THE EFFECT OF DURATION OF FEED RESTRICTION, PREBREEDER PROTEIN CONTENT, AND NESTING MATERIAL ON GROWTH AND REPRODUCTIVE PERFORMANCE OF COMMERCIAL LARGE WHITE TURKEY BREEDER HENS

HERMANN KLEIN-HESSLING

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D. Mike Denbow, Chair
Francis C. Gwazdauskas
Alvah T. Leighton, Jr.
Derek A. Emmerson
Kenneth K. Krueger

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(ABSTRACT)

Large White turkey breeder hens were used to examine the effect of duration of feed restriction, prebreeder protein content, and nesting material on subsequent growth and reproductive performance. Day old poults were raised following standard commercial practices with feed and water for *ad libitum* consumption until 6 wk of age (WOA). At this time, hens were equally divided among six grower feeding regimens. The treatments were as follows: a) a control group fed standard commercial diets for *ad libitum* consumption (CON); b) a second control group like (a) but fed plain white oats from 19 through 26 wk (OATS). In contrast, the 4 remaining treatment groups were feed restricted beginning at 6 WOA to achieve body weights 45% less than the full-fed CON at 16 WOA. Birds were kept at this level of restriction until either 17.0 (R17.0), 18.3 (R18.3), 19.6 (R19.6), or 20.9 (R20.9) WOA. Thereafter, feed allowance was gradually increased to achieve a predetermined minimum target BW of 10.8 kg at photostimulation. An additional prebreeder protein treatment was superimposed from 27 to 31 WOA.

Treatments reduced BW but none of the four quantitatively restricted groups achieved the target BW of 10.8 kg at photostimulation. Feed restriction reduced feed consumption and improved feed conversion. There were no differences in flock uniformity, sexual maturity, mortality, body composition at photostimulation, and total egg production. The R18.3 treatment achieved the highest peak production. The quantitative restriction treatments exhibited low laying persistency. There were no differences in number of large yellow follicles, egg weight, fertility, or hatchability, but poult weight was reduced in the R18.3 treatment. Dietary protein influenced the proportions of multiple follicle sets and percentage misshaped eggs.

Three nesting materials were compared and were as follows: 1) all nests filled with shavings (S), 2) all nests filled with paper chips (P), and 3) two nests filled with shavings and two nests with paper chips (S/P). There were significant differences in percentage floor and broken eggs. Nesting materials did not affect total egg production, fertility, or hatchability.

The data suggest, if restriction is too severe and is continued too near to the time of conventional photostimulation, BW recovery and egg production will be depressed. Oat feeding was the easiest treatment to implement and resulted in equivalent reproductive performance. Dietary protein content may affect proportions of multiple follicle sets. Turkey breeder hens can and do distinguish between nesting materials and this may affect floor laying. Combinations of various types of nesting materials within the same breeder unit should be avoided.

(*Key words*: turkey breeder hens, feed restriction, prebreeder protein, egg production, body composition, nesting material)

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TABLE OF CONTENTS

LIST OF TABLES

CHAPTER I

CHAPTER III

LIST OF FIGURES

CHAPTER I

CHAPTER II

INTRODUCTION

Body weights of turkey breeder hen replacements have increased significantly in the past ten years. Not surprisingly, many turkey breeder managers are concerned about the effects of lighting heavy hens on subsequent egg and poult production. These concerns are justified because of a negative correlation between BW and reproductive traits. For many years, the turkey industry has been attempting to extrapolate results obtained from feed restricted broiler breeders. However, as of yet, research has not shown any conclusive evidence that feed restriction is beneficial for turkey breeders. Results are often inconsistent or show no favorable reproductive responses. Nonetheless, there are reports (Hocking, 1992; Douglas and Wojcinski, 1997) suggesting that this type of management regimen has potential. For instance, a previous study at North Carolina State University compared the effect of degree of restriction during the growing period on subsequent reproductive performance of British United Turkey breeder hens. Among the 15, 30, and 45% BW restriction that were implemented, only the most severe feed restriction program resulted in a significant improvement in egg production and hatchability (Klein-Hessling, 1994). The research presented here today is a systematic continuation of the previous work. After having identified the optimum degree of restriction, the present study was aimed to elucidate the effect of duration of restriction during the growing and holding period on subsequent reproductive performance of commercial Large White Nicholas turkey breeder hens. In addition, the influence of prebreeder dietary protein content was also studied. The third part of the study compared the effectiveness of a commercial paper chip product as an alternative nesting material.

REVIEW OF LITERATURE

1. General Considerations of Turkey Feed Restriction

The first available reference regarding feed restriction in turkey breeder hens was published more than 50 years ago (Scott and Payne, 1941). While successful implementation of such a management system has been attempted many times since then, most efforts have not been very encouraging or have simply failed to show a beneficial effect on reproductive performance. Feed restriction appears to involve a rather complex array of factors that need to be evaluated and integrated simultaneously.

Obviously, strain differences exist and genetic selection is continuously taking place. The type or method of restriction chosen is important if the aim is to exert control over the sexual development of the bird. In addition, the age at initiation of restriction, the degree of restriction itself, and the duration of the restriction might have profound effects on subsequent feed intake, feed efficiency, and onset of sexual maturity. Other factors requiring consideration include the degree and extent of refeeding, the time of photostimulation in relation to body weight and age, and also dietary nutrient formulation and nutrient supply in terms of overall energy and protein content, energy/protein ratio, and nutrient density. With that in mind, the following is a chronological review of the pertinent literature, divided into the general categories of turkey and broiler breeder feed restriction, feed restriction and ovarian function, and biology of starvation.

2. Methods of Turkey Feed Restriction

2.1. Physical Restrictions

In one of the first feed restriction trials, Scott and Payne (1941) utilized Bronze turkeys that were either full fed or restricted to 61 or 78 % of the weight of the *ad libitum* fed control from 26 weeks of age (WOA) to the onset of lay. During lay, birds were fed a breeder diet *ad libitum*. At first egg, BW of the restricted group was significantly lower than the control. Body weights of the control birds plateaued at the beginning of egg production and declined thereafter. However, regardless of treatment, birds started to gain BW at approximately 10 wk after the onset of lay. During lay, feed consumption of the restricted birds was significantly higher than in the control. Egg production and average egg weight were not different but hatchability was significantly better in the full-fed treatment.

Anderson *et al.* (1963) investigated the effects of reducing the total nutrient intake of Large White turkey breeder hens during the growing and holding period (12-24, 12-40 or 24-40 WOA) on subsequent feed consumption, BW changes, body conformation, egg production, fertility, and hatchability. Birds were fed 85% of the allowance of the *ad libitum* fed control. A significant reduction in BW at 24 WOA in the restricted treatment was accompanied by a significantly lower breast width. Body depth and shank length were not affected. Restriction treatments improved hatchability significantly and the best results (+11%) were obtained when birds were restricted from 12-24 WOA. There were no differences in egg production.

Andrews and Morrow (1978) evaluated different restriction regimes for caged and floor-housed Orlopp turkey breeder hens. The following four feeding treatments were compared beginning at 8 WOA: (1) full-fed during rearing and laying: (2) full-fed during rearing and restricted during laying, (3) restricted during rearing and full-fed during laying, and (4) restricted during rearing and laying. The restricted hens were fed 80% of the amount consumed by the full-fed control during the previous week. All birds were photostimulated at 32 WOA. Birds fed *ad libitum* produced significantly more eggs than any other treatment. Proportions of misshaped and soft shelled eggs were significantly lower in restricted birds during lay. No significant differences were found among feeding regimens for egg weight and feed efficiency.

Krueger and co-workers (1978) implemented a skip-a-day feeding regimen from 22 to 30 WOA and restricted the feed allowance to 75% of the average consumption of the *ad libitum* fed control. Beginning at lighting (30 WOA), one half of the breeders was either fed a 14 or 18% protein diet with either 2744 or 2603 kcal ME/kg feed, respectively. Body weight of the restricted hens was significantly lower at 30 WOA. Sexual maturity commenced earlier in the full-fed group and egg production was reduced by restriction. Dietary protein treatments did not affect reproduction. Restricted birds had a significantly shorter keel length, breast width, and body depth at 30 WOA, but these differences disappeared at 40 WOA. The treatments did not affect shank length. Molting was found at a rate of 23% in the restricted hens *versus* only 4% in the full fed counterparts and the authors emphasized that molting was unrelated to broodiness.

The effect of controlled feeding of Large White turkey hens during the prebreeder period on subsequent reproductive performance was also the subject of a study by Potter *et al*. (1978). At 22 WOA, breeder candidates were assigned to one of the following treatments: (1) full-fed control; (2) fed *ad libitum* three days per week between 8 a.m. and 2 p.m. only, and (3) 80% of the feed intake of the *ad libitum* fed control on an every day basis. A 16.1% protein prebreeder diet with 3220 kcal ME/kg feed and an E/P ratio of 200:1 was used for all treatments from 22 to 38 WOA followed by a breeder diet available for *ad libitum* consumption. The rate of BW gain during the holding period from 26 to 38 WOA in the restricted groups was significantly less than that of the full-fed control. Treatments did not affect egg production, fertility, or hatchability.

Hocking (1992a) fed medium-sized British United Turkey (BUT) breeder hens (Strain 71) either *ad libitum* or restricted, beginning from 6 WOA to achieve a BW reduction of 40% relative to the BW of the control upon photostimulation at 18, 24, or 30 WOA. Restrictions continued until the first egg was laid. All treatments were provided a breeder diet for *ad libitum* consumption. The developer diet fed from 9 WOA to lighting contained 20.5% protein and 2796 kcal ME/kg feed, leading to an E/P ratio of 136:1. The photoperiod was decreased for all treatments as early as 10 WOA to 7 h of light and increased at 18, 24, or 30 WOA to 14 h/day. Upon lighting, the birds were moved into individual cages until 54 WOA. Body weight of the restricted birds was significantly reduced until 48 WOA regardless of age at lighting. At 54 WOA, restricted hens stimulated at 18 WOA weighed more than the *ad libitum* fed control. There was no difference in feed intake during lay. A large proportion of restricted turkeys stimulated at 18 WOA did not commence lay until 30 to 40 WOA and a significant number of hens lit at 24 WOA had short laying cycles. Hen-day egg production of settable eggs was significantly improved by restriction as well as delayed lighting. Conversely, the production of cracked, soft-shelled and double-yolked eggs was higher in *ad libitum* fed birds. The restricted birds laid significantly smaller eggs throughout the study but hatchability was significantly better, particularly when eggs were stored for two wk. Restricted hens were leaner than full-fed hens at 6 and 12 wk after lighting and at the end of the study. However, abdominal fat pad weight did not agree in all aspects with the chemical analysis for carcass fatness. The restriction exerted a significant effect on fat pad size only at 12 wk following photostimulation.

Felts (1993) investigated the effect of physical feed restriction during the adolescence and prebreeder period on reproductive performance of BUT turkey breeder hens. From 4 to 30 WOA, hens were either assigned to an *ad libitum* fed control group or a daily restriction treatment fed 90% of the feed consumed by the control. All diets were formulated according to NRC guidelines. The holder diet fed from 20 to 30 WOA contained 10.8% protein, 3175 kcal ME/kg feed with an E/P ratio of

294:1. Upon photostimulation (14 h/day) at 30 WOA, a breeder diet was fed *ad libitum*. Body weight of the restricted hens was significantly reduced at 30 WOA. However, there were no significant differences for any reproductive criterion, except for fertility from 41 to 44 WOA. During this time, eggs from the restricted hens had a significantly lower fertility than the ones from the control group.

Klein-Hessling (1994) restricted the BW of two lines of British United Turkey breeder hens by either 15, 30, or 45% of an *ad libitum* fed control at 16 WOA. Thereafter, all birds were gradually released from restriction to achieve a minimum target BW of 10.8 kg at photostimulation. During lay, feed was provided for *ad libitum* consumption. Only the treatment imposing the most severe restriction improved egg production and hatchability. Birds restricted to 45% during rearing had an approximately 10% lower feed consumption.

