of the yolk and fertilization of the ovum has been found to occur in the infundibulum. The process of fertilization should begin when the ovum comes into contact with the base of the infundibulum where a contingent of sperm storage tubules has been described. Following mating, sperm entered the oviduct and were stored within the sperm storage glands at either the utero-vaginal junction or at the infundibular-magnal junction. Motile sperm would normally enter these storage sites after mating or insemination. These glands have been found to store more than half a million sperm so that hens do not have to be inseminated or mated daily. Sperm released over the course of the daily ovulatory cycle have been reported to ascend to the site of fertilization at the infundibulum and fertilize the daily succession of ova (Ottinger et al., 1995). The infundibulum was found to be about 10 cm in length and the ovum has been found to reside in the infundibulum for 15 to 30 minutes (Robinson et al., 2003).

Magnum. Following fertilization, the ovum must move along the oviduct into the magnum. Egg albumen has been found to be released due to mechanical pressure exerted by the gradually descending ovum. There are two types of albumen, thin and thick, that have been described to be made up mostly of protein and water (Burley and Vadehra, 1989). These two albumen types serve to protect the yolk and embryo from bacteria and promote transport down the oviduct. The twisted strands of the chalazae were reported to interconnect the yolk, inner thick albumen, and outer thick albumen in a manner so as to stabilize the yolk in the center of the egg and prevent the yolk and embryo from contacting the inside of the shell when the egg moves. This arrangement has also been suggested to prevent the germinal disc from desiccation if it were to come to rest beside the egg shell. The length of the magnum in the chicken has been found to be about 33 cm and about 3 to 4 hours has been found to be normally required for passage (Robinson et al., 2003).

Isthmus. Both inner and outer shell membranes have been reported to be formed in the very short (10 cm) isthmus. The inner shell member was found to be formed in contact with the albumen while the outer shell membrane was formed in contact with the egg shell. Both shell membranes were reported to be comprised of protein fibers that form a mesh-like structure that hold the albumen in place and provide a barrier to prevent the entry of bacteria. The process of shell membrane formation has been reported to require around 1.5 hours (Robinson et al., 2003).

Shell Gland (Uterus). The shell gland, or uterus, has been shown to be the location where "plumping" of the albumen and formation of the final shape of the egg occurred. Plumping involved fluid addition to the albumen, forming the outer thin albumen. The expansion of this albumen in the "plumping" process has been thought to give the egg its final shape within the constraints of the shape of the uterus. Glands in the surface of the shell gland are known to secrete sodium bicarbonate, sodium chloride, potassium chloride, and calcium chloride in liquid form during the shell formation process. A crystalline calcium carbonate and glycoprotein matrix would normally be formed on the shell membrane during the initial stages of the process and the final layer of shell has been found to contain any egg shell pigments. The shell ultimately functions to provide calcium and other minerals to the growing embryo. The ovum was reported to remain in the shell gland for about 20-26 hours (Robinson et al., 2003).

Uterovaginal Junction. According to Romanoff (1960), the duration of fertility in the domestic hen was highly variable and has been found to range from 7 up to 34 d. The reason for this was that in hens there were sperm storage tubules that were located in the anterior end of the vagina (uterovaginal junction). The sperm from these sperm storage tubule have been found to be gradually released over a period of days in some species, or weeks in other species (Bakst and Wishart, 1994).

Vagina. The vagina has been described as being separated from the shell gland by the uterovaginal sphincter muscle and to terminate at the cloaca, the common opening of the reproductive, renal, and gastrointestinal systems. The vagina has no reported role in the formation of the egg other than participation in the expulsion of the egg through coordination with contractions of the shell gland. The expulsion of the egg would normally be with the large end first. The total length of time from fertilization to oviposition would normally be about 25 hours in broiler breeders.

Reproductive Problems In Broiler Breeder Females

Broiler breeders have become unable to self-regulate their feed intake to closely match their energy requirements for maintenance, growth, and reproduction (Richards et al., 2010). Selection for increased juvenile body weight (BW) and improved meat yield in broilers has been accompanied by an increase in voluntary feed consumption (Chambers et al., 1981) that has been negatively correlated with the onset of sexual maturity and reproductive performance of broiler breeders as evidence by effects on sexual maturity age, body composition, egg size, egg production, ovarian morphology, and multiple hierarchies (Hocking et al., 1987, 1993; Joseph et al., 2002; deBeer and Coon, 2007). Excessive feed consumption during egg production has led to an increased BW and abdominal fat pad weight that has been associated with lower egg production efficiency. Siegel and Dunnington (1985) suggested that excessive BW gain during the breeding phase of production accelerated ovarian follicular maturation such that more ovulations occurred than the oviduct could effectively process, which led to an increased production of defective or nonsettable eggs (Yu et al., 1992). Multiple hierarchies cause lower egg production through the loss of follicles as internal ovulations into the body cavity and through the production of double-yolked, soft shelled and misshapen eggs due to the hens' ovulation of several follicles each day (Hocking et al., 1987). Normally, the ovary of laying hens contain about 5-7 yellow follicles arranged in a hierarchy in an increasing size maintained by the daily recruitment of a single small follicle (Gilbert, 1972) with the most mature ova (F1) being the next to ovulate. Thus, poorly organized hierarchies frequently result in multiple ovulations (Johnson et al., 2009), inappropriate egg laying times, and poor eggshell quality (Yu et al., 1992). Because broiler breeders are hyperphagic, *ad libitum* feeding has been shown to recruit and ovulate more than one follicle per day, which caused an interruption of normal egg formation and low productivity (Hocking et al., 1987). Researchers have shown that this ovarian overgrowth can be controlled by feed restriction (Hocking, 1993; Hocking et al., 1987; Katanbaf et al., 1989; Renema et al., 1999) that slows the rate of follicle growth and therefore, improves egg quality and production (Renema et al., 1999). Hocking et al. (1987) conducted an experiment to compare the ovarian follicular populations of a small bodied, high producing egg stock fed either *ad libitum* or on a restricted feeding regimen until point of lay and subsequently found lower egg production from broiler breeders that had been fed *ad libitum*. They concluded that *ad libitum* fed broiler breeders produced too many yellow follicles resulting in multiple ovulations and reduced egg production, particularly during early lay. Restricting growth during rearing by restricted feeding during rearing has limited the production of yellow follicles and the incidence of double ovulations, and resulted in an increase in the number of eggs laid (Hocking et al., 1987). In order for feed restriction to be most effective, it had to be applied after 14 weeks of age when the ovary began to show follicular activity in birds fed *ad libitum* (Hocking et al., 1989; Hocking, 1993). Bruggeman (1999) also suggested that the most critical period for limiting BW gain, as well as the period that required the highest degree of feed restriction was between 7 and 15 wk of age during the pullet growth phase. However, studies by Hocking (1996) have shown that feed restriction after photostimulation was also necessary to optimize ovulation rate since birds that were fed *ad libitum* following prior restriction exhibited an increased ovarian follicle number as compared to hens restricted before and after the onset of lay. Wilson et al. (1995) stated that by controlling the feeding program during rearing and early lay the frame size and BM fleshing in the birds could be controlled. This was important with the development of high breast-yield strains where hens would divert more energy toward BM growth and less to reproductive processes. Thus, feed restriction has been shown to be necessary to control BW, improve egg weight and egg production (Siegel and Dunnington, 1985), improve ovarian function with fewer multiple ovulations, reduce numbers of abnormal eggs, and reduce mortality during the laying period (Renema and Robinson, 2004).

Benefits Of Delaying Photostimulation As a Result From Feed Restriction

We know that feed restriction during the rearing period has improved ovarian function and reduced the numbers of abnormal eggs through control of growth rate and BW of broiler breeders. Several authors (Katanbaf et al., 1989) have stated that quantitative feed restriction increased the period of time required to attain the BW and body composition needed for sexual maturation. Even though birds may achieve their hypothalamic maturation at a relatively young age, their BW or body composition may not be sufficient for sexual maturity and reproduction at the time (Katanbaf et al., 1989; Robinson et al., 1996). Since sexual maturation of broiler breeders has been shown to be dependent upon achieving minimum thresholds of age, BW, and body composition (Katanbaf et al., 1989), delayed photostimulation would benefit today's modern strains as it allows more time for birds to attain all prerequisites for reproduction.

One of the advantages of delayed photostimulation has been to improve flock reproductive uniformity (Hocking, 1996; Robinson et al., 1996) as birds that were ready for egg production were forced to wait for those that were still growing and maturing before all were signaled to begin final reproductive maturation. Once photostimulation occurred, the time needed for the entire flock to achieve sexual maturity was reduced as all hens could respond to the photostimulation cue as a synchronous group (Hocking, 1996). Robinson et al. (1996) conducted an experiment and found that by keeping birds 10 d longer (photostimulated at 160 d versus 150 d) in a short photoperiod, the time lapse between photostimulation and sexual maturity and the variability in BW at first egg were significantly reduced. This was because pullets photostimulated at 160 d of age had already begun partitioning energy toward those organs involved in reproductive function and sexual maturation progressed rapidly once photostimulation occurred. Joseph et al. (2002) also found similar results with pullets that were photostimulated at 23 wk of age and produced their first egg 15 d earlier than pullets that were photostimulated at 20 wk of age. These authors concluded that by delaying photostimulation, pullets had more time to complete growth and probably had begun to partition a greater proportion of their energy intakes to fat deposits and reproductive organ development. Once photostimulated, more nutrients were available to be immediately allocated toward egg production (Joseph et al., 2002).

Another effect of delaying photostimulation was to increase egg weight (EW). McDaniel et al. (1981) found that EW increased if the BW was increased as a result of delayed photostimulation since BW and EW were positively correlated. This finding was in an agreement with Joseph et al. (2002) who reported that by delaying photostimulation from 20 to 23 wk of age a higher mean EW throughout the entire laying cycle was attained. This was attributed mainly to differences in BW. Joseph et al. (2002) further stated that the heavier EW was due to heavier albumen weight rather than yolk weight, while the early photostimulation birds exhibited greater specific gravity, which means greater egg density, but often interpreted to mean better shell quality. There were no differences in hen day egg production since delaying age of photostimulation did not significantly shorten the production cycle (Joseph et al., 2002). Hatchability was not affected by photostimulation time as well (Robinson et al., 1996; Joseph et al., 2002). However, other studies have agreed that by delaying photostimulation, BW was increased but no subsequent difference in EW was found (Robinson et al., 1996).

Effect Of Heat Stress On Broiler Breeder Females

Ovarian Function. Heat stress is one of the major concerns of the modern poultry industry since current strains have been selected to grow very fast and to produce more breast meat. Heat stress has been shown to reduce reproductive performance in domestic birds (Etches et al., 1995) as evidenced by reduced egg weight, ovary weight, and egg production (Rozenboim et al., 2007). The effect of heat stress on egg production has been widely recognized, but the mechanisms involved in this reduction remain not clearly understood. One of the causes of reduced reproductive performance was the reduced feed consumption due to heat, but according to Smith and Oliver (1972), these reductions were not necessarily directly related to feed intake. There have been many previous experiments conducted concerning the effects of heat stress and associated regulatory mechanisms on reproductive efficiency in different species. Some studies have found that the reduction in egg production was at the level of the hypothalamus, but other studies have found a direct effect on ovarian functions. Example of the studies that found the cause of the reduction occurred at the level of the hypothalamus and pituitary were carried out by El Halawani et al. (1973), Saarela et al. (1977), El Halawani and Waibel (1978), Braganza and Wilson (1978a, b), and Jeronen et al. (1978). Heat stress was found to reduce LH levels and hypothalamic gonadotropin-releasing hormone-I content (Donoghue et al., 1989) leading to a reduction in preovulatory surges of LH (Novero et al., 1991) in hens. It has been long known that the release of progesterone from the ovary stimulated the release of gonadotropin releasing hormones (factors) from the hypothalamus and caused the LH surge from the anterior pituitary (adenohypophysis). Because ovulation occurred 4 to 6 hours following the culmination of the LH surge; the reduction of LH level caused by heat stress may have caused the reduced egg production. The diminished reproductive performance of heat stressed hens may also be related to an increased prolactin (PRL) secretion (El Halawani et al., 1984; Donoghue et al., 1989) since PRL secretion has been found to reduce gonadotropin levels (Youngren et al., 1991; Rozenboim et al., 1993; You et al., 1995). Studies in rats (Neill, 1970; Krulich et al., 1974), cows and goats (Johke, 1970), turkey poults (Opel and Proudman, 1982), laying hens (Johnson, 1981), and turkey hens (El Halawani et al., 1985; Rozenboim et al., 2004) have also showed that heat stress increased the circulating levels of prolactin (PRL), which resulted in decreased circulating levels of gonadotropins (LH and FSH).

Recent studies by Rozenboim et al. (2007) have shown that a reduction of egg production by an average of 20% after 2 d of heat exposure, egg weight was declined after 1 d of heat exposure, and ovary weight was reduced after 6 d of heat stress at 42.0^{o}C. Theses authors found little effect on plasma LH and FSH, suggesting a direct effect of heat stress on ovarian function. The results of this study were in agreement with data in cattle (Wolfenson et al., 1997). Wolfenson et al. (1997) reported a direct effect of heat stress on ovarian functions. They stated that the possible mechanism for the reduction of ovarian function might be the reduction of blood flow to the ovary.

Causes of Mortality. High environmental temperature is one of the important sources of excess stress in poultry production. Selection for high meat yields in combination with rapid growth rate has resulted in birds that can be more susceptible to heat stress. Chronic thermal stress (high or low environmental temperatures) has been shown to have a detrimental effect upon feed consumption and cause poor BW gain in broiler chickens as well as poor laying rate, egg weight, and shell quality in laying hens, increased incidence of metabolic diseases, and increased mortality (Washburn, 1985; Howlider and Rose, 1987; Marsden and Morris, 1987; Shane, 1988; Leeson and Summers, 1988; Yahav, 2000). In birds, as well as in other homeotherms, body temperature has long been known to be controlled by balancing heat loss against heat production. Heat stress occurs when animals were not able to lose more heat than they produced (Macleod and Hocking, 1993). Earlier studies with broilers of a ‘fat line’ genetically selected by Whitehead and Griffin (1984) showed higher mortality than their ‘lean line’ counterparts due to heat stress, particularly when they were fed *ad libitum*. MacLeod and Hocking (1993) and Geraert et al. (1993) also demonstrated a greater heat resistance in genetically lean broilers and hens when compared to fat birds. MacLeod and Hocking (1993) stated that the reason for this was that fat hens were unable to dissipate body heat as efficiently as lean hens when exposed to high ambient temperatures, which would result in a critical rise in deep body temperature.

Blood viscosity is an index reflecting the fluidity of blood and has been shown to be related to heat stress susceptibility. Increased blood viscosity has been shown to elevate resistance to blood flow (Chien, 1982) that would have greatest effect in the capillaries, which have the smallest diameter (Wells, 1972). The effect of reduced blood flow through capillaries would reduce flow rate through heat-exchange interfaces, such as the comb and legs. Increased blood viscosity would also be likely to reduce blood flow through lung alveolar capillaries, which would impair the efficiency of gaseous exchange and may also reduce convective and evaporative heat loss from the lungs (Wells, 1972). Further effects of lower blood flow would be an increased arterial blood pressure causing long-term effects on heart ventricular function that could result in mortality. Reduced feed intake has been suggested to alleviate the thermoregulatory incapacity of the fat-line hens since this could help increase the birds' ability to lose heat by reducing plasma triglyceride concentrations, thus reducing the severity of any associated cardiovascular impairment (Hocking et al., 1992). MacLeod and Hocking (1993) suggested the cause of the inability for birds to lose heat may have its origins in elevated blood viscosity and vascular resistance that result from high plasma triglyceride concentrations.

Effects Of Increase In Body Weight and Breast Muscle Weight On The Reproductive System

Many studies have demonstrated the relationship between the selection for increased juvenile BW and the detrimental effects on the reproductive potential of parental lines (Siegel and Dunnington, 1985; Reddy, 1994; Goerzen et al., 1996; Barbato, 1999). Nestor (1980) conducted experiments in turkeys and found turkeys that were selected for increased BW ended up produced fewer eggs while turkeys that had been selected for increased egg production exhibited a decreased mature BW. Subsequently, Lilburn and Nestor (1993) conducted a similar experiment and showed that the weight of the oviduct at the onset of production was greater in turkey lines selected for increased egg production when compared to those selected for increased BW. Studies concerning broiler breeder carcass and reproductive characteristics in different lines of commercial breeder pullets, two of which represented broiler breeders selected to produce heavy broilers with high breast muscle yield while the third was a commercial broiler line with considerable less breast yield, showed significantly heavier breast muscle weight as well as smaller oviduct weight from birds that had been selected for the production of heavy broilers with increased breast yield when compared to birds with less extreme breast yield evident (Reddish and Lilburn, 2004). The authors speculated that with a smaller breast muscle hen, a greater proportion of dietary protein intake could be diverted to high protein tissues such as the oviduct (Reddish and Lilburn, 2004). This finding was similar to the finding of Hudson et al. (2000) who found that birds with larger breast muscle produced fewer eggs when compared to smaller breast birds, possibly because less protein was used for egg production and more was used for muscle deposition. The interaction between nutritional and reproductive parameters has been found to be complex for broiler breeders. The concern was that the bird may carry additional breast muscle throughout its life and, in order to maintain this high energy-demanding tissue, the hen would have to divert nutrients it might otherwise have been able to use to support egg production (Renema et al., 2008). However, reproductive development could be manipulated by nongenetic factors such as lighting programs, plane of nutrition, or pattern of feed restriction (Yu et al., 1990; Robinson et al., 1998a, b;

Bruggeman et al., 1999). According to several workers (Van Middelkoop, 1971; Hocking et al., 1987; Yu et al., 1992), providing excess feed during sexual maturation can cause an over-stimulation of ovarian follicle development in the form of additional large yellow follicles (LYF). Over-feeding for as little as 2 wk between photostimulation and peak production can permanently hinder fertility and hatchability (Ingram and Wilson, 1987). Precision limited feeding has been found to ameliorate this problem but detailed knowledge of the reproductive physiology remains incomplete. Further, the feeding program from onset of production to peak feed may also play an important role during the laying phase. Feeding programs may interact and affect breast muscle and reproductive tract development. Based on our previous observations, BM development may influence reproductive development (Leksrisompong et al., 2007) resulting in differences in egg production and egg quality.

Development Of the Reproductive System

Sexual hormones of broiler breeder females has been known to be present during the embryonic stage to enable the conversion of the embryonic organ, the left Mullerian duct, into the functional oviduct and again at the time of sexual maturation to control synthesis of the mature oviduct (Sturkie, 1954). By the time of sexual maturation, the weight of the oviduct increased considerably from 0-l g to 40-60 g (Sturkie, 1954). Brenemann (1956) also stated that the reproductive system of the female bird has not been developed until sexual maturity or when seasonal breeding occurs. Following this earlier study, Joseph et al.

(2002) showed that oviduct weight increased dramatically from 22 wk of age to 32 wk of age and remained unchanged from 32 to 54 wk of age. They concluded that once peak egg production had been achieved, the size of the oviduct did not change. The oviduct has also been reported to begin to develop before the ovary during the sexual maturation, making it a good variable to determine the short-term response to photostimulation during this period (Melnychuk et al., 1997). Thus, the oviduct must be a priority tissue for nutrient partitioning during sexual maturation because it reaches a mature weight before the rest of the bird completes development (Joseph et al., 2002).

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MANUSCRIPT I. Effect of Feeder Space Allocations during Rearing, Female Strain, and Feed Increase Rate from Photostimulation to Peak Egg Production on Broiler Breeder Female and Broiler Progeny Performance

ABSTRACT

A study was conducted to determine if there were differences in broiler breeder performance and growth of broiler progeny from two strains (Ross 308 and 708) that had been subjected to two female feeder space allocations (5.3 cm or 7.0 cm) during the growing period followed by two female feeding to peak programs (Fast or Slow). Pullets were reared with a single feeding program to 23 wk of age and then assigned to two feed increase programs (Slow or Fast) from photostimulation to peak egg production. The flock was moved to the laying house and photostimulated at 23 wk of age when Ross 344 males were added to create 16 pens with 60 females and 7 males each in a 2 x 2 x 2 design. Egg production and mortality were determined on a daily basis while percentage fertility and fertile hatchability were evaluated on a weekly basis from sets of 90 eggs per replicate pen. Hen BW was determined on a regular basis. The Fast feed increase program significantly increased female BW at 31 wk of age that could have resulted in an increased female mortality during early lay (26-32 wk) during hot weather. The 708 females with 5.3 cm feeder space produced smaller EW at 28 and 30 wk of age. The 708 females exhibited better fertile hatchability than 308 females due to fewer late dead embryos. There were no differences in egg production, fertility, or fertile hatchability due to the main effects of feed

increase program or strain and there were no interactions for any variable measured. Eggs produced by these hens at 31 wk of age were incubated under standard conditions and the carryover effects on the broiler progeny evaluated. There were 19 male and 19 female broiler chicks mixed equally in each of 32 pens in a 2 x 2 x 2 design with 4 replicates per interaction cell. Broiler BW, feed consumption, adjusted feed conversion ratio (AdjFCR), and mortality were measured at 1, 14, 28, and 42 d of age. Broilers from the Ross 308 strain were significantly heavier at all ages that could have been initially due to a heavier EW. There were no effects on AdjFCR as well as mortality of broiler progeny. It could be concluded that a Slow feed increase from photostimulation to peak production was beneficial for broiler breeder females during the hot temperature irrespective of strain.

Key words: Broiler breeder females, feeder space, feeding program, strain

INTRODUCTION

Several studies have focused on the effects of improving growth rate and meat yield of broilers on broiler parent stock performance (Havenstein et al., 1994; Tona et al., 2004). Factors including genetics, nutrition, management, egg nutrient content, egg size, egg composition or quality, and embryo incubation physiology have been linked to weight of chicks at hatching and subsequent broiler performance (Wilson, 1991; Suarez et al., 1997; Tharrington et al., 1999; Silverside and Scott, 2001). Different broiler breeder strains have been shown to produce eggs with different yolk and albumen percentages, yolk:albumen ratio, percentage shell, and incubation time (Suarez et al., 1997; Joseph and Moran, 2005). This may be due to phenotypic and genetic differences among strains. Two popular strains within the United States and internationally are the Ross 308 and Ross 708. Ross 308 breeder hens have been selected to produce a high number of eggs combined with good hatchability while the Ross 708 breeder hens have been developed to produce high meat yielding broilers (Anonymous, 2010). Since these strains have been selected for different purposes, the recommendations for the breeder feeding programs do vary. Also, the development of modern high breast-yielding strains has complicated breeder management, because increased breast muscle mass has been typically carried on a smaller carcass frame. Reddish and Lilburn (2004) showed that there were differences on carcass and reproductive characteristics between birds that were selected for the production of heavy broilers with increased breast yield and a commercial broiler line that has considerable less breast yield. They found that birds with heavier breast muscle weight also had a smaller oviduct weight when compared to birds with less extreme breast yield. The oviduct is well known to be one of the main tissues involved in producing egg components. It has also been characterized as a priority tissue for nutrient partitioning during sexual maturation since the oviduct weight increased dramatically from 22 wk to 32 wk of age but remain unchanged from 32 to 54 wk of age (Joseph et al., 2002). Oviduct weight as percentage of body weight (BW) also declined from 2.2% at sexual maturity to 1.8 % by 40 wk of age (Joseph et al., 2002). As feeding to much feed during this period, birds may diverted more energy to carcass growth rather than to reproductive processes (Robinson et al., 1995). Therefore, the feeding program during this time period would likely affect reproductive tract development as a fast growth rate would result in overweight broiler breeders that would exhibit poor egg production, fertility, and hatchability (Havenstein et al., 1994; Tona et al., 2004). Feeding programs during rearing and laying periods have been shown to be important in the number of follicles on the ovary of broiler breeder hens (Hocking et al., 1987, 1989; Heck et al., 2004; Hocking and Robertson, 2005) as well as fertility problem (Walsh and Brake, 1997).

The present experiment was conducted to determine if two feeder space allocations during rearing and the rate of feed increase program from photostimulation to peak egg production would differentially affect two broiler breeder strains in terms of their livability and reproductive performance as well as their broiler progeny performance.

MATERIALS AND METHODS

Broiler Breeder Rearing Period. Broiler breeder males (Ross 344) and females (Ross 308SF and Ross 708SF) were placed in an enclosed fan-ventilated 32-pen litter floor rearing house with 16 (14.3 m^2 area) pens for females and 16 (4.6 m^2 area) pens for males. The rearing house was equipped with 5 space heaters and 6 upward directed fans in the central walkway with pens on either side to insure uniform temperature throughout the house. At placement, there were 75 females and 18 males in each female and male pen, respectively. There was either Ross 308SF or Ross 708SF strain females in each female rearing pen and either 3 or 4 tube feeders (Kuhl DH-4) in each female rearing pen as well as 1 tube feeder in each male rearing pen. Each feeder pan had a circumference of 132 cm. After 23 h of light per day for one week, all birds were reared to 23 wk of age with 8 h of light per day at an average light intensity of 15 lux using 12W fluorescent light bulbs. Access to water was limited by a time clock and solenoid system sufficient to control litter moisture and allow the birds to have unlimited access to water until at least one hour after all feed was consumed and a similar amount on non-feed days during rearing. This was typically 6 h daily. A group BW of all females and males was taken at placement (1 d) and individual female and male BW was taken at 20 wk of age.

Broiler Breeder Production Period. An average of 60 females and 7 males were moved as groups from each rearing pen into each of 16 slat-litter floor laying pens (15.9 m^2 total area/pen, 5.9 m^2 litter area/pen) at 23 wk of age. Birds were photostimulated with 14 h of light at movement. The day length was subsequently increased to 15 h 7 d later, and then to

15.5 h and 16 h at 5% and 50% rate of lay, respectively. Natural light entered the slat-litter house through open or translucent curtains during normal daylight hours. Supplemental light provided an average intensity of 35 lux at bird head level using 18W fluorescent light bulbs when natural light was not present. There were 4 tube feeders (8.8 cm feeder space) for females and 1 tube feeder for males in each pen. Water was limited to 8 h per day during the laying period with two bell-type drinkers in each of the 16 breeding pens. One 6-hole (50.8 cm wide nest spaces) conventional nest was provided in each breeding pen. Separation of sexes was insured by special grills (sixteen 4.8 x 5.8 cm holes) on each female feeder that prevented the non-dubbed males from accessing the feed. Individual female BW was determined at 31 and 64 wk of age. Group BW of all females were also taken at 43, 48, and 56 wk of age. At 28 wk of age, 488 individual eggs were collected and egg weight (EW) determined gravimetrically. The egg contents were then removed and shells dried to constant weight before cooling to room temperature. The eggshells were then weighed. At 30 wk of age, 591 individual eggs were collected and EW, yolk, albumen, and shell weight were determined as above.

Fertility and Hatchability. Eggs were collected twice daily from the nests and stored in an egg cooler at 16-18^{o}C and 60% RH until incubated. Eggs that were laid on the floor and slats were collected and enumerated separately but not incubated. Analysis of percentage fertility, hatchability, and embryo mortality was conducted from 28 to 64 wk of age by macroscopic examination of all unhatched eggs from weekly sets of 90 eggs per pen. All unhatched eggs were opened and examined macroscopically to determine fertility or infertility and, if fertile, to determine the stage of embryonic mortality. Embryos that died from 1-7 d of incubation were termed early deads, embryos that died after 7 d were termed late deads. Cracked eggs were deemed to be accidental in nature and were not included in the calculations. Eggs were set in a Jamesway model 252B incubator (Butler Manufacturing Co., Ft. Atkinson, WI 53538) that held fourteen 180-egg trays. Each tray was comprised of 6 cradles that held 30 eggs each.

Experimental Diets and Feeding Programs. Feed for broiler breeders was provided daily during the first 2 wk of age and then a 4/3 feed allocation program (feed Monday, Wednesday, Friday, and Saturday only) was used until 23 wk of age after which a daily feeding program was employed (Fig. I-1). Diets are shown in Table I-1. A common starter diet (17% CP) was fed to all pens for 6 wk followed by a common grower diet (15% CP) from 7 to 25 wk (approximately 10% rate of lay). Females received 25.7 Mcal of ME and 1,349 g of CP cumulative nutrient intake while males received 30 Mcal of ME and 1,600 g of CP cumulative nutrient intake to 21 wk of age. Two feed increase rates (Fast or Slow) were then used from photostimulation to peak egg production (Fig. I-2). The females that received the Fast feed increase rate reached their peak feed of 160 g per female per day at 76% rate of lay while the Slow feed increase rate reached peak feed 7 d later, also at 76% rate of lay. The feed allocation was then reduced once egg production across both treatments was the same for 5 d. The feed allocation was the same for all females thereafter. Male and female mortality was recorded daily and feed allocations adjusted accordingly throughout both experiments.

Broiler Trial. To evaluate the possible effects of female breeder treatment on the performance of broiler progeny, a broiler trial was conducted. Broiler hatching eggs were collected from the flock at 31 wk of age and incubated. A total of 1,440 eggs were set in a Natureform Model NMC-2000 incubator (Natureform International, Jacksonville, FL 32218) that held eleven 180-egg trays. Each tray contained 6 plastic flats that held 30 eggs each. There were 8 trays of eggs employed in the study. The incubator was initially operated for 3 d at 38.0^{o}C dry bulb and 29.4^{o}C wet bulb set point temperatures. The dry bulb temperature was then decreased to maintain the internal egg temperatures between 37.5^{o}C and 37.8^{o}C as measured with a Braun Thermoscan thermometer (Leksrisompong et al., 2007). At 21.5 d of incubation the chicks that had completed the hatching process were removed from the trays, counted, group weighed, and sexed using the feather-sexing method. After processing, the chicks were permanently identified with neck tags and then distributed among 32 floor pens on wood litter shavings. Each pen area was 4.43 m^2 with two tube feeders and one bell-type drinker. Male and female broilers were mixed equally and placed in each of the 32 pens with a total of 38 chicks per pen. During the first 7 d there were 3 egg flats used for supplemental feed with 1 supplemental chick font for water. Chicks were group weighed at placement and at 14, 28, and 42 d of age. Feed consumption was determined at 14, 28, and 42 d of age and adjusted feed conversion ratio (AdjFCR) was calculated. All dead birds were weighed and recorded twice daily and their BW was used in the AdjFCR calculation. A single starter or grower diet that met or exceeded the NRC (1994) minimum requirements was used during the starter and grower periods from 1-14 and 15-42 d of age, respectively (Table I-2). No finisher diet was used for the sake of simplicity.

Statistical Analyses. Broiler Breeder Trial. The fertility and hatchability data were analyzed on a weekly basis. A completely randomized design with a factorial (2 x 2 x 2) arrangement of breeder treatments was used. The main factors were breeder strain (Ross 308 or Ross 708), feeder space allocation during rearing (5.3 or 7.0 cm feeders), and feed increase rate (Fast or Slow). The treatments combinations were randomly distributed among 16 pens with 2 replicate pens per interaction cell. The general linear model (GLM) procedure of SAS Institute (2001) was used to analyze the continuous variables. The fertility data was analyzed as categorical data, where each individual egg was taken as a binomial event, either fertile or infertile, using the general model (GENMOD) procedure of SAS Institute (2001). Means were partitioned using LS MEANS and statements of statistical significance were based upon $P \leq 0.05$ unless otherwise stated.

Statistical Analyses. Broiler Trial. A randomized complete block design with a factorial (2 x 2 x 2) arrangement of breeder treatments was used. The main factors were breeder strain (Ross 308 or Ross 708), breeder feeder space allocation during rearing (5.3 or 7.0 cm of feeder space), and breeder feed increase rate (Fast or Slow) from photostimulation to peak as they affected broiler performance. Breeder treatment identity was maintained for all broiler progeny chicks that hatched through to the broiler pens. The treatments were randomly distributed among 32 progeny pens within 2 blocks of 16 pens each. There were 4 replicate pens per interaction cell. The general linear model (GLM) procedure of SAS

Institute (2001) was used to analyze the continuous variables. Means were partitioned using LS MEANS and statements of statistical significance were based upon $P \leq 0.05$ unless otherwise stated.

RESULTS

Broiler Breeders. The main effects of broiler breeder female feeder space allocation during growing, female strain, and feed increase rate from photostimulation to peak egg production, as well as the growing feeder space by strain interaction, growing feeder space by feed increase rate interaction, and strain by feed increase rate interaction on broiler breeder female BW as sampled at hatching (1d), 43, 48, and 56 wk of age are shown in Table I-3. Female BW at hatching was affected by the strain where females of the 708 strain were significantly heavier. There were no other significant main effects nor any interactions found.