Douglas and Wojcinski (1997) conducted field trials at Hybrid Turkey Breeder Farms. Feed restriction started between 6 and 8 WOA. Feed allowance per bird per day was calculated in order to achieve 40 to 45% reductions in BW at 16 WOA. There were no differences in uniformity between the two groups. Restricted birds had a consistently higher peak production and improved cumulative egg production. Initial egg weights did not differ between the two treatment groups.

Crouch *et al.* (1997) conducted two trials with Nicholas turkey breeder hens. In the first trial, hens were quantitatively restricted on a skip-a-day basis beginning at either three or six WOA to obtain a 45% reduction in BW relative to the weight of an *ad libitum* fed control at 16 WOA. Birds restricted from 3 to 16 WOA had higher egg production than the control or the birds restricted from 6 to 16 WOA. There were no significant differences in fertility or hatchability.

The second trial studied the effect of length of time of restriction. Birds were either raised on a skip-a-day program and quantitatively restricted from 3 to 16, 3 to 24, or 16 to 24 WOA while an *ad libitum* fed control was maintained throughout. Peak egg production for the restricted birds was significantly higher than in the control but as environmental temperature increased, egg production in the restricted birds declined more rapidly leading to a significantly lower cumulative egg production for the restricted hens. Although there were no differences in fertility, hatchability was better in eggs from the control treatment.

In summary, physical feed restriction in turkeys generally reduced BW but had usually no effect on egg weight, and fertility. Improvements in egg production were more prevalent in studies conducted over the last decade. This may indicate some genetic shift in commercial stocks. A similar conclusion has been drawn by Hester and Stevens (1990).

2.2 Energy Restrictions

Borron and McCartney (1972) studied the effect of energy restriction on breeder performance. They fed one of the following diets from 8 to 32 WOA: (A) an *ad libitum* fed control based on NRC requirements, (B) a 18% protein diet with 3000 kcal ME/kg feed fed *ad libitum* and, (C) a 18% protein diet with 2000 kcal ME/kg feed but restricted to the feed intake of treatment B. Females fed diet A, B, and C weighed 10.0, 9.7, and 6.4 kg, respectively at 32 WOA. More settable eggs were laid by the hens fed Diet C even though this improvement in egg production was associated with lower fertility. Neither onset of sexual maturity, egg weight, or hatchability were significantly influenced by any of the three dietary treatments.

The effect of dietary energy on reproductive performance of Large White turkey breeder hens was also investigated by McCartney *et al*. (1977). At 10 WOA, birds were fed either a control diet *ad libitum* with 18% protein and 3000 kcal ME/kg feed, or a diet with the same protein level but only 2000 kcal ME/kg feed that was quantitatively restricted to the feed intake of the high energy diet. The

E/P ratio was 167:1 and 111:1 for the control and the restricted treatment, respectively. Upon photostimulation both treatment groups were provided a breeder diet for *ad libitum* consumption. The low energy treatment was associated with a significantly lower BW. Once the birds had been placed on the breeder diet at 28 WOA, the low energy treatment group continued to gain BW, whereas the BW of the high energy control group plateaued. The low energy treatment laid five more eggs than those receiving the high energy diet. There were no differences in egg weight, fertility, hatchability, and feed per egg. Carcass fat content did not differ among treatments at photostimulation. However, at 50% production, the amount of fat accumulated in the birds photostimulated at 32 WOA was significantly greater as compared to the treatment groups photostimulated at 28 WOA.

In a second trial, birds were provided grower and finisher diets until 18 WOA followed by a holding diet containing 12% protein and either 2300, 3000, and 3700 kcal ME/kg feed. The E/P ratios were 192:1, 250:1, and 308:1 for the low, intermediate, and high energy diet, respectively. No statistical differences were found between the three dietary energy levels for BW, reproductive traits, or carcass fat content.

Nestor and co-workers (1981) used three large strains of turkeys that differed in mature BW and fed either a control or a high fiber diet (69% ground oat hulls) from 16 to 40 or 42 WOA. The high fiber diet resulted in a significantly decreased BW at 26, 34 and 40 WOA. Feeding the high fiber diet was associated with a significant increase in weight and size of the gastrointestinal tract but had no significant effect on egg weight, egg production, fertility, hatchability, or number of poults produced.

Taken together, it is not possible to establish a clear pattern for the effects of energy restriction. Egg weight, fertility and hatchability were commonly not affected. Some researchers were able to improve egg production in diets with lower energy contents.

2.3. Protein Restrictions

Reproductive responses due to dietary protein modifications have been inconsistent. For instance, Atkinson *et al*. (1960) fed laying diets containing 16, 19, 22, or 25% protein to Broad Breasted Bronze turkey breeder hens. The 22% protein diet resulted in the highest rate of egg production and superior feed efficiency. There were no differences in fertility or hatchability.

Bradley *et al*. (1972) used Beltsville Small White hens and fed diets containing either 15 or 18% protein with either milo or corn as the single grain source. Approximately 5% more eggs were produced from the birds receiving the 18% protein diet. The eggs from the 18% protein diet also had better fertility and hatchability. Birds fed the milo-based diet had better egg production than those fed the corn-based diet.

Cherms *et al*. (1976) fed female turkeys of an egg laying strain two protein levels (15.5 or 18.5%) from 22 to 32 WOA. A constant daily protein intake of 35 or 50 grams of protein per bird per day during the course of a 26 wk laying cycle was maintained. Neither age at first egg, egg production, hatchability, broodiness, or egg weight were affected by the nutritional regimes.

Large White turkey hens of a commercial variety were fed diets containing either 10, 12, or 14% protein from 12 to 32 WOA (Meyer *et al*., 1980). In addition, a 17% protein treatment was maintained from 12 to 20 WOA and subsequently divided into four additional protein treatments of 10, 12, 14, or 17% protein from 20 to 32 WOA. Birds were fed a breeder diet containing 17% protein and 3059 kcal ME/kg feed. Body weight gain increased significantly with every increment of dietary protein until the diets contained 14% protein. Average egg production of hens fed 17% protein from 12 to 20 WOA followed by at least a 14% protein diet from 20 to 32 WOA was 10 eggs higher when compared to feeding the low protein diets. Sexual maturity, egg weight, specific gravity, and shell thickness were not different among treatments.

Grimes *et al*. (1989) studied Hybrid Large White turkey breeder hens and fed either a 12, 15, or 18% protein diets containing an isocaloric energy content of 2882 kcal ME/kg feed (E/P ratios of 240, 192, and 160:1) from 24 to 32 WOA. All hens were maintained on a 16% protein diet (1970 kcal ME/kg feed; E/P ratio 125:1) during a regular laying cycle. There were no significant differences in BW, feed consumption, egg production, fertility, hatchability, poult weight, carcass moisture or fat content.

2.4 Combinations

2.4.1. Protein and Physical Restrictions

Voitle and Harms (1972) studied a skip-a-day feeding program and a low protein diet as means to delay the onset of sexual maturity. At 10 WOA, 360 Marston Broad White turkey hens were assigned to each of the following feeding regimes: (1) control diet (21% protein, 2154 kcal ME/kg feed, E/P ratio 103:1) until 24 WOA followed by a breeder diet (16.6% protein, 2152 kcal ME/kg feed, E/P ratio 130:1) from 25 WOA until termination, (2) a low protein diet *ad libitum* (10.2% protein, 2370 kcal ME/kg feed, E/P ratio 232:1), or (3) a skip-a-day diet equivalent to 75% of the feed allowance of the control from 10-30 WOA. Feeding regimes reduced BW at lighting and delayed sexual maturity significantly. No egg production data was provided.

Jones *et al*. (1976a) fed 12 wk old Large Broad Breasted White turkey hens either a (1) control diet *ad libitum* (18.9% protein, 2935 kcal ME/kg, E/P ratio 155:1), (2) the same diet until 20 WOA followed by a holding diet (14.8% protein, 2929 kcal ME/kg, E/P ratio 198:1), (3) the same control diet as in (1) but restricted to 80% of the intake of the control or, (4) the control diet with limited access feeding for 8 h per day on 3 days a week. A breeder diet (17.8% protein, 2860 kcal ME/kg feed, E/P ratio 161:1) was provided for *ad libitum* consumption at 32 WOA. Only the 80% restriction treatment and those birds fed 3 days a wk had a significantly lower BW. However, egg production, fertility and hatchability were not affected.

In another study, Voitle and Harms (1978) utilized Broad Breasted Large White Nicholas turkey hens and subjected them to one of the following feeding regimes: (1) a control diet fed from 10 to 25 WOA with 20.6% protein and 1.13% lysine (2969 kcal ME/kg feed, E/P ratio 144:1); (2) a low protein diet fed from 11 to 25 WOA with 9.9% protein and 0.32% lysine (3797 kcal ME/kg feed, E/P ratio 384:1); (3) same as diet (2) but fed from 11 to 30 WOA; (4) a low lysine diet fed from 11 to 30 WOA with 14.6% protein and 0.37% lysine (3033 kcal ME/kg feed, E/P ratio 208:1); and (5) same as diet (1) but fed every other day and limited to 75% of the feed intake of the *ad libitum* fed control. Feed consumption was inversely related to the energy content of the diet. Birds ate to meet their energy needs. Only egg production in the low protein treatment (3) was significantly reduced. There were no differences with regard to sexual maturity.

Owings and Sell (1980) restricted turkey breeder hens from 6 to 20 WOA. The following treatments were initiated: (1) an *ad libitum* fed control based on a low-protein (13.5%), low-energy diet (2750 kcal ME/kg feed; E/P ratio 204:1) from 18 to 32 WOA; (2) quantitative feed restricted to 70% of the BW of the control on a skip-a-day basis; and (3) daily feed restriction to 60% of the BW of the control. All restricted hens were fed a 19% protein finisher diet *ad libitum* from 20 to 32 WOA. Upon photostimulation, all three treatments were provided a breeder diet with 16% protein, 2820 kcal ME/kg feed and a resulting E/P ratio of 176:1. However, rearing treatment (3) that was restricted to 60% during the grower and holding period was further subdivided into one of four breeder treatments at 32 WOA: (a) a control diet fed *ad libitum*, (b) a 13% protein diet *ad libitum*, (c) a 19% protein diet *ad libitum* and, (d) a 16% protein diet limited to the breeder feed intake of the full-fed control. On a cumulative basis, feed restricted birds consumed approximately 10% less feed than the controls from 6 to 52 WOA but there were no carry-over effects of feed restriction on rate of egg production, feed per egg, hatchability, fertility, or egg weight. However, Treatment D, which was severely restricted during rearing and lay, was terminated before the end of the study because of poor egg production.

Renema *et al*. (1994, 1995) restricted Hybrid male-line hens from 4 WOA until point of lay (28 WOA) either quantitatively or qualitatively. The treatments were as follows: (1) an *ad libitum* fed control; (2) a low protein (12% CP) diet; (3) a quantitative restriction to achieve BW levels 10% less than the full-fed control (R10); and (4) like 3 but with a 20% reduction in BW (R20). At photostimulation (28 WOA), all hens were fed a standard breeder diet for *ad libitum* consumption. Rearing treatments reduced BW and frame size early in life. Quantitative restriction reduced breast muscle weight at the onset of production as well as fat pad weight throughout the breeder period. Protein changes over time were associated with breast muscle changes. There were no differences in egg production.

2.4.2 Energy and Physical Restrictions

Potter and Leighton (1973) fed Beltsville White breeder hens either a high fiber diet or limited the feed consumption of a high energy diet to 90% of the feed intake of an *ad libitum* fed control. All treatments were in place from 20 to 32 WOA. The high fiber diet had no effect on BW whereas the quantitative restriction reduced BW. There were no differences in egg production, fertility, and hatchability.

Balloun (1974) investigated the effects of BW control during the holding period from 20-31 WOA. Three dietary treatments were tested: (A) a full fed control (14.3% protein, 3125 kcal ME/kg feed, E/P ratio 219:1), (B) same diet as in (A) but limited to 350 grams/hen on 3 days per week, or (C) a diet with 14.2% protein, 2525 kcal ME/kg feed, and a E/P ratio 178:1 for *ad libitum* consumption. Restricted birds in group B not only laid at a higher rate, they also were much more feed efficient and showed a markedly reduced mortality. There were no effects on fertility or hatchability.