The main effects of broiler breeder female feeder space allocation during growing, female strain, and feed increase rate from photostimulation to peak egg production, as well as the growing feeder space by strain interaction, growing feeder space by feed increase rate interaction, and strain by feed increase rate interaction on individual broiler breeder female BW at 20, 31, and 64 wk of ages are shown in Table I-4. Individual female BW at 20 wk of age was affected by the strain where females of the 708 strain were significantly heavier. Female BW at 31 wk of age was affected by feed increase rate where females that received the Fast feed increase rate were significantly heavier. There were no significant main effects due to growing feeder space nor any interactions found.

The main effects of broiler breeder female feeder space allocation during growing, female strain, and feed increase rate from photostimulation to peak egg production, as well as the growing feeder space by strain interaction, growing feeder space by feed increase rate interaction, and strain by feed increase rate interaction on broiler breeder female coefficient of variation (CV) for individual BW at 20, 31, and 64 wk of age are shown in Table I-5. There were no significant main effects nor any interactions found.

The main effects of broiler breeder female feeder space allocation during growing, female strain, and feed increase rate from photostimulation to peak egg production, as well as the growing feeder space by strain interaction, growing feeder space by feed increase rate interaction, and strain by feed increase rate interaction on EW and percentage egg shell at 28 wk of age are shown in Table I-6. EW was affected by the growing feeder space as eggs produced by hens with 7.0 cm growing feeder space were significantly heavier. Percentage egg shell and EW were significantly greater in the 308 strain. Percentage egg shell was affected by the growing feeder space by feed increase rate interaction where percentage egg shell from the 5.3 cm growing feeder space by Slow feed increase rate combination hens was significantly greater than from the 5.3 cm growing feeder space by Fast feed increase rate combination hens while the 7.0 cm growing feeder space by Fast or Slow feed increase rate interactions were intermediate. There were no significant main effects due to feed increase rate as well as growing by strain or strain by feed increase rate interactions found.

The main effects of broiler breeder female feeder space allocation during growing, female strain, and feed increase rate from photostimulation to peak egg production, as well as the growing feeder space by strain interaction, growing feeder space by feed increase rate interaction, and strain by feed increase rate interaction on egg weight (EW) and egg components at 30 wk of age are shown in Table I-7. The EW was affected by the growing feeder space as hens with 7.0 cm growing feeder space produced significantly heavier eggs. Percentage egg shell and EW produced by the 308 hens were significantly greater. Percentage yolk was affected by feed increase rate as the yolk from hens subjected to the Fast feed increase rate was significantly greater because percentage yolk weight from the 5.3 cm growing feeder space by Fast feed increase rate interaction hens was significantly greater than from the 5.3 cm growing feeder space by Slow feed increase rate and the 7.0 cm growing feeder space by Slow feed increase rate interactions while the 7.0 cm growing feeder space by Fast feed increase rate interaction was intermediate. Percentage egg shell and the yolk:albumen ratio were affected by feed increase rate as the yolk:albumen ratio from hens subjected to the Fast feed increase rate was significantly greater, but percentage egg shell was significantly less. There were no significant effects due to the growing feeder space by strain or the strain by feed increase rate interaction found.

The main effects of broiler breeder female feeder space allocation during growing, female strain, and feed increase rate from photostimulation to peak egg production, as well as the growing feeder space by strain interaction, growing feeder space by feed increase rate interaction, and strain by feed increase rate interaction on egg production and female mortality are shown in Table I-8. Female mortality was greater due to the Fast feed increase rate as compared to the Slow feed increase rate. There were no significant effects due to growing feeder space and female strain nor any interactions found.

The main effects of broiler breeder female feeder space allocation during growing, female strain, and feed increase rate from photostimulation to peak egg production, as well as the growing feeder space by strain interaction, growing feeder space by feed increase rate interaction, and strain by feed increase rate interaction on broiler breeder fertility, hatchability of fertile eggs, hatchability of total eggs, and embryonic mortality from 28 to 64 wk of age are shown in Table I-9. Hatchability of fertile eggs and embryonic mortality were affected by female strain where hens from the 708 strain exhibited greater hatchability of fertile eggs as well as fewer late dead embryos. There were no significant effects due to growing feeder space and feed increase rate nor any interactions found.

Broilers. The main effects of broiler breeder female feeder space allocation during growing, female strain, and feed increase rate from photostimulation to peak egg production, as well as the growing feeder space by strain interaction, growing feeder space by feed increase rate interaction, and strain by feed increase rate interaction on mixed sex broiler BW at 1, 14, 28, and 42 d of age are shown in Table I-10. Mixed sex broiler BW at 1 d was increased by the 7.0 cm growing feeder space while the mixed sex broiler BW at 1, 14, 28, and 42 d of age were increased in the 308 strain. The 308 strain by Fast feed increase rate combination produced the largest chicks at hatching while the 708 strain by Fast or Slow feed increase rate combinations produced the smallest chicks with the 308 strain by Slow feed increase rate intermediate. There were no significant effects due to feed increase rate as well as the growing feeder space by female strain interaction and the growing feeder space by feed increase rate interaction found.

The main effects of broiler breeder female feeder space allocation during growing, female strain, and feed increase rate from photostimulation to peak egg production, as well as the growing feeder space by strain interaction, growing feeder space by feed increase rate interaction, and strain by feed increase rate interaction on the adjusted feed conversion ratio (AdjFCR) of mixed sex broilers from 1-14, 14-28, 1-28, 28-42, and 1-42 d of age are shown in Table I-11. The 308 strain in broilers exhibited the best AdjFCR for the 1-14 d period. There were no other significant main effects nor any interactions found.

The main effects of broiler breeder female feeder space allocation during growing, female strain, and feed increase rate from photostimulation to peak egg production, as well as the growing feeder space by strain interaction, growing feeder space by feed increase rate interaction, and strain by feed increase rate interaction on percentage mortality of mixed sex broilers from 1-14, 14-28, 1-28, 28-42, and 1-42 d of age are shown in Table I-12. The percentage mortality for the 14-28 d period was significantly affected by the growing feeder space where the 5.3 cm growing feeder space group exhibited increased mortality. The percentage mortality for the 14-28 d period was significantly affected by female strain where the 708 strain increased mortality. The 5.3 cm growing feeder space by 708 strain combination produced the most mortality during the 14-28 d period when compared to all other combinations. There were no significant effects due to feed increase rate as well as the growing feeder space by feed increase rate and female strain by feed increase rate combinations found.

DISCUSSION

Siegel and Dunnington (1985) stated that selection for increased juvenile BW has been negatively correlated with the onset of sexual maturity and fertility. Precision limited feeding has been found to ameliorate this problem. According to Melnychuk et al. (2004), feed level at the time of photostimulation will have an effect on reproductive tract development. The oviduct has been reported to be a priority tissue for nutrient partitioning during sexual maturation from 22 wk of age to 32 wk of age (Joseph et al., 2002) which was coincided with the time that we used Fast and Slow feeding to peak programs in the present study. As was observed, the Fast feeding to peak program produced hens with heavier BW at 31 wk of age that may have been associated with an increased mortality rate during the early laying period (26 to 32 wk) when compared to the Slow feed increase rate (Figure I-3). This 23 to 29 wk period coincided with the hottest environmental temperatures during this study. According to Melnychuk et al. (2004), even with limited feeding, broiler breeder hens preferentially used available nutrients for breast meat deposition. Thus, the Fast feeding to peak program probably increased the breast muscle mass of the higher yielding Ross 708 hens more than the Ross 308 hens, which explains the higher mortality rate during the hot weather. Ross 708 strain broiler breeders were significantly heavier than the 308 strain at 20 wk of age. The reported heat-loss deficiency in *ad libitum* fed hens may have its origins in elevated blood viscosity and vascular resistance that resulted from high blood plasma triglyceride concentrations (Chien, 1982). Increased viscosity has been shown to lead to an increased resistance to blood flow. An inability to control the distribution of blood flow would compromise an important thermoregulatory component during heat stress (Chien, 1982), which leads to higher mortality. However, the obligatory restricted feeding used in broiler breeders reduced heat production by 23% versus *ad libitum* feeding largely because of the reduction in BW (MacLeod and Hocking, 1993). Apparently, this effect may be evident over a reasonably wide range of restricted feeding and BW during the onset of lay. There were no significant differences in BW, egg production, fertility, or hatchability due to Fast or Slow feeding to peak program. However, the absence of significant differences in mortality between the two strains when exposed to the Slow feeding to peak program suggested that the same feeding program can be used for both strains. However, the hatchability of fertile eggs was about 1% greater due to lower late deads in the Ross 708 when compared to Ross 308 (Table I-9). This finding was in an agreement with the observation from Mr. John Blakely, Technical Manager, Aviagen. He stated that, "what we have seen is that the 708 hatches about 1% better than what we have seen with the 308". The reason for lower hatchability of fertile as well as higher late mortality in the Ross 308 might be because of the heavier EW and percentage egg shell (Table I-6, I-7). The percentage egg shell was significantly greater in the Ross 308, which means that the egg shell was probably thicker. This could be related to a lower eggshell conductance that caused higher late mortality as the metabolic rate of the embryo has been shown to increase during the second half of incubation as the embryo requires more oxygen during this period. The result from Lourens et al., (2005) also showed that the embryonic mortality was highest during the last week of incubation and that chick quality suffered when eggs were incubated during the final week of incubation higher than 38.9^{o}C eggshell temperatures compared with normal temperature of 37.8^{o}C temperatures. Differences in the AdjFCR and mortality of the broilers from 1-42 d period due to broiler breeder feeder space allocation, strains, and feed increase rate (Table I-11, I-12) were not observed. As expected, broilers that were hatched from the Ross 308 were significantly heavier due to heavier egg weight (Table I-10). Based upon our previous observations, breast muscle development may influence reproductive development as hens from the Slow feeding to peak program had smaller gross breast weight and heavier relative weights of magnum, infundibulum, isthmus, and total oviduct than hens from the Fast program (Leksrisompong et al., 2007). As a percentage of BW, hens on a feed-restriction program had significantly greater oviduct weights (Melnychuk et al., 2004) as compared to full-fed birds. It can be concluded that a Slow feeding to peak program was beneficial for broiler breeder females during hot weather because of reduced mortality, irrespective of strain. Larger than average pullets do not necessarily exhibit increased mortality if fed appropriately during the onset of lay.

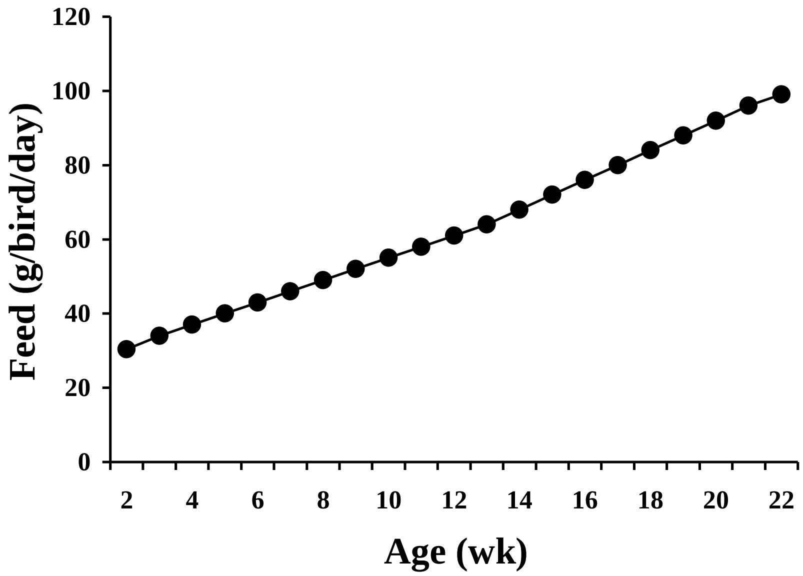

Figure I-1. Feeding program during the rearing period in Manuscript I. Ross 308 and 708SF pullets received feed according to this feeding program from placement to 22 wk of age.

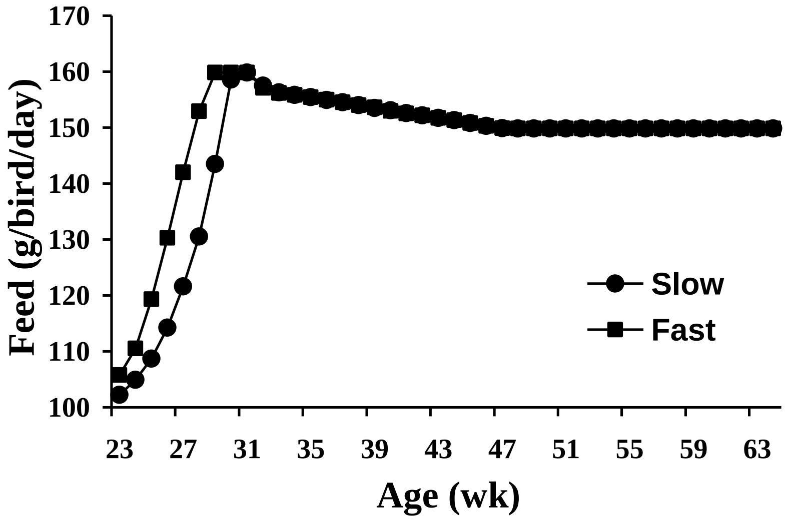

Figure I-2. Feeding to peak programs in Manuscript I. Ross 308 and 708SF hens received feed according to these two feeding programs. Either Fast feed from 23 to 29 wk of age or Slow feed from 23 to 30 wk of age. All the hens received the same feed rate thereafter. Rectangles represent the Fast feeding to peak program and circles represent the Slow feeding to peak program.

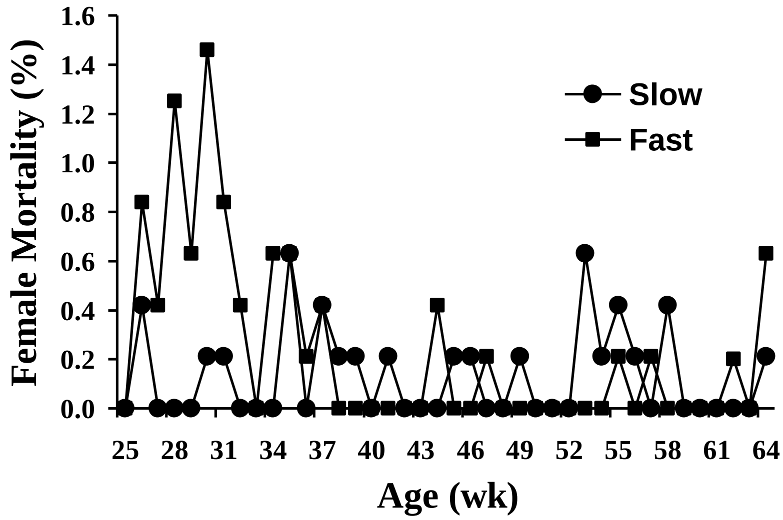

Figure I-3. Percentage female mortality during the laying period as affected by female feeding to peak program in Manuscript I. The hottest temperature occurred from 23 to 29 wk of age. Rectangles represent the mortality due to the Fast feeding to peak program and circles represent the mortality due to the Slow feeding to peak program.

Table I-1. Composition of starter (1 to 6 wk), grower (7 to 21 wk), and breeder (22 to 64) diets in Manuscript I-V.

Ingredient and analysis	Starter Diet	Grower Diet	Breeder Diet
		(%)	
Corn	64.30	65.49	66.73
Soybean meal (48 % CP)	22.17	16.53	19.17
Wheat bran	7.98	12.61	3.00
Dicalcium phosphate	2.04	1.99	1.70
Limestone	1.13	1.02	5.94
Mineral premix[1]	0.20	0.20	0.20
Vitamin premix[2]	0.10	0.10	0.10
Salt	0.63	0.64	0.50
Coccidiostat (Amprol)	0.05	0.05	0.05
D,L-Methionine	0.07	0.04	0.06
Selenium premix	0.10	0.10	0.10
Lysine, HCl	-	0.01	-
Choline chloride, 60%	0.20	0.20	0.20
Poultry fat	1.00	1.00	2.23
Antibiotic	0.03	0.03	0.03
Totals	100.00	100.00	100.00
Calculated analysis[3]			
Crude protein, %	17.00	15.00	15.00
ME, kcal/g	2.93	2.93	2.93
Lysine, %	0.88	0.75	0.77
Methionine + Cysteine, %	0.71	0.63	0.63
Calcium, %	0.95	0.90	2.70
Available Phosphorous, %	0.45	0.45	0.40

[1] Mineral premix contained the following in milligrams per kilogram of diet: manganese, 120; zinc, 120; iron, 80; copper, 10; iodine, 2.5; and cobalt, 1.0.

[2] Vitamin premix contained the following per kilogram of diet: Vitamin A, 13,200 IU; cholecalciferol, 4,000 IU; Vitamin E, 66 IU; Vitamin B-12, 34.6 ug; riboflavin, 13.2 mg; niacin, 110 mg; pantothenic acid, 22 mg; Vitamin K, 4 mg; folic acid, 2.2 mg; thiamine, 4 mg; pyridoxine, 8 mg; and biotin, 252 ug.

[3]Data presented as a percentage of dry matter.

Table I-2. Composition of broiler diets in Manuscript I, II, III, and V.

Ingredient and analysis	(1-14 d) Starter Diet	(14-42 d) Grower Diet
	(%)	
Corn	54.04	62.83
Soybean meal (48 % CP)	36.80	29.03
Dicalcium phosphate	2.10	1.85
Limestone	0.96	1.01
Mineral premix[1]	0.20	0.20
Vitamin premix[2]	0.05	0.05
Salt	0.55	0.50
Coccidiostat (Coban)	0.08	0.08
D,L-Methionine	0.19	0.14
Selenium premix	0.10	0.10
L-Lysine, HCL	-	0.05
L-Threonine	0.05	-
Choline chloride, 60%	0.20	0.20
Poultry fat	4.69	3.98
Totals	100.00	100.00
Calculated analysis[3]		
Crude protein, %	23.00	20.00
ME, kcal/g	3.10	3.15
Lysine, %	1.28	1.10
Methionine + Cysteine, %	0.94	0.82
Calcium, %	0.90	0.85
Available Phosphorous, %	0.45	0.40

[1] Mineral premix contained the following in milligrams per kilogram of diet: manganese, 120; zinc, 120; iron, 80; copper, 10; iodine, 2.5; and cobalt, 1.0.

[2] Vitamin premix contained the following per kilogram of diet: Vitamin A, 6,600 IU; cholecalciferol, 2,000 IU; Vitamin E, 33 IU; Vitamin B-12, 20 ug; riboflavin, 6 mg; niacin, 55 mg; pantothenic acid, 11 mg; Vitamin K, 2 mg; folic acid, 1.1 mg; thiamine, 2 mg; pyridoxine, 3.95 mg; and biotin, 125 ug.

[3]Data presented as a percentage of dry matter.

TABLE I-3. Broiler breeder female BW (group samples) as affected by broiler breeder female feeder space allocation during growing, female strain, and feed increase rate from photostimulation to peak egg production, as well as the growing feeder space by strain interaction, growing feeder space by feed increase rate interaction, and strain by feed increase rate interaction in Experiment I.

Feeder Space During Growing[1]	Strain[2]	Peak Feed Increase[3]	Age: d 1	wk 43	wk 48	wk 56
(cm)			(g)	(kg)		
5.3			38.6	3.782	3.875	4.003
7.0			38.6	3.670	3.773	3.921
	308		35.7[B]	3.741	3.861	3.960
	708		41.5[A]	3.711	3.787	3.965
		Fast	38.5	3.779	3.856	3.974
		Slow	38.7	3.673	3.792	3.951
	SEM		0.1[4]	0.036[5]	0.035[5]	0.046[5]
5.3	308		35.5	3.770	3.857	4.012
5.3	708		41.6	3.794	3.893	3.995
7.0	308		35.9	3.712	3.864	3.908
7.0	708		41.4	3.628	3.682	3.935
5.3		Fast	38.5	3.832	3.942	4.052
5.3		Slow	38.7	3.732	3.809	3.955
7.0		Fast	38.6	3.725	3.770	3.896
7.0		Slow	38.7	3.615	3.776	3.947
	308	Fast	35.5	3.782	3.857	3.994
	308	Slow	36.0	3.701	3.865	3.926
	708	Fast	41.6	3.776	3.855	3.954
	708	Slow	41.4	3.646	3.720	3.976
	SEM		0.1[6]	0.051[7]	0.050[7]	0.065[7]

[A,B] Means in a column that possess different superscripts differ significantly ($P \leq 0.01$).
[1] Feeder space allocations of 5.3 or 7.0 cm per each of 75 pullets during growing.
[2] Female breeder strain was Ross 308 or 708.
[3] Feed increase rates (see Fig. I-2) from photostimulation to peak egg production.
[4] SEM for n=8 pens with 75 pullets per pen weighed.
[5] SEM for n=8 pens with 20 hens per pen weighed.
[6] SEM for n=4 pens with 75 pullets per pen weighed.
[7] SEM for n=4 pens with 20 hens per pen weighed.

TABLE I-4. Broiler breeder female BW (individual) as affected by broiler breeder female feeder space allocation during growing, female strain, and feed increase rate from photostimulation to peak egg production, as well as the growing feeder space by strain interaction, growing feeder space by feed increase rate interaction, and strain by feed increase rate interaction in Experiment I.

Feeder Space During Growing[1]	Strain[2]	Peak Feed Increase[3]	Wk of Age		
			20	31	64
(cm)			(kg)		
5.3			2.301	3.313	3.910
7.0			2.301	3.250	3.820
	308		2.272[B]	3.313	3.845
	708		2.330[A]	3.250	3.885
		Fast	2.301	3.334[A]	3.867
		Slow	2.302	3.229[B]	3.863
	SEM		0.012[4]	0.021[5]	0.045[5]
5.3	308		2.274	3.327	3.867
5.3	708		2.328	3.298	3.953
7.0	308		2.270	3.298	3.824
7.0	708		2.333	3.201	3.817
5.3		Fast	2.313	3.371	3.922
5.3		Slow	2.289	3.254	3.898
7.0		Fast	2.289	3.296	3.813
7.0		Slow	2.314	3.203	3.828
	308	Fast	2.262	3.355	3.840
	308	Slow	2.282	3.270	3.851
	708	Fast	2.339	3.312	3.894
	708	Slow	2.321	3.187	3.876
	SEM		0.017[6]	0.029[7]	0.063[7]

[A,B] Means in a column that possess different superscripts differ significantly ($P \leq 0.01$).
[1] Feeder space allocations of 5.3 or 7.0 cm per each of 75 pullets during growing.
[2] Female breeder strain was Ross 308 or 708.
[3] Feed increase rates (see Fig. I-2) from photostimulation to peak egg production.
[4] SEM for n=8 pens with 75 pullets per pen weighed.
[5] SEM for n=8 pens with 60 hens per pen weighed.
[6] SEM for n=4 pens with 75 pullets per pen weighed.
[7] SEM for n=4 pens with 60 hens per pen weighed.

TABLE I-5. Coefficient of variation (CV) of broiler breeder female BW as affected by broiler breeder female feeder space allocation during growing, female strain, and feed increase rate from photostimulation to peak egg production, as well as the growing feeder space by strain interaction, growing feeder space by feed increase rate interaction, and strain by feed increase rate interaction in Experiment I.

			Wk of Age		
Feeder Space During Growing[1]	Strain[2]	Peak Feed Increase[3]	20	31	64
(cm)				(%CV)	
5.3			11.68	8.33	11.25
7.0			11.05	8.08	11.15
	308		11.46	8.25	11.49
	708		11.26	8.13	10.92
		Fast	11.44	8.41	11.27
		Slow	11.28	7.97	11.13
	SEM		0.40[4]	0.36[5]	0.38[5]
5.3	308		11.07	8.57	10.92
5.3	708		11.02	8.03	11.38
7.0	308		11.85	7.93	12.05
7.0	708		11.51	8.24	10.45
5.3		Fast	11.45	8.84	11.50
5.3		Slow	10.65	7.76	10.81
7.0		Fast	11.44	7.98	11.04
7.0		Slow	11.91	8.18	11.46
	308	Fast	11.78	8.28	11.46
	308	Slow	11.14	8.22	11.52
	708	Fast	11.11	8.54	11.09
	708	Slow	11.42	7.72	10.75
	SEM		0.56[6]	0.51[7]	0.54[7]

[1] Feeder space allocations of 5.3 or 7.0 cm per each of 75 pullets during growing.
[2] Female breeder strain was Ross 308 or 708.
[3] Feed increase rates (see Fig. I-2) from photostimulation to peak egg production.
[4] SEM for n=8 pens with 75 pullets per pen weighed and CV calculated on a pen basis.
[5] SEM for n=8 pens with 60 hens per pen weighed and CV calculated on a pen basis.
[6] SEM for n=4 pens with 75 pullets per pen weighed and CV calculated on a pen basis.
[7] SEM for n=4 pens with 60 hens per pen weighed and CV calculated on a pen basis.

TABLE I-6. Egg weight (EW) and percentage egg shell at 28 wk of age as affected by broiler breeder female feeder space allocation during growing, female strain, and feed increase rate from photostimulation to peak egg production, as well as the growing feeder space by strain interaction, growing feeder space by feed increase rate interaction, and strain by feed increase rate interaction in Experiment I.

Feeder Space During Growing[1]	Strain[2]	Peak Feed Increase[3]	Egg Weight	Egg Shell
(cm)			(g)	(%EW)
5.3			51.56[B]	9.01
7.0			52.20[A]	8.93
	308		52.86[A]	9.15[A]
	708		50.90[B]	8.78[B]
		Fast	51.67	8.91
		Slow	52.08	9.03
	SEM[4]		0.13	0.07
5.3	308		52.40	9.20
5.3	708		50.71	8.81
7.0	308		53.31	9.10
7.0	708		51.09	8.75
5.3		Fast	51.35	8.83[b]
5.3		Slow	51.76	9.18[a]
7.0		Fast	52.00	8.98[ab]
7.0		Slow	52.40	8.87[ab]
	308	Fast	52.79	9.06
	308	Slow	52.92	9.24
	708	Fast	50.56	8.75
	708	Slow	51.24	8.81
	SEM[5]		0.19	0.10

[a,b] Means in a column that possess different superscripts differ significantly ($P \leq 0.05$).
[A,B] Means in a column that possess different superscripts differ significantly ($P \leq 0.01$).
[1] Feeder space allocations of 5.3 or 7.0 cm per each of 75 pullets during growing.
[2] Female breeder strain was Ross 308 or 708.
[3] Feed increase rates (see Fig. I-2) from photostimulation to peak egg production.
[4] SEM for n=8 pens with approximately 20 to 40 eggs weighed per pen.
[5] SEM for n=4 pens with approximately 20 to 40 eggs weighed per pen.

TABLE I-7. Egg weight (EW) and egg components at 30 wk of age as affected by broiler breeder female feeder space allocation during growing, female strain, and feed increase rate from photostimulation to peak egg production, as well as the growing feeder space by strain interaction, growing feeder space by feed increase rate interaction, and strain by feed increase rate interaction in Experiment I.

Feeder space During Growing[1]	Strain[2]	Peak Feed Increase[3]	Egg Weight	Yolk Weight	Egg Shell	Albumen	Yolk:Alb ratio
(cm)			(g)	(%EW)			(g:g)
5.3			53.59[b]	26.54	9.48	63.97	0.416
7.0			54.14[a]	26.50	9.45	64.05	0.414
	308		55.04[A]	26.43	9.66[A]	63.91	0.414
	708		52.68[B]	26.61	9.28[B]	64.11	0.416
		Fast	53.67	26.73[a]	9.38[B]	63.89	0.419[a]
		Slow	54.06	26.31[b]	9.55[A]	64.14	0.411[b]
	SEM[4]		0.16	0.09	0.35	0.10	0.21
5.3	308		54.58	26.44	9.65	63.91	0.414
5.3	708		52.61	26.65	9.32	64.04	0.417
7.0	308		55.51	26.42	9.67	63.91	0.414
7.0	708		52.76	26.58	9.24	64.18	0.415
5.3		Fast	53.30	26.91[a]	9.39	63.69	0.423
5.3		Slow	53.89	26.18[b]	9.57	64.25	0.408
7.0		Fast	54.04	26.55[ab]	9.37	64.08	0.415
7.0		Slow	54.23	26.44[b]	9.54	64.02	0.413
	308	Fast	55.08	26.55	9.62	63.83	0.416
	308	Slow	55.01	26.31	9.70	63.99	0.412
	708	Fast	52.27	26.92	9.15	63.94	0.422
	708	Slow	53.10	26.31	9.41	64.28	0.410
	SEM[5]		0.23	0.13	0.05	0.14	0.30

[a,b] Means in a column that possess different superscripts differ significantly ($P \leq 0.05$).
[A,B] Means in a column that possess different superscripts differ significantly ($P \leq 0.01$).
[1] Feeder space allocations of 5.3 or 7.0 cm per each of 75 pullets during growing.
[2] Female breeder strain was Ross 308 or 708.
[3] Feed increase rates (see Fig. I-2) from photostimulation to peak egg production.
[4] SEM for n=8 pens with approximately 28 to 45 eggs weighed per pen.
[5] SEM for n=4 pens with approximately 28 to 45 eggs weighed per pen.

TABLE I-8. Broiler breeder egg production and female mortality from 25 to 64 wk of age as affected by broiler breeder female feeder space allocation during growing, female strain, and feed increase rate from photostimulation to peak egg production, as well as the growing feeder space by strain interaction, growing feeder space by feed increase rate interaction, and strain by feed increase rate interaction in Experiment I.

Feeder space During Growing[1]	Strain[2]	Peak Feed Increase[3]	Egg Production: Eggs per Hen Housed	Egg Production: Hen-day Production	Female Mortality
(cm)			(n)	(%)	(%)
5.3			162	61.0	7.7
7.0			162	60.1	7.1
	308		160	60.1	8.3
	708		164	61.0	6.5
		Fast	157	60.4	9.6^{A}
		Slow	166	60.7	5.2^{B}
	SEM[4]		3	1.2	0.9
5.3	308		158	60.7	10.0
5.3	708		165	61.4	5.5
7.0	308		161	60.0	6.7
7.0	708		162	60.7	7.5
5.3		Fast	157	60.8	10.5
5.3		Slow	167	61.3	5.0
7.0		Fast	158	60.1	8.8
7.0		Slow	165	60.2	5.4
	308	Fast	156	60.3	10.8
	308	Slow	164	60.0	5.9
	708	Fast	159	60.6	8.4
	708	Slow	168	61.5	4.6
	SEM[5]		5	1.6	1.2

^{A,B} Means in a column that possess different superscripts differ significantly ($P \leq 0.01$).
[1] Feeder space allocations of 5.3 or 7.0 cm per each of 75 pullets during growing.
[2] Female breeder strain was Ross 308 or 708.
[3] Feed increase rates (see Fig. I-2) from photostimulation to peak egg production.
[4] SEM for n=8 pens of 60 hens.
[5] SEM for n=4 pens of 60 hens.

TABLE I-9. Broiler breeder fertility, hatchability, and embryonic mortality from 28 to 64 wk of age from weekly set of 90 eggs as affected by broiler breeder female feeder space allocation during growing, female strain, and feed increase rate from photostimulation to peak egg production, as well as the growing feeder space by strain interaction, growing feeder space by feed increase rate interaction, and strain by feed increase rate interaction in Experiment I.

Feeder space During Growing[1]	Strain[2]	Peak Feed Increase[3]	Incubation Variables[4]				
			Fertility	Hatchability of Fertile Egg	Hatchability of Total Eggs	Early[5] Dead	Late[6] Dead
(cm)			(%)				
5.3			94.82	94.44	89.55	2.88	2.68
7.0			94.43	94.59	89.34	2.88	2.53
	308		94.14	94.01^{b}	88.50	3.00	2.99^{A}
	708		95.11	95.02^{a}	90.38	2.77	2.21^{B}
		Fast	94.27	94.27	88.87	3.12	2.61
		Slow	94.98	94.77	90.01	2.64	2.59
5.3	308		94.75	93.91	88.97	3.04	3.06
5.3	708		94.89	94.98	90.12	2.73	2.29
7.0	308		93.52	94.12	88.03	2.96	2.92
7.0	708		95.34	95.07	90.64	2.80	2.13
5.3		Fast	95.09	93.81	89.21	3.31	2.88
5.3		Slow	94.54	95.07	89.89	2.46	2.48
7.0		Fast	93.45	94.72	88.53	2.93	2.35
7.0		Slow	95.41	94.47	90.14	2.83	2.70
	308	Fast	94.14	93.64	88.15	3.25	3.11
	308	Slow	94.13	94.38	88.85	2.75	2.87
	708	Fast	94.41	94.89	89.59	3.00	2.11
	708	Slow	95.82	95.15	91.17	2.53	2.31

[a,b] Means in a column that possess different superscripts differ significantly ($P \leq 0.05$).
[A,B] Means in a column that possess different superscripts differ significantly ($P \leq 0.01$).
[1] Feeder space allocations of 5.3 or 7.0 cm per each of 75 pullets during growing.
[2] Female breeder strain was Ross 308 or 708.
[3] Feed increase rates (see Fig. I-2) from photostimulation to peak egg production.
[4] Categorical analysis does not generate SEM.
[5] Embryos that died from 1-7 d.
[6] Embryo that died after 7 d.

TABLE I-10. The BW of mixed sex broiler chickens produced from egg laid at 31 wk of age as affected by broiler breeder female feeder space allocation during growing, female strain, and feed increase rate from photostimulation to peak egg production, as well as the growing feeder space by strain interaction, growing feeder space by feed increase rate interaction, and strain by feed increase rate interaction in Experiment I.

Broiler Breeder			Mixed Sex Broiler BW For Ages Shown			
Feeder Space During Growing[1]	Strain[2]	Peak Feed Increase[3]	1 d	14 d	28 d	42 d
(cm)			(g)			
5.3			38.1^{B}	481.0	1407.9	2449.7
7.0			38.7^{A}	487.0	1411.1	2466.8
	308		39.3^{A}	509.4^{A}	1461.6^{A}	2543.2^{A}
	708		37.5^{B}	458.6^{B}	1357.4^{B}	2373.3^{B}
		Fast	38.6	482.0	1415.0	2448.2
		Slow	38.3	486.0	1404.0	2468.2
	SEM[4]		0.2	4.1	12.7	15.9
5.3	308		39.1	508.9	1461.7	2535.6
5.3	708		37.1	453.2	1354.0	2363.7
7.0	308		39.5	510.0	1461.5	2550.9
7.0	708		38.0	464.0	1360.7	2382.8
5.3		Fast	38.1	479.3	1431.3	2448.4
5.3		Slow	38.1	482.8	1384.4	2450.9
7.0		Fast	39.1	484.8	1398.7	2448.1
7.0		Slow	38.4	489.2	1423.5	2485.6
	308	Fast	39.7^{a}	507.5	1461.9	2540.0
	308	Slow	38.9^{b}	511.3	1461.2	2546.5
	708	Fast	37.5^{c}	456.6	1368.0	2356.5
	708	Slow	37.6^{c}	460.7	1346.7	2390.0
	SEM[5]		0.2	5.8	18.0	22.5

[a,b,c] Means in a column that possess different superscripts differ significantly ($P \leq 0.05$).
[A,B] Means in a column that possess different superscripts differ significantly ($P \leq 0.01$).
[1] Feeder space allocations of 5.3 or 7.0 cm per each of 75 pullets during growing.
[2] Female breeder strain was Ross 308 or 708.
[3] Feed increase rates (see Fig. I-2) from photostimulation to peak egg production.
[4] SEM for n=16 pens with 38 broilers per pen.
[5] SEM for n=8 pens with 38 broilers per pen.

TABLE I-11. Adjusted feed consumption ratio (AdjFCR) of mixed sex broiler chickens produced from egg laid at 31 wk of age produced from egg laid at 31 wk of age as affected by broiler breeder female feeder space allocation during growing, female strain, and feed increase rate from photostimulation to peak egg production, as well as the growing feeder space by strain interaction, growing feeder space by feed increase rate interaction, and strain by feed increase rate interaction in Experiment I.

Broiler Breeder			Mixed Sex Broiler AdjFCR For Ages Shown				
Feeder Space During Growing[1]	Strain[2]	Peak Feed Increase[3]	1-14	14-28	1-28	28-42	1-42
(cm)					(g:g)		
5.3			1.36	1.65	1.55	1.98	1.73
7.0			1.33	1.62	1.53	1.99	1.72
	308		1.31[B]	1.63	1.52	2.03	1.74
	708		1.37[A]	1.64	1.56	1.94	1.72
		Fast	1.34	1.59	1.51	2.01	1.72
		Slow	1.34	1.68	1.57	1.96	1.74
	SEM[4]		0.02	0.04	0.03	0.04	0.02
5.3	308		1.34	1.65	1.54	2.04	1.73
5.3	708		1.37	1.65	1.56	1.91	1.70
7.0	308		1.28	1.61	1.50	2.02	1.72
7.0	708		1.37	1.63	1.55	1.96	1.73
5.3		Fast	1.35	1.60	1.52	2.05	1.73
5.3		Slow	1.36	1.70	1.59	1.91	1.73
7.0		Fast	1.33	1.58	1.50	1.97	1.70
7.0		Slow	1.32	1.66	1.55	1.02	1.75
	308	Fast	1.30	1.59	1.49	2.05	1.73
	308	Slow	1.32	1.67	1.55	2.02	1.75
	708	Fast	1.38	1.59	1.52	1.97	1.71
	708	Slow	1.37	1.69	1.59	1.90	1.72
	SEM[5]		0.02	0.05	0.04	0.05	0.03

[A,B] Means in a column that possess different superscripts differ significantly ($P \leq 0.01$).
[1] Feeder space allocations of 5.3 or 7.0 cm per each of 75 pullets during growing.
[2] Female breeder strain was Ross 308 or 708.
[3] Feed increase rates (see Fig. I-2) from photostimulation to peak egg production.
[4] SEM for n=16 pens with 38 broilers per pen.
[5] SEM for n=8 pens with 38 broilers per pen.

TABLE I-12. Percentage mortality (deaths) of mixed sex broiler chickens produced from egg laid at 31 wk of age as affected by broiler breeder female feeder space allocation during growing, female strain, and feed increase rate from photostimulation to peak egg production, as well as the growing feeder space by strain interaction, growing feeder space by feed increase rate interaction, and strain by feed increase rate interaction in Experiment I.

Broiler Breeder			Mixed Sex Broiler Deaths For Ages Shown				
Feeder Space During Growing[1]	Strain[2]	Peak Feed Increase[3]	1-14	14-28	1-28	28-42	1-42
(cm)			(%)				
5.3			0.82	0.82[a]	1.64	1.15	2.80
7.0			1.16	0.00[b]	1.16	0.99	2.15
	308		1.48	0.00[b]	1.48	1.48	2.96
	708		0.49	0.82[a]	1.32	0.66	1.98
		Fast	1.16	0.16	1.32	1.15	2.47
		Slow	0.82	0.06	1.48	0.99	2.47
	SEM[4]		0.41	0.22	0.51	0.53	0.61
5.3	308		1.32	0.00[b]	1.32	1.32	2.63
5.3	708		0.33	1.64[a]	1.97	0.99	2.96
7.0	308		1.65	0.00[b]	1.65	1.64	3.30
7.0	708		0.66	0.00[b]	0.66	0.34	1.00
5.3		Fast	0.66	0.33	0.99	1.97	2.96
5.3		Slow	0.99	1.32	2.30	0.33	2.63
7.0		Fast	1.65	0.00	1.65	0.33	1.98
7.0		Slow	0.66	0.00	0.66	1.65	2.31
	308	Fast	1.65	0.00	1.65	1.64	3.30
	308	Slow	1.32	0.00	1.32	1.32	2.63
	708	Fast	0.66	0.33	0.99	0.66	1.64
	708	Slow	0.33	1.32	1.64	0.67	2.31
	SEM[5]		0.59	0.31	0.72	0.74	0.86

[a,b] Means in a column that possess different superscripts differ significantly ($P \leq 0.05$).
[1] Feeder space allocations of 5.3 or 7.0 cm per each of 75 pullets during growing.
[2] Female breeder strain was Ross 308 or 708.
[3] Feed increase rates (see Fig. I-2) from photostimulation to peak egg production.
[4] SEM for n=16 pens with 38 broilers per pen.
[5] SEM for n=8 pens with 38 broilers per pen.

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MANUSCRIPT II. Effect of Feeder Space during the Growing and Laying Periods and the Rate of Feed Increase at the Onset of Lay on Uniformity and Reproductive Function

ABSTRACT

A study was conducted to examine how two feeder space allocations during the rearing period followed by two feeder space allocations after photostimulation and two female feeding to peak programs (Fast or Slow) affected broiler breeder female reproductive performance, mortality, and performance of broiler progeny. Sixteen pens of 76 breeder females each were equipped with either 4 tube feeders (7.0 cm/female) or 6 tube feeders (10.4 cm/female) from 1 to 21 wk of age. Thereafter, 7 males and 64 females were moved to each of 16 breeding pens, photostimulated, and fed sex-separate. The females were then fed from either 3 (6.2 cm/female) or 5 (10.3 cm/female) tube feeders (138 cm circumference pan) per pen and either Fast or Slow feeding to peak feeding programs were applied to complete a 2 x 2 x 2 factorial design with two replicate pens per interaction cell. The four feeder space combinations produced were 7.0-6.2 cm, 7.0-10.3 cm, 10.4-6.2 cm, and 10.4-10.3 cm. These represented a small decrease in feeder space per female (7.0-6.2 cm), a similar feeder space (10.4-10.3 cm), an increase in feeder space (7.0-10.3 cm), and a decrease in feeder space (10.4-6.2 cm) as pullets were moved and photostimulated. Individual female BW was determined at 6, 20, and 32 wk of age and BW uniformity assessed. Broiler breeder females that were grown on greater feeder space during the rearing were heavier at 32 wk of age while females that were grown on greater feeder space during lay and with the Slow feeding to peak program were smaller at 32 wk. There were no differences in BW due to different feeder space combinations. The Fast feeding to peak program increased yolk weight as well as yolk:albumen ratio at 28 and 30 wk of age. However, EW was the same in all of the treatments. Increased mortality for the decreased feeder space combination started immediately during the laying period, but increased mortality coincided with hot weather for the increase in feeder space combination. The best livability was from the least change in feeder space group.

Eggs produced by these hens at 28 wk of age were incubated under standard conditions and the carryover effects on the broiler progeny evaluated. There were 15 male and 15 female broiler chicks mixed equally and placed in each of 32 pens in a 2 x 2 x 2 design with 4 replicates per interaction cell. Broiler BW, feed consumption, adjusted feed conversion ratio (AdjFCR), and mortality were measured at 1, 21, and 40 d of age. Greater feeder space during the rearing and laying periods produced heavier broiler chicks at hatching (1d). There were no effects on AdjFCR as well as mortality of broiler progeny. These data indicated that either high or low feeder space as well as increased or decreased feeder space between the growing and laying periods did not affect broiler breeder female BW, uniformity, and broiler progeny but did affect broiler breeder female livability.

Key words: broiler breeders, feeder space, uniformity

INTRODUCTION

Historically, the brood-grow-lay housing system where broiler breeders reside for 65 wk in a single facility has been popular internationally while the brood-grow and lay housing system where broiler breeders have been moved from growing quarters to laying quarters at about 21 wk of age has been popular in the USA. Even though the USA system has economic advantages, production results have been generally acknowledged among industry personnel to favor the brood-grow-lay system. One of the differences between the brood-grow-lay versus brood-grow and lay systems has been the difference in feeding systems and feeder space between the growing and laying houses. Many of the primary breeder management guide programs have suggested that adequate feeder space to insure that all birds have access to the feed at the same time was a critical point and that feeder space should increase as the birds age (Anonymous, 1986, 2000). Also, inadequate feeder space has been generally associated with poor uniformity of flock BW (Anonymous, 1997, 2009). However, our studies with males (24 wk of age) with an increased feeder space produced a poorer coefficient of variation for feed consumption when compared to males with less feeder space (40.58 and 20.45 %CV, respectively) (unpublished data). This mean that having "adequate feeder space" or an increase in feeder at moving was not necessarily good, as it could lower the uniformity of feed consumption that could lead to poorer bird performance.

The ovary and oviduct develop rapidly during the time of sexual maturity that follows movement to the laying quarters. The increment of the ovary and oviduct was reported to be several thousand percent in only a few weeks at sexual maturity (Breneman, 1956). Both the ovary and oviduct have been shown to be sensitive organs to the feed allocation program at the time of photostimulation during sexual maturation. According to Zuidhof et al. (2007), the growth and development of the oviduct can be very responsive to feed allocation during sexual maturation. While overfeeding during reproductive development has been found to increase the formation of large yellow ovarian follicles, which are more likely to be arranged in multiple hierarchies of large follicles (Hocking et al., 1987; Katanbaf et al., 1989; Yu et al., 1992). Overfeeding for as little as 2 wk between photostimulation and peak egg production can permanently harm fertility and hatchability (Ingram and Wilson, 1987). Thus, this study was conducted to examine how two feeder space allocations during rearing and two feeder space allocations during laying incubation with two feed increase rates from photostimulation to peak egg production affected both broiler breeder female and broiler progeny performance.

MATERIALS AND METHODS

***Broiler Breeder Rearing Period*.** Broiler breeder males (Ross 344) and females (Ross 708SF) were placed in an enclosed fan-ventilated 32-pen litter floor rearing house with 16 (14.3 m^2 area) pens for females and 16 (4.6 m^2 area) pens for males. The rearing house was equipped with 5 space heaters and 6 upward directed fans in the central walkway with pens on either side to insure a uniform temperature throughout the house. At placement, there were 76 females and 25 males in each female and male pen, respectively. There were either

4 or 6 tube feeders (Kuhl DH-4) per female rearing pen as well as 1 tube feeder per male rearing pen. Each feeder pan had a circumference of 132 cm. After 23 h of light per day for one week all birds were reared to 21 wk of age with 8 h of light per day at an average light intensity of 15 lux using 12W fluorescent lamps. Access to water was limited by a time clock and solenoid system sufficient to control litter moisture and allow the birds to have unlimited access to water until at least one hour after all feed was consumed and a similar amount on non-feed days during rearing. This was typically 6 h daily. A group BW of all females and males was taken at placement (1d) and individual female and male BW was taken at 6 and 20 wk of age.

Broiler Breeder Production Period. An average of 64 females and 7 males were moved as groups from each rearing pen to each of 16 slat-litter floor laying pens (17.5 m^2 total area/pen, 4.6 m^2 litter area/pen) at 21 wk of age. Birds were photostimulated with 14 h of light at the time of movement. The day length was subsequently increased to 15 h 7 d later, and then to 15.5 h and 16 h at 5% and 50% rate of lay, respectively. Natural light entered the slat-litter house through open or translucent curtains during normal daylight hours. Supplemental light provided an average intensity of 35 lux at bird head level using 18W fluorescent lamps when natural light was not present. There were either 3 or 5 tube feeders for females and 1 tube feeder for males in each laying pen. Water was limited to 8 h per day during the laying period using two bell-type drinkers in each of the 16 breeding pens. One 6-hole (50.8 cm wide nest spaces) conventional nest was provided in each breeding pen. Separation of sexes was insured by special grills (sixteen 4.8 x 5.8 cm holes per pan) on each female feeder that prevented the non-dubbed males from accessing the feed. Individual female BW was taken at 32 wk of age. Group BW of all females were also taken at 48 wk of age. At 28 and 30 wk of age, 458 and 635 individual eggs, respectively, were collected and egg weight (EW) as well as yolk and albumen weight were determined gravimetrically. The contents were then removed and shells dried to constant weight before cooling to room temperature. The eggshells were then weighed. At 51 and 62 wk of age, a 20-egg sample was collected from each pen and EW and shell weight were determined as above.

Fertility and Hatchability. Eggs were collected twice daily from the nests and stored in an egg cooler at 16-18^{o}C and 60% RH until incubated. Eggs that were laid on the floor and slats were collected and enumerated separately but not incubated. Analysis of percentage fertility, hatchability, and embryo mortality was conducted from 26 to 63 wk of age by macroscopic examination of all unhatched eggs from weekly sets of 60 eggs per pen. All unhatched eggs were opened and examined macroscopically to determine fertility or infertility and, if fertile, to determine the stage of embryonic mortality. Embryos that died from 1-7 d of incubation were termed early deads and embryos that died after 7 d were termed late deads. Cracked eggs were deemed to be accidental in nature and were not included in the calculations. Eggs were set in a Jamesway model 252B incubator (Butler Manufacturing Co., Ft. Atkinson, WI 53538) that was comprised of fourteen 180-egg trays of which 6 trays were used. Each tray contained 6 cradles that held 30 eggs each. At 65 wk of age, all males were removed from the breeding pens so that eggs could be collected without males present to determine persistency of fertility in the females. Eggs were collected for the next 16 d and placed in an incubator daily to determine fertility following 12 d of incubation.

Experimental Diets and Feeding Programs. Feed for broiler breeders was provided daily during the first 2 wk of age and then a 4/3 feed allocation program (feed Monday, Wednesday, Friday, and Saturday only) was used until 21 wk of age after which a daily feeding program was employed (Fig. II-1). Diets are shown in Table I-1. A common starter diet (17% CP) was fed to all pens for 6 wk followed by a common grower diet (15% CP) from 7 to 25 wk (approximately 10% rate of lay). Females received 25.1 Mcal of ME and 1,349 g of CP cumulative nutrient intake while males received 30 Mcal of ME and 1,600 g of CP cumulative nutrient intake to 21 wk (147 d) of age. Two feed increase rates (Fast or Slow) were then used from photostimulation to peak egg production (Fig. II-2). The females that received the Fast feed increase rate reached peak feed of 160 g per female per day at 83% rate of lay while the Slow feed increase rate reached their peak feed 7 d later at 84% rate of lay. The feed allocation was then reduced once egg production across both treatments was similar for 5 d. The daily feed allocation was the same for all females thereafter. Male and female mortality was recorded daily and feed allocation adjusted accordingly.

Broiler Trial. To evaluate the possible effects of female breeder treatment on the performance of broiler progeny, a broiler trial was conducted. Broiler hatching eggs were collected from every pen at 28 wk of age. A total of 1,440 eggs were set in a Jamesway model 252B incubator. The incubator was initially operated for 3 d at 38.0^{o}C dry bulb and gradually decreased from that point to maintain egg temperature less than 37.8^{o}C as measured with a Braun thermoscan thermometer (Leksrisompong et al., 2007). The wet bulb temperature was 28.9^{o}C. At 21.5 d of incubation the chicks that had completed the hatching process were removed from the trays, counted, group weighed, and sexed using the feather-sexing method. After this processing was completed, the chicks were permanently identified with neck tags and then distributed among 32 floor pens with wood litter shavings. Each pen area was 4.4 m^2 with two feeders and one bell-type drinker provided in each of the 32 broiler pens. Males and females were mixed equally and placed in each pen with a total of 30 chicks per pen. During the first 7 d there were 3 egg flats used for supplemental feed with 1 supplemental chick font for water. Chicks were group weighed at placement and at 21 and 40 d of age. Feed consumption was determined at 21 and 40 d of age and adjusted feed conversion ratio (AdjFCR) was calculated. All dead birds were weighed and recorded twice daily and their BW was used in the AdjFCR calculation. A single starter or grower diet that met or exceeded the NRC (1994) minimum requirements was used during the starter and grower periods from 0-18 and 19-40 d of age, respectively (Table I-2). No finisher diet was used for the sake of simplicity.

Statistical Analyses. Broiler Breeders. The fertility and hatchability data were analyzed on a weekly basis. A completely randomized design with a factorial (2 x 2 x 2) arrangement of treatments was used. The main factors were feeder space allocation during rearing (7.0 or 10.4 cm feeders), feeder space allocation during production (6.2 or 10.3 cm feeders), and feed increase rate (Fast or Slow) from photostimulation to peak. The treatments were randomly distributed among 16 pens with 2 replicate pens per interaction cell. The general linear model (GLM) procedure of SAS Institute (2001) was used to analyze the continuous variables. The fertility data was analyzed as categorical data, where each individual egg was taken as a binomial event, either fertile or infertile, using the general model (GENMOD) procedure of SAS Institute (2001). Means were partitioned using LS MEANS and statements of statistical significance were based upon $P \leq 0.05$ unless otherwise stated.

Statistical Analyses. Broiler Trial. A randomized complete block design with a factorial (2 x 2 x 2) arrangement of breeder treatments was used. The main factors were breeder feeder space allocation during rearing (7.0 or 10.4 cm feeders), breeder feeder space allocation during production (6.2 or 10.3 cm feeders), and breeder feed increase rate (Fast or Slow). Breeder treatment identity was maintained for all broiler progeny chicks that were hatched through to the broiler pens. The treatments were randomly distributed among 32 progeny pens within 2 blocks of 16 pens each. There were 4 replicate pens per interaction cell. The general linear model (GLM) procedure of SAS Institute (2001) was used to analyze the continuous variables. Means were partitioned using LS MEANS and statements of statistical significance were based upon $P \leq 0.05$ unless otherwise stated.

RESULTS

Broiler Breeder. The main effects of broiler breeder female feeder space allocation during growing and laying, and feed increase rate from photostimulation to peak egg production, as well as the growing feeder space by laying feeder space interaction, growing feeder space by feed increase rate interaction, and laying feeder space by feed increase rate interaction on broiler breeder female BW as sampled at placement (1d) and 48 wk of age in are shown in Table II-1. There were no significant main effects as well as no interactions found.

The main effects of broiler breeder female feeder space allocation during growing and laying, and feed increase rate from photostimulation to peak egg production, as well as the growing feeder space by laying feeder space interaction, growing feeder space by feed increase rate interaction, and laying feeder space by feed increase rate interaction on individual broiler breeder female BW at 6, 20, and 32 wk of age are shown in Table II-2. Female BW at 32 wk of age was affected by growing feeder space, laying feeder space, and peak feed increase rate where females from the 10.4 cm allocation, 6.2 cm allocation, and Fast feed increase rate were significantly heavier, respectively. There were no significant interactions found.

The main effects of broiler breeder female feeder space allocation during growing and laying, and feed increase rate from photostimulation to peak egg production, as well as the growing feeder space by laying feeder space interaction, growing feeder space by feed increase rate interaction, and laying feeder space by feed increase rate interaction on broiler breeder female coefficient of variation (CV) of individual BW at 6, 20, and 32 wk of age are shown in Table II-3. There were no significant main effects or interactions found.

The main effects of broiler breeder female feeder space allocation during growing and laying, and feed increase rate from photostimulation to peak egg production, as well as the growing feeder space by laying feeder space interaction, growing feeder space by feed increase rate interaction, and laying feeder space by feed increase rate interaction on egg weight (EW) and egg components at 28 wk of age are shown in Table II-4. Percentage egg shell was increased by 10.3 cm laying feeder space. Percentage yolk, percentage albumen, and the yolk:albumen ratio were affected by feed increase rate as the yolk and yolk:albumen ratio from hens subject to the Fast feed increase rate were significantly greater, but percentage albumen was significantly less. Percentage albumen was affected by the growing feeder space by laying feeder space interaction where albumen from the 10.4 to 6.2 cm combination hens was significantly greater than from the 10.4 to 10.3 cm combination while the 7.0 to 6.2 cm and the 7.0 to 10.3 cm combinations were intermediate. Percentage egg shell was affected by the growing feeder space by feed increase rate interaction where egg shells from the 10.4 cm by Slow feed increase rate combination hens was significantly greater than those from the 7.0 cm by Slow feed increase rate and the 10.4 cm by Fast feed increase rate combination while the 7.0 cm by Fast feed increase rate combination was intermediate. There were no significant effects due to growing feeder space or the laying feeder space by feed increase rate interaction found.

The main effects of broiler breeder female feeder space allocation during growing and laying, and feed increase rate from photostimulation to peak egg production, as well as the growing feeder space by laying feeder space interaction, growing feeder space by feed increase rate interaction, and laying feeder space by feed increase rate interaction on EW and egg components at 30 wk of age are shown in Table II-5. Percentage yolk, percentage albumen, and the yolk:albumen ratio were affected by the feed increase rate where the percentage yolk and the yolk:albumen ratio from Fast feed increase rate hens were significantly greater, but percentage albumen was significantly less. Percentage yolk, percentage albumen, and the yolk:albumen ratio were also affected by the growing feeder space by laying feeder space interaction where percentage yolk and the yolk:albumen ratio from the 7.0 to 6.2 cm combination hens were both significantly greater than that of the 10.4 to 6.2 cm combination hens with the 7.0 to 10.3 cm and the 10.4 to 10.3 cm combination hens intermediate. Percentage albumen from the 10.4 to 6.2 cm combination hens was significantly greater than from the 7.0 to 6.2 cm and 10.4 to 10.3 cm combination hens with the 7.0 to 10.3 group intermediate. There were no significant effects due to growing feeder space, laying feeder space, the growing feeder space by feed increase rate interaction, and the laying feeder space by feed increase rate interaction.

The main effects of broiler breeder female feeder space allocation during growing and laying, and feed increase rate from photostimulation to peak egg production, as well as growing feeder space by laying feeder space interaction, growing feeder space by feed increase rate interaction, and laying feeder space by feed increase rate interaction on EW and percentage egg shell at 51 and 62 wk of age are shown in Table II-6. The EW at 51 wk of age was significantly heavier from the 10.4 cm growing feeder space as compared to the 7.0 cm feeder space. There were no significant main effects due to laying feeder space or feed increase rate nor any interactions found.

The main effects of broiler breeder female feeder space allocation during growing and laying, and feed increase rate from photostimulation to peak egg production, as well as the growing feeder space by laying feeder space interaction, growing feeder space by feed increase rate interaction, and laying feeder space by feed increase rate interaction on egg production and female mortality are shown in Table II-7. Hen-day egg production was increased by the 10.3 cm laying feeder space as compared to the 6.2 cm feeder space because percentage hen-day egg production of the 10.4 to 10.3 cm combination hens was significantly greater than of all other feeder space combinations. Eggs per hen housed, hen-day egg production, and female mortality were affected by the growing feeder space by laying feeder space interaction. Hens from the 10.4 to 10.3 cm combination produced a significantly greater number of eggs as compared to the 7.0 to 10.3 cm and 10.4 to 6.2 cm combinations with the 7.0 to 6.2 cm combination intermediate. Female mortality in the 7.0 to 10.3 cm feeder space combination hens was significantly greater than in the 10.4 to 10.3 cm combination hens while the 7.0 to 6.2 cm and the 10.4 to 6.2 cm combination hens were intermediate. There were no significant effects due to growing feeder space, feed increase rate, the growing feeder space by feed increase rate interaction, or the laying feeder space by feed increase rate interaction found.

The main effects of broiler breeder female feeder space allocation during growing and laying, and feed increase rate from photostimulation to peak egg production, as well as the growing feeder space by laying feeder space interaction, growing feeder space by feed increase rate interaction, and laying feeder space by feed increase rate interaction on broiler breeder fertility, hatchability of fertile eggs, hatchability of total eggs, and embryonic mortality from 26 to 63 wk of age are shown in Table II-8. There were no significant main effects or interactions found.

The main effects of broiler breeder female feeder space allocation during growing and laying, and feed increase rate from photostimulation to peak egg production, as well as the growing feeder space by laying interaction, growing feeder space by feed increase rate interaction, and laying feeder space by feed increase rate interaction on broiler breeder fertility at 65 wk of age are shown in Table II-9. There were no significant main effects or interactions found.

Broilers. The main effects of broiler breeder female feeder space allocation during growing and laying, and feed increase rate from photostimulation to peak egg production, as well as the growing feeder space by laying feeder space interaction, growing feeder space by feed increase rate interaction, and laying feeder space by feed increase rate interaction on mixed sex broiler BW at 1, 21, and 40 d of age are shown in Table II-10. Mixed sex broiler BW at 1d was affected by the growing feeder space and the laying feeder space where chicks from the 7.0 cm and 6.2 cm allocations, respectively, were significantly smaller because chicks from the 7.0 to 6.2 cm combination were significantly smaller than all other combinations. There were no other significant effects due to feed increase rate, the growing feeder space by laying feeder space interaction, or the laying feeder space by feed increase rate interaction found.

The main effects of broiler breeder female feeder space allocation during growing and laying, and feed increase rate from photostimulation to peak egg production, as well as the growing feeder space by laying feeder space interaction, growing feeder space by feed increase rate interaction, and laying feeder space by feed increase rate interaction on the adjusted feed conversion ratio (AdjFCR) of mixed sex broilers from 1-21, 21-40, and 1-40 d of age are shown in Table II-11. There were no significant main effects found but the AdjFCR for the 1-21 d period was significantly affected by the growing feeder space by laying feeder space interaction because the 7.0 to 10.3 cm combination decreased (improved) AdjFCR when compared to all other combinations. There were no other significant effects due to the growing feeder space by feed increase rate interaction or the laying feeder space by feed increase rate interaction found.

The main effects of broiler breeder female feeder space allocation during growing and laying, and feed increase rate from photostimulation to peak egg production, as well as the growing feeder space by laying feeder space interaction, growing feeder space by feed increase rate interaction, and laying feeder space by feed increase rate interaction on percentage mortality of mixed sex broilers from 1-21, 21-40, and 1-40 d of age are shown in Table II-12. There were no significant main effects or interactions found.

DISCUSSION

It was not surprising that breeders that were grown on greater feeder space during the rearing were heavier at 32 wk of age, but the differences did not persist to 48 wk. Birds from the less crowded feeder space during laying and Fast feeding to peak program were also heavier at 32 wk. However, there were no differences in BW or uniformity due to feeder space during either rearing or laying periods. The feed increase from photostimulation to peak egg production and feeder space program had no effect on BW uniformity. This may be because all birds were ready to respond to photostimulation when moved to the laying house at the end of the 21 wk. As Renema et al. (2007) stated, delaying photostimulation from 18 to 22 wk of age regardless of the strain improved the uniformity of sexual maturation and was a great breeder management tool to achieve uniformity of onset of lay. We also feed adequate feed in rearing as suggested by Walsh and Brake (1997). Birds that were given similar feeder space (10.4 to 10.3 cm) between the rearing and laying periods produced the most eggs as well as exhibited the greatest hen-day egg production with the least percentage mortality. Birds from the small decrease in feeder space (7.0 to 6.2 cm) between the rearing and laying periods was the next best egg production group, while birds from the increased (7.0 to 10.3 cm) or decreased (10.4 to 6.2 cm) feeder space combinations produced equally poor egg production while the increased feeder space combination exhibited the highest percentage mortality (Table II-7). As seen in Fig. II-3, the mortality in the decrease in feeder space combination group occurred early in the production period between 24-30 wk. This may be due to the stress of increased competition for feed following the move to the laying house. The most deaths in the group with the most increase in feeder space coincided with hot weather, which suggested more breast muscle in this group that resulted in greater body temperature. As Ross 708 hens have the characteristic of greater breast muscle, too much feeder space may have allowed some birds to consume more feed, thus, adding more breast meat. Renema et al. (2008) also showed that hens that received an aggressive feed increase carried a slightly increased proportion of breast muscle at sexual maturity. By 58 wk of age, the same high feeding profile hens still had the most breast muscle as well as a smaller ovary and less abdominal fat, which reflects lower ovarian activity (Renema et al. 2008). This can be one of the reasons why hens that were exposed to the increase feeder space combination produced fewer eggs than hens with no change in feeder space since hens with excess feed tended to direct nutrients toward breast muscle rather than reproductive system development during the time of sexual maturity (Hudson et al., 2000; Reddish and Lilburn, 2004). A higher percentage mortality was another reason why hens with the greatest increase in feeder space combination produced the fewest eggs. High mortality during hot weather suggested this group of birds to have the most breast muscle. As mentioned earlier, there were no differences in the BW among hens in all the feeder space combinations (Tables II-1, II-2). Therefore, the best possible reason for high mortality due to an increase in feeder space was greater breast muscle that would contribute to higher body temperature during hot weather (Fig. II-3). However, we did not observe many double yolk eggs, which would be indicative of ovary dysfunction, as well as no differences in fertility, hatchability, or broiler progeny performance. This suggested that these birds did not have enough excess feed to over-stimulate ovarian follicle development as shown in other experiments (Hocking et al., 1987; Yu et al., 1992). We also fed our birds based on the commercial situation not too overfeeding our birds as in many other studies. Increased or decreased feeder space may have upset a delicate developmental balance between, in this case, the breast muscle and oviduct. This could lead to the difference in the number of eggs produced as well as mortality of broiler breeders during periods of high temperature. Keeping the same feeder space between the rearing and laying periods resulted in more egg production, and less mortality. There were no significant effects due to the feed increase rate from photostimulation to peak egg production, which suggested that control of feeder space change between rearing and laying periods was the most important factor to consider.