Borron *et al*. (1974) fed Large White turkey breeder hens diets during the growing period from 8-32 WOA that were: (A) equivalent to NRC recommendation and fed *ad libitum*, (B) a high energy-high protein diet (18% protein, 3000 kcal ME/kg feed, E/P ratio 167:1) *ad libitum*, or (C) a low energy-high protein diet (18% protein, 2000 kcal ME/kg feed, E/P ratio 111:1) restricted to the feed intake of group (B). At 32 WOA, all birds were fed the same breeder diet (17.1% protein, 2917 kcal ME/kg feed, E/P ratio 176:1). Energy restriction reduced BW, shank length and delayed sexual maturity. However, egg production, fertility, hatchability, and poults per hen were not affected.

2.4.3. Protein and Energy Restrictions

Jones *et al*. (1976b) used 960 Large Broad Breasted White turkey hens to study the effect of breeder protein (15 versus 18%) and metabolizable energy levels (2666, 2893, and 3101 kcal ME/kg diet) on reproductive performance. Dietary protein levels had no effect on BW, feed consumption, egg production, fertility, and hatchability. Conversely, hens that were fed the higher energy diets produced larger eggs but it did not affect egg production. Only the highest energy content led to a significant improvement in fertility while hatchability of fertile eggs was better for birds receiving the intermediate energy level.

Ferket and Moran (1986) compared the effect of plane of nutrition during the growing and breeding period in Nicholas turkey breeder hens. The high plane (HP) and low plane (LP) diets had the same E/P ratio but varied in their nutrient density. The LP treatments led to a reduced BW at 31 and 57 WOA but neither egg production, egg weight, fertility, or hatchability were affected by the two planes of nutrition. However, eggs from the LP treatment had a significantly lower yolk content.

2.4.4. Other Restriction Combinations

Touchburn *et al.* (1968) restricted turkey hens from 18 to 28 WOA. The chosen restriction techniques consisted of limited feeding (70% of *ad libitum* fed control), use of a high fiber diet (60% oat hulls, 10.7% protein, 920 kcal ME/kg, E/P ratio 86:1), and the addition of a distasteful chemical (1% MAM 100) to the otherwise identical control diet (14% protein, 2156 kcal ME/kg feed, E/P ratio 154:1). At 29 WOA, all birds received a 17% protein breeder diet for *ad libitum* consumption. Restrictions reduced BW significantly. Turkeys compensated for low density diets by increasing their feed intake by 70%. Body weight control delayed the commencement of sexual maturity and reduced egg production. Neither fertility, nor hatchability, or egg size were affected by the restriction regimes.

In a subsequent trial, the degree of BW restriction was reduced to 80% of the full fed control and restriction was already terminated at 24 instead of 28 WOA. Limiting the daily feed intake to 80% of the control was effective in reducing BW gain through 24 WOA but this response had diminished by 29 WOA. There were no effects on egg production, fertility, and hatchability but egg weight was significantly reduced.

Miles and Leeson (1990) used Nicholas parent stock to study the effect of BW restriction and age at photostimulation on reproductive performance. The six treatments were as follows: (1) *ad libitum* fed control and photostimulated at 10 kg BW; (2) skipping 1 day per week and stimulated at 29 WOA; (3) photostimulated at 10 kg BW; (4) restricted to 95% of *ad libitum* fed control and photostimulated at 29 WOA; (5) same as (4) but stimulated at 10 kg BW; (6) photostimulated at 29 WOA. The skip 1-day program began at 4 WOA whereas the 95% restriction was initiated at 2 WOA. The *ad libitum* fed breeder diet contained 15% protein, 2860 kcal ME/kg feed and an E/P ratio of 191:1. Hens in Treatment 1, 3, and 5 reached the 10 kg BW at 26, 28, and 29 WOA, respectively but only birds quantitatively restricted to 95% of the BW of the control produced significantly more eggs than any other treatment. Photostimulation based on the attainment of a 10 kg BW versus lighting at 29 WOA had no effect on egg production but was associated with a significant reduction in fertility and hatchability.

The effect of feed restriction and breeder regimen on reproductive performance of Nicholas turkey breeder hens was tested in a factorial experiment by Noll *et al*. (1993). The six grower treatments were 1) a corn-soy control diet fed *ad libitum*, 2) a high nutrient density diet with added fat provided *ad libitum*, 3) a low protein diet (9.9% protein), 4) low protein with 2% added feather meal, 5) skip-a-day feeding of Treatment 1 beginning at 2 WOA and, 6) feeding a low protein diet (Treatment 3) followed by daily feed restriction of Treatment 1 at a level of 90% of the BW of the control after 6 WOA. All grower treatments were fed one of four breeder diets: a) a 15% protein corn-soy control diet, b) as in (a) but with 6% added fat, c) as in (a) but with 18% protein and, d) as (c) starting at 28 WOA followed by Treatment (a) at 33 WOA. Treatments (a), (b), and (c) started at 30 WOA. Grower treatments did reduce BW but egg production was not affected significantly. Feeding feather meal resulted in the lowest BW (10.2 kg) at photostimulation and was associated with the poorest egg production. Feeding high protein from 28 to 33 WOA or after 30 WOA improved egg production significantly. Weight and mortality of hen progeny tended to be poorer for those breeders restricted in weight. Mortality for tom progeny was greater in restricted than in control fed birds, however, tom BW was unaffected.

In summary, turkey breeder feed restriction in the past was usually associated with a reduced BW and had no affect on egg weight, fertility and hatchability. Effects on egg production have been more variable. Genetic selection in recent years may not only have altered the genetic predisposition for growth rate and increased BW in parent breeder stock but, perhaps, altered the responsiveness to feed restriction programs in a more favorable way.

3. Broiler Breeder Feed Restriction

3.1. General Aspects

According to Costa (1981) the control of the growth rate of a broiler breeder is an important management tool to ensure the best performance in the laying house. Obtaining a predetermined target BW at 20 WOA (photostimulation) and at point of lay is important as well as manipulating the growth rate in order to reach the target BW without impairing flock uniformity. Furthermore, Costa considered the task of synchronizing growth and sexual maturity as one of the most important, and yet, one of the most difficult areas of broiler breeder management. The need to counteract the high appetite of the modern breeding stock calls for severe feed restriction programs during the rearing period, which in turn is typically accompanied by a delay in sexual maturity and egg production. Broiler breeders also require accurate feeding at the beginning of production, during peak of lay, and upon decline in production. In other words, a feeding program must be designed to challenge peak production while reducing feed allocations as performance declines after peak of lay.

The recommended feeding program for broiler breeders usually consists of severe to moderate feed restriction during rearing, an increased feed allowance during the prebreeder period, and a moderate feed withholding extended throughout the breeding cycle (Robbins *et al*. (1986). This is in agreement with the fundamental principles of broiler breeder nutrition and the design of feed restriction programs outlined by Costa (1981). In contrast to broiler breeders, turkeys normally lose BW coinciding with the commencement of egg production (Indiana Agric. Exp. Station, 1934; Asmundson *et al*., 1946; Harper, 1950) and, therefore, in broiler breeders, the main objective is to limit BW and/or gain. Currently, there is general agreement on the beneficial effects of feed restriction during the growing and breeding period on subsequent reproductive performance of broiler breeders in the scientific community as well as in the broiler breeder industry. This has been documented in numerous studies (Harms *et al*., 1968; Fuller *et al*., 1969; Pym and Dillion, 1974; Watson, 1975; Robblee *et al*., 1979; Bornstein and Lev, 1982; Bornstein *et al*., 1984; Cave, 1984; Brake *et al*., 1985; Pearson and Herron, 1982; Robbins *et al*., 1986; Hocking *et al*., 1989; Yu *et al*., 1992a,b,c; Fattori *et al*., 1991a; Robinson *et al*., 1991; Robinson *et al*., 1993a,b).

3.2. Initiation and Duration of Restriction

The effect of restricted feeding during rearing and laying in two commercial broiler female lines was examined by Pym and Dillion (1974). Birds were either fed *ad libitum* or restricted to 80, 60, or 40% of the feed intake of the full-fed control beginning at 10 wk of age. Additional restrictions were superimposed during lay. The more severe the restriction, the more delayed the onset of sexual maturity. Mortality was not affected by restriction during rearing. The restricted hens consumed more feed than the control during the first 10 wk of lay. The extent of the compensation was approximately proportional to the previous degree of restriction. Hen-day production of settable eggs was highest in birds most severely restricted during rearing and fed *ad libitum* during lay.

A re-evaluation of the effects of feed restriction on growth, body composition, and egg production was conducted by Robbins *et al*. (1986). Heavy, rapidly growing Hubbard female broiler breeder chicks were either fed a) *ad libitum* through 68 WOA; b) restricted to 50% of the feed consumption of the full fed control through 68 WOA; c) provided feed *ad libitum* through the first 24 WOA and then restricted to 50% or, d) first restricted to 50% and then fed *ad libitum* following 24 WOA. Feed restriction during rearing delayed the onset of sexual maturity by 17 days and BW at first egg was significantly higher in the full fed birds. Birds restricted during rearing and fed *ad libitum* during lay, produced 50% more eggs than hens provided feed *ad libitum* throughout. The data clearly underlined the necessity for a carefully chosen level of restriction during the laying period as indicated by the complete failure of the 50% restriction during lay. Highly significant difference existed for abdominal fat pad weight between treatments at 68 WOA.

Lilburn *et al*. (1987) investigated the interactions of dietary protein, method of feed restriction, and environment during rearing on subsequent reproductive performance. There were no significant differences in BW between birds fed 13.5 or 15.5% dietary protein. However, the birds fed the 13.5% protein diet required a significantly greater quantity of feed to produce an equivalent BW. Protein levels in the rearing diet did not influence sexual maturity. Total egg production as well as hen-day production were significantly higher in both strains when fed the higher protein content. Egg size was unaffected.

Fattori *et al*. (1991a) placed Arbor Acres broiler breeder females on feeding treatments ranging from 8% above the breeder recommended standard BW growth curve to 24% below the standard. All birds were raised on a skip-a-day basis through 20 WOA upon which feed was provided daily. All treatments paralleled the STD BW growth curve through 62 WOA. Body weight uniformity was significantly better for the -8% treatment only. The -16 and -24% treatment reduced frame size significantly. Onset of sexual maturity was significantly delayed in the two most severely restricted treatments. These treatments also had the lowest egg production. Restriction treatments had no significant effects on egg weight, fertility, hatchability, or mortality but shell quality improved significantly in the -16 and -24% feeding regime. Each wk of delayed sexual maturity increased the total rearing cost for each pullet by approximately 1%. However, increased pullet rearing costs were offset by breeder feed savings and better egg production (Fattori *et al*. 1991b).

Robinson *et al*. (1991) examined the effects of *ad libitum* versus restricted feeding during the laying period. Sexual maturity did not differ among the treatments but BW of the *ad libitum* fed hens at first egg was significantly higher. Feed restriction improved egg production significantly. In addition, a significantly longer prime laying sequence (consecutive days of laying) was found in the restricted hens. There was no treatment effect on fertility or hatchability.

Even though Costa (1981) advocated the necessity of implementing a restriction during both rearing and lay, this issue has not been resolved completely. Pym and Dillion (1974) and Robbins *et al*. (1986, 1988) provided evidence that *ad libitum* feeding during part or all of the laying period improved egg production. However, McDaniel *et al*. (1981) and Robinson *et al*. (1991) reported that *ad libitum* feeding during breeding resulted in lower egg production. Yu *et al*. (1992a,b,c) followed up on this controversial issue and conducted a study to further clarify the need for a restriction during both rearing and laying. Indian River broiler breeder chicks were reared following commercial standard practice until 4 WOA and were fed either *ad libitum* or restricted throughout the trial, or restricted during rearing and fed *ad libitum* during lay, or *vice versa* . The feed allotments for the restricted birds were provided according to the Indian River breeder guide recommendation. At 18 WOA, the restricted birds weight significantly less and had significantly shorter shanks than the *ad libitum* fed control. Despite a large difference in BW, percentage carcass protein at 18 WOA did not differ significantly but percentage carcass fat content was almost four times higher in the full-fed control than in the restricted birds. During the prebreeder period from 18 to 23 WOA, the feed intake of the RF birds was 209% that of the RR and 133% that of the FF birds. Age at sexual maturity was significantly affected by rearing treatment. Compared with *ad libitum* feeding, controlled feeding during breeding improved settable egg production significantly. Birds that had been restricted during both rearing and breeding obtained the highest fertility and hatchability.