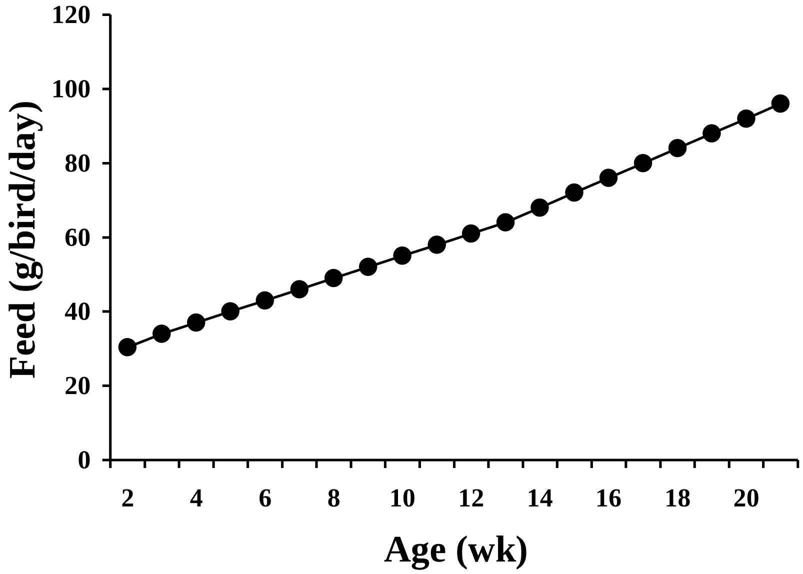

Figure II-1. Feeding program during the rearing period in Manuscript II. Ross 708SF pullets received feed according to this feeding program from placement to 21 wk of age.

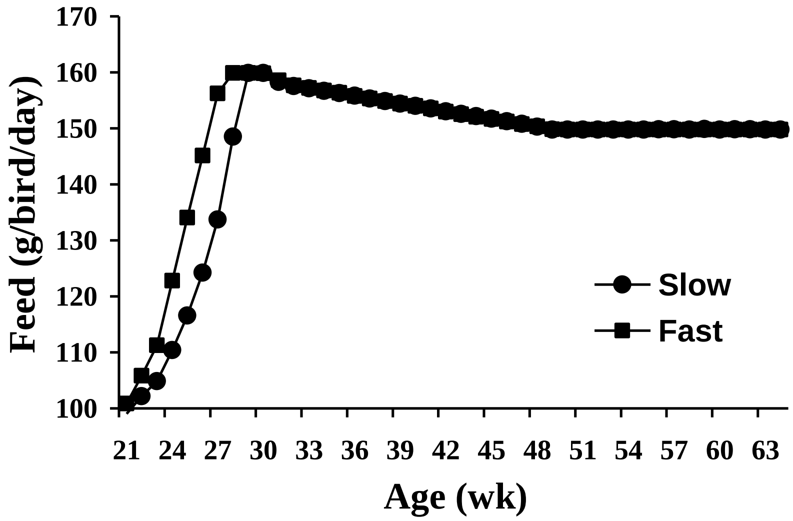

Figure II-2. Feeding to peak programs in Manuscript II. Ross 708SF hens received feed according to these two feeding programs, either Fast feed from 21 to 28 wk of age or Slow feed from 21 to 29 wk of age. All hens received the same feed rate thereafter. Rectangles represent the Fast feeding to peak program and circles represent the Slow feeding to peak program.

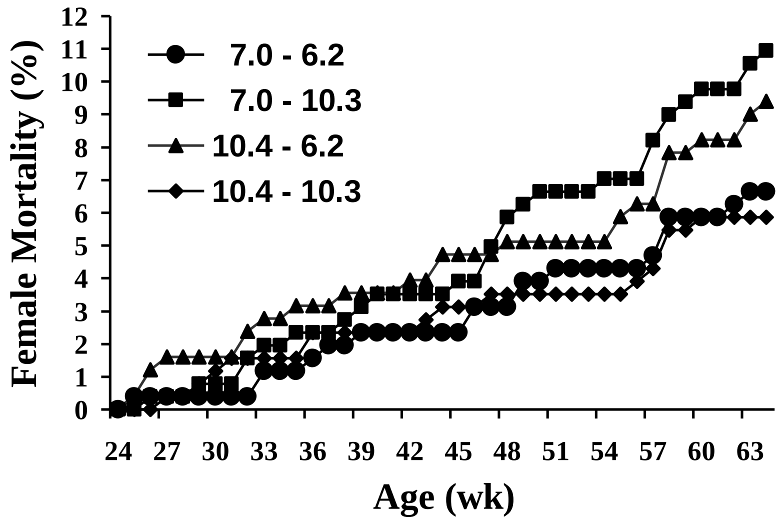

Figure II-3. Percentage female mortality during the laying period as affected by female feeding to peak program in Manuscript II. Circles represent a small decrease in feeder space (7.0-6.2 cm.), rectangles represent an increase in feeder space (7.0-10.3 cm.), triangles represent a decrease in feeder space (10.4-6.2 cm.), and diamonds represent no change in feeder space (10.4-10.3 cm). The percentage mortality from a decrease in feeder space combination occurred early in the production period between 24-30 wk.

TABLE II-1. Broiler breeder female BW (group sample) as affected by broiler breeder female feeder space allocation during growing and laying, and feed increase rate from photostimulation to peak egg production, as well as the growing feeder space by laying feeder space interaction, growing feeder space by feed increase rate interaction, and laying feeder space by feed increase rate interaction in Experiment II.

Feeder Space			Age	
Growing[1]	Laying[2]	Peak Feed Increase[3]	1 d	48 wk
(cm)	(cm)		(g)	(kg)
7.0			40.5	4.050
10.4			40.9	4.076
	6.2		40.7	4.094
	10.3		40.6	4.033
		Fast	41.0	4.090
		Slow	40.4	4.036
	SEM		0.4[4]	0.038[5]
7.0	6.2		40.5	4.038
7.0	10.3		40.5	4.063
10.4	6.2		41.0	4.150
10.4	10.3		40.8	4.003
7.0		Fast	41.0	4.080
7.0		Slow	40.0	4.020
10.4		Fast	41.0	4.100
10.4		Slow	40.8	4.053
	6.2	Fast	41.0	4.113
	6.2	Slow	40.5	4.075
	10.3	Fast	41.0	4.068
	10.3	Slow	40.3	3.998
	SEM		0.5[6]	0.053[7]

[1] Feeder space allocations of 7.0 or 10.4 cm per each of 76 pullets during growing.
[2] Feeder space allocations of 6.2 or 10.3 cm per each of 64 hens during laying.
[3] Feed increase rates (see Fig. II-2) from photostimulation to peak egg production.
[4] SEM for n=8 pens with 76 chicks weighed per pen.
[5] SEM for n=8 pens with 20 hens weighed per pen.
[6] SEM for n=4 pens with 76 chicks weighed per pen.
[7] SEM for n=4 pens with 20 hens weighed per pen.

TABLE II-2. Broiler breeder female BW (individual) as affected by broiler breeder female feeder space allocation during growing and laying, and feed increase rate from photostimulation to peak egg production, as well as the growing feeder space by laying feeder space interaction, growing feeder space by feed increase rate interaction, and laying feeder space by feed increase rate interaction in Experiment II.

Feeder Space			Age		
Growing[1]	Laying[2]	Peak Feed Increase[3]	6 wk	20 wk	32 wk
(cm)	(cm)		(kg)		
7.0			0.790	2.263	3.449[b]
10.4			0.800	2.263	3.507[a]
	6.2		0.799	2.276	3.498[a]
	10.3		0.791	2.250	3.458[b]
		Fast	0.794	2.258	3.531[A]
		Slow	0.796	2.269	3.425[B]
	SEM		0.011[4]	0.011[4]	0.011[5]
7.0	6.2		0.805	2.279	3.455
7.0	10.3		0.776	2.247	3.444
10.4	6.2		0.794	2.274	3.542
10.4	10.3		0.806	2.253	3.472
7.0		Fast	0.787	2.255	3.517
7.0		Slow	0.794	2.271	3.381
10.4		Fast	0.802	2.261	3.546
10.4		Slow	0.798	2.266	3.468
	6.2	Fast	0.796	2.272	3.561
	6.2	Slow	0.803	2.281	3.436
	10.3	Fast	0.793	2.244	3.502
	10.3	Slow	0.789	2.256	3.414
	SEM		0.016[6]	0.016[6]	0.016[7]

[a,b] Means in a column that possess different superscripts differ significantly ($P \leq 0.05$).
[A,B] Means in a column that possess different superscripts differ significantly ($P \leq 0.01$).
[1] Feeder space allocations of 7.0 or 10.4 cm per each of 76 pullets during growing.
[2] Feeder space allocations of 6.2 or 10.3 cm per each of 64 hens during laying.
[3] Feed increase rates (see Fig. II-2) from photostimulation to peak egg production.
[4] SEM for n=8 pens with 76 pullets weighed per pen.
[5] SEM for n=8 pens with 64 hens weighed per pen.
[6] SEM for n=4 pens with 76 pullets weighed per pen.
[7] SEM for n=4 pens with 64 hens weighed per pen.

TABLE II-3. Coefficient of variation (CV) of broiler breeder female BW as affected by broiler breeder female feeder space allocation during growing and laying, and feed increase rate from photostimulation to peak egg production, as well as the growing feeder space by laying feeder space interaction, growing feeder space by feed increase rate interaction, and laying feeder space by feed increase rate interaction in Experiment II.

Feeder Space			Age		
Growing[1]	Laying[2]	Peak Feed Increase[3]	6 wk	20 wk	32 wk
(cm)	(cm)		(%CV)		
7.0			13.40	13.39	9.21
10.4			14.36	14.57	9.41
	6.2		13.80	14.24	9.23
	10.3		13.95	13.72	9.39
		Fast	13.58	13.98	9.31
		Slow	14.17	13.98	9.31
	SEM		0.56[4]	0.74[4]	0.41[5]
7.0	6.2		13.02	13.73	9.08
7.0	10.3		13.77	13.06	9.34
10.4	6.2		14.58	14.75	9.39
10.4	10.3		14.13	14.39	9.44
7.0		Fast	13.10	13.65	9.20
7.0		Slow	13.69	13.14	9.21
10.4		Fast	14.06	14.31	9.41
10.4		Slow	14.65	14.82	9.42
	6.2	Fast	13.39	14.53	9.19
	6.2	Slow	14.21	13.95	9.27
	10.3	Fast	13.77	13.43	9.42
	10.3	Slow	14.13	14.01	9.35
	SEM		0.79[6]	1.04[6]	0.58[7]

[1] Feeder space allocations of 7.0 or 10.4 cm per each of 76 pullets during growing.
[2] Feeder space allocations of 6.2 or 10.3 cm per each of 64 hens during laying.
[3] Feed increase rates (see Fig. II-2) from photostimulation to peak egg production.
[4] SEM for n=8 pens with 76 pullets per pen weighed and CV calculated on a pen basis.
[5] SEM for n=8 pens with 64 pullets per pen weighed and CV calculated on a pen basis.
[6] SEM for n=4 pens with 76 pullets per pen weighed and CV calculated on a pen basis.
[7] SEM for n=4 pens with 64 pullets per pen weighed and CV calculated on a pen basis.

TABLE II-4. Egg weight (EW) and egg components at 28 wk of age as affected by broiler breeder female feeder space allocation during growing and laying, and feed increase rate from photostimulation to peak egg production, as well as the growing feeder space by laying feeder space interaction, growing feeder space by feed increase rate interaction, and laying feeder space by feed increase rate interaction in Experiment II.

Feeder Space							
Growing[1]	Laying[2]	Peak Feed Increase[3]	Egg Weight	Yolk Weight	Egg Shell	Albumen	Yolk:Alb ratio
(cm)	(cm)		(g)	(%EW)	(%EW)	(%EW)	(g:g)
7.0			51.79	26.75	9.48	63.77	0.420
10.4			51.71	26.73	9.52	63.74	0.420
	6.2		51.90	26.79	9.40[B]	63.80	0.421
	10.3		51.60	26.69	9.61[A]	63.71	0.420
		Fast	51.80	26.99[a]	9.51	63.49[b]	0.426[a]
		Slow	51.70	26.49[b]	9.50	64.02[a]	0.414[b]
	SEM[4]		0.22	0.12	0.02	0.12	0.27
7.0	6.2		51.62	26.98	9.40	63.62[ab]	0.425
7.0	10.3		51.96	26.52	9.56	63.92[ab]	0.416
10.4	6.2		52.19	26.61	9.40	63.99[a]	0.417
10.4	10.3		51.23	26.85	9.65	63.50[b]	0.424
7.0		Fast	52.04	26.91	9.53[ab]	63.55	0.424
7.0		Slow	51.54	26.58	9.43[b]	63.98	0.416
10.4		Fast	51.57	27.07	9.49[b]	63.44	0.428
10.4		Slow	51.86	26.39	9.56[a]	64.05	0.413
	6.2	Fast	52.17	27.02	9.39	63.59	0.426
	6.2	Slow	51.63	26.56	9.42	64.02	0.416
	10.3	Fast	51.43	26.96	9.64	63.40	0.426
	10.3	Slow	51.77	26.41	9.58	64.01	0.413
	SEM[5]		0.31	0.17	0.03	0.17	0.38

[a,b] Means in a column that possess different superscripts differ significantly ($P \leq 0.05$).
[A,B] Means in a column that possess different superscripts differ significantly ($P \leq 0.01$).
[1] Feeder space allocations of 7.0 or 10.4 cm per each of 76 pullets during growing.
[2] Feeder space allocations of 6.2 or 10.3 cm per each of 64 hens during laying.
[3] Feed increase rates (see Fig. II-2) from photostimulation to peak egg production.
[4] SEM for n=8 pens with mean of approximately 30 eggs weighed per pen.
[5] SEM for n=4 pens with mean of approximately 30 eggs weighed per pen.

TABLE II-5. Egg weight (EW) and egg components at 30 wk of age as affected by broiler breeder female feeder space allocation during growing and laying, and feed increase rate from photostimulation to peak egg production, as well as the growing feeder space by laying feeder space interaction, growing feeder space by feed increase rate interaction, and laying feeder space by feed increase rate interaction in Experiment II.

Feeder Space							
Growing[1]	Laying[2]	Peak Feed Increase[3]	Egg Weight	Yolk Weight	Egg Shell	Albumen	Yolk:Alb ratio
(cm)	(cm)		(g)	(%EW)	(%EW)	(%EW)	(g:g)
7.0			54.84	28.03	9.24	62.73	0.448
10.4			54.98	27.86	9.16	62.98	0.444
	6.2		55.01	27.91	9.19	62.90	0.445
	10.3		54.80	27.97	9.22	62.81	0.446
		Fast	55.10	28.24^{A}	9.16	62.60^{b}	0.453^{A}
		Slow	54.72	27.64^{B}	9.25	63.11^{a}	0.439^{B}
	SEM[4]		0.30	0.12	0.03	0.12	0.25
7.0	6.2		54.60	28.23^{a}	9.25	62.52^{b}	0.452^{a}
7.0	10.3		55.08	27.82^{ab}	9.23	62.94^{ab}	0.443^{ab}
10.4	6.2		55.43	27.60^{b}	9.13	63.28^{a}	0.439^{b}
10.4	10.3		54.52	28.13^{ab}	9.20	62.68^{b}	0.450^{ab}
7.0		Fast	55.13	28.36	9.17	62.47	0.455
7.0		Slow	54.55	27.69	9.31	63.00	0.440
10.4		Fast	55.06	28.13	9.14	62.73	0.451
10.4		Slow	54.89	27.59	9.19	63.22	0.437
	6.2	Fast	55.35	28.20	9.19	62.61	0.453
	6.2	Slow	54.68	27.63	9.18	63.19	0.438
	10.3	Fast	54.85	28.29	9.12	62.59	0.453
	10.3	Slow	54.76	27.66	9.31	63.03	0.440
	SEM[5]		0.43	0.17	0.05	0.18	0.36

[a,b] Means in a column that possess different superscripts differ significantly ($P \leq 0.05$).
[A,B] Means in a column that possess different superscripts differ significantly ($P \leq 0.01$).
[1] Feeder space allocations 7.0 or 10.4 cm per each of 76 pullets during growing.
[2] Feeder space allocations 6.2 or 10.3 cm per each of 64 hens during laying.
[3] Feed increase rates (see Fig. II-2) from photostimulation to peak egg production.
[4] SEM for n=8 pens with mean of approximately 40 eggs weighed per pen.
[5] SEM for n=4 pens with mean of approximately 40 eggs weighed per pen.

TABLE II-6. Egg weight (EW) and percentage egg shell at 51 and 62 wk of age as affected by broiler breeder female feeder space allocation during growing and laying, and feed increase rate from photostimulation to peak egg production, as well as the growing feeder space by laying feeder space interaction, growing feeder space by feed increase rate interaction, and laying feeder space by feed increase rate interaction in Experiment II.

Feeder Space			Wk of Age			
			51		62	
Growing[1]	Laying[2]	Peak Feed Increase[3]	EW	Egg Shell	EW	Egg Shell
(cm)	(cm)		(g)	(%EW)	(g)	(%EW)
7.0			63.2[b]	8.4	65.4	9.3
10.4			64.7[a]	8.4	66.0	8.4
	6.2		64.1	8.3	66.8	8.3
	10.3		63.8	8.4	64.6	9.3
		Fast	63.9	8.3	65.6	9.3
		Slow	64.0	8.4	65.9	8.4
	SEM[4]		0.3	0.1	0.8	0.7
7.0	6.2		63.0	8.3	66.3	8.3
7.0	10.3		63.3	8.5	64.5	10.2
10.4	6.2		65.1	8.3	67.3	8.3
10.4	10.3		64.3	8.4	64.8	8.4
7.0		Fast	62.9	8.3	64.7	10.2
7.0		Slow	63.5	8.5	66.1	8.4
10.4		Fast	64.9	8.3	66.4	8.3
10.4		Slow	64.5	8.4	65.7	8.4
	6.2	Fast	63.6	8.3	67.1	8.2
	6.2	Slow	64.6	8.4	66.5	8.4
	10.3	Fast	64.2	8.4	64.1	10.3
	10.3	Slow	63.4	8.5	65.2	8.4
	SEM[5]		0.5	0.1	1.1	1.0

[a,b] Means in a column that possess different superscripts differ significantly ($P \leq 0.05$).
[1] Feeder space allocations of 7.0 or 10.4 cm per each of 76 pullets during growing.
[2] Feeder space allocations of 6.2 or 10.3 cm per each of 64 hens during laying.
[3] Feed increase rates (see Fig. II-2) from photostimulation to peak egg production.
[4] SEM for n=8 pens with mean of 20 eggs weighed per pen.
[5] SEM for n=4 pens with mean of 20 eggs weighed per pen.

TABLE II-7. Broiler breeder egg production and female mortality from 24 to 64 wk affected by broiler breeder female feeder space allocation during growing and laying, and feed increase rate from photostimulation to peak egg production, as well as the growing feeder space by laying feeder space interaction, growing feeder space by feed increase rate interaction, and laying feeder space by feed increase rate interaction in Experiment II.

Feeder Space			Egg Production		
Growing[1]	Laying[2]	Peak Feed Increase[3]	Eggs per Hen Housed	Hen-day Production	Female Mortality
(cm)	(cm)		(n)	(%)	(%)
7.0			172	62.3	8.8
10.4			175	63.2	7.8
	6.2		172	62.2^{b}	8.2
	10.3		175	63.3^{a}	8.4
		Fast	173	62.7	9.0
		Slow	174	62.8	7.6
	SEM[4]		2	0.3	1.0
7.0	6.2		175^{AB}	62.9^{B}	6.6^{ab}
7.0	10.3		169^{B}	61.7^{B}	10.9^{a}
10.4	6.2		168^{B}	61.5^{B}	9.8^{ab}
10.4	10.3		181^{A}	65.0^{A}	5.9^{b}
7.0		Fast	171	62.2	10.9
7.0		Slow	173	62.4	6.6
10.4		Fast	176	63.1	7.0
10.4		Slow	174	63.3	8.6
	6.2	Fast	172	62.6	9.8
	6.2	Slow	171	61.8	6.6
	10.3	Fast	174	62.8	8.2
	10.3	Slow	176	63.9	8.6
	SEM[5]		2	0.5	1.5

^{a,b} Means in columns that possess different superscripts differ significantly ($P \leq 0.05$).
^{A,B} Means in columns that possess different superscripts differ significantly ($P \leq 0.01$).
[1] Feeder space allocations of 7.0 or 10.4 cm per each of 76 pullets during growing.
[2] Feeder space allocations of 6.2 or 10.3 cm per each of 64 hens during laying.
[3] Feed increase rates (see Fig. II-2) from photostimulation to peak egg production.
[4] SEM for n=8 pens of 64 hens per pen.
[5] SEM for n=4 pens of 64 hens per pen.

TABLE II-8. Broiler breeder fertility, hatchability, and embryonic mortality from 26 to 63 wk of age from weekly set of 60 eggs as affected by broiler breeder female feeder space allocation during growing and laying, and feed increase rate from photostimulation to peak egg production, as well as the growing feeder space by laying feeder space interaction, growing feeder space by feed increase rate interaction, and laying feeder space by feed increase rate interaction in Experiment II.

Feeder Space			Incubation Variables[4]				
				Hatchability of			
Growing[1]	Laying[2]	Peak Feed Increase[3]	Fertility	Fertile Eggs	Total Eggs	Early Dead[5]	Late Dead[6]
(cm)	(cm)		(%)				
7.0			95.79	94.74	90.75	2.90	1.88
10.4			95.38	95.05	90.67	2.63	1.72
	6.2		95.17	94.86	90.29	2.71	1.72
	10.3		96.00	94.92	91.13	2.81	1.89
		Fast	95.46	94.92	90.63	2.69	1.71
		Slow	95.71	94.86	90.80	2.83	1.89
7.0	6.2		95.73	94.87	90.83	2.65	1.88
7.0	10.3		95.85	94.60	90.68	3.15	1.89
10.4	6.2		94.61	94.85	89.75	2.77	1.56
10.4	10.3		96.16	95.24	91.59	2.48	1.88
7.0		Fast	95.59	94.87	90.69	2.91	1.80
7.0		Slow	95.99	94.61	90.81	2.88	1.96
10.4		Fast	95.34	94.98	90.56	2.46	1.62
10.4		Slow	95.43	95.12	90.78	2.79	1.82
	6.2	Fast	94.89	94.73	89.90	2.58	1.80
	6.2	Slow	95.46	95.00	90.68	2.84	1.64
	10.3	Fast	96.04	95.12	91.35	2.79	1.63
	10.3	Slow	95.96	94.73	90.91	2.83	2.15

[1] Feeder space allocations of 7.0 or 10.4 cm per each of 76 pullets during growing.
[2] Feeder space allocations of 6.2 or 10.3 cm per each of 64 hens during laying.
[3] Feed increase rates (see Fig. II-2) from photostimulation to peak egg production.
[4] Categorical analysis does not generate SEM.
[5] Embryos that died from 1-7d.
[6] Embryos that died after 7 d.

TABLE II-9. Broiler breeder female fertility after removing males at 64 wk of age as affected by broiler breeder female feeder space allocation during growing and laying, and feed increase rate from photostimulation to peak egg production, as well as the growing feeder space by laying feeder space interaction, growing feeder space by feed increase rate interaction, and laying feeder space by feed increase rate interaction in Experiment II.

Feeder Space			Percentage Fertility After Removing Males[4]	
Growing[1]	Laying[2]	Peak Feed Increase[3]	1-7 d	8-14 d
(cm)	(cm)		(%)	
7.0			87.46	42.19
10.4			89.93	42.71
	6.2		88.73	42.66
	10.3		88.66	42.24
		Fast	88.72	43.04
		Slow	88.67	41.86
	SEM[5]		1.56	1.55
7.0	6.2		86.64	41.54
7.0	10.3		88.29	42.83
10.4	6.2		90.83	43.78
10.4	10.3		89.03	41.65
7.0		Fast	86.88	41.18
7.0		Slow	88.05	43.20
10.4		Fast	90.57	44.91
10.4		Slow	89.29	40.52
	6.2	Fast	89.58	43.81
	6.2	Slow	87.89	41.51
	10.3	Fast	87.87	42.27
	10.3	Slow	89.45	42.20
	SEM[6]		2.20	2.20

[1] Feeder space allocations of 7.0 or 10.4 cm per each of 76 pullets during growing.
[2] Feeder space allocations of 6.2 or 10.3 cm per each of 64 hens during laying.
[3] Feed increase rates (see Fig. II-2) from photostimulation to peak egg production.
[4] All males were removed at 64 wk.
[5] SEM for n=8 pens with all eggs collected for 14 d and incubated.
[6] SEM for n=4 pens with all eggs collected for 14 d and incubated.

TABLE II-10. The BW of mixed sex broiler chickens produced from eggs laid at 28 wk as affected by broiler breeder female feeder space allocation during growing and laying, and feed increase rate from photostimulation to peak egg production, as well as the growing feeder space by laying feeder space interaction, growing feeder space by feed increase rate interaction, and laying feeder space by feed increase rate interaction in Experiment II.

Broiler Breeder			Mixed Sex Broiler BW At Ages Shown		
Feeder Space					
Growing[1]	Laying[2]	Peak Feed Increase[3]	1 d	21 d	40 d
(cm)	(cm)			(g)	
7.0			38.4^{b}	884.5	2564.9
10.4			38.8^{a}	887.4	2585.9
	6.2		38.3^{B}	888.0	2592.6
	10.3		38.9^{A}	883.9	2558.2
		Fast	38.6	890.4	2579.0
		Slow	38.6	881.6	2571.7
	SEM[4]		0.1	6.1	17.3
7.0	6.2		37.9^{b}	889.7	2588.7
7.0	10.3		38.9^{a}	879.4	2541.0
10.4	6.2		38.6^{a}	886.4	2596.5
10.4	10.3		38.9^{a}	888.4	2575.3
7.0		Fast	38.3	891.7	2569.7
7.0		Slow	38.5	877.4	2561.0
10.4		Fast	38.9	889.0	2589.4
10.4		Slow	38.7	885.8	2582.3
	6.2	Fast	38.4	888.2	2588.7
	6.2	Slow	38.2	887.9	2596.4
	10.3	Fast	38.7	892.5	2569.4
	10.3	Slow	39.0	875.3	2546.9
	SEM[5]		0.1	8.6	24.5

[a,b] Means in a column that possess different superscripts differ significantly ($P \leq 0.05$).
[A,B] Means in a column that possess different superscripts differ significantly ($P \leq 0.01$).
[1] Feeder space allocations of 7.0 or 10.4 cm per each of 76 pullets during growing.
[2] Feeder space allocations of 6.2 or 10.3 cm per each of 64 hens during laying.
[3] Feed increase rates (see Fig. II-2) from photostimulation to peak egg production.
[4] SEM for n=16 pens with 30 broilers per pen.
[5] SEM for n=8 pens with 30 broilers per pen.

TABLE II-11. Adjusted feed consumption ratio (AdjFCR) of mixed sex broiler chickens produced from eggs laid at 28 wk as affected by broiler breeder female feeder space allocation during growing and laying, and feed increase rate from photostimulation to peak egg production, as well as the growing feeder space by laying feeder space interaction, growing feeder space by feed increase rate interaction, and laying feeder space by feed increase rate interaction in Experiment II.

Broiler Breeder			Mixed Sex Broiler AdjFCR At Ages Shown		
Feeder Space					
Growing[1]	Laying[2]	Peak Feed Increase[3]	1-21 d	21-40 d	1-40 d
(cm)	(cm)		(g:g)		
7.0			1.43	1.74	1.64
10.4			1.44	1.74	1.64
	6.2		1.44	1.74	1.64
	10.3		1.44	1.75	1.64
		Fast	1.44	1.75	1.64
		Slow	1.44	1.73	1.63
	SEM[4]		0.01	0.02	0.01
7.0	6.2		1.45[a]	1.74	1.64
7.0	10.3		1.42[b]	1.74	1.63
10.4	6.2		1.43[a]	1.73	1.63
10.4	10.3		1.45[a]	1.75	1.65
7.0		Fast	1.43	1.76	1.64
7.0		Slow	1.44	1.72	1.63
10.4		Fast	1.45	1.75	1.65
10.4		Slow	1.44	1.74	1.64
	6.2	Fast	1.44	1.75	1.64
	6.2	Slow	1.45	1.73	1.63
	10.3	Fast	1.44	1.76	1.65
	10.3	Slow	1.44	1.73	1.63
	SEM[5]		0.01	0.02	0.01

[a,b] Means in a column that possess different superscripts differ significantly ($P \leq 0.05$).
[1] Feeder space allocations of 7.0 or 10.4 cm per each of 76 pullets during growing.
[2] Feeder space allocations of 6.2 or 10.3 cm per each of 64 hens during laying.
[3] Feed increase rates (see Fig. II-2) from photostimulation to peak egg production.
[4] SEM for n=16 pens with 30 broilers per pen.
[5] SEM for n=8 pens with 30 broilers per pen.

TABLE II-12. Percentage mortality (deaths) of mixed sex broiler chickens produced from eggs laid at 28 wk as affected by broiler breeder female feeder space allocation during growing and laying and feed increase rate from photostimulation to peak egg production, as well as the growing feeder space by laying feeder space interaction, growing feeder space by feed increase rate interaction, and laying feeder space by feed increase rate interaction in Experiment II.

Broiler Breeder			Mixed Sex Broiler Deaths At Ages Shown		
Feeder Space					
Growing[1]	Laying[2]	Peak Feed Increase[3]	1-21 d	21-40 d	1-40 d
(cm)	(cm)			(%)	
7.0			1.25	1.25	2.50
10.4			2.71	1.46	4.17
	6.2		1.67	1.04	2.71
	10.3		2.29	1.67	3.96
		Fast	2.08	1.88	3.96
		Slow	1.88	0.83	2.71
	SEM[4]		0.73	0.57	0.94
7.0	6.2		1.25	0.83	2.08
7.0	10.3		1.25	1.67	2.92
10.4	6.2		2.08	1.25	3.33
10.4	10.3		3.33	1.67	5.00
7.0		Fast	0.83	2.08	2.92
7.0		Slow	1.67	0.42	2.08
10.4		Fast	3.33	1.67	5.00
10.4		Slow	2.08	1.25	3.33
	6.2	Fast	0.83	1.25	2.08
	6.2	Slow	2.50	0.83	3.33
	10.3	Fast	3.33	2.50	5.83
	10.3	Slow	1.25	0.83	2.08
	SEM[5]		1.03	0.81	1.33

[1] Feeder space allocations of 7.0 or 10.4 cm per each of 76 pullets during growing.
[2] Feeder space allocations of 6.2 or 10.3 cm per each of 64 hens during laying.
[3] Feed increase rates (see Fig. II-2) from photostimulation to peak egg production.
[4] SEM for n=16 pens with 30 broilers per pen.
[5] SEM for n=8 pens with 30 broilers per pen.

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MANUSCRIPT III. Effect of Feeding Program During Rearing and Early Lay on Performance of Broiler Breeder Females and Their Progeny

ABSTRACT

A study was conducted to evaluate the effects on broiler breeder females and their progeny of two feed allocation programs during the rearing period followed by two feed increase rates from photostimulation to peak egg production. Twelve replicate pens of 190 females each were randomly assigned to two rearing feeding program treatments (Sigmoid or Line) from 1 to 21 wk of age and two feed increase treatments (Slow or Fast) from photostimulation to peak egg production in a 2 x 2 factorial design with three replicate pens each. The flock was photostimulated at 21 wk of age when Ross 344 males and Ross 308SF females were housed and mixed together in the production facility. Females from the Sigmoid rearing program weighed more at 4, 6, 8, 10, and 12 wk but less at 18, 40, 48, and 56 wk of age. There were no differences in rate of lay but females that had been reared on the Sigmoid feeding program exhibited significantly reduced mortality during the laying period, which included summer during the peak laying period, and produced a numerically increased number of eggs per hen housed. Fertility was not affected but fertile hatchability was significantly improved by the Sigmoid rearing program. No differences due to the two different feed increase programs from photostimulation to peak egg production were found other than the Slow program produced a greater egg weight at 28 wk of age. Eggs produced by these hens at 28 wk of age were incubated under standard conditions and the carryover effects on the broiler progeny evaluated. There were 15 male and 15 female broiler chicks randomly assigned sex separate to each of 72 pens in a 2 x 2 design with 18 replicates per interaction cell. Broiler BW, feed consumption, adjusted feed conversion ratio (AdjFCR), and mortality were measured at 1, 21, and 42 d of age. The AdjFCR and mortality were significantly affected by feed increase rate from photostimulation to peak egg production in that male broilers from the Slow feed increase program exhibited poorer AdjFCR and the highest mortality.

Key words: broiler breeders, broiler progeny, feeding programs, fertility, mortality

INTRODUCTION

Broiler breeders have been shown to be hyperphagic that has necessitated quantitative feed restriction during rearing and production (Blair et al., 1976). However, the pattern of feed restriction during rearing, without differences in total feed consumption, could influence early egg production (Lilburn et al., 1987) and long term fertility (Walsh and Brake, 1997). Further, increased feed consumption prior to onset of lay enhanced sexual maturity and increased total egg production (Pym and Dillon, 1974; McDaniel, 1983; Robbins et al., 1986, 1988), but may have negative effects on reproduction in some cases (Leeson and Summers, 1983). As a result, feed management during rearing could lead to long-term effects on body composition and egg size (deBeer and Coon, 2007). Hocking (1993) stated that feeding less feed to broiler breeder females after 14 wk of age helped reduce the incidence of multiple ovulations as well as increases in egg production. Walsh and Brake (1999) showed that fertility can be improved by providing breeder pullets with slow and consistent feed increments late in the rearing period. Not only was the pattern of feed allocation important during the rearing period, the feed allocation during the early production phase was also important. Robinson et al. (1995) also stated that feeding programs during rearing and early lay can change frame size and breast muscle fleshing in the birds. According to Walsh and Brake (1997), the pattern of feed allocation and dietary CP during the growing phase and early production phase can influence both BW and overall performance, affecting egg production, egg weight, and long term fertility. Additionally, feed restriction during the rearing and laying periods reduced the development of an abnormally large number of large follicles on the ovary of broiler breeder hens (Hocking et al., 1987, 1989; Heck et al., 2004; Hocking and Robertson, 2005). More important, broiler breeder hens that have been feed restricted produced more eggs (Yu et al., 1992). The aim of this study was to evaluate the interaction between two feeding programs during the growing phase and two rates of feeding to peak on overall performance of broiler breeder females as well as their progeny produced at 28 wk of age.

MATERIALS AND METHODS

***Broiler Breeder Rearing Period*.** Broiler breeder males (Ross 344) and females (Ross 308SF) were placed in an enclosed fan-ventilated 24-pen litter floor rearing house with 12 (40.1 m^2 area) pens for females and 12 (6.1 m^2 area) pens for males. The rearing house was equipped with “black-out” light control curtains and was fan ventilated. At placement, there were 205 females and 30 males in each female and male pen, respectively. There were 8 tube feeders (Kuhl DH-4) per female growing pen that was increased to 10 tube feeders per pen at 15 wk of age while there were 2 tube feeders in each male rearing pen. After 23 h of light per day for one wk, with 100 W incandescent lamps, all birds were reared to 21 wk of age with 8 h of light per day at an average intensity of 15 lux using 40W incandescent lamps. Access to water was limited by a time clock and solenoid system sufficient to control litter moisture and allow the birds to have unlimited access to water until at least one hour after all feed was consumed and a similar amount on non-feed days during rearing. This was typically 6 h daily. A random group of 50 females per pen were weighed every two weeks until moving at 21 wk of age.

Broiler Breeder Production Period. An average of 190 females and 19 males were moved as groups from each rearing pen into each of 12 slat-litter floor laying pens (40.1 m^2 total area/pen, 13.4 m^2 litter area/pen) at 21 wk of age. Birds were photostimulated with 14 h of light at the time of movement. The day length was subsequently increased to 15 h 7 d later, and then to 15.5 h and 16 h at 5% and 50% rate of lay, respectively. Natural light entered the slat-litter house through open or translucent curtains during normal daylight hours. Supplemental light provided an average intensity of 35 lux at bird head level using four 100 W incandescent lamps and one 50 W high pressure sodium lamp per pen when natural light was not present. There were 10 female tube feeders and 2 male tube feeders in each laying pen. Water was limited to 8 h per day during the laying period using four bell-type drinkers in each of the 12 breeding pens. Four 12-hole conventional nests were provided in each breeding pen. Separation of sexes was insured by special grills (sixteen 4.8 x 5.8 cm holes per pan) on each female feeder that prevented the non-dubbed males from accessing the feed. Group BW of 50 females per pen were taken at 24, 40, 48, and 56 wk of age. At 28, 34, 40, 46, 52, 58, and 64 wk of age 20 eggs per pen were collected and egg weight (EW) was determined gravimetrically. The contents were then removed and shells dried to constant weight before cooling to room temperature. The eggshells were then weighed.

Fertility and Hatchability. Eggs were collected twice daily from the nests and stored in an egg cooler at 16-18^{o}C and 60% RH until incubated. Eggs that were laid on the floor and slats were collected and enumerated separately but not incubated. Analysis of percentage fertility, hatchability, and embryo mortality was conducted from 27 to 64 wk of age by macroscopic examination of all unhatched eggs from biweekly sets of 180 eggs per pen. All unhatched eggs were opened and examined macroscopically to determine fertility or infertility and, if fertile, to determine the stage of embryonic mortality. Embryos that died from 1-7 d of incubation were termed early deads and embryos that died after 7 d were termed late deads. Cracked eggs were deemed to be accidental in nature and were not included in the calculations. Eggs were set in a Natureform model I-14 incubator (Natureform International, Jacksonville, FL 32202).

Experimental Diets and Feeding Programs. Feed for broiler breeders was provided daily during the first 2 wk of age and then a 4/3 feed allocation program (feed Monday, Wednesday, Friday, and Saturday only) was used until 21 wk of age after which a daily feeding program was employed. Diets are shown in Table I-1. A common starter diet (17% CP) was fed to all pens for 4 wk followed by a common grower diet (15% CP) from 5 to 25 wk (approximately 10% rate of lay). From 3-21 wk, Sigmoid and Line feeding programs were used that provided the same cumulative nutrition to 21 wk (147 d) (25.7 Mcal of ME and 1,337 g of CP) of age (Fig III-1). Two feed increase rates (Fast or Slow) were then used from photostimulation to peak egg production (Fig. III-2). The females that received the Fast feed increase rate reached their peak feed of 165 g per female per day at 83% rate of lay while the Slow feed increase rate reached peak feed at 82% rate of lay at the same time. The feed allocation was then reduced once egg production across both treatments was similar for 5 d. The daily feed allocation was the same for all females thereafter. Male and female mortality was recorded daily and feed allocations adjusted accordingly.

Broiler Trial. To evaluate the possible effects of female breeder treatment on the performance of broiler progeny, a broiler trial was conducted. Broiler hatching eggs were collected from every pen at 28 wk of age and incubated together. A total of 2,160 eggs, 180 eggs per pen, were set in a Natureform Model I-14 incubator. The incubator was initially operated at 37.5^{o}C dry bulb. The machine has not been adjusted to gradually decrease egg temperatures to less than 37.8^{o}C. The wet bulb temperature was 28.9^{o}C. At 21.5 d of incubation the chicks that had completed the hatching process were removed from the trays, counted, group weighed, and sexed using the feather-sexing method. After this processing was completed, the chicks were permanently identified with neck tags and then distributed among 72 single-sex floor pens with wood litter shavings. The area of each pen was 1.49 m^2 with two feeders and three nipple drinkers provided in each of the 72 broiler pens. There were 15 chicks per each of 36 pens of each sex. During the first 5 d, there were 2 egg flats used for supplemental feed with 1 supplemental chick font for water. Chicks were group weighed at placement, and at 21 and 42 d of age. Feed consumption was determined at 21 and 42 d of age and adjusted feed conversion ratio (AdjFCR) was calculated. All dead birds were weighed and recorded twice daily and their BW was used in the AdjFCR calculation. A single starter or grower diet that met or exceeded the NRC (1994) minimum requirements was used during the starter and grower periods from 0-21 and 21-42 d, respectively (Table 2). No finisher diet was used for the sake of simplicity.

Statistical Analyses. Broiler Breeder Trial. The fertility and hatchability data were analyzed on a biweekly basis. A completely randomized design with a factorial (2 x 2) arrangement of treatments was used. The main factors were feed allocation program (Sigmoid or Line) and feed increase rate (Fast or Slow). The treatments were randomly distributed among 12 pens with 3 replicate pens per interaction cell. The general linear model (GLM) procedure of SAS Institute (2001) was used to analyze the continuous variables. The fertility data was analyzed as categorical data, where each individual egg was taken as a binomial event, either fertile or infertile, using the general model (GENMOD) procedure of SAS Institute (2001). Means were partitioned using LS MEANS and statements of statistical significance were based upon $P \leq 0.05$ unless otherwise stated.

Statistical Analyses. Broiler Trial. A completely randomized design with a factorial (2 x 2) arrangement of breeder treatments was used. The main factors were feed allocation program (Sigmoid or Line) and feed increase rate (Fast or Slow). Breeder treatment identity was maintained for all broiler progeny chicks that were hatched through to the broiler pens. The treatments were randomly distributed among 72 progeny pens. There were 18 replicate pens per interaction cell. The general linear model (GLM) procedure of SAS Institute (2001) was used to analyze the continuous variables. Means were partitioned using LS MEANS and statements of statistical significance were based upon $P \leq 0.05$ unless otherwise stated.

RESULTS

Broiler Breeder. The main effects of broiler breeder female feed allocation program during growing and feed increase rate from photostimulation to peak egg production, as well as the feed allocation by feed increase rate interaction on broiler breeder female BW as sampled at 2, 4, 6, 8, 10, 12, 14, 16, 18, and 20 wk of age in Experiment III are shown in Table III-1. Female BW at 4, 6, 8, 10, and 12 wk of age was affected by the feed allocation program where females fed with the Sigmoid feed allocation program were significantly heavier while at 18 wk of age the Line program females were heavier. Female BW at 20 wk was affected by the feed allocation program by feed increase rate interaction where BW for the Line feed allocation program by Fast feed increase rate combination hens was significantly greater than from the Sigmoid feed allocation program by Fast feed increase rate combination with the Line or Sigmoid feed allocation programs by Slow feed increase rate combinations intermediate. There was no significant main effect due to feed increase rate found.

The main effects of broiler breeder female feed allocation program during growing and feed increase rate from photostimulation to peak egg production, as well as feed allocation by feed increase rate interaction on broiler breeder female BW as sampled at 24, 40, 48, and 56 wk of age in Experiment III are shown in Table III-2. Female BW at 40, 48, and 56 wk of age was affected by the feed allocation program where females from the Line feed allocation program were significantly heavier. There was no significant effect due to feed increase rate as well as no interaction effect found.

The main effects of broiler breeder female feed allocation program during growing and feed increase rate from photostimulation to peak egg production, as well as the feed allocation by feed increase rate interaction on egg weight (EW) and percentage egg shell at 28, 34, 40, and 46 wk of age in Experiment III are shown in Table III-3. The EW at 28 wk of age was significantly heavier from the Slow feed increase rate group as compared to the Fast feed increase rate group. There was no other significant main effect due to feed allocation program as well as no interaction effect found.

The main effects of broiler breeder female feed allocation program during growing and feed increase rate from photostimulation to peak egg production, as well as the feed allocation by feed increase rate interaction on egg weight (EW) and percentage shell at 52, 58, and 64 wk of age in Experiment III are shown in Table III-4. There were no significant main effects as well as no interaction effect found.

The main effects of broiler breeder female feed allocation program during growing and feed increase rate from photostimulation to peak egg production, as well as the feed allocation by feed increase rate interaction on egg production and female mortality in Experiment III are shown in Table III-5. Female mortality was greater due to the Line feed allocation program as compared to the Sigmoid feed allocation program. There was no other significant main effect due to feed increase rate as well as no interaction effect found.

The main effects of broiler breeder female feed allocation program during growing and feed increase rate from photostimulation to peak egg production, as well as the feed allocation by feed increase rate interaction on broiler breeder fertility, hatchability of fertile eggs, hatchability of total eggs, and embryonic mortality from 27 to 64 wk of age in Experiment III are shown in Table III-6. Hatchability of fertile eggs, early dead, and late dead were affected by feed allocation where hens from the Sigmoid feed allocation program exhibited greater hatchability of fertile eggs as well as lower early and late dead embryos. There was no other significant main effect due to feed increase rate as well as no interaction effect found.

Broilers. The main effects of broiler breeder female feed allocation program during growing and feed increase rate from photostimulation to peak egg production, as well as the feed allocation by feed increase rate interaction on male broiler BW at 1, 21, and 42 d of age in Experiment III are shown in Table III-7. There were no significant main effects found. However, male broiler BW at 1 d was affected by the feed allocation by feed increase rate combination where chicks from the Line feed allocation program by Slow feed increase rate and the Sigmoid feed allocation program by Fast feed increase rate combinations were significantly heavier than from the Sigmoid feed allocation program by Slow feed increase rate combination while the Line feed allocation program by Fast feed increase rate combination was intermediate.

The main effects of broiler breeder female feed allocation program during growing and feed increase rate from photostimulation to peak egg production, as well as the feed allocation by feed increase rate interaction on female broiler BW at 1 d, and 42 d of age in Experiment III are shown in Table III-8. There were no significant main effects as well as no interaction effect found.

The main effects of broiler breeder female feed allocation program during growing and feed increase rate from photostimulation to peak egg production, as well as the feed allocation by feed increase rate interaction on the adjusted feed conversion ratio (AdjFCR) of male broilers from 1-21, 21-42, and 1-42 d of age in Experiment III are shown in Table III-9. The Fast feed increase rate for broiler breeders produced broilers that exhibited the best AdjFCR for the 0-42 d period. There was no other significant main effect due to feed allocation program as well as no interaction effect found.

The main effects of broiler breeder female feed allocation program during growing and feed increase rate from photostimulation to peak egg production, as well as the feed allocation by feed increase rate interaction on the adjusted feed conversion ratio (AdjFCR) of female broilers from 1-21, 21-42, and 1-42 d of age in Experiment III are shown in Table III-10. The Sigmoid feed increase rate in broiler breeders produced broilers that exhibited the best AdjFCR for the 21-42 d period because the AdjFCR of the Sigmoid feed increase rate by Slow feed increase rate interaction was significantly better than of all other interactions. The Sigmoid feed increase rate in broiler breeders produced broilers that exhibited the best AdjFCR for the 1-42 d period. There was no other significant main effect due to feed increase rate and as well as no other interaction effect found.

The main effects of broiler breeder female feed allocation program during growing and feed increase rate from photostimulation to peak egg production, as well as the feed allocation by feed increase rate interaction on percentage mortality of male broilers from 1-21, 21-42, and 1-42 d of age in Experiment III are shown in Table III-11. The percentage mortality for the 21-42 and 1-42 d periods was significantly affected by the feed increase rate where the Slow feed increase rate group produced broilers that exhibited an increased mortality. There was no other significant main effect due to feed allocation program as well as no interaction effect found.

The main effects of broiler breeder female feed allocation program during growing and feed increase rate from photostimulation to peak egg production, as well as feed allocation by feed increase rate interaction on percentage mortality of female broilers from 1-21, 21-42, and 1-42 d of age in Experiment III are shown in Table III-12. There were no significant main effects as well as no interaction effect found.

DISCUSSION

Birds on the Sigmoid feeding program received more feed early in the rearing period from 3 to 11 wk than did birds on the Line feeding program. The feed increase rate then slowed later during the rearing period before photostimulation. This may have caused the mortality rate of hens from the Sigmoid feeding program to be lower than from the Line feeding program in the subsequent production period (13.9 and 19.5%, respectively) (Table III-5). The Sigmoid feeding program pullets probably had more breast muscle during the early rearing period as a nutrient reserve before the feeding program was slowed after 13 wk of age. Once the feed increase was slowed, the pullets probably had to draw from their breast muscle causing their breast muscle to become smaller prior to coming into egg production. A subjective evaluation of the hens confirmed this conjecture. This could produce some advantages during hot weather. Birds from the Line feeding program had received more rapid feed increments during the late rearing period that would have maintained their breast muscle and may have caused lower egg production. According to Hudson et al. (2000), birds with the larger breast produced fewer eggs when compared to smaller breast birds, possibly because less protein was used for egg production and more was available for muscle deposition. Sturkie (1954) and Breneman (1956) stated that the weight of the oviduct increases tremendously in only a few weeks at the time of sexual maturation. Joseph et al. (2002) also stated that the oviduct weight was increased from 22 wk of age to 32 wk of age and remained unchanged from 32 to 54 wk of age. For this reason, there was no need to increase feed very rapidly prior to photostimulation since the oviduct was not fully developed until after photostimulation and that the Fast feed increase could lead to more large yolk follicles, more breast muscle, lower production, and a higher mortality rate. In this study, we also found a higher rate of mortality occurred during the hot weather (between 32 and 38 wk of age) (data not shown). The high rate of mortality was from birds that were reared with the Line feeding program, probably due to greater breast muscle as discussed above. We found a higher fertility due to fewer early and late dead embryos from the birds that were fed with the Sigmoid feeding program. This finding was in an agreement with Walsh and Brake (1997) that the pattern of feed allocation during the growing phase and early production phase could influence BW and overall performance, affecting egg production, egg weight, and long-term fertility. The authors stated the cause of the decline in late fertility was deficit daily intake of ME due to greater in BW as a result of prior greater feed increments. In the present study, the egg production was numerically greater from the Sigmoid than from the Line rearing feeding program (176 versus 167, respectively) (Table III-5). However, we did not observe any differences in egg weight and broiler performance due to feeding program during rearing except for a better adjusted feed conversion ratio (AdjFCR) for female broilers at 21-42 d and 1-42 d from the Sigmoid feeding program hens.

The ovary and oviduct are both sensitive to the feed allocation program at the time of photostimulation that triggers final sexual maturation. According to Zuidhof et al. (2007), the growth and development of the oviduct can be very responsive to feed allocation during sexual maturation. Hocking et al. (1987, 1989); Heck et al. (2004); Hocking and Robertson (2005) stated that feed restriction during the rearing and laying periods reduces the development of an abnormally large number of large follicles on the ovary of broiler breeder hens. Overfeeding for as little as 2 wk between photostimulation and peak production can permanently hinder fertility and hatchability (Ingram and Wilson, 1987). Thus, too much feed intake before and after photostimulation could cause an increase in breast muscle that may lead to a higher mortality rate as well as poorer egg production. However, we did not see any differences in the BW, production, and mortality due to the Fast or Slow feeding to peak programs. Our results only showed a difference in the egg weight at 28 wk. Females that were grown on the Slow feed increase program produced larger eggs at 28 wk, which was also the time that we collected eggs for our broiler trial. We grew our broiler trial at 28 wk of age because it was about the time that every hen started to lay their eggs and we wanted to see the early effect of the feeding programs. There was no effect on the breeders from laying feeding to peak program due to hot weather during this 28 wk of age when we collected eggs for broiler trail. Decreased fertile hatchability and increased embryo mortality before breeder heat stress occurred suggested that a different egg was produced due to different reproductive development. The fertile hatchability from the Fast feeding to peak program at 28 wk of age was higher due to lower late embryo mortality than from the Slow program (93.6 versus 90.2%, respectively for fertile hatchability, and 2.6 versus 4.1%, respectively for late dead) (data not shown). The slow increase hens produced male broilers that exhibited greater mortality, poorer 1-42 d AdjFCR, as well as numerical smaller BW, which also suggested a different egg that may have influenced embryo development. The larger eggs in this group were probably hotter during incubation. Since modern broiler breeder has been selected for increased proportion of breast meat, this would extended into the embryo, and that the modern broiler embryo, particularly in the male, has a higher proportion of breast weight (Meijerhof, 2002). This higher breast weight embryo produced more heat and required more oxygen consumption causing problem during the incubation. In this particular experiment, we did not adjust our incubator’s temperature to have the egg temperature at about 37.5^{o}C-37.8^{o}C by the end of incubation period as in other experiments; therefore, those eggs became hotter causing detrimental effect on embryo development. Evidence has shown that chicks that were hatched from high incubation temperature were having an abnormal appearance that could lead to a reduction in chick growth if they survived (Thompson et al., 1976; Leksrisompong et al., 2007). Chick that survived exposure to high incubation temperature probably had a greater chance of higher mortality and lower feed consumption as compared to chicks that were exposed to lower incubation temperature (Ernst et al., 1984; Henken et al., 1987; Leksrisompong et al., 2009). The effect of this high incubation temperature carries throughout the growing period resulting in smaller hatching male BW from Slow feeding program than Fast feeding program and remained to smaller to the end of the experiment at 40 d of age (Table III-7). In conclusion, the Sigmoid feeding program may have helped control the development of the breast muscle, increased fertility, increased hatchability of fertile eggs, and reduced mortality during hot weather at the time of peak egg production. The most critical period on the pattern of feeding program on the early egg size (28 wk) and broiler progeny was the period after photostimulation to peak egg production since this was the period of the most rapid increase in reproductive development. The reason why Slow feed increase hens produced heavier EW than Fast feed increase maybe because of more energy surplus from Fast feed increase were diverted to carcass growth and less to reproductive process results in less than optimal chick production (Robinson et al., 1995). However, these heavier EW may lead to higher LD or decrease in broiler BW if incubation temperature has not been adjusted correctly.

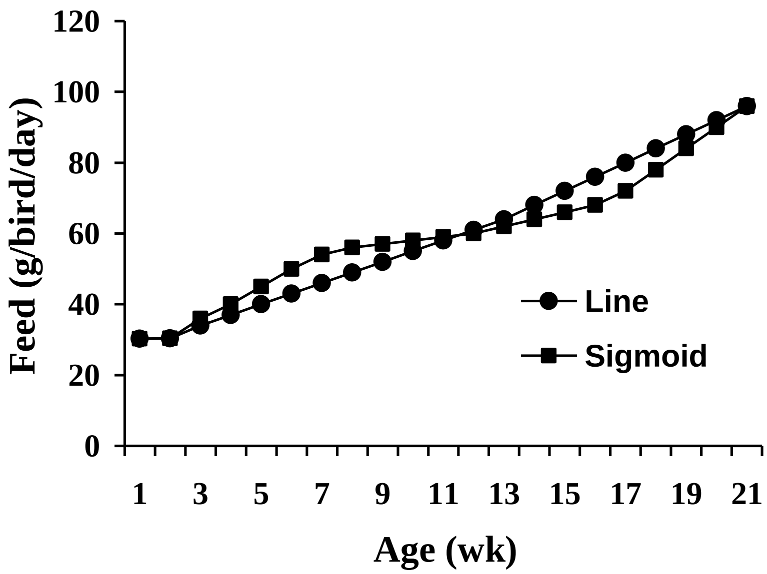

Figure III-1. Feeding programs during the rearing period in Manuscript III. Ross 308SF hens received feed according to these two feeding programs from placement to 21 wk of age. Circles represent the Line feeding program and rectangles represent the Sigmoid feeding program.

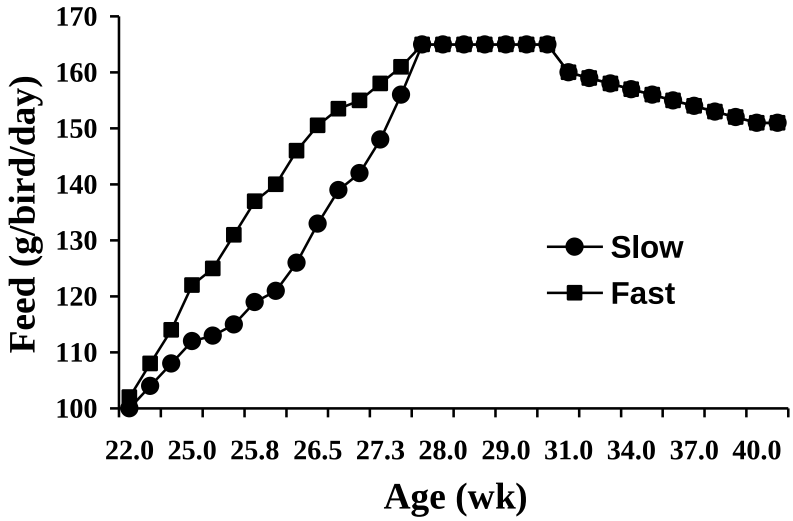

Figure III-2. Feeding to peak program in Manuscript III. Ross 308SF hens received feed according to these two feeding program. Both Fast and Slow feeding programs reached their peak at the same time, 27.5 wk of age. All the hens received the same feed rate thereafter. Rectangles represent the Fast feeding to peak program and circles represent the Slow feeding to peak program**.**

TABLE III-1. Broiler breeder female BW (group samples) as affected by broiler breeder female feed allocation program during growing, feed increase rate from photostimulation to peak egg production, and growing feed allocation program by feed increase rate interaction in Experiment III.

Growing Feed Program[1]	Peak Feed Increase[2]	Wk of Age 2	4	6	8	10	12	14	16	18	20
		(kg)									
Line		0.244	0.485[B]	0.674[B]	0.864[B]	1.087[B]	1.306[B]	1.537	1.828	2.099[A]	2.244
Sigmoid		0.254	0.515[A]	0.740[A]	0.982[A]	1.195[A]	1.392[A]	1.568	1.805	2.018[B]	2.210
	Fast	0.246	0.499	0.707	0.922	1.140	1.362	1.549	1.829	2.055	2.218
	Slow	0.252	0.501	0.707	0.924	1.142	1.337	1.556	1.803	2.062	2.236
SEM[3]		0.004	0.003	0.007	0.007	0.008	0.011	0.013	0.011	0.015	0.019
Line	Fast	0.241	0.484	0.678	0.864	1.077	1.324	1.526	1.842	2.119	2.269[a]
Line	Slow	0.246	0.485	0.671	0.863	1.097	1.288	1.548	1.813	2.079	2.219
Sigmoid	Fast	0.250	0.513	0.736	0.979	1.203	1.399	1.572	1.816	1.991	2.168
Sigmoid	Slow	0.257	0.516	0.744	0.984	1.188	1.385	1.563	1.793	2.045	2.253
SEM[4]		0.006	0.004	0.010	0.010	0.011	0.016	0.019	0.015	0.021	0.027

[a,b] Means in a column that possess different superscripts differ significantly ($P \leq 0.05$).
[A,B] Means in a column that possess different superscripts differ significantly ($P \leq 0.01$).
[1] Feed allocation program (see Fig. III-1) during growing.
[2] Feed increase rates (see Fig. III-2) from photostimulation to peak egg production.
[3] SEM for n=6 pens with 50 pullets weighed per pen.
[4] SEM for n=3 pens with 50 pullets weighed per pen.

TABLE III-2. Broiler breeder female BW (group samples) as affected by broiler breeder female feed allocation program during growing, feed increase rate from photostimulation to peak egg production, and growing feed allocation program by feed increase rate interaction in Experiment III.

Growing Feed Program[1]	Peak Feed Increase[2]	Wk of Age			
		24	40	48	56
		(kg)			
Line		2.756	3.521[a]	3.803[a]	4.047[a]
Sigmoid		2.805	3.442[b]	3.708[b]	3.815[b]
	Fast	2.747	3.506	3.763	3.920
	Slow	2.814	3.457	3.748	3.943
SEM[3]		0.071	0.019	0.023	0.066
Line	Fast	2.677	3.543	3.809	4.054
Line	Slow	2.835	3.499	3.798	4.041
Sigmoid	Fast	2.817	3.469	3.718	3.785
Sigmoid	Slow	2.793	3.415	3.699	3.845
SEM[4]		0.100	0.027	0.032	0.094

[a,b] Means in a column that possess different superscripts differ significantly ($P \leq 0.05$).
[1] Feed allocation program (see Fig. III-1) during growing.
[2] Feed increase rates (see Fig. III-2) from photostimulation to peak egg production.
[3] SEM for n=6 pens with 50 hens weighed per pen.
[4] SEM for n=2 pens with 50 hens weighed per pen.

TABLE III-3. Egg weight (EW) and percentage shell at 28, 34, 40, and 46 wk of age as affected by broiler breeder female feed allocation program during growing, feed increase rate from photostimulation to peak egg production, and growing feed allocation program by feed increase rate interaction in Experiment III.

		28 wk		34 wk		40 wk		46 wk	
Growing Feed Program[1]	Peak Feed Increase[2]	Egg Weight	Egg Shell	Egg Weight	Egg Shell	Egg Weight	Egg Shell	Egg Weight	Egg Shell
		(g)	(%EW)	(g)	(%EW)	(g)	(%EW)	(g)	(%EW)
Line		54.7	9.1	57.6	8.5	58.7	9.2	64.3	8.9
Sigmoid		54.0	9.2	57.5	8.3	59.7	9.2	65.0	8.8
	Fast	53.8[b]	9.1	57.4	8.5	59.4	9.2	64.8	8.9
	Slow	55.0[a]	9.2	57.6	8.4	59.1	9.2	64.4	8.9
SEM[3]		0.3	0.1	0.3	0.1	0.6	0.1	0.2	0.1
Line	Fast	54.2	9.0	57.4	8.5	58.6	9.1	64.1	9.0
Line	Slow	55.2	9.2	57.8	8.4	58.9	9.2	64.4	8.8
Sigmoid	Fast	53.3	9.2	57.5	8.4	60.1	9.2	65.5	8.8
Sigmoid	Slow	54.7	9.2	57.5	8.3	59.3	9.3	64.4	8.9
SEM[4]		0.4	0.1	0.4	0.1	0.8	0.1	0.3	0.1

[a,b] Means in a column that possess different superscripts differ significantly ($P \leq 0.05$).
[1] Feed allocation program (see Fig. III-1) during growing.
[2] Feed increase rates (see Fig. III-2) from photostimulation to peak egg production.
[3] SEM for n=6 pens with mean of 20 eggs weighed per pen.
[4] SEM for n=3 pens with mean of 20 eggs weighed per pen.

TABLE III-4. Egg weight (EW) and percentage shell at 52, 58, and 64 wk of age as affected by broiler breeder female feed allocation program during growing, feed increase rate from photostimulation to peak egg production, and growing feed allocation program by feed increase rate interaction in Experiment III.

Growing Feed Program[1]	Peak Feed Increase[2]	52 wk Egg Weight	52 wk Egg Shell	58 wk Egg Weight	58 wk Egg Shell	64 wk Egg Weight	64 wk Egg Shell
		(g)	(%EW)	(g)	(%EW)	(g)	(%EW)
Line		67.2	8.8	67.6	9.1	71.4	9.1
Sigmoid		68.1	8.8	68.3	9.1	71.0	9.0
	Fast	67.8	8.8	68.1	9.2	71.7	9.0
	Slow	67.5	8.8	67.7	9.1	70.7	9.0
SEM[3]		0.4	0.1	0.4	0.1	0.5	0.1
Line	Fast	67.6	8.9	67.7	9.2	72.1	9.1
Line	Slow	66.8	8.7	67.4	9.1	70.7	9.0
Sigmoid	Fast	68.0	8.8	68.5	9.2	71.3	8.9
Sigmoid	Slow	68.2	8.9	68.1	9.1	70.7	9.0
SEM[4]		0.5	0.1	0.6	0.1	0.7	0.1

[1] Feed allocation program (see Fig. III-1) during growing.
[2] Feed increase rates (see Fig. III-2) from photostimulation to peak egg production.
[3] SEM for n=6 pens with mean of 20 eggs weighed per pen.
[4] SEM for n=3 pens with mean of 20 eggs weighed per pen.

TABLE III-5. Broiler breeder egg production and female mortality from 25 to 64 wk of age as affected by broiler breeder female feed allocation program during growing, feed increase rate from photostimulation to peak egg production, and growing feed allocation program by feed increase rate interaction in Experiment III.

Growing Feed Program[1]	Peak Feed Increase[2]	Egg Production		Female Mortality
		Eggs per Hen Housed	Hen-day Production	
		(n)	(%)	(%)
Line		167	67.7	19.5[a]
Sigmoid		176	67.6	13.9[b]
	Fast	173	68.1	16.8
	Slow	170	67.3	16.6
SEM[3]		3	0.6	1.4
Line	Fast	167	67.3	18.8
Line	Slow	167	68.1	20.2
Sigmoid	Fast	179	68.8	14.7
Sigmoid	Slow	173	66.5	13.0
SEM[4]		4	0.9	1.9

[a,b] Means in a column that possess different superscripts differ significantly ($P \leq 0.05$).
[1] Feed allocation program (see Fig. III-1) during growing.
[2] Feed increase rates (see Fig. III-2) from photostimulation to peak egg production.
[3] SEM for n=6 pens of 190 hens per pen.
[4] SEM for n=3 pens of 190 hens per pen.

TABLE III-6. Broiler breeder fertility, hatchability, and embryonic mortality from 27 to 64 wk of age as affected by broiler breeder female feed allocation program during growing, feed increase rate from photostimulation to peak egg production, and growing feed allocation program by feed increase rate interaction in Experiment III.