3.3. Pullet - Layer Transition Time

McDaniel *et al*. (1981) raised chicks on a conventional skip-a-day feeding program and assigned the birds to five treatments to 24 WOA. Feeding levels were selected to obtain BW gains that would range from below recommended to above recommended levels as suggested by the primary breeder. Hens that received the larger feed allocation exhibited a lower egg production, fertility, and hatchability. Moreover, increased feed intake was associated with greater BW and egg weight while it reduced shell quality.

Brake and McDaniel (1981) investigated the effects of daily feed intake relative to the reproductive performance of second cycle hens. The experimental treatments comprised different daily feed intake levels ranging from as low as 127.2 to 172.5 g per hen per day. The lower feed allocation was associated with a significant improvement in specific gravity and feed conversion. Fertility and hatchability responded similarly. Conversely, egg weight and BW decreased significantly with the lower feed allocation. No additional improvements in any reproductive trait were elicited when the feed allowance dropped below 145.2 g/hen/day.

Leeson and Summers (1982) fed broiler breeder pullets different quantities of feed in such a way to attain the same mature BW but at different ages. Upon reaching the target BW, the birds were then moved to laying cages and provided a breeder diet (15% protein, 2835 kcal ME/kg, E/P ratio 189:1) according to the primary breeder's recommendation. The birds that were moved early to the laying house commenced egg production first but they lacked persistency after peak production and displayed a 10% decline in egg production within 4 wk.

Bornstein and Lev (1982) attempted to determine the energy requirement of broiler breeders during the pullet-layer transition time. They noted increases in egg production were the product of gradually changing ratios of laying to non-laying birds within a flock. When *ad libitum* fed hens reached 7% production, the rate of lay of the actual layers (11% of the flock population) averaged already 57%. When flock production reached 12%, the rate of the hens actually laying (18% of the flock population) amounted to 67%. A few days later, flock performance had averaged 32% but the performance of the actual layers had reached already 97%. In general, a similar performance between the flock average and individually laying hens was not obtained until 4 wk following the onset of lay. The best performance was obtained when birds were provided a daily energy allowance of 440 kcal/bird/day beginning 2 to 3 wk before the onset of egg production. Most importantly, a severe sub-optimal energy supply at a time of 30 to 55% flock production could not be corrected by providing adequate or even higher than normal energy allocations afterwards.

Similarly, McDaniel (1983) recognized the importance of the pullet-layer transition time and attempted to determine the optimum time for increases in feed allotments with respect to overall reproductive efficiency. Sixteen-week old, conventionally skip-a-day reared Arbor Acre females were caged individually and divided into the following treatments: (1) full-fed from 17 to 21 WOA and 136 g of feed/hen/day from 22 to 60 WOA; (2) gradual increase in feed to 136 g/hen/day from 18 to 26 WOA and kept constant to 60 WOA; (3) gradual increase in feed to 136 g/hen/day from 21 to 30 WOA and kept constant to 60 WOA. All treatments started out with 68 g per hen per day. A 16% protein ration (2805 kcal ME/kg feed (E/P ratio 175:1) was fed to all birds beginning at 22 WOA. Age at sexual maturity, eggs per hen housed, and feed conversion were significantly affected by pre-production feeding regimens. Treatment 1 birds matured significantly earlier than hens in Treatment 2 and 3. In addition, shell quality and egg weights were lower for Treatment 1 throughout most of the experiment. On the basis of percentage hen-housed egg production, birds from Treatment 2 laid significantly more eggs than hens from Treatment 3 and 1, with Treatment 1 birds being the worst.

According to Harms (1984), many commercial broiler breeder flocks fail to reach a high peak in egg production and often suffer marked declines after peak production. A total of 49 commercial flocks were evaluated to determine whether or not they had maintained a sufficient BW gain until after peak production. Each flock was categorized as making adequate or inadequate gains. Flocks that were allowed a steady and adequate BW gain peaked at a significantly higher rate. In addition, flocks with adequate BW gain had also a much better persistency in production as compared to flocks with inadequate gain.

Brake *et al*. (1985) raised Arbor Acres females according to primary breeder's recommendation through 18 WOA. Four different diets were fed in a factorial arrangement consisting of high and low protein as well as high and low energy. Feed intake and BW were very similar among the treatments during the production period. However, hen-day production was significantly higher for the high protein birds at wk 31 to 35, 38, and 61. In contrast, the high energy diet improved egg production only during wk 26 to 28, but significantly reduced the performance during wk 36, 55 to 59, and from 61 to 64. The author concluded that the nutritional status of the breeder during the prebreeder period had a critical role in determining subsequent reproductive performance.

In summary, broiler breeder flocks are subjected to rigorous feed restriction programs throughout their life. Research has delineated many of the underlying principles in great detail. The conclusions drawn have been incorporated in the development of feeding programs. Feed restriction in broiler breeders leads repeatedly to significant improvements in reproductive performance. The current feeding programs have allowed the industry to continue to place emphasis on growth traits without sacrificing reproductive capacity substantially.

4. Ovarian and Oviduct Function

Hocking (1992b) attempted to relate the effects of rearing regimen and time of photostimulation to changes in ovarian function. The results showed that non-photostimulated turkeys at 18, 24, or 30 WOA, whether restricted or not, did not have follicles greater than 5.0 mm in diameter. In addition, the patterns and counts of small white follicles and the number of larger (> 8mm) yellow follicles were similar in restricted and in *ad libitum* fed turkeys for birds in lay at the same age, regardless of the time elapsed since photostimulation. However, a general decline in the number of normal yellow follicles, groups of yellow follicles, and the proportion of multiple yellow follicles was observed with age. The author concluded that the absence of any effect of age at photostimulation on the pattern of follicular development of birds in lay suggested that follicular dynamics were a function of age *per se* rather than an effect of time of photostimulation. The growth of small yellow follicles from 8 mm in diameter to large yellow follicles at ovulation takes normally nine to ten days and, on average, turkeys typically do not recruit small white follicles into the yellow hierarchy at a sufficient rate to support the production of one egg per day (Hocking *et al*. 1987; Hocking, 1992b) Taken together, the results were consistent with the lower peak and relatively poor persistency of egg production in turkeys compared with broiler breeders and commercial egg layers which both show better rates of recruitment over longer periods of time (Hocking, 1992c).

To further clarify the relationship between the number of yellow follicles and BW, Hocking (1992c) undertook another study where he used four strains of turkeys that were characterized by a 2.6 fold difference in mature BW. The birds were again either fed *ad libitum* or restricted to reach 60 or 80% of the BW of the full-fed control at 24 WOA. There were more yellow follicles at 24 WOA as compared to 30 WOA and the number of yellow follicles increased as the strains became heavier. The implementation of feed restriction successfully reduced the number and the proportion of similar sized yellow follicles. However, the effect of restriction diminished with increasing BW of the strain. It was possible to establish a significant linear relationship of .63 between the number of yellow follicle and BW using regression analysis. The intercept was higher across strains in hens photostimulated at 24 as compared to 30 WOA.

Klein-Hessling (1994) implemented a quantitative feed restriction program in two lines of turkey breeder hens to establish BW reductions of 15, 30, or 45% less than the weight of the *ad libitum* fed control.   A random sample of birds was sacrificed at lighting, first egg, and peak production. Contrary to what might have been expected there was no significant difference in follicle count among treatments at peak of lay.

A series of quantitative and qualitative restriction treatments from 4 WOA until point of lay was employed by Renema *et al*. (1994,1995) in Hybrid male-line turkeys. Feed allowance was provided in such a way as to allow reductions in BW of 10 or 20% relative to the weight of the control. Throughout the laying cycle, the number of large ovarian follicles did not differ between treatments but feed restriction reduced the proportion of multiple follicle sets and increased follicular atresia early in lay.

Melnychuk *et al*. (1997) compared ovary and oviduct development following photostimulation in male and female-line turkey breeder hens. Male-line breeders had significantly more large yellow follicles and a greater proportion of multiple follicle sets than female-line hens. Moreover, the developing oviduct of the female-line birds reached maturity three days earlier than the ovary, while in the male-line hens ovary and oviduct reached maturity simultaneously. The average number of unreconciled postovulatory follicles at first egg was significantly higher in male line hens than in female line breeders.

In broiler breeders, Zelenka *et at.* (1986) reported on the two major categories of multiple ovulations as being sequential or simultaneous. Typically, the former ones result in extra-calcified compressed-sided eggs, and the latter ones are eggs with more than one yolk. Significant differences were found between parental lines suggesting that there is a genetic predisposition for multiple ovulations in certain stocks.

Searching for a more specific explanation why feed restriction in broiler breeders improves egg production so considerably, Hocking *et al*. (1987) investigated the ovarian activity in both *ad libitum* or restricted White Leghorns, dwarf Ross broiler breeders, and normal Ross broiler breeders. The results showed that the Leghorns and restricted dwarfs produced significantly more settable eggs than the full-fed dwarf and broiler breeder hens. In this context it is important to note that the low egg production in *ad libitum* fed broiler breeders was associated, initially, with an excess rather than a deficiency of ovulable yellow follicles leading to a significantly larger number of defective eggs.

Furthermore, the restricted feed allocation in the dwarf breeders caused a significant reduction in the number of yellow follicles. It was found that atretic yellow follicles and multiple ovulations were common among broiler breeders but not in Leghorns or restricted dwarfs at the time when the first egg was laid. The poor performance of the older broiler breeders (later in lay) was associated with those hens that had only a few or no developing yellow follicles, atresia of yellow follicles, or even a continued occurrence of multiple hierarchies. Finally, there was no relationship between the amount of abdominal fat and the number of yellow follicles, implying that feed consumption *per se* influenced the number of yellow follicles.

The beneficial effect of feed restriction in broiler breeders has been well established, yet there is little known concerning the range of age over which it is actually necessary to keep birds on restriction to insure an improved reproductive performance from an ovarian follicular point of view. Hocking *et al*. (1989) addressed this issue by chronologically quantifying the time of the appearance, the size, and the number of yellow and white follicles. The growth of follicles greater than 1 mm in diameter commenced at 14 to 16 WOA in the *ad libitum* fed birds and at 22 to 24 WOA in the restricted hens. More importantly, the number of yellow follicles (> 8 mm) at the time of first egg was not reduced when the restriction had been terminated before, or at 14 WOA. However, follicle count declined linearly the longer the birds remained on restriction. Even a restriction extended to 22 WOA produced only half of the response in number of yellow follicles as compared to a restriction until point of lay. In addition, the effect of restriction on follicular development was associated with yellow follicles only and no relationship was found with respect to atresia or small white (< 8 mm) follicles.

The short term consequences of a sudden increase in feed allowance on selected morphological and reproductive traits of Indian River broiler breeder hens at 44 WOA were studied by Robinson *et al*. (1993b). Previously restricted hens were placed on ad libitum feeding for one and two wk, respectively. After only 7 days of *ad libitum* feeding, significant increases were seen in BW, liver weight, percentage liver fat, plasma lipid concentration, and ovary weight. More importantly, formation of a double hierarchy among the large follicles was evidenced. After 14 days of *ad libitum* feeding, significant increases were also observed in fat pad weight, individual weights of the four largest preovulatory follicles, and the number of large preovulatory follicles. However, the short-term egg production at the intermediate stage of the laying cycle was not significantly affected.