Growing Feed Program[1]	Peak Feed Increase[2]	Variables[3] Fertility	Hatchability of Fertile Eggs	Hatchability of Total Eggs	Early[4] Dead	Late[5] Dead
		(%)				
Line		94.01	90.88[b]	85.43	5.42[a]	2.96[a]
Sigmoid		92.52	93.11[a]	86.15	3.99[b]	2.26[b]
	Fast	94.06	91.81	86.35	4.72	2.83
	Slow	92.47	92.18	85.23	4.68	2.39
Line	Fast	95.38	90.83	86.64	5.20	3.26
Line	Slow	92.63	90.92	84.21	5.63	2.65
Sigmoid	Fast	92.73	92.79	86.05	4.24	2.39
Sigmoid	Slow	92.31	93.43	86.25	3.74	2.12

[a,b] Means in a column that possess different superscripts differ significantly ($P \leq 0.05$).
[1] Feed allocation program (see Fig. III-1) during growing.
[2] Feed increase rates (see Fig. III-2) from photostimulation to peak egg production.
[3] Categorical analysis does not generate SEM. Biweekly sets of 180 eggs used.
[4] Embryo that died from 1-7d.
[5] Embryo that died after 7 d but before breaking the egg shell.

TABLE III-7. The BW of male broiler chickens produced from eggs laid at 28 wk of age as affected by broiler breeder female feed allocation program during growing, feed increase rate from photostimulation to peak egg production, and growing feed allocation program by feed increase rate interaction in Experiment III.

Broiler Breeder		Broiler Male BW for Ages Shown		
Growing Feed Program[1]	Peak Feed Increase[2]	1 d	21 d	42 d
		(g)		
Line		36.5	789.0	2396.3
Sigmoid		36.3	801.7	2423.8
	Fast	36.6	800.9	2429.9
	Slow	36.2	789.7	2390.2
SEM[3]		0.2	9.1	40.4
Line	Fast	36.4^{AB}	794.9	2439.8
Line	Slow	36.6^{A}	783.1	2352.8
Sigmoid	Fast	36.8^{A}	806.9	2420.0
Sigmoid	Slow	35.8^{B}	796.4	2427.6
SEM[4]		0.2	12.8	57.1

^{A,B} Means in a column that possess different superscripts differ significantly ($P \leq 0.01$).
[1] Feed allocation program (see Fig. III-1) during growing.
[2] Feed increase rates (see Fig. III-2) from photostimulation to peak egg production.
[3] SEM for n=36 pens with 15 male broilers per pen.
[4] SEM for n=18 pens with 15 male broilers per pen.

TABLE III-8. The BW of female broiler chickens produced from eggs laid at 28 wk of age as affected by broiler breeder female feed allocation program during growing, feed increase rate from photostimulation to peak egg production, and growing feed allocation program by feed increase rate interaction in Experiment III.

Broiler Breeder		Broiler Female BW for Ages Shown		
Growing Feed Program[1]	Peak Feed Increase[2]	1 d	21 d	42 d
		(g)		
Line		36.4	757.2	2083.8
Sigmoid		36.1	745.9	2100.2
	Fast	36.3	747.8	2081.0
	Slow	36.3	755.2	2103.0
SEM[3]		0.2	5.8	17.7
Line	Fast	36.2	748.9	2083.8
Line	Slow	36.7	765.5	2083.9
Sigmoid	Fast	36.3	746.8	2078.1
Sigmoid	Slow	35.9	745.0	2122.2
SEM[4]		0.3	8.2	25.1

[1] Feed allocation program (see Fig. III-1) during growing.
[2] Feed increase rates (see Fig. III-2) from photostimulation to peak egg production.
[3] SEM for n=36 pens with 15 female broilers per pen.
[4] SEM for n=18 pens with 15 female broilers per pen.

TABLE III-9. Adjusted feed consumption ratio (AdjFCR) of male broiler chickens produced from eggs laid at 28 wk of age as affected by broiler breeder female feed allocation program during growing, feed increase rate from photostimulation to peak egg production, and growing feed allocation program by feed increase rate interaction in Experiment III.

Broiler Breeder		Male Broiler AdjFCR For Ages Shown		
Growing Feed Program[1]	Peak Feed Increase[2]	1-21 d	21-42 d	1-42 d
			(g:g)	
Line		1.53	1.69	1.64
Sigmoid		1.50	1.69	1.63
	Fast	1.50	1.67	1.61[b]
	Slow	1.53	1.72	1.66[a]
SEM[3]		0.02	0.02	0.01
Line	Fast	1.50	1.68	1.62
Line	Slow	1.56	1.70	1.65
Sigmoid	Fast	1.49	1.66	1.60
Sigmoid	Slow	1.51	1.73	1.66
SEM[4]		0.03	0.03	0.02

[a,b] Means in a column that possess different superscripts differ significantly ($P \leq 0.05$).
[1] Feed allocation program (see Fig. III-1) during growing.
[2] Feed increase rates (see Fig. III-2) from photostimulation to peak egg production.
[3] SEM for n=36 pens with 15 male broilers per pen.
[4] SEM for n=18 pens with 15 male broilers per pen.

TABLE III-10. Adjusted feed consumption ratio (AdjFCR) of female broiler chickens produced from eggs laid at 28 wk of age as affected by broiler breeder female feed allocation program during growing, feed increase rate from photostimulation to peak egg production, and growing feed allocation program by feed increase rate interaction in Experiment III.

Broiler Breeder		Female Broiler AdjFCR For Ages Shown		
Growing Feed Program[1]	Peak Feed Increase[2]	1-21 d	21-42 d	1-42 d
			(g:g)	
Line		1.55	1.74[A]	1.67[A]
Sigmoid		1.54	1.67[B]	1.62[B]
	Fast	1.54	1.71	1.65
	Slow	1.54	1.70	1.64
SEM[3]		0.02	0.02	0.01
Line	Fast	1.57	1.72[a]	1.66
Line	Slow	1.53	1.76[a]	1.68
Sigmoid	Fast	1.52	1.70[a]	1.64
Sigmoid	Slow	1.55	1.64[b]	1.61
SEM[4]		0.03	0.02	0.02

[a,b] Means in a column that possess different superscripts differ significantly ($P \leq 0.05$).
[A,B] Means in a column that possess different superscripts differ significantly ($P \leq 0.01$).
[1] Feed allocation program (see Fig. III-1) during growing.
[2] Feed increase rates (see Fig. III-2) from photostimulation to peak egg production.
[3] SEM for n=36 pens with 15 female broilers per pen.
[4] SEM for n=18 pens with 15 female broilers per pen.

TABLE III-11. Percentage mortality (deaths) of male broiler chickens produced from eggs laid at 28 wk of age as affected by broiler breeder female feed allocation program during growing, feed increase rate from photostimulation to peak egg production, and growing feed allocation program by feed increase rate interaction in Experiment III.

Broiler Breeder		Male Broiler Deaths For Ages Shown		
Growing Feed Program[1]	Peak Feed Increase[2]	1-21d	21-42d	1-42d
		(%)		
Line		3.70	4.07	7.78
Sigmoid		1.85	5.19	7.04
	Fast	2.59	1.85[B]	4.44[B]
	Slow	2.96	7.41[A]	10.37[A]
SEM[3]		0.95	1.08	1.37
Line	Fast	2.96	1.48	4.44
Line	Slow	4.44	6.67	11.11
Sigmoid	Fast	2.22	2.22	4.44
Sigmoid	Slow	1.48	8.15	9.63
SEM[4]		1.35	1.53	1.93

[A,B] Means in a column that possess different superscripts differ significantly ($P \leq 0.01$).
[1] Feed allocation program (see Fig. III-1) during growing.
[2] Feed increase rates (see Fig. III-2) from photostimulation to peak egg production.
[3] SEM for n=36 pens with 15 male broilers per pen.
[4] SEM for n=18 pens with 15 male broilers per pen.

TABLE III-12. Percentage mortality (deaths) of female broiler chickens produced from eggs laid at 28 wk of age as affected by broiler breeder female feed allocation program during growing, feed increase rate from photostimulation to peak egg production, and growing feed allocation program by feed increase rate interaction in Experiment III.

Broiler Breeder		Female Broiler Deaths For Ages Shown		
Growing Feed Program[1]	Peak Feed Increase[2]	1-21d	21-42d	1-42d
		(%)		
Line		0.74	0.74	1.48
Sigmoid		1.11	1.85	2.96
	Fast	0.74	1.11	1.85
	Slow	1.11	1.48	2.59
SEM[3]		0.57	0.63	0.75
Line	Fast	0.74	0.00	0.74
Line	Slow	0.74	1.48	2.22
Sigmoid	Fast	0.74	2.22	2.96
Sigmoid	Slow	1.48	1.48	2.96
SEM[4]		0.81	0.89	1.06

[1] Feed allocation program (see Fig. III-1) during growing.
[2] Feed increase rates (see Fig. III-2) from photostimulation to peak egg production.
[3] SEM for n=36 pens with 15 female broilers per pen.
[4] SEM for n=18 pens with 15 female broilers per pen.

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MANUSCRIPT IV. Effect of Quantity of Starter Feed for Males and Females and Form of Female Feeding Program during Rearing on Broiler Breeder Reproductive Performance and Mortality

ABSTRACT

A study examined how length of starter feed use (2 wk versus 6 wk) for both broiler breeder males and females interacted with the shape of the female feeding program during rearing to affect subsequent reproductive performance and mortality in a 2 x 2 x 2 factorial design. Ross 344 males and Ross 708 SF females were reared separately to 21 wk of age. An 18% CP starter diet was fed to females and males to either 2 wk or 6 wk of age followed by 15% CP grower and layer diets. From 3 to 21 wk of age, two female feeding programs (Line or Sigmoid) were used followed by the same feeding program and diet from 22 to 64 wk of age. The Line and Sigmoid feeding programs provided the same cumulative female nutrition to 21 wk of age. At 21 wk of age, birds were moved to a curtain-sided slat-litter house and photostimulated. There were 60 females and 6 males allocated to each of the 16 pens during the laying period. Hen BW was determined on a regular basis. Egg production and mortality were determined on a daily basis while percentage fertility and hatchability were evaluated on a weekly basis from sets of 60 eggs per replicate pen. The Sigmoid feeding program produced heavier females at 4, 6, and 10 wk of age while the Line feeding program produced heavier female BW at 19 wk. The 6 wk starter feeding period significantly decreased female, but not male, mortality. The interaction of 2 wk of starter

feed for females with 6 wk of starter feed for males produced the numerically greatest female mortality while the interaction of 6 wk starter feed on females by both 2 or 6 wk starter feed on males produced the numerically lowest female mortality. The latter may have been related to a more robust female that could better withstand the rigors of mating and activity in a slat-litter pen. There were no other significant effects due to starter feed feeding period or female feeding program on hen-day egg production, fertility, or hatchability.

Key words: broiler breeder, starter diet, mortality, feeding program, livability

INTRODUCTION

It has been long known that dietary protein influences body growth and composition of domestic fowl. According to Leeson and Summers (1984), skeletal growth was increased when the level of dietary protein was increased during the early life of a pullet. Lilburn et al. (1989) and Lilburn and Myers-Miller (1990) also stated that the body composition of pullets with similar BW was influenced by protein intake while the energy consumption and BW gain of these pullets were related during the rearing period. One breeder management guide has stated that an important aspect of early protein intake on growth and development during the first 6 wk of life was to improve BW uniformity of the flock (Anonymous, 2008). Therefore, feeding a low protein diet to pullets during their early life could cause a disturbance in their growth and development (Kim and McGinnis, 1976; Hussein et al., 1996). There have been many studies concerning early protein intake as well as growth and development of pullets (Leeson and Summers, 1984; Brake et al., 1985; Lilburn et al., 1987; Yaissle and Lilburn, 1998; Hudson et al., 2000), but none concerning the length of the starter feed use and the long-term effects of early crude protein (CP) intake on broiler breeders. A recent Cobb manual recommended the use of 4 wk of starter feed of 18.54% CP before changing to a grower feed of 14.45% CP (Anonymous, 2010). Yaissle and Lilburn (1998) also stated that pullets were normally changed to a lower protein grower diet after 4 wk of age although there was no clear study concerning the use of different lengths of starter feed with males and females and the effect on their performance and mortality after mixing with each other at photostimulation. Since males that were relatively deprived of feed were aggressive toward females and sometimes killed them (Duncan and Wood-Gush, 1971; Mench, 1993; Brake, 1998), the length of the starter feed and the combination of the males with females at photostimulation were thought to be somewhat important. Males have been shown to be more photosensitive than females under natural conditions and entered sexual maturity about 2 wk ahead of the females during the spring season thus; males learn to mate homosexually and would be ready to service females once females reaching their sexual maturity in the best of circumstances (Meier and MacGregor, 1972; Brake, 1990). When males and females were grown under a light stimulation program where males and females achieved sexual maturity at the same time such that initial male-to-male and male-to-female interactions took place at the same time, initial mating could be less than totally successful and would lead to a decline in fertility later in the production period (Brake, 1990). As suggested by this previous study, the length of the starter feed and the timing of combination of the males and females were important. Not only was the length of the starter feed thought to be important for achieving good fertility, the pattern of the feed increase during rearing was also thought to be important. Walsh and Brake (1997) demonstrated the importance of the pattern of feed restriction during rearing without differences in total feed consumption on early egg production and long-term fertility. They were also the first to demonstrate that an acceptable persistence of fertility and reproductive performance during lay could be achieved by providing at least 1,180 g of CP to pullets by 20 wk of age. Walsh and Brake (1999) also showed that fertility was improved by feeding breeder pullets with slow and consistent feed increments late in the rearing period. In a similar manner, male broiler breeders also required a minimum cumulative nutrient intake during rearing to sustain subsequent reproductive performance (deReviers and Seigneurin, 1990; Brake and Peak, 1999; Romero-Sanchez et al., 2004, 2007). The objective of this study was to determine the effect of quantity of starter feed for males and females and the form of the female feeding program during rearing on broiler breeder reproductive performance and mortality.

MATERIALS AND METHODS

***Broiler Breeder Rearing Period*.** Broiler breeder males (Ross 344) and females (Ross 708SF) were placed in an enclosed fan-ventilated 32-pen litter floor rearing house with 16 (14.3 m^2 area) pens for females and 16 (4.6 m^2 area) pens for males. The rearing house was equipped with 5 space heaters and 6 upward directed fans in the central walkway with pens on either side to insure uniform temperature throughout the house. At placement, there were 80 females and 25 males in each female and male pen, respectively. Three tube feeders (Kuhl DH-4) were initially used in each female growing pen followed by an increase to 4 tube feeders per pen at 15 wk of age while one tube feeder was used continually in each male pen. Each feeder pan had a circumference of 132 cm. After 23 h of light per day for one week all birds were reared to 21 wk of age with 8 h of light per day at an average light intensity of 15 lux using 12W fluorescent lamps. Access to water was limited by a time clock and solenoid system sufficient to control litter moisture and allow the birds to have unlimited access to water until at least one hour after all feed was consumed and a similar amount on non-feed days during rearing. This was typically 6 h daily. A group weight of all females and males was taken at placement (1 d); thereafter, a group of 20 females at 4 and 10 wk of age was weighed while individual female and male BW was taken at 6 and 19 wk of age. Shank length of the males was measured at 6 wk of age.

Broiler Breeder Production Period. An average of 60 females and 6 males were moved as groups from each rearing pen into each of 16 slat-litter floor laying pens (16.0 m^2 total area/pen, 6.0 m^2 litter area/pen) at 21 wk of age. Birds were photostimulated with 14 h of light at the time of movement. The day length was subsequently increased to 15 h 7 d later, and then to 15.5 h and 16 h at 5% and 50% rate of lay, respectively. Natural light entered the slat-litter pens through open or translucent curtains during normal daylight hours. Supplemental light provided an average intensity of 35 lux at bird head level using 18W fluorescent lamps when natural light was not present. There were 4 tube feeders for females and 1 tube feeder for males in each laying pen. Water was limited to 8 h per day during the laying period using two bell-type drinkers in each of the 16 breeding pens. One 6-hole (50.8 cm wide nest spaces per pen) conventional nest was provided in each breeding pen. Separation of sexes was insured by special grills (sixteen 4.8 x 5.8 cm holes) on each female feeder that prevented the non-dubbed males from accessing the feed. Individual female BW was taken at 29 wk of age. Group BW of all females were also taken at 25, 48, 56, and 64 wk of age. At 32, 45, and 64 wk of age, 30, 20, and 20 eggs per pen, respectively, were collected and egg weight (EW) was determined gravimetrically. The egg contents were then removed and shells dried to constant weight before cooling to room temperature. The eggshells were then weighed.

Fertility and Hatchability. Eggs were collected twice daily from the nests and stored in an egg cooler at 16-18^{o}C and 60% RH until incubated. Eggs that were laid on the floor and slats were collected and enumerated separately but not incubated. Analysis of percentage fertility, hatchability, and embryo mortality was conducted from 26 to 64 wk of age by macroscopic examination of all unhatched eggs from weekly sets of 60 eggs per pen. All unhatched eggs were opened and examined macroscopically to determine fertility or infertility and, if fertile, to determine the stage of embryonic mortality. Embryos that died from 1-7 d of incubation were termed early deads and embryos that died after 7 d were termed late deads. Cracked eggs were deemed to be accidental in nature and were not included in the calculations. Eggs were set in a Jamesway model 252B incubator (Butler Manufacturing Co., Ft. Atkinson, WI 53538).

Experimental Diets and Feeding Programs. Feed for broiler breeders was provided daily during the first 2 wk of age and then a 4/3 feed allocation program (feed Monday, Wednesday, Friday, and Saturday only) was used until 21 wk of age after which a daily feeding program was employed. Diets are shown in Table I-1. A common starter diet (18% CP) was fed for either 2 or 6 wk to either sex followed by a common grower diet (15% CP) for both sexes from either 3 or 7 to 25 wk (approximately 10% rate of lay), respectively. From 3 to 21 wk, two feed allocation program (Sigmoid or Line) were used followed by the same feeding program from 22 wk to the end of the production (Fig IV-1, IV-2). Females in rearing pens with 2 wk starter feed by Sigmoid or Line received 25.7 Mcal of ME and 1,331 g of CP and females in rearing pens with 6 wk starter feed by Sigmoid or Line received 25.7 Mcal of ME and 1,365 g of CP cumulative nutrient intake. Males in rearing pens with 2 wk starter feed by Sigmoid or Line received 30.2 Mcal of ME and 1,566 g of CP while males in rearing pens with 6 wk starter feed by Sigmoid or Line received 30.2 Mcal of ME and 1,613 g of CP cumulative nutrient intake. All females were provided peak feed of 159 g at 30 wk of age. The feed allocation was then reduced once egg production across both treatments was similar for 5 d. Male and female mortality was recorded daily and feed allocations adjusted accordingly.

Statistical Analyses. The fertility and hatchability data were analyzed on a weekly basis. A completely randomized design with a factorial (2 x 2 x 2) arrangement of treatments was used. The main factors were female starter feed (2 or 6 wk), male starter feed (2 or 6 wk), and feed allocation program (Sigmoid or Curve). The treatments were randomly distributed among 16 pens with 2 replicate pens per interaction cell. The general linear model (GLM) procedure of SAS Institute (2001) was used to analyze the continuous variables. The fertility data was analyzed as categorical data, where each individual egg was taken as a binomial event, either fertile or infertile, using the general model (GENMOD) procedure of SAS Institute (2001). Means were partitioned using LS MEANS and statements of statistical significance were based upon $P \leq 0.05$ unless otherwise stated.

RESULTS

The main effects of weeks of broiler breeder female starter feed, weeks of male starter feed, and feed allocation program during growing, as well as female starter feed by male starter feed interaction, female starter feed by feed allocation program interaction, and male starter feed by feed allocation program interaction on broiler breeder female BW as sampled at 1, 4, 10, 25, 48, 56, and 64 wk of age are shown in Table IV-1. Female BW at 4 wk of age was affected by female starter feed where females that consumed 6 wk of starter feed were significantly heavier. Female BW at 4 wk of age was affected by feed allocation program where females that were fed with the Sigmoid feed allocation program were significantly heavier because female BW for the 2 wk male starter feed by Sigmoid feed allocation program combination was significantly heavier than from the 6 wk male starter feed by Line or Sigmoid feed allocation program combinations while the 2 wk male starter feed by Line feed allocation program combination was the smallest. Female BW at 10 wk of age was also affected by feed allocation program where females from the Sigmoid feed allocation program were significantly heavier. There were no significant effects due to male starter feed or female starter feed by male starter feed interaction and female starter feed by feed allocation program interaction found.

The main effects of weeks of broiler breeder female starter feed, weeks of male starter feed, and feed allocation program during growing, as well as female starter feed by male starter feed interaction, female starter feed by feed allocation program interaction, and male starter feed by feed allocation program interaction on individual broiler breeder female BW at 6, 19, and 29 wk of age are shown in Table IV-2. Female BW at 6 wk of age was affected by female starter feed and feed allocation program where females from the 6 wk female starter feed and Sigmoid feed allocation program groups were significantly heavier, respectively, than the 2 wk starter feed or Line feed allocation program groups. Female BW at 19 wk of age was affected by feed allocation program where females from the Line feed allocation program were significantly heavier. There were no significant effects due to male starter feed as well as no interaction effects found.

The main effects of weeks of broiler breeder female starter feed, weeks of male starter feed, and feed allocation program during growing, as well as female starter feed by male starter feed interaction, female starter feed by feed allocation program interaction, and male starter feed by feed allocation program interactions on broiler breeder female coefficient of variation (CV) of individual BW at 6, 19, and 29 wk of age are shown in Table IV-3. There were no significant main effects as well as no interaction effects found.

The main effects of weeks of broiler breeder female starter feed, weeks of male starter feed, and feed allocation program during growing, as well as female starter feed by male starter feed interaction, female starter feed by feed allocation program interaction, and male starter feed by feed allocation program interaction on broiler breeder female EW and percentage shell at 32, 45, and 64 wk of age are shown in Table IV-4. The EW at 45 wk of age was significantly heavier for the 2 wk male starter feed group. Percentage egg shell was significantly smaller in eggs from the 6 wk female starter feed group because percentage shell from the 6 wk female starter feed by 2 wk male starter feed combination was less when compared to all other combinations and percentage egg shell for the 2 wk female starter feed by Line or Sigmoid feed allocation program combinations was significantly greater than for the 6 wk female starter feed by Line feed allocation program combination hens with the 6 wk female starter feed by Sigmoid feed allocation program combination hens intermediate.

The main effects of weeks of broiler breeder female starter feed, weeks of male starter feed, and feed allocation program during growing, as well as female starter feed by male starter feed interaction, female starter feed by feed allocation program interaction, and male starter feed by feed allocation program interaction on egg production and female mortality are shown in Table IV-5. Female mortality was greater in the 2 wk female starter feed treatment as compared to the 6 wk female starter feed treatment. There were no significant main effects due to male starter feed or feed allocation program as well as no interaction effects found.

The main effects of weeks of broiler breeder female starter feed, weeks of male starter feed, and feed allocation program during growing, as well as female starter feed by male starter feed interaction, female starter feed by feed allocation program interaction, and male starter feed by feed allocation program interaction on broiler breeder fertility, hatchability of fertile eggs, hatchability of total eggs, and embryonic mortality from 26 to 64 wk of age are shown in Table IV-6. There we no significant main effects as well as no interaction effects found.

DISCUSSION

There was no surprise that the pullets that received a greater length of starter diet were heavier than pullets that received a shorter length of starter diet during the early rearing period. Our results showed significantly greater female BW at 4 and 6 wk of age from the females that received 6 wk of starter feed. However, all females received the same 15% CP grower diet during subsequent rearing and females that received 2 wk of starter feed were numerically heavier at 29 wk of age. This finding was in an agreement with Hudson et al.

(2000) who fed low (12% CP), medium (16% CP), and high (20% CP) starter diets to 6 wk of age and found a greater BW from high CP starter diet birds at 2 and 6 wk, but higher BW from low starter diet birds at 14 and 33 wk of age with medium CP diets intermediate. The reason for this was because birds that were provided a lower CP diet but with similar energy intake required more feed to reach a specific early BW, but when birds from both treatments received the same grower diet, birds that had been started with higher CP required more nutrients to maintain their growth and development. However, it has been suggested that birds that received high protein early seemed to have more adverse effects on physical development and uniformity as well as skeletal development problems than birds that received low protein early (Lilburn et al., 1987). Further studies by Lilburn and Myers-Miller (1990) showed that birds that received low CP early ended up with more fat pad because of more energy reserves due to lower requirements for fat to support body functions. In other words, growth from low CP birds was limited by CP but energy was likely in excess and this resulted in larger fat pads. Many authors stated that estrogen levels of restricted-fed birds were lower than *ad libitum* feed birds until 2-3 wk prior to onset of lay and this was the reason why low CP birds started to grow faster than high CP birds (Brake, 1993; Eitan et al., 1998; Hudson et al., 2000).

Our data showed that the 6 wk starter feeding period significantly decreased female mortality. This might be because the females were more physically prepared to withstand mating and transfer to slat-litter pens. This finding was similar to the study by Hudson et al. (2000) that showed that high CP starter diet birds had the least mortality rate at 6 wk of age when compared to the low CP starter diet birds with a medium CP starter diet intermediate.

We found the mortality to be highest during 26-28 wk, 39-41 wk, and 49-54 wk from the females fed 2 wk of starter feed (data not shown). This result was somewhat in agreement with the statement from Millman et al. (2000) that aggression of males toward females peaks at 5 wk following mixing. The reason that male aggression may have arisen as a result of feed restriction was that males were not ready to properly mate at the time of moving. There were no differences in BW and mortality rate due to male starter feed. The reason for this might be because males were less sensitive to an early starter diet than females. The length of the shank of males was one of the most concerns during the laying period. Shank lengths that were too short or too long would affect the fertility and mortality of the female. Hudson et al. (2000) reported shank length related to an early CP intake where the low protein birds had the longest shanks at 14 wk or thereafter. The high protein treatment birds were also found to have shorter femurs than the medium and low protein birds at 22 wk. Our results showed that there were no differences in the shank length at 6 wk of age due to male or female starter feed (data not shown).

We did not observe any differences in hen-day production or fertility due to the use of 2 wk versus 6 wk of starter feed for males and females. This finding was similar to the study from Robey et al. (1988) concerning feeding different protein levels to 3 wk of age (12, 14, 16, and 18% CP). No differences in fertility with both 2 and 6 wk of starter feed was probably due to a higher than 1,180 g pullet of cumulative CP intake for females as suggested by Walsh and Brake (1997) to achieve persistent fertility throughout lay and at least 1,470 g of CP by 20 wk for males as suggested by Romero-Sanchez et al. (2007) for subsequent male reproductive performance. Hudson et al. (2000) looked at the cumulative egg production per hen and found greater hen-day production in birds provided higher early protein intakes only during the 25 to 33 wk of age period. They suggested that the early rearing period may be the period with the most sensitivity to CP intake. When we looked at our data concerning hen-day production by quartile period, we also found numerically greater egg production per hen housed for birds fed 6 wk of starter feed when compared to 2 wk of starter feed at period 1 (29-34 wk) (64.4 versus 62.6 eggs, respectively) and 2 (35-44 wk) (67.7 versus 66.0 eggs, respectively), but not during period 3 (45-55 wk) (60.0 versus 62.6 eggs, respectively), and period 4 (56-64 wk) (46.5 versus 49.1 eggs, respectively). We did not observe any effects of feeding program during rearing on these birds except for a heavier BW from Sigmoid program at 4, 6, and 10 wk and a heavier BW from the Line feeding program at 19 wk, similar to the finding in Manuscript III (Table III-1, III-2) where pullets from Sigmoid program was heavier early. There were no differences in the fertility of the starter feed combination between males and females, which probably mean that our males were less aggressive and less sensitive to the starter feed than were the females. We also found some similarity as in Manuscript III that hens from Sigmoid program seem to produce eggs with a better hatchability of fertile than birds from Line program. This maybe related to the relationship between breast muscle and hot weather as discussed in Manuscript III. The length of males shanks was not too short or too long so as to contribute to female injury during mating. We did not observe any combinations due to starter feed of males and females on mortality, but the combination between 2 wk of starter feed on females by 6 wk of starter feed on males caused the most female mortality while the 6 wk starter feed on females by both 2 or 6 wk starter feed on males caused the least female mortality (Table IV-5). The reduced mortality may have been related to a physically more robust female due to early protein consumption (6 wk versus 2 wk) so that the hens could better withstand the rigors of mating and activity in a slat-litter pen.

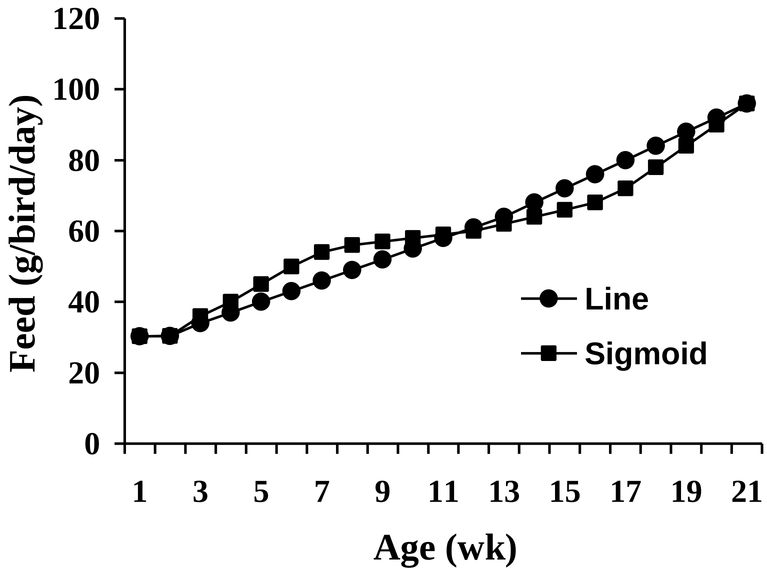

Figure IV-1. Feeding programs during the rearing period in Manuscript IV. Ross 708SF pullets received feed according to these two feeding programs from placement to 21 wk of age. Circles represent the Line feeding program and rectangles represent the Sigmoid feeding program.

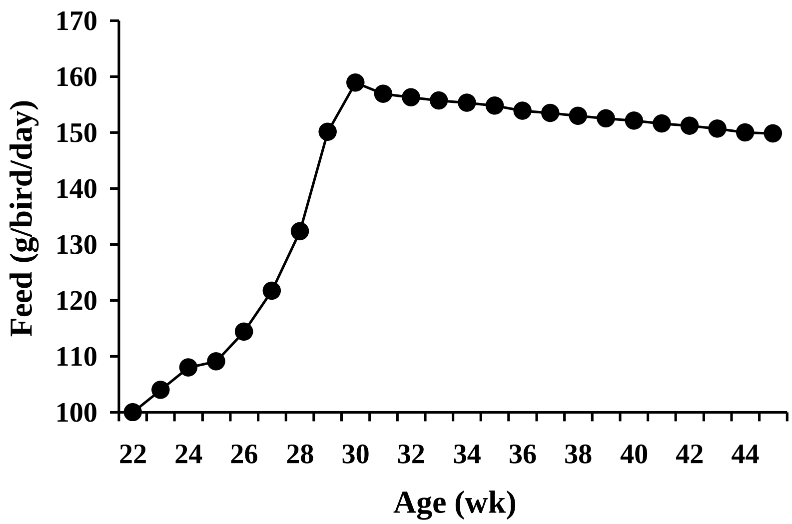

Figure IV-2. Feeding program during the laying period in Manuscript IV. Ross 708SF hens received feed according to this feeding program from 22 to 64 wk of age.

TABLE IV-1. Broiler breeder female BW (group samples) as affected by weeks of broiler breeder female starter feed, weeks of male starter feed, feed allocation program during growing, and female starter feed by male starter feed, female starter feed by feed allocation program, and male starter feed by feed allocation program interactions in Experiment IV.

Starter Feed		Growing Feed Program[3]	Age						
			d	Wk					
Female[1]	Male[2]		1	4	10	25	48	56	64
(wk)	(wk)		(g)	(kg)					
2			42.7	0.516^{B}	1.203	2.738	3.667	3.891	3.946
6			42.6	0.554^{A}	1.222	2.788	3.717	3.832	3.878
	2		42.7	0.535	1.217	2.717	3.686	3.799	3.874
	6		42.6	0.536	1.209	2.808	3.698	3.924	3.949
		Line	42.8	0.518^{B}	1.160^{B}	2.753	3.612	3.863	3.919
		Sigmoid	42.5	0.552^{A}	1.266^{A}	2.773	3.772	3.860	3.905
	SEM		0.1[4]	0.004[5]	0.015[5]	0.040[5]	0.083[5]	0.042[5]	0.025[5]
2	2		42.8	0.513	1.211	2.686	3.594	3.828	3.944
2	6		42.7	0.519	1.196	2.790	3.741	3.954	3.949
6	2		42.7	0.554	1.222	2.749	3.779	3.770	3.805
6	6		42.5	0.554	1.222	2.826	3.655	3.894	3.950
2		Line	42.9	0.504	1.145	2.706	3.656	3.878	3.989
2		Sigmoid	42.5	0.528	1.262	2.770	3.679	3.904	3.903
6		Line	42.7	0.532	1.174	2.799	3.568	3.848	3.849
6		Sigmoid	42.5	0.576	1.270	2.776	3.866	3.816	3.906
	2	Line	42.8	0.504^{C}	1.176	2.743	3.590	3.804	3.876
	2	Sigmoid	42.7	0.564^{A}	1.257	2.692	3.782	3.794	3.873
	6	Line	42.9	0.533^{B}	1.143	2.763	3.633	3.922	3.962
	6	Sigmoid	42.2	0.540^{B}	1.275	2.853	3.763	3.925	3.937
	SEM		0.1[6]	0.006[7]	0.021[7]	0.056[7]	0.118[7]	0.060[7]	0.035[7]

[A,B,C] Means in a column that possess different superscripts differ significantly ($P \leq 0.01$).
[1] Female starter feed for 2 or 6 wk for each pen of 80 pullets during growing.
[2] Male starter feed for 2 or 6 wk for each pen of 25 cockerels during growing.
[3] Feed program (see Fig. IV-1) during growing.
[4] SEM for n=8 pens with 80 pullets weighed per pen.
[5] SEM for n=8 pens with 20 birds weighed per pen.
[6] SEM for n=4 pens with 80 pullets weighed per pen.
[7] SEM for n=4 pens with 20 pullets weighed per pen.

TABLE IV-2. Broiler breeder female BW (individual) as affected by weeks of broiler breeder female starter feed, weeks of male starter feed, feed allocation program during growing, and female starter feed by male starter feed, female starter feed by feed allocation program, and male starter feed by feed allocation program interactions in Experiment IV.

Starter Feed Female[1]	Starter Feed Male[2]	Growing Feed Program[3]	Wk of Age 6	Wk of Age 19	Wk of Age 29
(wk)	(wk)		(kg)		
2			0.736^{B}	2.127	3.154
6			0.781^{A}	2.138	3.151
	2		0.756	2.130	3.130
	6		0.761	2.134	3.175
		Line	0.730^{B}	2.156^{a}	3.142
		Sigmoid	0.787^{A}	2.108^{b}	3.163
	SEM		0.004[4]	0.012[4]	0.014[5]
2	2		0.736	2.134	3.131
2	6		0.736	2.119	3.178
6	2		0.776	2.127	3.129
6	6		0.785	2.149	3.173
2		Line	0.707	2.149	3.129
2		Sigmoid	0.765	2.104	3.179
6		Line	0.753	2.163	3.156
6		Sigmoid	0.808	2.112	3.146
	2	Line	0.723	2.143	3.097
	2	Sigmoid	0.789	2.117	3.163
	6	Line	0.737	2.169	3.187
	6	Sigmoid	0.784	2.099	3.163
	SEM		0.006[6]	0.025[6]	0.020[7]

^{a,b} Means in a column that possess different superscripts differ significantly ($P \leq 0.05$).
^{A,B} Means in a column that possess different superscripts differ significantly ($P \leq 0.01$).
[1] Female starter feed for 2 or 6 wk for each pen of 80 pullets during growing.
[2] Male starter feed for 2 or 6 wk for each pen of 25 cockerels during growing.
[3] Feed rates (see Fig. IV-1) during growing.
[4] SEM for n=8 pens with 80 pullets weighed per pen.
[5] SEM for n=8 pens with 60 hens weighed per pen.
[6] SEM for n=4 pens with 80 pullets weighed per pen.
[7] SEM for n=4 pens with 60 hens weighed per pen.

TABLE IV-3. Coefficient of variation (CV) of broiler breeder female BW as affected by weeks of broiler breeder female starter feed, weeks of male starter feed, feed allocation program during growing, and female starter feed by male starter feed, female starter feed by feed allocation program, and male starter feed by feed allocation program interactions in Experiment IV.

Starter Feed		Growing Feed	Wk of Age		
Female[1]	Male[2]	Program[3]	6	19	29
(wk)	(wk)			(%CV)	
2			14.81	14.14	7.86
6			14.48	14.05	8.14
	2		14.40	13.69	8.02
	6		14.88	14.51	7.98
		Line	14.35	13.47	7.73
		Sigmoid	14.94	14.72	8.27
	SEM		0.77[4]	0.54[4]	0.41[5]
2	2		14.00	13.33	7.70
2	6		15.61	14.96	8.02
6	2		14.81	14.04	8.34
6	6		14.16	14.06	7.94
2		Line	14.62	13.11	7.70
2		Sigmoid	14.99	15.18	8.01
6		Line	14.08	13.83	7.75
6		Sigmoid	14.89	14.27	8.53
	2	Line	13.93	13.15	7.70
	2	Sigmoid	14.88	14.22	8.01
	6	Line	14.77	13.79	7.75
	6	Sigmoid	15.00	15.23	8.53
	SEM		1.08[6]	0.76[6]	0.59[7]

[1] Female starter feed for 2 or 6 wk for each pen of 80 pullets during growing.
[2] Male starter feed for 2 or 6 wk for each pen of 25 cockerels during growing.
[3] Feed rates (see Fig. IV-1) during growing.
[4] SEM for n=8 pens with 80 pullets weighed per pen and CV calculated on a pen basis.
[5] SEM for n=8 pens with 60 hens weighed per pen and CV calculated on a pen basis.
[6] SEM for n=4 pens with 80 pullets weighed per pen and CV calculated on a pen basis.
[7] SEM for n=4 pens with 60 hens weighed per pen and CV calculated on a pen basis.

TABLE IV-4. Egg weight (EW) and percentage shell at 32, 45, and 64 wk of age as affected by weeks of broiler breeder female starter feed, weeks of male starter feed, feed allocation program during growing, and female starter feed by male starter feed, female starter feed by feed allocation program, and male starter feed by feed allocation program interactions in Experiment IV.

Starter Feed		Growing	32 wk		45 wk		64 wk	
Female[1]	Male[2]	Feed Program[3]	Egg Weight	Egg Shell	Egg Weight	Egg Shell	Egg Weight	Egg Shell
(wk)	(wk)		(g)	(EW)	(g)	(EW)	(g)	(EW)
2			56.8	9.4	61.5	9.0[a]	68.5	8.6
6			56.7	9.3	61.6	8.7[b]	68.4	8.8
	2		57.1	9.3	62.3[a]	8.8	69.4	8.7
	6		56.4	9.3	60.8[b]	8.9	68.5	8.8
		Line	56.6	9.4	61.8	8.9	69.5	8.7
		Sigmoid	56.9	9.2	61.3	8.9	68.4	8.8
	SEM		0.3[4]	0.1[4]	0.4[5]	0.1[5]	0.8[5]	0.1[5]
2	2		56.9	9.3	62.1	9.1[A]	69.3	8.7
2	6		56.6	9.4	61.0	8.9[A]	69.7	8.6
6	2		57.3	9.2	62.5	8.6[B]	69.5	8.6
6	6		56.2	9.3	60.7	8.9[A]	67.4	9.1
2		Line	56.5	9.4	61.7	9.1[a]	69.9	8.7
2		Sigmoid	57.0	9.3	61.3	8.9[a]	69.0	8.6
6		Line	56.6	9.3	61.9	8.6[b]	69.0	8.7
6		Sigmoid	56.8	9.2	61.3	8.8[ab]	67.8	9.0
	2	Line	56.7	9.3	62.5	8.8	69.9	8.6
	2	Sigmoid	57.5	9.3	62.2	8.9	68.9	8.7
	6	Line	56.4	9.4	61.2	9.0	69.1	8.7
	6	Sigmoid	56.4	9.2	60.5	8.9	68.0	8.9
	SEM		0.4[6]	0.1[6]	0.6[7]	0.1[7]	1.1[7]	0.2[7]

[a,b] Means in a column that possess different superscripts differ significantly ($P \leq 0.05$).
[A,B] Means in a column that possess different superscripts differ significantly ($P \leq 0.01$).
[1] Female starter feed for 2 or 6 wk for each pen of 80 pullets during growing.
[2] Male starter feed for 2 or 6 wk for each pen of 25 cockerels during growing.
[3] Feed rates (see Fig. IV-1) during growing.
[4] SEM for n=8 pens with mean of 30 eggs weighed per pen.
[5] SEM for n=8 pens with mean of 20 eggs weighed per pen.
[6] SEM for n=4 pens with mean of 30 eggs weighed per pen.
[7] SEM for n=4 pens with mean of 20 eggs weighed per pen.

TABLE IV-5. Broiler breeder egg production and female mortality from 25 to 64 wk of age as affected by weeks of broiler breeder female starter feed, weeks of male starter feed, feed allocation program during growing, and female starter feed by male starter feed, female starter feed by feed allocation program, and male starter feed by feed allocation program interactions in Experiment IV.

Starter Feed		Growing Feed Program[3]	Egg Production		Female Mortality	Male Mortality
Female[1]	Male[2]		Eggs per Hen Housed	Hen-day Production		
(wk)	(wk)		(n)	(%)	(%)	(%)
2			156	60.3	13.0[a]	30.0
6			159	59.8	8.1[b]	31.3
	2		157	59.5	9.2	27.9
	6		158	60.6	11.9	33.3
		Line	157	60.1	10.7	27.9
		Sigmoid	157	60.0	10.4	33.3
	SEM[3]		2	1.2	1.4	7.9
2	2		156	59.8	10.5	18.3
2	6		155	60.8	15.9	41.7
6	2		157	59.2	8.3	37.5
6	6		161	60.4	7.9	25.0
2		Line	153	59.7	13.8	22.5
2		Sigmoid	158	60.9	12.1	37.5
6		Line	161	60.5	7.5	33.3
6		Sigmoid	156	59.1	8.8	29.2
	2	Line	160	60.5	8.4	26.7
	2	Sigmoid	153	58.5	10.0	29.2
	6	Line	162	60.5	7.5	29.2
	6	Sigmoid	156	59.1	8.8	37.5
	SEM[4]		3	1.7	2.0	11.2

[a,b] Means in columns that possess different superscripts differ significantly ($P \leq 0.05$).
[1] Female starter feed for 2 or 6 wk for each pen of 80 pullets during growing.
[2] Male starter feed for 2 or 6 wk for each pen of 25 cockerels during growing.
[3] Feed rates (see Fig. IV-1) during growing.
[4] SEM for n=8 pens of 60 hens per pen.
[5] SEM for n=4 pens of 60 hens per pen.

TABLE IV-6. Broiler breeder fertility, hatchability, and embryonic mortality from 26 to 64 wk of as affected by weeks of broiler breeder female starter feed, weeks of male starter feed, feed allocation program during growing, and female starter feed by male starter feed, female starter feed by feed allocation program, and male starter feed by feed allocation program interactions in Experiment IV.

Starter Feed		Growing Feed Program[3]	Incubation Variables[4]				
				Hatchability of			
Female[1]	Male[2]		Fertility	Fertile Eggs	Total Eggs	Early Dead[5]	Late Dead[6]
(wk)	(wk)		(%)				
2			89.84	94.20	84.67	3.42	2.38
6			88.86	93.90	83.43	3.65	2.45
	2		88.77	94.24	83.66	3.47	2.29
	6		89.93	93.86	84.43	3.60	2.54
		Line	90.39	93.77	84.77	3.60	2.63
		Sigmoid	88.31	94.32	83.32	3.48	2.20
2	2		90.10	94.67	85.32	3.23	2.10
2	6		89.58	93.72	84.01	3.62	2.66
6	2		87.43	93.81	82.01	3.71	2.48
6	6		90.28	93.99	84.84	3.58	2.43
2		Line	91.34	94.48	86.32	3.16	2.36
2		Sigmoid	88.35	93.92	83.02	3.69	2.40
6		Line	89.44	93.07	83.23	4.03	2.90
6		Sigmoid	88.27	94.73	83.62	3.27	2.01
	2	Line	87.88	93.71	82.35	3.86	2.43
	2	Sigmoid	89.65	94.78	84.98	3.08	2.14
	6	Line	92.90	93.84	87.20	3.33	2.83
	6	Sigmoid	86.96	93.87	81.66	3.87	2.26

[1] Female starter feed for 2 or 6 wk for each pen of 80 pullets during growing.
[2] Male starter feed for 2 or 6 wk for each pen of 25 cockerels during growing.
[3] Feed rates (see Fig. IV-1) during growing.
[4] Categorical analysis does not generate SEM. Weekly sets of 60 eggs per pen were used.
[5] Embryos that died from 1-7d.
[6] Embryo that died after 7 d.

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MANUSCRIPT V. Effect of Feeder Space Allocation During Rearing, Strain, and Feed Increase Rate From Photostimulation To Peak Egg Production of Individually Caged Broiler Breeder Females on Growth of Broiler Progeny

ABSTRACT

A study was conducted to determine if there were differences in reproductive traits and growth of broiler progeny from two breeder strains (Ross 308 and 708) that had been subjected to two female feeder space allocations (5.3 cm versus 7.0 cm) during the growing period in floor pens followed by two female feeding to peak programs in individual cages. There were 16 pens of 75 females each assigned to the two feeder space allocations from 1 to 23 wk. At 23 wk, 128 females that were evenly distributed throughout the BW range of each pen, 8 per pen, were placed in individual cages and subjected to one of two feeding to peak feed increase programs (Slow or Fast) to complete a 2 x 2 x 2 factorial design with 16 hens per interaction cell and 64 hens per main effect. Individual females were weighed at 20, 22, 25, 29, 33, 48, and 53 wk. Breeder females from the 708 strain were heavier than those of the 308 strain at all ages and exhibited the greatest BW increase. Two eggs from each hen were weighed and yolk weight, shell weight, and albumen weight and height determined at 29 and 48 wk of age. The Fast feeding to peak program and the 708 strain produced eggs with greater albumen height at both 29 and 48 wk. Eggs produced at 31 wk of age were collected for 5 consecutive days and then incubated and chicks hatched for a broiler trial. Seven male and 7 female broiler chicks were randomly assigned together to 32 pens in a 2 x 2 x 2 design with 4 replicate pens per interaction cell. Broilers from the Fast feeding to peak program and 708 strain and were smaller at 14, 28, and 42 d of age. There was no difference in BW due to growing feeder space but 5.3 cm of breeder female growing feeder space in combination with the Slow feed increase to peak program produced the heaviest broilers at 42 d. The greater albumen height of the Slow feed increase program and 708 strain may have negatively affected embryological development and post-hatch growth.

Key words: broiler breeders, broiler progeny, feeding programs, feeder space, strains

INTRODUCTION

There have been many studies that have focused on the effects that improving growth rate and meat yield of broilers have on broiler parent stock performance (Havenstein et al., 1994; Tona et al., 2004). Overweight broiler breeders have been reported to exhibit poor egg production, fertility, and hatchability (Hocking 1993; Bruggeman et al., 1999). These negative effects have been thought to be due to the genetic effects associated with selection for rapid juvenile growth on the reproductive potential of broiler breeder females. Thus, factors including genetics, nutrition, management, egg nutrient content, and embryo incubation physiology have been linked to weight of chicks at hatching and subsequent broiler performance (Wilson, 1991; Suarez et al., 1997; Tharrington et al., 1999; Silverside and Scott, 2001). Different broiler breeder strains have been reported to produce eggs with different percentage yolk or albumen, yolk:albumen ratio, percentage shell, and incubation time (Suarez et al., 1997; Joseph and Moran, 2005). Albumen characteristics can also be influenced by feeding factors such as dietary protein (Shafer et al., 1998; Novak et al., 2004) as well as pattern of feed allocation at the time of sexual maturation. These differences may help produce broiler progeny with different post hatching performance potential. Therefore, this study was conducted to determine if there were differences in growth of broiler progeny from two broiler breeder strains that had been subjected to two female feeder space allocations during the growing period in floor pens followed by two female feeding to peak programs in individual cages.

MATERIALS AND METHODS

Broiler Breeder Rearing Period. Broiler breeder males (Ross 344) and females (Ross 308SF and Ross 708SF) were placed in an enclosed fan-ventilated 32-pen litter floor rearing house with 16 (14.3 m^2 area) pens for females and 16 (4.6 m^2 area) pens for males. The rearing house was equipped with 5 space heaters and 6 upward directed fans in the central walkway with pens on either side to insure uniform temperature throughout the house. At placement, there were 75 females and 18 males in each female and male pen, respectively. There were either Ross 308SF or Ross 708SF strain females in each female rearing pen and either 3 or 4 tube feeders (Kuhl DH-4) in each female rearing pen while there was 1 tube feeder in each male rearing pen. Each feeder pan had a circumference of 66.1 cm. After 23 h of light per day for one week all birds were reared to 23 wk of age with 8 h of light per day at an average light intensity of 15 lux using 12W fluorescent lamps. Access to water was limited by a time clock and solenoid system sufficient to control litter moisture and allow the birds to have unlimited access to water until at least one hour after all feed was consumed and a similar amount on non-feed days during rearing. A group weight of all females and males was taken at placement (1 d) and individual female and male BW was taken at 20 wk of age.

Broiler Breeder Production Period. There were 128 females, which were evenly distributed throughout the BW range of each pen, moved to individual cages (33.0 cm W x 38.1 cm D x 40.6 cm H) while 108 males not moved to the slat-litter house for a simultaneous study were moved to individual cages (33.0 cm W x 38.1 cm D x 50.8 cm H) at 23 wk of age. Birds were photostimulated with 14 h of light at the time of movement. The day length was subsequently increased to 15 h 7 d later and then to 15.5 h and 16 h at 5% and 50% rate of lay, respectively. Natural light entered the cage laying houses through open or translucent curtains during normal daylight hours. Supplemental light provided an average intensity of 35 lux at bird head level using 12W fluorescent lamps when natural light was not present. Individual female BW was taken at 22, 25, 29, 33, 48, and 53 wk of age. At 29 and 48 wk of age, individual eggs were collected from all hens in lay and EW, yolk, albumen, and albumen height were determined gravimetrically. The egg contents were then removed and shells dried to constant weight before cooling to room temperature. The eggshells were then weighed.

Fertility and Hatchability. At 31 wk of age, all females were artificially inseminated a single time and eggs were collected for the next 7 d so that eggs could be incubated and chicks hatched for a broiler progeny performance trial. Egg collections were continued for a subsequent 7 d and these eggs were incubated to determine fertility only. At 48 wk of age, all females were again artificially inseminated on 2 consecutive days and eggs were collected for the next 14 d to determine fertility only.

Experimental Diets and Feeding Programs. Feed for broiler breeders was provided daily during the first 2 wk of age and then a 4/3 feed allocation program (feed Monday, Wednesday, Friday, and Saturday only) was used until 21 wk of age after which a daily feeding program was employed (Fig. I-1). Diets are shown in Table I-1. A common starter diet (17% CP) was fed to all pens for 6 wk followed by a common grower diet (15% CP) from 7 to 25 wk (approximately 10% rate of lay). Females received 25.7 Mcal of ME and

1,349 g of CP cumulative nutrient intake while males received 30 Mcal of ME and 1,600 g of CP cumulative nutrient intake to 21 wk (147 d) of age. Two feed increase rates (Fast versus Slow) were then used from photostimulation to peak egg production (Fig. V-1). The females that received the Fast feed increase rate reached their peak feed of 160 g per female per day at 86% rate of lay while the Slow feed increase rate reached their peak feed 7 d later at 84% rate of lay. The feed allocation was then reduced by 5 g per hen per day once egg production across both treatments was the same for 5 d. The feed allocation was gradually decreased the same for all females thereafter. Male and female mortality was recorded daily and feed allocations adjusted accordingly.

Broiler Trial. To evaluate the possible effects of female breeder treatments on the performance of broiler progeny, a broiler trial was conducted. Broiler hatching eggs were collected from every pen at 31 wk of age. A total of 512 eggs were set in a Natureform Model NMC-2000 incubator. The incubator was initially operated for 3 d at 38.0°C dry bulb and 29.4°C wet bulb set point temperatures. The dry bulb temperature was then decreased to maintain the internal egg temperatures between 37.5°C and 37.8°C as measured with a Braun Thermoscan thermometer (Leksrisompong et al., 2007). At 21.5 d of incubation the chicks that had completed the hatching process were removed from the trays, counted, group weighed, and sexed using the feather-sexing method. After this processing was completed, the chicks were permanently identified with neck tags and distributed among 32 floor pens with wood litter shavings. Each pen area was 4.4 m^2 with two tube feeders and one bell-type drinker. Male and female broilers that were hatched were mixed equally and placed in each pen with a total of about 14 chicks per pen. Floor space per bird was more than adequate. There were two extra pens in each corner of the house with a total of 8 extra pens. During the first 7 d of age there were 3 egg flats used for supplemental feed with 1 supplemental chick font for water. Chicks were group weighed at placement and at 14, 28, and 42 d of age. Feed consumption was determined at 14, 28, and 42 d and adjusted feed conversion ratio (AdjFCR) was calculated. All dead birds were weighed and recorded twice daily and their BW was used in the AdjFCR calculation. A single starter followed by a single grower diet that met or exceeded the NRC (1994) minimum requirements was used during the starter and grower periods from 1-14 and 15-42 d, respectively (Table I-2). No finisher diet was used for the sake of simplicity.

Statistical Analyses. Broiler Breeders. The fertility and hatchability data were analyzed on either a weekly or biweekly basis. A completely randomized design with a factorial (2 x 2 x 2) arrangement of treatments was used in both experiments. The main factors were breeder strain (Ross 308 or Ross 708), feeder space allocation during rearing (5.3 or 7.0 cm of feeder space), and feed increase rate (Fast or Slow) from photostimulation to peak as they affected broiler performance. The treatments were randomly distributed among 16 pens with 2 replicate pens per interaction cell and among 128 cages with 16 individual replicate cages in each strain, rearing, and feed increase rate combination. The general linear model (GLM) procedure of SAS Institute (2001) was used to analyze the continuous variables. The fertility data was analyzed as categorical data, where each individual egg was taken as a binomial event, either fertile or infertile, using the general model (GENMOD) procedure of SAS Institute (2001). Means were partitioned using LS MEANS and statements of statistical significance were based upon $P \leq 0.05$ unless otherwise stated.

Statistical Analyses. Broiler Trials. A randomized complete block design with a factorial (2 x 2 x 2) arrangement of breeder treatments was used. The main factors were strain (Ross 308 or Ross 708), breeder feeder space allocation during rearing (5.3 or 7.0 cm of feeder space), breeder and breeder feed increase rate (Fast or Slow) from photostimulation to peak as they affected on broiler performance. Breeder treatment identity was maintained for all broiler progeny chicks that hatched through to the broiler pens. The broiler breeder treatments were randomly distributed among 32 progeny pens within 2 blocks of 16 pens each. There were 4 replicate pens per interaction cell. The general linear model (GLM) procedure of SAS Institute (2001) was used to analyze the continuous variables. Means were partitioned using LS MEANS and statements of statistical significance were based upon $P \leq 0.05$ unless otherwise stated.

RESULTS

The main effects of broiler breeder female feeder space allocation during growing, strain, and feed increase rate from photostimulation to peak egg production, as well as the growing feeder space by strain interaction, growing feeder space by feed increase rate interaction, and strain by feed increase rate interaction on broiler breeder female BW at 20, 22, 25, 29, 33, 48, and 53 wk of age are shown in Table V-1. Female BW at all ages was affected by strain where females of the 708 strain were significantly heavier. Female BW at 33 wk was affected by strain where females of the 708 strain were significantly heavier because females from the 5.3 or 7.0 cm growing feeder space by 708 strain combinations hens were significantly heavier than females from the 5.3 or 7.0 cm growing feeder space by 308 strain combinations. There were no other significant main effects nor any other significant interactions found.

The main effects of broiler breeder female feeder space allocation during growing, female strain, and feed increase rate from photostimulation to peak egg production, as well as the growing feeder space by strain interaction, growing feeder space by feed increase rate interaction, and strain by feed increase rate interaction on egg weight (EW) and egg components at 29 wk of age are shown in Table V-2. Percentage egg shell and albumen height were affected by strain where the percentage egg shell produced by the 308 strain hens was significantly greater, but the albumen height was significantly less. Albumen height produced by the Fast feed increase rate hens was significantly higher. There were no significant effect due to growing feeder space nor any interactions found.

The main effects of broiler breeder female feeder space allocation during growing, strain, and feed increase rate from photostimulation to peak egg production, as well as the growing feeder space by strain interaction, growing feeder space by feed increase rate interaction, and strain by feed increase rate interaction on egg weight (EW) and egg components at 48 wk of age are shown in Table V-3. Percentage egg shell and albumen height were affected by strain where percentage egg shell produced by the 308 strain hens were significantly greater, but the albumen height was significantly less. Albumen height produced by the Fast feed increase rate hens was significantly increased. There were no significant effects due to growing feeder space nor any interactions found.

The main effects of broiler breeder female feeder space allocation during growing, female strain, and feed increase rate from photostimulation to peak egg production, as well as the growing feeder space by strain interaction, growing feeder space by feed increase rate interaction, and strain by feed increase rate interaction on broiler breeder fertility at 1-7 d and 8-14 d of incubation from 31 and 48 wk of age hens are shown in Table V-4. Fertility at 8-14 d of incubation from 48 wk hens was affected by feed increase rate where hens from the Fast feed increase rate exhibited greater fertility. There were no significant effects due to growing feeder space and strain nor any interactions found.

The main effects of broiler breeder female feeder space allocation during growing, female strain, and feed increase rate from photostimulation to peak egg production, as well as the growing feeder space by strain interaction, growing feeder space by feed increase rate interaction, and strain by feed increase rate interaction on egg production are shown in Table V-5. There were no significant main effects as well as no interactions found.

Broilers. The main effects of broiler breeder female feeder space allocation during growing, female strain, and feed increase rate from photostimulation to peak egg production, as well as the growing feeder space by strain interaction, growing feeder space by feed increase rate interaction, and strain by feed increase rate interaction concerning mixed sex broiler BW at 1, 14, 28, and 42 d of age are shown in Table V-6. Mixed sex broiler BW at 1 d was increased by the 7.0 cm growing feeder space. Mixed sex broiler BW at 1, 14, 28, and 42 d of age were increased in the 308 strain. Mixed sex broiler BW at 14, 28, and 42 d of age were increased by the Slow feed increase rate. Mixed sex broiler BW at 14 d was increased in the 308 strain because the 5.3 cm growing feeder space by 308 strain combination produced the largest chicks while the 5.3 or 7.0 cm growing feeder space by 708 strain combinations produced the smallest chicks with the 7.0 cm growing feeder space by 308 strain intermediate. Mixed sex broiler BW at 28 d was increased in the 308 strain because the 5.3 or 7.0 cm growing feeder space by 308 strain combinations produced the largest chicks when compared to the 5.3 or 7.0 cm growing feeder space by 708 strain combinations. Mixed sex broiler BW at 42 d was increased by the Slow feed increase rate because the 5.3 cm growing feeder space by Slow feed increase combination produced the largest chicks at 42 d of age while the 5.3 cm growing feeder space by Fast feed increase combination produced the smallest chicks while the 7.0 cm growing feeder space by Slow combination produced similar BW chicks as the 5.3 cm growing feeder space by Slow feed increase combination but larger BW chicks than 5.3 cm growing feeder space by Fast feed increase combination. The 7.0 cm growing feeder space by Fast feed increase combination produced similar BW chicks as 5.3 cm growing feeder space by Fast feed increase combination and 7.0 cm growing feeder space by Slow feed increase combination but produced smaller BW chicks than 5.3 cm feeder space by Slow feed increase combination. There was no significant effect due to breeder strain by feed increase rate interaction found.

The main effects of broiler breeder female feeder space allocation during growing, strain, and feed increase rate from photostimulation to peak egg production, as well as the growing feeder space by strain interaction, growing feeder space by feed increase rate interaction, and strain by feed increase rate interaction on the adjusted feed conversion ratio (AdjFCR) of mixed sex broilers from 1-14, 14-28, 1-28, 28-42, and 1-42 d of age are shown in Table V-7. There were no significant main effects nor any interactions found.

The main effects of broiler breeder female feeder space allocation during growing, strain, and feed increase rate from photostimulation to peak egg production, as well as the growing feeder space by strain interaction, growing feeder space by feed increase rate interaction, and strain by feed increase rate interaction on percentage mortality of mixed sex broilers from 1-14, 14-28, 1-28, 28-42, and 1-42 d of age are shown in Table V-8. The percentage mortality for the 1-42 d period was significantly affected by the growing feeder space and feed increase rate where the 7.0 cm growing feeder space and Fast feed increase groups exhibited increased mortality because the 7.0 cm growing feeder space by Fast feed increase combination produced the most mortality when compared to all other combinations. There were no significant effects due to strain as well as the growing feeder space by strain and strain by feed increase rate combinations found.

DISCUSSION

The Ross 708 breeder has been developed to maximize breeder performance without compromising the efficiency of meat production and still maintaining good efficiency of feed conversion while Ross 308 breeder hens have been developed to produce a high number of eggs combined with good hatchability (Anonymous, 2010). In the present study, we observed that the BW of Ross 708 hens were significantly heavier than the BW of Ross 308 hens at all ages when given the same feed allocations (Table V-1). This differential effect on the BW of these two breeder stains was clearly shown by the birds that were maintained in cages as compared to the birds that were maintained in floor pens in

Manuscript I (Table V-1, Table I-3, I-4). Beside, Ross 308 that were grown in floor pens was numerically heavier than Ross 708 at some ages. This might be because once all the birds in cages began to consume a similar amount of feed each day, the difference between the strains was more evident but when there was competition among the birds at the feeders, the difference between the strains disappeared. Greater albumen height was found in the Ross 708 strain and from the birds that were fed the Fast feed increase rate from photostimulation to peak egg production (Table V-2, V-3). Suarez et al. (1997) and Joseph and Moran (2005) also found differences in yolk and percentage albumen, yolk:albumen ratio, and percentage shell among different strains of broiler breeders. Feeding level at the time of photostimulation has also been found to have an effect on reproductive tract development (Melnychuk et al., 2004) probably because the oviduct has been reported to be one of the main tissues involved in producing egg components and has been characterized as a priority tissue for nutrient partitioning during sexual maturation (Joseph et al., 2002). This might be the reason why the difference in the albumen height was apparent with the Fast feed increase birds. Walsh and Brake (1997) stated that the pattern of feed allocation during the growing phase and early production phase influenced BW and overall performance, affecting egg production, egg weight, and long-term fertility.

The Ross 708 strain and the Fast feeding to peak program produced eggs with greater albumen height (Table V-2) that may have been associated with a smaller broiler BW at 42 d of age (Table V-6). Peebles et al. (2000) showed that relative embryo weight at E16 was significantly higher in low albumen height eggs when compared with high albumen height eggs. Thus, thick albumen may slow vital gas diffusion, limit nutrient availability to the embryo, and subsequently increase the incidence of embryonic deaths (Benton and Brake, 1996). High albumen height increased hatching time and had a significant negative effect on hatchability of eggs from young broiler breeder flocks (Benton et al., 1997). The high albumen height in our 31 wk breeder hens was matched with statement from Benton et al. (1997). Burley and Vadehra (1989) as well as Stern (1991) stated that a decreased albumen height could enhance the flow of water and solute across the vitelline membrane and into the yolk. Therefore, eggs from the Ross 708 as well as the Fast feed increase rate exhibited better albumen quality and possibly should be stored for a longer time in order to achieve higher hatchability (Brake et al., 1997) which could also help decrease broiler mortality. During egg storage, the albumen viscosity tends to decrease through a process known as albumen liquefaction. This facilitates the movement of various nutritive substances from the albumen towards the embryo (Burley and Vadehra, 1988). This might also reduce any physical barrier to gaseous diffusion of oxygen that the albumen may present (Meuer and Baumann, 1988). These changes that occur within the albumen probably have profound effects upon the developing embryo that result in a better BW gain as well as better AdjFCR of the broiler progeny.