5. Physiological Responses

Restricted feeding in early and late feathering broiler breeder females was the subject of a comprehensive study by Katanbaf *et al*. (1989a,b). Birds were restricted on a daily, skip-a-day, or skip-two-day programs. However, all restricted birds received the same cumulative quantity of feed over time. Surface and cloacal temperature at 7 WOA were significantly reduced due to restriction. The analysis of the blood constituents for the restricted birds showed, in general, that plasma glucose and lipid content decreased while plasma protein increased. As part of the physiological response to cope with the restriction, the birds adapted temporarily by increasing the relative weights and lengths of the gastrointestinal tract (GIT). A similar response was also observed in a study by Pinchasov and Nir (1985). Moreover, the restricted birds retained the consumed feed longer in the GIT. This response diminished upon greater feed allowance at an older age. Restriction not only reduced the relative weight of the abdominal fat pad, the liver lipid, and carcass fat content but also the number of rapidly developing follicles. Settable egg production, as well as the duration of fertility were significantly increased by restriction.

Mbugua *et al*. (1985) conducted a series of experiments to evaluate the effects of feed restriction on lipid and protein metabolism of commercial egg type pullets. Birds were restricted either by limiting the daily time at which the birds had access to feed (RDF) or by alternate day feeding (ADF). The results showed that RDF and ADF led to increased lipogenesis and increased utilization of amino acids as sources of energy.

According to Okumura and Tasaki (1969) uric acid is the main end-product in nitrogen metabolism in birds. Thus, uric acid content in tissues would be expected to reflect the dietary protein, nutritional state, and extent or direction of protein metabolism in avian species. Five month old, male, single comb White Leghorns were fed experimental diets with 5, 10, 15, 20, 30, or 40% protein. Blood plasma concentration of uric acid increased proportionally with dietary protein content, and was highest 2 h after feeding. Protein levels less or equal to 10% had no effect on blood ammonia concentration while higher levels elevated ammonia concentration. In addition, fasting birds for 3 to 10 days caused a marked increase in plasma uric acid concentration that was 10 to 40 times higher than the initial concentration before the restriction began. However, the rise in uric acid concentration was reduced to normal levels within 6 h after refeeding. Miles *et al*. (1987) confirmed the findings by Okumura and Tasaki (1969) in a study conducted with broiler breeder pullets. The plasma uric acid concentration was directly related to dietary protein content. Other known factors that influence uric acid production such as reproductive state, health, and feed intake were reported by Sturkie (1961).

Fattori *et al*. (1993) attempted to characterize how the physiological and physical attributes associated with sexual maturity would be affected by feed allocation as female broiler breeders pass through the pullet-layer transition time. The severe levels of feed restriction retarded skeletal growth and resulted in lower BW at sexual maturity, while delaying sexual maturity significantly. Pubic spread, comb and wattle size, ovary, oviduct, and fat pad weight were all significantly affected by dietary treatments. Feed restriction retarded the normal development of the bursa of fabricius as well as the normal involution of the bursa upon approaching sexual maturity. In addition, feed restriction significantly reduced the plasma lipid content.

6. Biology of Starvation

6.1. Historic Review

The physiology of prolonged fasting and starvation has a long tradition in human nutrition research. Literature sources are scarce and researchers have drawn evidence from a variety of situations which mimic starvation in some respect (Harrision, 1988). For instance, studies exist on food deprived prisoners of war held in concentration camps established by the Germans and Japanese during World War II. A second major source are the few experimental studies of semi-starvation in humans. The "Carnegie Experiment" by Benedict (1915) was a first pioneering effort in this regard and four decades later, Keys *et al.* (1950) conducted the so called "Minnesota Experiment" which was summarized in “The Biology of Starvation”. It is still the most thorough account available up to date (Rivers, 1988).

6.2. Adaptation to Starvation

6.2.1. Physiological Adaptation

Weight loss in starvation is due to loss of both body fat and protein that are both catabolized as metabolic fuels. The loss of protein is concomitant with the loss of body water. Carbohydrate stores take only a few days to deplete and are unimportant in this context. Overall, energy expenditure as well as basic metabolic rate (BMR) decrease as BW is lost (Rivers, 1988). However, the decline in BMR does not exactly parallel the reduction in BW for two reasons. First, there is a decline in the metabolic intensity of specific tissues during starvation, and secondly, various tissues with different metabolic activities are lost at different rates to each other and also disproportional to overall weight loss. For example, adipose tissue that has commonly a low metabolic rate, is usually lost at a high rate during starvation. The five metabolically most active organs (brain, liver, heart, kidney, and skeletal muscle) account for almost 90% of the BMR of normally fed subjects. Starvation is characterized by an obligatory protein loss as well as by an obligatory energy expenditure reduction (decreased BMR) that allows the body to achieve a new equilibrium state. It is the attainment of a new equilibrium that facilitates survival. According to Rivers (1988) it is the catabolism of metabolically active visceral tissue (protein) that kills animals or individuals during prolonged starvation. Furthermore, there is no justification for feeding high protein foods during starvation (Rivers, 1988). The body requires energy. Protein will be catabolized to meet these demands.

Protein turnover in the body is continuous. In the healthy adult, synthesis and degradation approximately balance one another. This is in sharp contrast to starvation. During starvation, there is a definite decrease in protein synthesis. Even tissues like plasma proteins which typically have a very rapid turnover rate, are synthesized at a rate of 30 to 40% below normal. In muscle, protein synthesis rates drop even further. Without physiological adjustments, the body is destined to die. That this does not often occur is the result of a concurrent decrease in protein degradation that minimizes nitrogen loss (Tepperman and Tepperman, 1987). As starvation continues, body tissues not only continue to metabolize fatty acids and glucose for energy, but also begin to use ketone bodies formed in the liver from fatty acid oxidation. A decrease in protein catabolism and gluconeogenesis occurs concurrently with the adaptation of the brain and other tissues to use ketones as a source of energy. Glutamine catabolism increases in the kidney as starvation continues because of on going acidosis.

6.2.2. Endocrine Adaptation

Individual body proteins vary in their turnover rate from only a few minutes to as much as several months (Kinney and Elwyn, 1983). Visceral proteins such as plasma proteins, have a turnover rate three times greater than that of muscle protein (Anon, 1989). Moreover, neither the turnover rate of an individual protein nor that of total body protein remains constant when an animal or individual is exposed to different environmental conditions. The rate of synthesis and degradation is influenced by a variety of factors related to nutrition including the time of last food intake, composition of previous diet, and overall nutritional status. However, the most significant factor influencing protein turnover rate is stress, including stress derived from nutritional adversities such as starvation (Waterlow, 1984).

The principle mechanism that mediates an adjustment to starvation is a change in hormone balance. During starvation, there is a sharp decrease in insulin production. Muscle and adipose tissue become increasingly refractory to the action of insulin. Thus, whatever gluconeogenically-activated insulin is circulating, it is rather ineffective in promoting the characteristic cellular nutrient uptake with which it is associated (Groff , 1995). Since there are certain tissues in the body that depend on glucose supplies (brain, red blood cells, etc.), counter regulatory hormones like glucagon and glucocorticoids (primarily corticosterone in the fowl) are increasing. They promote both fatty acid as well as amino acid mobilization that function as substrate to stimulate gluconeogenesis. Another hormonal alteration facilitating adjustment to starvation includes a decreased synthesis of tri-iodothyronine (T_3) which lowers basic metabolic rate. The glycogen stores of the liver are the first to be depleted during the initial stages of starvation. As muscle tissues undergo proteolysis a mixture of amino acids rich in alanine and glutamine are released. Alanine is the preferred substrate for gluconeogenesis and serves to stimulate the secretion of glucagon. Although insulin secretion increases with stress, the glucagon-to-insulin ratio favors glucagon. The tissues become resistant to insulin action and hyperglycemia persists. In addition, cortisol concentrations may remain elevated for prolonged periods of time following severe starvation and continue to contribute to proteolysis and hyperglycemia.

7. Synopsis

Turkey breeder feed restriction research has not greatly advanced from the 1940s to the late 1980s. Past research has shown that feed restriction reduces BW and is usually associated with a delay in sexual maturity. Generally, these methods have not improved fertility and hatchability. Similarly, egg weight and egg production have commonly been unaffected but a few exceptions were reported. However, over the last 10 years more effort has been devoted in trying to elucidate some of the basic underlying mechanisms of restriction, particularly in the area of ovarian function. Turkey feed restriction research in the past used a bewildering array of restriction techniques without placing emphasis on defining or identifying crucial elements in a restriction program as postulated by Costa (1981). Recent attempts have been more systematic in nature and feed restriction has now gained considerable interest among one of the primary breeding companies. As selection for growth rate continues, the problem of managing a negative correlation between BW and reproductive traits becomes more difficult. Successful feed restriction of turkey breeder hens will likely become a more significant development in the turkey industry in the near future.

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CHAPTER I

Effect of Duration of Feed Restriction and Prebreeder Protein Content of Feed on Growth and Carcass Composition of Commercial Large White Turkey Breeder Hens

ABSTRACT

The effect of duration of feed restriction and prebreeder protein content of feed on subsequent growth and carcass characteristics of commercial Large White Nicholas turkey breeder hens was investigated. The treatments were as follows: a) a control group fed standard commercial diets for *ad libitum* consumption (CON); b) a second group like (a) but fed plain white oats from 19 through 26 wk (OATS). In contrast, the four remaining treatment groups were feed restricted beginning at 6 wk of age (WOA) to achieve body weights 45% less than the full-fed CON at 16 WOA and were kept at this level of restriction until either 17.0 (R17.0), 18.3 (R18.3), 19.6 (R19.6), or 20.9 (R20.9) WOA. At these times, feed allotments were increased and birds began realimentation attempting to increase BW to meet a predetermined minimum target of 10.8 kg at photostimulation. An additional treatment (18 *versus* 15% protein) was superimposed from 27 to 31 WOA. Approximate differences in BW of 45% were achieved, but none of the four restriction treatments met the target BW at lighting. Feed restriction reduced feed consumption and improved feed conversion significantly. Flock uniformity, mortality, sexual maturity, percent breast and fat pad weight at photostimulation were unaffected by restriction treatments. Body weight restriction did not alter carcass composition, and shank length increased little after 20 WOA. Effects of dietary protein were negligible. In conclusion, if restriction is too severe and is continued too near to photostimulation, birds are unable to reach an essential minimum target BW for photostimulation. Feed restriction alters many conformational and compositional traits only transiently.

(*Key words*: turkey breeder hens, feed restriction, body composition, body conformation, dietary protein)

INTRODUCTION

Every broiler breeder company relies on feed restriction programs (Robinson *et al*., 1993a). Chicks are subjected to rigorous feeding programs at an early age to control BW gain during the growing and laying period (Costa, 1981; Karunajeewa, 1987; Yu *et al*., 1992a). These feeding regimens improve egg production (Robbins *et al*., 1986; Hocking, 1987; Robinson, 1991), fertility (Hocking, 1990) and hatchability (Wilson and Harms, 1986; Yu *et al*., 1992b). In fact, failure to control BW of broiler breeders is the major reason for not attaining optimum reproductive performance (Classen, 1984).

In recent years, the turkey industry has been attempting to extrapolate results from broiler breeder feed restriction programs (Miles and Leeson, 1990a). This renewed interest has been stimulated by the primary breeder's decision to shift selection emphasis towards higher growth rates in their female pedigree lines in the late 1980s (Hester and Stevens, 1990) to meet the demand for heavier turkeys for further processing (Renema *et al*.,1994). At the same time, this decision created an urgent need to find possible solutions to circumvent the effects of an existing negative correlation between BW and egg production (Nestor *et al*., 1980). Numerous restriction techniques have been employed to determine whether limitation of growth during the rearing period confers any productive advantage on female turkeys (Whitehead, 1989). These methods included feeding of high fiber and/or low energy diets, distasteful compounds, various skip-a-day feeding programs with limited feed allowance, and the use of dietary protein restrictions, either on a percentage basis or through quantitative restriction of certain essential amino acids (Hester and Stevens 1990). However, physical feed restriction has received the most attention and is the method of choice in broiler breeders (Robinson *et al*., 1993b; Zuidhof *et al*., 1995).