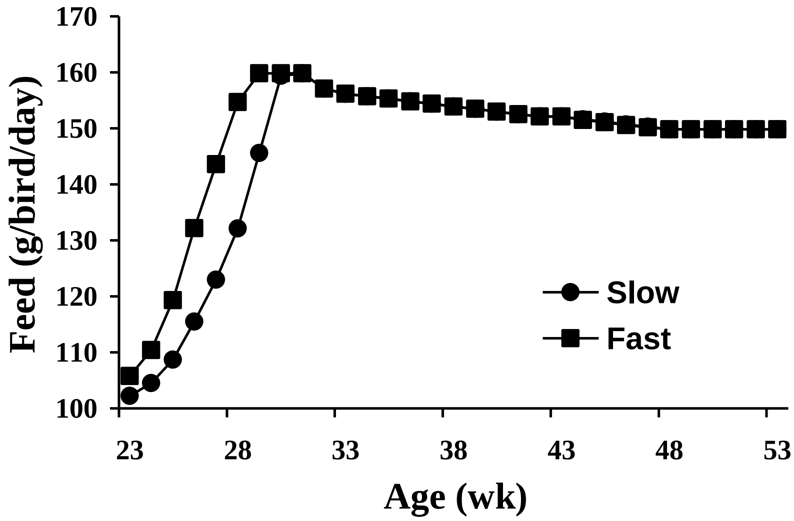

Figure V-1. Feeding to peak program in Manuscript V. Ross 308 and 708SF hens received feed according to these two feeding programs. Either Fast feed from 23 to 29 wk of age or Slow feed from 23 to 30 wk of age. All the hens received the same feed rate thereafter. Rectangles represent the Fast feeding to peak program and circles represent the Slow feeding to peak program.

TABLE V-1. Broiler breeder female BW as affected by broiler breeder female feeder space allocation during growing, strain, and feed increase rate from photostimulation to peak egg production, as well as the growing feeder space by strain interaction, growing feeder space by feed increase rate interaction, and strain by feed increase rate interaction in Experiment V.

Feeder Space During Growing[1]	Strain[2]	Peak Feed Increase[3]	Wk of Age 20	22	25	29	33	48	53
(cm)			(kg)						
5.3			2.290	2.508	2.992	3.158	3.581	4.447	4.690
7.0			2.277	2.479	2.950	3.082	3.552	4.409	4.629
	308		2.252^{B}	2.452^{B}	2.861^{B}	3.016^{B}	3.386^{B}	4.115^{B}	4.423^{B}
	708		2.316^{A}	2.535^{A}	3.081^{A}	3.224^{A}	3.750^{A}	4.745^{A}	4.898^{A}
		Fast	2.293	2.504	2.948	3.166	3.621	4.528	4.735
		Slow	2.274	2.483	2.993	3.070	3.510	4.324	4.580
	SEM[4]		0.016	0.018	0.032	0.043	0.041	0.063	0.062

A,B Means in a column that possess different superscripts differ significantly ($P \leq 0.01$).
[1] Feeder space allocations of 5.3 or 7.0 cm per each of 75 pullets during growing.
[2] Female breeder strain was Ross 308 or Ross 708.
[3] Feed increase rates (see Fig. V-1) from photostimulation to peak egg production.
[4] SEM for n=58 cages.

TABLE V-1 (continued). Broiler breeder female BW as affected by broiler breeder female feeder space allocation during growing, strain, and feed increase rate from photostimulation to peak egg production, as well as the growing feeder space by strain interaction, growing feeder space by feed increase rate interaction, and strain by feed increase rate interaction in Experiment V.

Feeder Space During Growing[1]	Strain[2]	Peak Feed Increase[3]	Wk of Age 20	22	25	29	33	48	53
(cm)			(kg)						
5.3	308		2.246	2.462	2.875	3.015	3.324[b]	4.045	4.404
5.3	708		2.332	2.552	3.100	3.291	3.821[a]	4.820	4.955
7.0	308		2.256	2.443	2.849	3.016	3.439[b]	4.175	4.439
7.0	708		2.331	2.519	3.062	3.154	3.676[a]	4.667	4.839
5.3		Fast	2.309	2.524	2.991	3.236	3.675	4.635	4.792
5.3		Slow	2.273	2.494	2.992	3.085	3.495	4.271	4.595
7.0		Fast	2.309	2.524	2.991	3.236	3.675	4.635	4.792
7.0		Slow	2.273	2.494	2.992	3.085	3.495	4.271	4.595
	308	Fast	2.267	2.464	2.837	3.074	3.435	4.234	4.518
	308	Slow	2.237	2.440	2.884	2.961	3.341	4.003	4.334
	708	Fast	2.318	2.541	3.052	3.252	3.796	4.803	4.938
	708	Slow	2.314	2.530	3.114	3.191	3.698	4.681	4.854
	SEM[4]		0.023	0.025	0.046	0.060	0.059	0.090	0.089

[a,b] Means in a column that possess different superscripts differ significantly ($P \leq 0.05$).
[1] Feeder space allocations of 5.3 or 7.0 cm per each of 75 pullets during growing.
[2] Female breeder strain was Ross 308 or Ross 708.
[3] Feed increase rates (see Fig. V-1) from photostimulation to peak egg production.
[4] SEM for n=29 cages.

TABLE V-2. Egg weight (EW) and egg components at 29 wk of age as affected by broiler breeder female feeder space allocation during growing, strain, and feed increase rate from photostimulation to peak egg production, as well as the growing feeder space by strain interaction, growing feeder space by feed increase rate interaction, and strain by feed increase rate interaction in Experiment V.

Feeder Space During Growing[1]	Strain[2]	Peak Feed Increase[3]	Egg Weight	Yolk Weight	Egg Shell	Albumen	Yolk:Alb ratio	Albumen Height
(cm)			(g)		(%EW)		(g:g)	(mm)
5.3			53.86	26.88	9.19	63.94	0.421	6.97
7.0			54.67	26.86	9.40	63.74	0.422	7.06
	308		54.62	26.81	9.43[a]	63.76	0.421	6.74[B]
	708		53.93	26.92	9.16[b]	63.92	0.422	7.28[A]
		Fast	54.02	26.80	9.32	63.89	0.420	7.25[a]
		Slow	54.53	26.94	9.27	63.79	0.423	6.77[b]
	SEM[4]		0.49	0.18	0.07	0.20	0.42	0.14
5.3	308		54.07	26.94	9.32	63.74	0.423	6.79
5.3	708		53.67	26.82	9.06	64.12	0.419	7.13
7.0	308		55.13	26.69	9.54	63.77	0.419	6.69
7.0	708		54.19	27.03	9.26	63.71	0.424	7.44
5.3		Fast	53.75	26.78	9.12	64.10	0.418	7.27
5.3		Slow	53.98	26.97	9.26	63.77	0.423	6.66
7.0		Fast	54.28	26.81	9.51	63.69	0.421	7.23
7.0		Slow	55.06	26.91	9.29	63.80	0.422	6.88
	308	Fast	54.98	26.62	9.55	63.83	0.417	6.90
	308	Slow	54.25	27.01	9.31	63.68	0.424	6.57
	708	Fast	53.07	26.97	9.08	63.94	0.422	7.60
	708	Slow	54.80	26.87	9.24	63..89	0.421	6.97
	SEM[5]		0.70	0.27	0.11	0.28	0.59	0.20

[a,b] Means in a column that possess different superscripts differ significantly ($P \leq 0.05$).
[A,B] Means in a column that possess different superscripts differ significantly ($P \leq 0.01$).
[1] Feeder space allocations of 5.3 or 7.0 cm per each of 75 pullets during growing.
[2] Female breeder strain was Ross 308 or Ross 708.
[3] Feed increase rates (see Fig. V-1) from photostimulation to peak egg production.
[4] SEM for n=60 cages.
[5] SEM for n=30 cages

TABLE V-3. Egg weight (EW) and egg components at 48 wk of age as affected by broiler breeder female feeder space allocation during growing, strain, and feed increase rate from photostimulation to peak egg production, as well as the growing feeder space by strain interaction, growing feeder space by feed increase rate interaction, and strain by feed increase rate interaction in Experiment V.

Feeder Space During Growing[1]	Strain[2]	Peak Feed Increase[3]	Egg Weight	Yolk Weight	Egg Shell	Albumen	Yolk:Alb Ratio	Albumen Height
(cm)			(g)		(%EW)		(g:g)	(mm)
5.3			69.66	32.37	8.46	59.18	0.548	6.61
7.0			70.32	32.31	8.70	58.98	0.548	6.22
	308		69.99	32.11	8.81^{A}	59.09	0.544	6.17^{b}
	708		70.00	32.60	8.33^{B}	59.07	0.552	6.68^{a}
		Fast	70.28	32.38	8.58	59.04	0.549	6.65^{a}
		Slow	69.70	32.30	8.59	59.12	0.547	6.16^{b}
	SEM[4]		0.63	0.21	0.11	0.22	0.55	0.14
5.3	308		69.68	32.14	8.73	59.13	0.544	6.46
5.3	708		69.63	32.61	8.16	59.23	0.551	6.76
7.0	308		70.27	32.08	8.88	59.04	0.544	5.89
7.0	708		70.37	32.58	8.50	58.92	0.554	6.59
5.3		Fast	70.39	32.49	8.30	59.21	0.550	6.87
5.3		Slow	68.93	32.25	8.61	59.14	0.546	6.34
7.0		Fast	70.18	32.28	8.83	58.89	0.549	6.44
7.0		Slow	70.46	32.35	8.57	59.09	0.548	5.98
	308	Fast	70.85	32.07	8.80	59.12	0.543	6.44
	308	Slow	69.12	32.14	8.81	59.05	0.545	5.90
	708	Fast	69.67	32.71	8.33	58.96	0.556	6.87
	708	Slow	70.35	32.48	8.33	59.19	0.549	6.47
	SEM[4]		0.90	0.30	0.16	0.31	0.76	0.20

[a,b] Means in a column that possess different superscripts differ significantly ($P \leq 0.05$).
[A,B] Means in a column that possess different superscripts differ significantly ($P \leq 0.01$).
[1] Feeder space allocations of 5.3 or 7.0 cm per each of 75 pullets during growing.
[2] Female breeder strain was Ross 308 or Ross 708.
[3] Feed increase rates (see Fig. V-1) from photostimulation to peak egg production.
[4] SEM for n=60 cages.
[5] SEM for n=30 cages.

TABLE V-4. Broiler breeder fertility at 31 and 48 wk of age as affected by broiler breeder female feeder space allocation during growing, strain, and feed increase rate from photostimulation to peak egg production, as well as the growing feeder space by strain interaction, growing feeder space by feed increase rate interaction, and strain by feed increase rate interaction in Experiment V.

			Wk 31		Wk 48	
Feeder Space During Growing[1]	Strain[2]	Peak Feed Increase[3]	Fertility 1-7 d	Fertility 8-14 d	Fertility 1-7 d	Fertility 8-14 d
(cm)			(%)			
5.3			81.83	12.56	88.41	71.59
7.0			82.75	11.67	93.12	68.37
	308		82.67	12.73	90.65	71.21
	708		81.72	11.33	91.15	68.21
		Fast	80.72	10.22	91.33	77.44^{A}
		Slow	84.15	14.46	90.41	62.37^{B}
	SEM[4]		2.49	2.79	2.15	3.75
5.3	308		80.10	13.20	88.48	76.89
5.3	708		84.25	11.67	88.33	66.03
7.0	308		85.61	12.20	92.30	66.90
7.0	708		79.05	10.98	94.44	70.74
5.3		Fast	78.48	10.76	87.17	82.67
5.3		Slow	85.34	14.44	89.49	61.96
7.0		Fast	82.86	9.71	94.67	73.27
7.0		Slow	82.59	14.48	91.36	62.80
	308	Fast	86.60	14.32	92.76	73.85
	308	Slow	82.32	8.83	88.47	68.47
	708	Fast	79.22	11.33	89.39	82.37
	708	Slow	86.60	14.32	92.83	54.75
	SEM[5]		3.52	3.93	3.04	5.28

^{A,B} Means in a column that possess different superscripts differ significantly ($P \leq 0.01$).
[1] Feeder space allocations of 5.3 or 7.0 cm per each of 75 pullets during growing.
[2] Female breeder strain was Ross 308 or Ross 708.
[3] Feed increase rates (see Fig. V-1) from photostimulation to peak egg production.
[4] SEM for n=52 cages.
[5] SEM for n=26 cages.

TABLE V-5. Broiler breeder egg production from 25 to 53 wk of age as affected by broiler breeder female feeder space allocation during growing, strain, and feed increase rate from photostimulation to peak egg production, as well as the growing feeder space by strain interaction, growing feeder space by feed increase rate interaction, and strain by feed increase rate interaction in Experiment V.

Feeder Space During Growing[1]	Strain[2]	Peak Feed Increase[3]	Egg Production Eggs per Hen Housed
(cm)			(n)
5.3			139
7.0			140
	308		143
	708		137
		Fast	141
		Slow	139
	SEM[4]		3
5.3	308		142
5.3	708		137
7.0	308		144
7.0	708		136
5.3		Fast	142
5.3		Slow	137
7.0		Fast	139
7.0		Slow	141
	308	Fast	142
	308	Slow	144
	708	Fast	139
	708	Slow	134
	SEM[5]		4

[1] Feeder space allocations of 5.3 or 7.0 cm per each of 75 pullets during growing.
[2] Female breeder strain was Ross 308 or Ross 708.
[3] Feed increase rates (see Fig. V-1) from photostimulation to peak egg production.
[4] SEM for n=64 cages.
[5] SEM for n=32 cages.

TABLE V-6. The BW of mixed sex broiler chickens produced from eggs laid at 31 wk of age as affected by broiler breeder female feeder space allocation during growing, female strain, and feed increase rate from photostimulation to peak egg production, as well as the growing feeder space by strain interaction, growing feeder space by feed increase rate interaction, and strain by feed increase rate interaction in Experiment V.

Broiler Breeder			Mixed Sex BW For Ages Shown			
Feeder Space During Growing[1]	Strain[2]	Peak Feed Increase[3]	1 d	14 d	28 d	42 d
(cm)			(g)			
5.3			38.9[b]	463.5	1393.6	2452.9
7.0			39.9[a]	458.8	1392.7	2453.0
	308		39.8[a]	478.7[A]	1460.3[A]	2545.1[A]
	708		38.9[b]	443.6[B]	1326.0[B]	2360.7[B]
		Fast	39.1	454.0[b]	1367.8[B]	2370.1[B]
		Slow	39.6	468.3[a]	1418.6[A]	2535.8[A]
	SEM[4]		0.3	3.7	11.6	31.6
5.3	308		39.1	486.9[a]	1480.3[a]	2563.2
5.3	708		38.6	440.1[c]	1306.9[b]	2342.6
7.0	308		40.4	470.5[b]	1440.3[a]	2527.1
7.0	708		39.3	447.1[c]	1345.1[b]	2378.8
5.3		Fast	39.1[b]	455.2	1360.1	2307.8[c]
5.3		Slow	38.7[b]	471.8	1427.1	2598.0[a]
7.0		Fast	39.1[b]	452.9	1375.5	2432.4[bc]
7.0		Slow	40.6[a]	464.8	1410.0	2473.6[ab]
	308	Fast	39.9	471.9	1428.0	2475.5
	308	Slow	39.7	485.5	1492.6	2614.7
	708	Fast	38.3	436.1	1307.5	2264.7
	708	Slow	39.6	451.0	1344.5	2456.8
	SEM[5]		0.4	5.3	16.4	44.6

[a,b,c] Means in a column that possess different superscripts differ significantly ($P \leq 0.05$).
[A,B] Means in a column that possess different superscripts differ significantly ($P \leq 0.01$).
[1] Feeder space allocations of 5.3 or 7.0 cm per each of 75 pullets during growing.
[2] Female breeder strain was Ross 308 or Ross 708.
[3] Feed increase rates (see Fig. V-1) from photostimulation to peak egg production.
[4] SEM for n=16 pens with 14 broilers per pen.
[5] SEM for n=32 pens with 14 broilers per pen.

TABLE V-7. Adjusted feed consumption ratio (AdjFCR) of mixed sex broiler chickens produced from eggs laid at 31 wk of age as affected by broiler breeder female feeder space allocation during growing, strain, and feed increase rate from photostimulation to peak egg production, as well as the growing feeder space by strain interaction, growing feeder space by feed increase rate interaction, and strain by feed increase rate interaction in Experiment V.

Broiler Breeder			Mixed Sex Broiler AdjFCR For Ages Shown				
Feeder Space During Growing[1]	Strain[2]	Peak Feed Increase[3]	1-14	14-28	1-28	28-42	1-42
(cm)			(g:g)				
5.3			1.49	1.81	1.71	1.87	1.77
7.0			1.49	1.76	1.67	1.95	1.79
	308		1.46	1.75	1.66	1.97	1.79
	708		1.51	1.81	1.72	1.85	1.77
		Fast	1.49	1.82	1.72	1.95	1.82
		Slow	1.49	1.74	1.66	1.87	1.75
	SEM[4]		0.02	0.05	0.04	0.06	0.04
5.3	308		1.45	1.74	1.65	1.88	1.75
5.3	708		1.53	1.88	1.77	1.86	1.80
7.0	308		1.48	1.77	1.68	2.05	1.84
7.0	708		1.49	1.74	1.66	1.85	1.74
5.3		Fast	1.50	1.82	1.72	1.90	1.79
5.3		Slow	1.48	1.80	1.70	1.84	1.76
7.0		Fast	1.48	1.83	1.72	2.01	1.84
7.0		Slow	1.50	1.68	1.62	1.89	1.74
	308	Fast	1.47	1.81	1.70	1.97	1.81
	308	Slow	1.46	1.69	1.62	1.96	1.77
	708	Fast	1.51	1.84	1.73	1.93	1.82
	708	Slow	1.51	1.79	1.70	1.77	1.72
	SEM[5]		0.03	0.07	0.05	0.09	0.05

[1] Feeder space allocations of 5.3 or 7.0 cm per each of 75 pullets during growing.
[2] Female breeder strain was Ross 308 or Ross 708.
[3] Feed increase rates (see Fig. V-1) from photostimulation to peak egg production.
[4] SEM for n=16 pens with 14 broilers per pen.
[5] SEM for n=32 pens with 14 broilers per pen.

TABLE V-8. Percentage mortality (deaths) of mixed sex broiler chickens produced from eggs laid at 31 wk of age as affected by broiler breeder female feeder space allocation during growing, strain, and feed increase rate from photostimulation to peak egg production, as well as the growing feeder space by strain interaction, growing feeder space by feed increase rate interaction, and strain by feed increase rate interaction in Experiment V.

Broiler Breeder			Mixed Sex Broiler Deaths For Ages Shown				
Feeder Space During Growing[1]	Strain[2]	Peak Feed Increase[3]	1-14d	14-28d	1-28d	28-42d	1-42d
(cm)					(%)		
5.3			0.00	0.00	0.00	0.00	0.00[b]
7.0			0.89	0.48	1.37	0.89	2.27[a]
	308		0.89	0.00	0.89	0.89	1.79
	708		0.00	0.48	0.48	0.00	0.48
		Fast	0.89	0.48	1.37	0.89	2.27[a]
		Slow	0.00	0.00	0.00	0.00	0.00[b]
	SEM[4]		0.36	0.34	0.50	0.36	0.62
5.3	308		0.00	0.00	0.00	0.00	0.00
5.3	708		0.00	0.00	0.00	0.00	0.00
7.0	308		1.79	0.00	1.79	1.79	3.57
7.0	708		0.00	0.96	0.96	0.00	0.96
5.3		Fast	0.00	0.00	0.00	0.00	0.00[b]
5.3		Slow	0.00	0.00	0.00	0.00	0.00[b]
7.0		Fast	1.79	0.96	2.75	1.79	4.53[a]
7.0		Slow	0.00	0.00	0.00	0.00	0.00[b]
	308	Fast	1.79	0.00	1.79	1.79	3.57
	308	Slow	0.00	0.00	0.00	0.00	0.00
	708	Fast	0.00	0.96	0.96	0.00	0.96
	708	Slow	0.00	0.00	0.00	0.00	0.00
	SEM[5]		0.52	0.48	0.70	0.52	0.87

[a,b] Means in a column that possess different superscripts differ significantly ($P \leq 0.05$).
[1] Feeder space allocations of 5.3 or 7.0 cm per each of 75 pullets during growing.
[2] Female breeder strain was Ross 308 or Ross 708.
[3] Feed increase rates (see Fig. V-1) from photostimulation to peak egg production.
[4] SEM for n=16 pens with 14 broilers per pen.
[5] SEM for n=32 pens with 14 broilers per pen.

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SUMMARY AND CONCLUSIONS

Many broiler breeder management guides and knowledgeable members of the poultry industry have generally recommended for many years that it was necessary to have "adequate" feeder space or an increase in feeder space for broiler breeders as pullets and hens become older and larger. The intention of this general management recommendation was for all birds to consume feed simultaneously in a restricted feed environment. However, "adequate" has only been described in general terms with little or no supporting data. In order to investigate this industry paradigm, four experiments in industry typical (mimicking) all-litter and slat-litter pens dealing with feeder space in conjunction with industry typical feeding programs employed during the rearing and laying periods were conducted. Four experiments (Manuscripts I-IV) involved feeder space change (increase, decrease, or no change), two experiments compared the same growing feeding programs (Line or Sigmoid), one experiment investigated different lengths of starter feed (2 or 6 wk), and three experiments investigated two feeding to peak programs (Fast or Slow) in this extensive study.

In Manuscript II where an increase, decrease, or no change in feeder space was directly compared, it was found that maintaining similar feeder space between the rearing and laying periods produced better egg production and lower hen mortality while an increase in feeder space at movement between growing and laying quarters in conjunction with photostimulation increased hen mortality and decreased egg production (Tables VI-1 and II-7). In a similar manner, eggs per hen housed was generally better in Manuscripts II and

Table VI-1. Overview of feeder space changes and other experimental details.

Manuscript	Feeder Space[1]	Description	Age Flock Moved	Female Strain	Age When High Temperature Occurred and Temperature Range	EHH[2]	Mortality During Laying Period
	(cm)		(wk)		(wk/^{o}C)	(n)	(%)
I	5.3 → 8.8	Increase	23	308	23-29 wk	162	7.7
	7.0 → 8.8	Increase		708	29-38^{o}C		
II	7.0 → 6.2	Small Decrease	21	708	48-49 wk	175	6.6
	7.0 →10.3	Increase			30-32^{o}C	169	10.9
	10.4 → 6.2	Decrease			57-61 wk	168	9.8
	10.4 →10.3	No Change			30-37^{o}C	181	5.9
III	6.6 → 6.9	No Change	21	308	31-39 wk	171	16.7
					31-36^{o}C		
IV	6.8 → 8.8	Increase	21	708	42-46 wk	157	10.7
					34-37^{o}C		

[1]Circumferential space on a 132 diameter tube feeder.
[2]EHH= Eggs per hen housed.

III where feeder space was maintained similarly between growing and laying quarters as compared to Manuscripts I and IV (Tables VI-1, I-8, and IV-5) that exposed females to an increase in feeder space. This was even true for Manuscript III where peak egg production and maximum body heat production coincided with hot weather causing higher hen mortality (Tables VI-1 and III-5). As can be discerned from Table VI-1, the increase in feeder space in Manuscript I was greater than in Manuscript IV but the overall EHH was not reduced. This may be interpreted to mean that when the change in feeder space exceeded a certain point a threshold was passed where greater negative impacts were not evident. This was also evidenced by the similar percentage hen mortality observed in Manuscript I (mean = 7.4%) for the two feeder space changes (5.3 cm to 8.8 cm and 7.0 cm to 8.8 cm) (Tables VI-1 and I-8). By comparison, the percentage female mortality in Manuscript IV was 10.7% while having an increased feeder space of 6.8 to 8.8 cm (Tables VI-1 and IV-5). The 7.0 cm to 10.3 cm combination of Manuscript II (Tables VI-1 and II-7) also exhibited 10.9% hen mortality. Taken together, the overall series of four experiments supported the key findings of Manuscript II concerning the effects of change in feeder space on overall egg production. It was concluded that not changing feeder space between the growing and laying periods at the time of movement and photostimulation improved egg production regardless of ambient temperatures while increasing or decreasing feeder space produced poorer results. Contrary to expectations, BW uniformity was not affected by feeder space so this often used explanation of differences in performance was not available. These data provide explanatory insight into the long known fact that birds managed in brood-grow-lay facilities typical of the poultry industry in Asia and Latin

America, which did not require bird movement at photostimulation, produced more eggs and exhibited good livability.

Growing feeding programs (Line or Sigmoid) were investigated during the studies reported in Manuscripts III and IV and the effects of an interaction appeared to influence the overall study results. There was little change in feeder space for all hens in Manuscript III (6.6 cm to 6.9 cm) while there was an increased feeder space for all hens in Manuscript IV (6.8 cm to 8.8 cm) (Table VI-1). Even with the same feeding program, hens in the study detailed in Manuscript III generally produced more eggs than hens in Manuscript IV (Tables VI-1, III-5, and IV-5). Two apparent differences between the two studies was the difference in change in feeder space and weather. In the presence of no change in feeder space in Manuscript III, the Sigmoid program hens laid similarly to the Line hens on a hen-day basis but produced greater EHH due to lower female mortality during hot weather (Tables VI-1 and III-5). Subjective evaluation of breast muscle suggested less development for hens reared on the Sigmoid growing feeding program in Manuscript III, which could have reduced body temperature. However, the rearing feeding program and breast meat was not an issue in the experiment reported in Manuscript IV as the temperature was cooler during the critical period of peak lay and, consequently, there was no difference in female mortality (Tables VI-1 and IV-5). Given that these two feeding programs provided the same cumulative nutrition during rearing, it was not surprising to find no major differences in rate of lay apart from heat stress effects.

Manuscript IV showed that the length of starter feed for females and males influenced female mortality in the presence of a feeder space increase. Consumption of a greater quantity of crude protein in early life produced lower female mortality during the laying period (Table IV-5), probably due to greater physical strength in the hens reared on 6 wk of starter feed as compared to 2 wk. The BW data shown in Tables IV-1 and IV-2 suggested that the 6 wk of starter feed also produced an early rearing BW profile that somewhat reflected that of the Sigmoid growing program. This would argue that slightly accelerated growth during the early growing period of broiler breeder pullets, regardless of method employed to achieve the effect, was beneficial.

Examination of the feeding to peak program comparison indicated that there were no significant effects on female mortality in the studies detailed in Manuscripts II and III (Tables II-7 and III-5). However, the Slow feeding to peak program produced lower female mortality in the presence of hot weather early in the laying period and a large increase in feeder space in Manuscript I as compared to no change in feeder space and later hot weather in the hens of Manuscript III (Table VI-1). In Manuscript III, the Fast feeding to peak treatment had little negative effect on mortality, which was probably related to the absence of a large increase in feeder space (Table III-5). In Manuscript II, the Slow feeding to peak program produced numerically lower female mortality while the 7.0 cm rearing feeder space to Fast feeding to peak program combination had numerically the highest female mortality (10.9%) (Table II-7). This was somewhat similar to the 9.6% mortality of the Fast feeding to peak hens in Manuscript I where all birds were exposed to a large increase in feeder space (Table I-8).

Hot weather was evident in all of the experiments of this overall study. During periods of high temperature, birds loose more CO_2 from panting resulting in a lower concentration of

CO_2 and H^+ ions in the blood, which could reduce the levels of CO_3^{2-} available in the uterus. As CO_3^{2-} has been shown to be formed from CO_2 in the uterus and combine with calcium to form $CaCO_3$ crystals that comprise the bulk of the eggshell, loosing too much CO_2 during hot weather could affect egg shell quality and the number of collectable eggs (Etches, 1996) as well as disturb acid-base balance and contribute to heat stress related mortality. However, in spite of expectations, effects on egg shell quality were not evident. This may have been due to the simple fact that the daily consumption of calcium was relatively high in the broiler breeders of this study and that the heat stress was well managed except in the case of Manuscript III, which was the only flock housed in that particular facility.

The effects of feeder space and feeding programs on hatchability of fertile eggs were also of interest as this was another economically important endpoint. There were no significant effects on hatchability of fertile eggs in Manuscripts II and IV (Tables II-8 and IV-6) while the Ross 708 strain hens and hens reared with the Sigmoid feeding program both exhibited significantly improved hatchability of fertile eggs in Manuscripts I and III, respectively (Tables I-9 and III-6). The results of this study suggested that there were no consistent effects of feeder space and feeding program during rearing and laying period on hatchability of fertile eggs.

Peak feed increase effects on egg weight (EW), yolk weight (YW), albumen weight (AW), and yolk:albumen (YW:AW) ratio was examined in studies detailed in the first three manuscripts. An increased feeder space in Manuscript I was associated with smaller eggs at both 28 and 30 wk of age, where the largest increase in feeder space in combination with Fast feeding to peak (5.3 cm to Fast) increased YW while the least increase in feeder space in combination with Slow feeding to peak (7.0 cm to Slow) decreased YW (Tables I-6 and I-7). However, EW was similar in both feeder space-peak feed increase combinations, which suggested a difference in major egg components that could result in altered incubation requirements. Furthermore, the Fast feeding to peak approach significantly increased YW, decreased AW, and changed the YW:AW ratio in Manuscript II (Table II-4). In Manuscript III, where the same feeder space was maintained during both growing and laying periods (Table VI-1), a smaller EW at 28 wk was produced by the Fast feeding to peak program (Table III-3). There were no differences in EW or YW found in the study detailed in Manuscript IV where there were no differences in peak feed increase program. The effects on EW, YW, and YW:AW ratio reported in Manuscripts I-III suggested different ovary and oviduct development and function as a result of differences in feeder space and feeding to peak programs in slat-litter broiler breeder hens.

No effect on broiler BW, adjusted feed conversion ratio (AdjFCR), and mortality at the ultimate age of the broiler trials of Manuscripts I and II was observed. However, in Manuscript III, the Fast feeding to peak program produced male broilers with a better AdjFCR as well as decreased mortality when compared to the Slow feeding to peak program. The Sigmoid feeding program also produced female broilers with better AdjFCR in Manuscript III. A probable contributing factor for this was the significantly smaller eggs at 28 wk from the Fast feeding to peak program hens and numerically smaller eggs from the Sigmoid program hens (Table III-3). As stated in Manuscript III, we did not adjust the incubation temperature to control the egg temperature throughout the incubation period. This management factor probably caused smaller eggs to produce better quality chicks that grew and lived better as detailed in previous studies (Leksrisompong et al., 2007, 2009). As modern broiler breeders come from breeding lines that have been selected for an increased proportion of breast meat, this trait most likely extended into the embryo where, particularly the male, the embryos had a higher proportion of breast weight (Meijerhof, 2002). This higher breast weight embryo probably produced more heat and required more oxygen that caused problems during incubation if egg temperature was not completely controlled. Previous experiments have demonstrated that chicks hatched from eggs subject to elevated incubation temperatures had what could be described as "premature" development at hatching that could lead to a reduction in chick growth if they survived (Leksrisompong et al., 2007). Chicks that survived exposure to a high incubation temperature, more likely in larger eggs, probably have had a greater chance of higher mortality and lower feed consumption as compared to chicks that were exposed to lower incubation temperature (Leksrisompong et al., 2009).

We also conducted an experiment, detailed in Manuscript V, where hens were placed in individual cages after 23 wk of age with a fixed amount of feeder space with no competition during feeding throughout the laying period. Some comparisons between the hens in cages and those in the slat-litter floor pens could be drawn as Manuscript I detailed the results of the sister hens. Cages allowed collection of eggs from every hen for EW, YW, albumen height, broiler performance, etc. where this was physically not possible within the limitations of the facilities for the slat-litter hens in Manuscript I. In the experiment of Manuscript V, an increased albumen height at both 29 and 48 wk of age due to the Fast feeding to peak program was observed (Tables V-2 and V-3). The Ross 708 broiler breeder strain also produced eggs with higher albumen height when compared to the 308 strain. Thus, it was not surprising that the Fast feeding to peak program as well as the 708 strain produced smaller broiler BW since they produced eggs with greater albumen height as it has been shown that thick albumen may slow vital gas diffusion, limit nutrient availability to the embryo, and subsequently increase the incidence of embryonic deaths (for review, see Benton and Brake, 1996). For an apparently similar reason, broiler mortality was increased by the Fast feeding to peak program.

In conclusion, maintaining the same feeder space during the rearing and laying periods improved egg production, primarily as a result of reduced hen mortality during the laying period. The Sigmoid rearing program also reduced percentage mortality as well as improved hatchability of fertile during hot weather which suggested a difference in body temperature might have occurred, probably as a result of less breast muscle in the Sigmoid hens. Lower body temperature may have affected embryonic development during passage of the oviduct. The use of a starter feed to 6 wk of age also reduced hen mortality, probably by increasing the physical strength of the hens and by mimicking the BW profile during rearing of the Sigmoid program. The feeding to peak production program appeared to be most important when there was a change in feeder space. Slow feeding to peak reduced percentage mortality while increasing EW during early production. However, the larger chicks that can be produced from larger eggs can be negatively affected by less than perfect incubation.

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