Presently, effects of feed restriction on reproductive performance of commercial turkey breeder hens is inconclusive (Hester and Stevens, 1990; Hocking, 1992a; Klein-Hessling, 1994; Renema *et al*., 1994; Douglas and Wojcinski, 1997; Crouch *et al*., 1997). Feed restriction in the past has generally led to a reduction in BW and a delay in sexual maturity with no effect on egg weight, fertility, or hatchability (Miles and Leeson, 1990a). Effects on egg production have been inconsistent. Earlier work by Jones *et al*. (1976), Andrews and Morrow (1978), and Voitle and Harms (1978) indicated significantly lower egg production. In contrast, experiments by Potter *et al*. (1978), Owings and Sell (1980), Nestor *et al*. (1981), and Ferket and Moran (1986) did not show differences in egg production, while reports by Balloun (1974), McCartney *et al*. (1977) and Miles and Leeson (1990a) indicated significantly improved egg production with feed restriction.

More recently, Hocking (1992a) showed significantly greater settable egg production and hatchability in a small strain of caged British United Turkeys using a severe (40%) feed restriction program until point of lay. It was suggested that only drastic BW reductions were able to synchronize ovarian and oviduct function. Klein-Hessling (1994) implemented BW reductions of 15, 30, or 45% at 16 WOA in two lines of Large White BUT stocks. Only the 45% restriction treatment improved egg production and hatchability. Renema *et al*. (1994), using Hybrid male-line turkey breeder hens selected for growth characteristics, found that BW restrictions of 10 or 20% until photostimulation did not improve egg production. Crouch *et al*. (1997) employed a 45% BW reduction in Nichoas Large White turkey breeder hens beginning at either 3 or 6 WOA until 16 WOA and obtained significantly greater egg production when restriction started at 3 WOA.

In broiler breeders, body composition and conformation relate significantly to performance traits (Soller *et al*., 1965; Wilson and Harms, 1986; Hocking and Duff, 1989). In contrast, the variability for these traits in turkey feed restriction trials is largely due to differences in experimental design (age at initiation, intensity, and duration of restriction). For instance, Borron *et al*. (1974), Hocking (1992a), and Renema *et al*. (1994) reported a significant reduction in shank length while Anderson *et al.* (1963) found no differences for either shank length or body depth but breast width was significantly reduced. This is in agreement with Krueger *et al*. (1978) who also reported a reduced breast width, keel length, and body depth, but no affect on shank length. Klein-Hessling (1994) found that breast width and body depth were only transiently effected during the time of severe feed restriction, while shank width and shank length were reduced permanently.

Miles and Leeson (1990b) concluded that quantitative feed restriction may be the only method to successfully reduce breeder obesity. They found reduced carcass dry matter and fat content with a concomitant increase in crude protein. Renema *et al*. (1994, 1995) compared quantitative restriction with feeding a low protein diet and found that the low protein diet, on average, resulted in the largest fat pad and highest carcass fat content, while quantitative restriction reduced percentage carcass fat content at sexual maturity with no effect on carcass protein content. Similarly, Hocking (1992a,b) restricted breeder hens to achieve BW reductions of either 20 or 40% relative to the BW of an *ad libitum* fed control and reported decreased fat content with increasing severity of restriction and decreased age at photostimulation. Moreover, *ad libitum* fed turkeys from four strains characterized by a 2.6 fold difference in mature BW had similar proportions of carcass fatness. Feed restriction decreased the fat content more effectively in the smaller than in the larger strains (Hocking, 1992b). Restriction as severe as 40% did not affect carcass protein content, which is in agreement with Renema *et al*. (1994).

In an industry survey, Halloran and Wilgus (1982) reported that commercial turkey nutritionists fed prebreeder diets with a protein content ranging between 10-17%. This wide variation indicates a lack of defined nutrient requirements for breeder replacements and the lack of monitoring the effects of growth rate on subsequent egg production (Hulet *et al*., 1993). According to Grimes *et al*. (1989), prebreeder protein intake did not affect BW, feed consumption, body composition, egg production, fertility or hatchability. Similarly, Mitchell *et al*. (1962), Voitle *et al*. (1973), and Cherms *et al*. (1976) reported that prebreeder protein had little effect on breeder performance, while others (Meyer *et al*., 1980; Noll *et al*., 1993) reported beneficial effects when the protein content was increased.

In a effort to develop a successful feed restriction program for turkey breeder hens, the following study was conducted to investigate the influence of duration of restriction during the growing period and level of dietary prebreeder protein content on subsequent growth and carcass characteristics of commercial Large White turkey breeder hens.

MATERIALS AND METHODS

General Management

Day old Nicholas Turkey poults (Line 700) were raised according to commercial standard practices until 6 WOA with feed and water available for *ad libitum* consumption. At this time, birds were wing-banded and randomly assigned to one of 36 floor pens with 20 birds each. Linear troughs replaced tube feeders at 4 WOA. This allowed the birds to adapt to the new feeding system 2 wk prior to the implementation of the experimental treatments. The pens in the light controlled house measured 2.7 m x 3.7 m while feeder space averaged 12 cm per bird.

Initially, all birds had unlimited access to suspended bell drinkers. However, with the implementation of experimental treatments, it was necessary to limit water availability to about 45 min twice a day. Water was turned on just before the birds were fed. Four diets, identical to those used in a previous restriction trial (Klein-Hessling, 1994) were fed during the brooding, grower, developer and holding period. A sequential outline of the diets used in each treatment is depicted in Table 1 while diet ingredients and compositions are shown in Table 2. All poults were exposed to continues light on Day 1. The photoperiod was then gradually reduced to 14 h of light (L) and 10 h of darkness (D) at 2 WOA. This lighting schedule continued until 17 WOA. The photoperiod was then further reduced to 8L:16D, 7L:17D, and 6L:18D at 18, 22, and 26 WOA, respectively. The birds were moved into a laying house at 31 WOA. Initially, the breeders were photostimulated with a lighting schedule of 13.5L:10.5D which was increased to 14L:10D at first egg, and extended to 15L:9D at peak egg production. Further increments of stimulatory light were added in the morning until a 17.5L:6.5D photoperiod was reached at the end of the study. During lay, feed and water were provided for *ad libitum* consumption. Laying pens measured 4.0 m x 3.6 m and were equipped with four trap nests per pen. Generally, birds were cared for according to commercial standard practices.

Experimental Procedures

At 6 WOA, all hens were equally divided among six grower feeding regimens. The first two treatment groups served as controls and were as follows: a) a control group fed standard commercial diets for *ad libitum* consumption (CON); b) a second control group that was fed standard commercial diets through 18 wk, followed by plain white oats provided for *ad libitum* consumption from 19 through 26 WOA (OATS) and then again the same standard diets *ad libitum* as in the CON from 27-31 WOA. In contrast, the 4 remaining grower treatment groups were physically feed restricted on a skip-a-day basis beginning at 6 WOA in order to achieve body weights 45% less than the full-fed CON group at 16 WOA. These birds remained feed restricted until either 17.0 (R17.0), 18.3 (R18.3), 19.6 (R19.6), or 20.9 (R20.9) WOA. At these times, birds were released from restriction and began realimentation attempting to increase BW to a predetermined minimum target of 10.8 kg at photostimulation. When it became evident that the four quantitatively restricted groups would not be able to reach their target BW for photostimulation, an additional dietary treatment was superimposed on the previous treatments from 27 to 31 WOA. Half of the birds were fed a 15% crude protein diet while the other half received an 18% crude protein diet in order to accelerate BW gain.

Measurements

Birds were individually weighed weekly to the nearest 0.01 kg (Fattori *et al.*, 1992a,b). Feed consumption was determined weekly on a pen basis. Body weight and feed consumption data were utilized to calculate a weekly feed allotment for each pen for the following week. Feed consumption was calculated as total feed consumption in kg/bird, feed/bird/day, and feed/bird/day per kg BW to account for significant differences in BW among treatments. Feed to gain ratios for the rearing period were determined. Total BW gain and BW changes during specific time periods were calculated.

Sexual maturity was expressed as either days post photostimulation until first egg or as days post photostimulation until hens reached 50% production. Keel and shank length measurements were taken as indicators of frame size. Shank length was defined as the distance between the top of the hock joint and the spur.

Tissue samples were taken from six randomly selected birds per treatment at 17, 20, and 23 WOA. As differences in BW declined, sample size was increased to seven birds per treatment at 26 WOA, followed by eight birds per treatment at lighting (31 WOA) and first egg (34 WOA), and 10 birds per treatment at peak production (37 WOA). Breast muscle, gizzard, liver, heart, and abdominal fat pad were excised and weighed. The fat pad was defined as fat lining the abdominal cavity plus the fat surrounding the gizzard and proventriculus. In addition to the regular tissue sampling, a whole body composition analysis (including feathers and organs) was performed on all carcasses selected at 31, 34, and 37 WOA (Renema *et al.*, 1994). Composition analysis followed standard procedures for determination of total dry matter, protein, lipid, and ash content (Association of Official Analytical Chemists, 1980).

Statistical Analysis

Data were subjected to analysis of variance using the General Linear Models procedures (SAS Institute, 1988). There were six feeding regimens (first independent variable) and two dietary treatments (second independent variable) in a factorial arrangement. Tests of significance were made for the main effects and the corresponding interaction. The experimental unit was the pen. However, BW and the data from the necropsy and whole body chemical composition were analyzed on an individual bird basis. All percentage data were transformed using an arc sine square root transformation prior to analysis. Differences among main effect means for treatments were partitioned using Duncan’s multiple range test. Statements of statistical significance were based upon $P \leq 0.05$ unless otherwise stated.

RESULTS

Body Weight and Rate of Gain

Figure 1 shows the BW development from 6 through 52 WOA. The birds in the four quantitatively restricted groups started to segregate from the two full-fed groups as early as 7 WOA. The magnitude of these differences in BW increased over time. A fowl pox vaccination delayed the weekly BW assessment at 15 WOA and the birds in the quantitative restriction treatments became more severely restricted than intended. Ultimately, there was a significant difference in BW of approximately 51% at 16 WOA (Table 3). The feed allowance was increased and average BW reductions of 43.2% were established for the R17.0 (40.6%), R18.3 (43.7%), R19.6 (43.3%), and R20.9 (45.2%) treatment at 18.0, 19, 20, and 21 WOA, respectively.

Significant differences in BW among the four quantitatively restricted treatments gradually declined after the restriction was terminated. No differences existed at 32 WOA and average BW remained statistically similar among these four groups throughout the remainder of the laying cycle (Table 3). Similarly, differences in BW between the two control groups and the four restriction treatments persisted beyond the realimentation period until the end of the laying cycle.

Feeding oats at 19 WOA was accompanied by a significant decline in BW at 20 WOA (Figure 1). The birds reluctantly accepted the new feed and spent more time at the drinkers. Hens in the OATS treatment required approximately two wk to adjust to the new feeding regimen. Thereafter, they resumed growth at a rate similar to the CON birds. Differences in BW between the CON and OATS treatment existed until 32 WOA, but not thereafter. The OATS treatment surpassed the desired target BW of 10.8 kg for photostimulation (11.2 kg). At the end of the study, all hens had lower BW than at the onset of egg production (Figure 1). There was no interaction between feeding regimens and dietary protein.

The effect of duration of restriction on BW changes before and after photostimulation is shown in Table 4. The highest weight gain from 6-31 WOA was obtained in the CON followed by the OATS treatment. The R17.0 group gained significantly more weight than the R20.9 treatment.

From 31-34 WOA, BW gain was significantly higher in the four quantitative restriction treatments and lowest in the CON. In contrast, the OATS treatment exhibited a significantly lower weight gain than the four restriction treatments, but it was significantly higher than in the CON. Birds in the CON group lost significantly more weight than the hens in the R17.0 and R19.6 treatment from 34 WOA to the time of lowest BW during lay (LBL). A significant duration of restriction x prebreeder protein interaction was found for BW changes from the time of LBL to 52 WOA. At the 15% protein level, the R19.6 treatment had the highest weight gain of all treatments while it had one of the lowest weight gains at the 18% protein level (Table 5).

Increasing the prebreeder protein level did not accelerate BW gain significantly. Across feeding regimens, BW for the 15 and 18% protein diets at 31 WOA averaged 10.74 and 10.73 kg, respectively. At the same age, BW of the CON, OATS, R17.0, R18.3, R19.6, and the R20.9 treatment was 11.6, 11.2, 10.3, 10.1, 10.1, and 10.0 kg, respectively (Table 3). This average BW for the four quantitative restriction treatments was substantially below the desired minimum target weight of approximately 10.8 kg.

Flock Uniformity

Figure 2 shows the coefficient of variation for BW as a measure of flock uniformity. Initially, quantitative restriction resulted in a progressive increase in coefficient of variation for BW. Significant differences in variation occurred as early as 12 WOA and reached a maximum at 16 WOA (Table 6). However, as feed allotments were gradually increased and realimentation was implemented, flock uniformity improved and the coefficient of variation for BW was statistically the same among all six treatments at 26 WOA. Feeding oats increased the coefficient of variation for BW by approximately one percent and variation remained elevated even after the birds had been returned to a regular commercial feed (Figure 2). Coefficient of variation increased in all treatments as egg production started to decline during the second half of the laying cycle. Although there were no significant differences, numeric differences were most prevalent in the R20.9 treatment. Figure 3 shows a histogram for BW distribution for each of the six feeding regimens at photostimulation (31 WOA). Contrary to what might have been expected, BW distributions for the quantitative restriction treatments were not skewed to the left. Kurtosis was similar in all groups, except the R20.9 treatment which was neither normally distributed nor did the distribution have a well defined peak.

Feed Consumption

Table 7 shows the effect of duration of restriction on average feed consumption. From 6-53 WOA, the CON and OATS treatment had a significantly higher feed consumption than the four quantitative restriction treatments. Average feed consumption for the CON, OATS, R17.0, R18.3, R19.6, and the R20.9 treatment was 86.7, 86.9, 77.6, 77.0, 77.7, and 75.8 kg per bird, respectively. The differences amounted to approximately 11.0%. During the growing period from 6-31 WOA, birds in the quantitative restriction treatments had a significantly better feed conversion than the OATS or the CON treatment. There were no significant differences among the four quantitative restriction treatments (Table 7).

Differences in feed intake were a direct result of the implementation of the restriction treatments during the growing and holding period from 6 to 31 WOA (Table 7, Figure 3). No significant differences in total feed consumption (kg/bird) existed during the laying period from 32-53 WOA. In contrast, when feed consumption was expressed as feed per bird per day per kg BW instead of total feed consumption (Klein-Hessling, 1994), significant differences in feed intake were revealed (Table 7). All of the quantitative restriction treatments and the OATS treatment had significantly more feed available on a per kg BW basis than the full-fed control from 17-31 WOA and during the transition time from 17-37 WOA. During lay, however, only the four quantitatively restricted groups differed significantly from the CON (Figure 3, Table 7). There were no significant differences in feed per bird per day per kg BW from 6-53 WOA (Table 7). The interaction of feeding regimen x dietary protein was not significant for feed intake. Dietary protein did not affect feed consumption or feed to gain ratios (Table 8). Birds that were fed oats from 19 through 26 WOA consumed on average 256.3 g or 0.56 lb. of oats per bird per day.

Mortality and Culls

Table 9 summarizes the percentage of birds lost due to mortality and culling. No significant differences were found for mortality from 6 through 53 WOA. Mortality ranged between 1.5 and 5% overall, and was numerically the highest in the CON, R17.0, and the R20.9 treatment. Even mortality during the growing period from 6 to 31 WOA did not differ significantly. Means were 2.50, 2.55, 2.46, 0.79, 0.83, and 1.59 % for the CON, OATS, R17.0, R18.3, R19.6, and the R20.9 treatment, respectively. A common cause of mortality was leg problems. Prolapse of the reproductive tract was not a problem in this study. Increasing the dietary protein content from 15 to 18% did not exert an effect on mortality (data not shown). The fowl pox outbreak mentioned previously was first detected in the OATS treatment and did not spread to any of the 4 quantitative restriction treatments.

Approximately 11% of the birds in each of the four quantitative restriction treatments were removed from the study due to insufficient BW. Birds weighing less than 9.48 kg at photostimulation were not used. None of the birds in the CON or OATS treatment had to be culled. The differences were highly significant. Increasing dietary protein did not significantly alter the culling rate (data not shown).

Sexual Maturity

Table 10 displays the effect of duration of restriction and prebreeder protein level on onset of sexual maturity. No significant differences among treatments were found for either days to first egg or days to 50% production. There was no restriction x prebreeder protein interaction for the onset of sexual maturity. On average, egg production began at approximately 17 days post-lighting across all feeding regimens, while 50% production was reached approximately 3 wk after photostimulation. Prebreeder protein level did not significantly affect age at sexual maturity.

Body Composition

Tables 11 through 15 show the effect of duration of restriction on organ and tissue weights taken during necropsy. Large treatment differences existed for abdominal fat pad (Table 11) and breast muscle weight (Table 12) on an absolute, as well as on a percentage of BW basis at 17, 20, 23, and 26 WOA. These results indicate that the four restriction treatments and the birds on oats were significantly leaner and less fleshed than the control birds. However, there were two exceptions. Percent fat pad and breast weight for the R18.3 and R17.0 treatment, respectively, were not statistically different from the CON at 26 WOA. There were no significant differences for absolute and percent fat pad weight at photostimulation (31 WOA). In contrast, the CON treatment had a significantly higher fat pad weight than all other feeding regimens at 34 WOA except the R17.0 treatment. However, the R17.0 treatment had a significantly lower fat pad weight than either the CON or OATS treatment at 37 WOA.

Significant differences in breast weight on an absolute weight basis remained at 31 WOA between the CON (2.97 kg) and the four quantitative restriction treatments (2.63, 2.55, 2.46, and 2.52 kg for the R17.0, R18.3, R19.6, and the R20.9 treatment, respectively). The breast weight of birds fed oats was statistically not different from the CON and the R17.0 treatment but it was significantly higher than in the R18.3, R19.6, and R20.9 treatments. All restriction treatments and the OATS treatment had a proportionally higher percentage breast meat accretion than the full-fed control birds from 26 to 31 WOA (Table 12). No significant differences were found for either absolute or percentage breast weight at 34 or 37 WOA.

Absolute liver weights were significantly affected by restriction at 23, 26, and 37 WOA, whereas percent liver weight was significantly altered from 17 through 26 WOA (Table 13). Absolute liver weights were highest in the R20.9 treatment and lowest in the OATS group.

Feed restriction increased gizzard weight significantly on a percentage basis from 17 through 31 WOA and from 23 to 31 WOA on an absolute weight basis (Table 14). The average weight of the gizzard in the OATS treatment increased by approximately 60% from 20 to 23 WOA and another 12% from 23 to 26 WOA.

The data from the whole body composition analysis is shown in Table 15. The substantial feed restriction employed in this experiment did not significantly alter percent dry matter, ash, fat, or protein content at either 31, 34, or 37 WOA. There were no effects of dietary prebreeder protein on the weight of tissues sampled or on whole body composition for any of these criteria (Tables 16, 17, 18, 19, and 20).

Body Conformation

The effects of duration of restriction on shank and keel length are shown in Table 21. Reductions in BW of approximately 51% at 16 WOA resulted in significantly shorter shanks at 17, 20, and 26 WOA but not at 23, 31 and 34 WOA. Currently, there is no explanation available for the significant increase in shank length for the OATS treatment at 26 WOA. Shank length differed again significantly at 37 WOA but, over time, it increased only very little after 20 WOA. There was a significant dietary protein effect on shank length at 37 WOA (Table 22) which indicated that shank length was greater when birds were fed a 18% protein diet. Keel length was significantly altered from 17 to 23 WOA and 31 to 34 WOA, but not at 26 and 37 WOA.

DISCUSSION

Quantitative feed restriction limited BW. The present results are in agreement with numerous other studies (Hester and Stevens, 1990; Hocking *et al*., 1992a,b; Renema *et al*., 1994; Crouch *et al*., 1997) and substantiate the conclusions drawn by Miles and Leeson (1990a,b) who suggested that physical feed restriction was the most effective method in controlling BW. Klein-Hessling (1994) reported that physical restriction could be implemented which controlled rate of gain while not causing a loss in BW. Unlike physical feed restriction, feeding plain white oats initially reduced BW. Upon recovery from this growth depression, little control remained over the BW development in this treatment. The OATS treatment surpassed the desired target BW. This response emphasizes the importance of accurate initiation and termination of oat feeding in order to meet a pre-determined target weight considered optimal for photostimulation.

According to the fundamental principles in broiler breeder feed restriction, maximum reproductive performance necessitates adequate weekly BW gains during the pullet-layer transition time to obtain a predetermined target BW at photostimulation and at point of lay. Evidence exists in turkeys to support the necessity of achieving a threshold BW to keep birds in lay. (Hulet *et al.*, 1993). Similarly, Krueger (1980) and Waibel (1981) emphasized that heavier BW at the time of photostimulation appears to aid in sustaining egg production. According to Harms (1984), if broiler breeders do not have sufficient BW at the time of photostimulation, there is a risk of obtaining poor persistency in production. Based on the results from a previous trial (Klein-Hessling, 1994), excellent production was obtained when restricted birds achieved 10.8 kg at photostimulation. However, in this trial, a significant proportion of the birds in the quantitatively restricted treatments failed to reach the desired target BW. The restriction may have been to severe for the Nicholas strain to develop sufficient compensatory growth. A similar result in Nicholas stock was obtained by Crouch *et al*. (1997), and high environmental temperatures exacerbated the problem. Differences among commercial strains cannot be excluded.

In the past, dietary modifications aimed at overcoming insufficient BW gain in restricted turkeys have failed (Whitehead, 1989). This is in accordance with the lack of response seen in raising the prebreeder protein content from 15 to 18% in the present study. Therefore, if feed restriction is too severe and is continued too near to the time of conventional photostimulation, birds will not have enough time to recuperate sufficient BW to meet an essential minimum target BW for photostimulation. The present data clearly indicate that the problem cannot be overcome by increasing the dietary protein content during the last 5 wk prior to photostimulation.

Feed restriction did not adversely affect flock uniformity at photostimulation. This result is consistent with previous studies by Klein-Hessling (1994) and Douglas and Wojcinski (1997), but contradicts with reports by Hocking (1992a) and Renema *et al*. (1994). The two latter laboratories restricted breeder hens between 10 and 40% until photostimulation and found significantly reduced uniformity regardless of degree of restriction. Thus, if flock uniformity is of concern, then feed allocation has to increase at the appropriate time prior to photostimulation. Uniform flocks reach peak production earlier and they will also peak at a higher level than non-uniform flocks (Petitte *et al*., 1982).

According to Douglas and Wojcinski (1997) feeder space is critical and all birds should have access to the feed at the same time. However, Van Krey and Weaver (1988) reported equivalent or better uniformity in broiler breeder pullets with only 45% of the recommended feeder space rather than 90%. Robbins *et al*. (1986) provided evidence suggesting that flock uniformity was not solely a function of available feeder space *per se*, but a variable that could be influenced by management. An abrupt rather than a gradual increase in feeding level during the pullet-layer transition time promoted flock uniformity. Bartov *et al*. (1988) showed that skip-a-day feeding programs maintain uniformity at a higher level than every-day feeding programs. This was a result of increased feed availability on feeding days, thus allowing all birds a sufficient intake.

When combining the results from the present study with the reports in the literature, it is apparent that duration of restriction and, thus, the timing of initiation of re-feeding and the intensity of refeeding play a much more important role in preventing low uniformity than the imposed level of restriction *per se*.

An increase in coefficient of variation for BW occurred during the second half of the laying cycle. This decline in flock uniformity is typically a result of an increasing proportion of broody or out-of-lay hens. Nutrients are allocated to body reserves instead of being vested in ovarian development. This observation is common in turkey (Renema *et al*., 1994) and broiler breeder flocks (Zuidhof *et al*., 1995).

Body weight restriction reduced feed consumption. It is difficult to compare these results with other studies due to differences in experimental design. For example, Crouch *et al*. (1997) restricted hens from 3-16 or 24 WOA and found reductions in feed consumption between 5 and 24%. Hocking (1992a,b) restricted breeder hens by 40% from 6-30 WOA and showed reductions in feed intake of approximately 30%. On the other hand, Renema *et al*. (1994) restricted replacement breeders to either 10 or 20% from 4 to 28 WOA and reported savings in feed of 11.3 and 19.5%, respectively.

All four quantitatively restricted groups had significantly better feed conversion than either the CON or the OATS treatment during the growing period. Although not statistically significant, numeric improvements in feed conversion also were reported by Renema *et al*. (1994). This difference is the result of a lower maintenance requirement of the restricted birds during much of the growing period. However, Nestor *et al*. (1981) reported that feeding of a high fiber diet was associated with a significant increase in weight and size of the gastrointestinal tract. This may have improved nutrient digestion and absorption.

Both oat feeding and quantitative restriction were associated with an increase in litter moisture content presumably due to an increase in water consumption. With the OATS treatment, drastic changes in feed texture and digestibility could have triggered a nutritionally inflicted stress response leading to the release of corticosterone. This hormone is known to have fundamental effects on metabolic processes such as gluconeogenesis leading to an almost immediate protein catabolism. As this metabolic shift occurs, there is an increase in nitrogen excretion in the form of uric acid that requires an increased urine flow for glomerular clearance (Adams, 1968). Increased urine flow stimulates an increase in water consumption (Siegel and Van Kampen, 1984). Furthermore, some of the extra water is retained to maintain osmotic pressure because of the increase in sodium retention that occurs concurrently with the elevated corticosterone levels (Holmes and Philips, 1976). This “stress response” might explain the increased water consumption in the quantitative restriction treatments. Therefore, caution is necessary not to limited water too severely during feed restriction particularly during the hot weather season. However, research has also shown that increased boredom may also lead to increased water consumption.

Feed restriction did not increase mortality during rearing and breeding. In contrast, initial field trials on restricted feeding indicated significantly higher mortality in restricted versus *ad* *libitum* fed birds (Douglas and Wojcinski, 1997). However, after adjustments had been made to raise the temperature in the buildings during the winter and increases in feeder space, mortality rates were not different. Feed restriction was not associated with adverse bird behavior (Hocking (1992a). However, the birds were much more active during feeding (Douglas and Wojcinski, 1997).

The fact that feed restriction did not delay sexual maturity is consistent with a previous trial on restriction (Klein-Hessling, 1994), but disagrees with reports by Renema *et al*.(1994) and Hocking (1992a) for a small strain of birds (BUT Strain 71) photostimulated at 18 and 24 WOA, but not when photostimulated at 30 WOA. A minimum BW and age are necessary for reproduction in birds (Lister *et al*., 1966; Brody *et al.*, 1980; Dunnington and Siegel 1984). Other important factors are body fat content (Bornstein *et al*., 1984; Frisch and McArthur ,1974), rate of food intake (Robbins *et al*., 1986; Kennedy and Mitra, 1963), growth rate (Glass *et al*., 1976), percentage lean tissue mass (Soller *et al*., 1984), and a minimum quantity of breast tissue (Zelenka *et al*., 1986; Zelenka *et al.*, 1987).

The fact that prebreeder protein level does not affect age at sexual maturity has been confirmed in other laboratories (Meyer *et al*., 1980; Grimes *et al*., 1989).

The implementation of the restriction was not associated with a significant reduction in abdominal fat pad weight at photostimulation. This observation was unexpected and conflicts with the results from a previous trial (Klein Hessling, 1994). Strain differences could be contributing to these differences (Renema *et al*., 1994). In the current study, percentage fat pad weight averaged approximately 3% at lighting. Hocking (1992b) reported average levels of 2.5 to 4% when comparing strains characterized by a 2.6 fold difference in BW. Miles and Leeson (1990b) implemented mild (minus 5-15%) quantitative restrictions until point of lay and reported significantly reduced fat levels with a concomitant increase in carcass protein.

Feed restriction did not affect body composition. Hocking (1992a) restricted birds by 40% until photostimulation and reported no difference in carcass protein content 6 wk following photostimulation. No data were provided for the time at photostimulation. On the other hand, Renema *et al*. (1994) was also unable to detect significant differences in carcass protein and ash content for birds that were restricted to either 10 or 20% at photostimulation. No differences were found during mid-lay or at the end of the laying cycle. The large turkey hen of today appears to tolerate high levels of feed restriction without effects on carcass composition (Hocking, 1992b; Renema *et al*., 1994).

Integration of the tissue sampling data for breast and abdominal fat pad weight with the results from the carcass analysis for protein and fat from 31 to 37 WOA, reveal an interesting observation. Breast muscle mass decreased, while carcass protein content increased. Similarly, abdominal fat pad weight decreased, while carcass fat content increased. However, on a percentage basis, breast weight alterations were 16 times as large as abdominal fat pad changes. This observation may suggest that the breast muscle may serve as a significant reservoir of readily available metabolic fuels as has been proposed by Klein-Hessling, (1994). Moreover, breast muscle metabolism may be concealed during a whole body chemical analysis. The response of the OATS treatment with regard to the breast muscle and carcass protein relationship was identical to those of the restricted birds. However, the relationships reversed when fatness was considered. Abdominal fat pad weight increased and carcass fat content decreased for birds fed whole oats.

The effect of duration of restriction on shank and keel length appears to be similar even among experiments with different durations and intensities of restrictions (Hocking, 1992a,b;

Klein-Hessling, 1994; Renema *et al*., 1994). According to Sullivan and Al-Ubaidi (1963) the length of the tibia bone of Broad Breasted Bronze turkey hens attained a plateau at approximately 16 WOA. Anderson *et al*. (1963) reported the existence of a priority of bone growth over tissue growth. This would also explain the similar measurements in shank length at 30 and at 40 WOA obtained by Krueger *et al*. (1978).

In summary, the results from the present study suggest that BW restriction need not necessarily lead to a delay in puberty and this effect can be circumvented by appropriate management practices. Depending on the severity of restriction, the time of initiation of refeeding and the extent of refeeding during a phase of rapid gain altogether determine the timing of this event. In addition, severe and prolonged BW control in commercial turkey breeders up to 21 WOA transiently alters many of the conformational and compositional traits, however, most of them do not persist anymore at the time of photostimulation. Definite alterations will only be achieved when restrictions are continued for longer periods of time, for example, until photostimulation or point of lay. The analysis of compositional changes over time led to a characterization of a differential utilization of body tissues. Finally, the breast muscle may be an important tissue that might provide metabolic fuel during egg production.

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TABLE 1. Sequential outline of experimental diets[1]

	Feeding regimens[2]											
Age (wk)	CON		OATS		R17.0		R18.3		R19.6		R20.9	
0-3	T1		T1		T1		T1		T1		T1	
4-7	T2		T2		T2		T2		T2		T2	
8-11	T3		T3		T3		T3		T3		T3	
12-16	T4		T4		T3		T3		T3		T3	
17-18	T4		T4		T4		T4		T4		T4	
19-26	T4		OATS		T4		T4		T4		T4	
27-31[3]	T4	T5	T4	T5	T4	T5	T4	T5	T4	T5	T4	T5
32-53	TB	TB	TB	TB	TB	TB	TB	TB	TB	TB	TB	TB

[1] Diets: T1 = Turkey Starter 1; T2 = Turkey Starter 2; T3 = Turkey Grower; T4 = Turkey Developer; T5 = Turkey Prebreeder; TB = Turkey Breeder.

[2] CON = Birds fed a standard commercial diet *ad libitum*; OATS = Birds fed a commercial diet through 18 wk and then oats from 19-26 wk; R17.0 = Birds restricted to 45% of the BW of the CON till 17.0 wk of age; R18.3 = Birds restricted to 45% of the BW of the CON till l8.3 wk of age; R19.6 = Birds restricted to 45% of the BW of the CON till 19.6 wk of age; R20.9 = Birds restricted to 45% of the BW of the CON till 20.9 wk of age

[3] A dietary treatment was superimposed on feeding regimens from 27 to 31 wk of age. Half of the birds remained on a 15% protein diet (T4) while the other half received a 18% protein diet (T5).

TABLE 2. Composition of experimental diets

Ingredient	Diets[1] T1	T2	T3	T4	T5	Oats	TB
	(%)						
Corn	47.21	58.95	64.78	66.94	64.77	----	56.09
Dehulled							
Soybean meal (48%)	36.98	31.15	24.37	9.35	22.80	----	8.83
Poultry meal (60%)	5.00	2.00	2.00	4.50	2.50	----	5.00
Wheat middlings	-----	-----	3.50	14.00	4.00	----	11.00
Dicalcium phosphate	3.25	2.59	2.65	1.69	2.40	----	1.21
Alfalfa meal (17%)	2.50	----	----	----	----	----	2.50
Fish meal	----	----	----	----	----	----	2.50
Whey	1.50	2.50	----	----	----	----	1.50
Limestone	1.35	1.65	1.44	1.39	1.46	----	4.70
Poultry fat	1.09	0.18	0.25	1.24	1.14	----	4.60
Choline Cl (60%)	0.25	0.25	0.25	0.25	0.25	----	0.25
DL-methionine	0.23	0.04	0.02	----	0.01	----	----
Mineral premix[2]	0.20	0.20	0.20	0.20	0.20	----	0.20
Salt	0.18	0.25	0.25	0.17	0.19	----	0.21
Peltex 1050	----	----	----	----	----	----	1.25
L-lysine	0.11	0.09	0.14	0.12	0.13	----	----
Vitamin premix[3]	0.10	0.10	0.10	0.10	0.10	----	0.10
Copper sulfate	0.05	0.05	0.05	0.05	0.05	----	0.06
Calculated analysis							
Protein, %	25.50	21.50	19.00	15.00	18.00	11.40	16.00
ME, kcal/kg	2,794.00	2,860.00	2,915.00	2,970.00	2,945.00	2,550.00	3,003.00
Energy protein ratio	110:1	133:1	153:1	198:1	164:1	224:1	188:1
Lysine, %	1.55	1.30	1.15	0.80	1.05	0.50	0.87
Methionine/cystine, %	1.05	0.77	0.68	0.56	0.63	0.40	0.60

[1] Diets: T1 = Turkey Starter 1; T2 = Turkey Starter 2; T3 = Turkey Grower; T4 = Turkey Developer; T5 = Turkey Prebreeder; Oats = Plain White Oats; TB = Turkey Breeder.

[2] Mineral composition in g/kg of diet: Zinc sulfate, Zn 120; Manganous sulfate, Mn 120; Ferrus sulfate, Fe 80; Copper sulfate, Cu 10; Calcium iodite, I 2.5; Cobalt sulfate, Co 1.0.

[3] Vitamin composition: Vitamin A 13,200 IU; Vitamin D_3 4,000 ICU; Vitamin E 66 IU; Vitamin B_{12} 39.6 ug; Riboflavin 13.2 mg; Niacin 110 mg; D-pantothenate 0.22 mg; Menadione (K_3) 0.4 mg; Folic acid 39.7 2.2 mg; Thiamine 4.0 mg; Pyridoxine 7.9 mg; D-biotin 253 ug; Selenium, Se (as $Na_2 SeO_3$) 0.3 mg .

TABLE 3. Effect of duration of body weight restriction on body weight of turkey breeder hens (mean ± SEM)

	Feeding regimens[1]					
Age (wks)	CON	OATS	R17.0	R18.3	R19.6	R20.9
	kg					
6	1.61 ± 0.01	1.62 ± 0.01	1.60 ± 0.01	1.60 ± 0.01	1.61 ± 0.01	1.57 ± 0.01
14	6.11 ± 0.05^{A}	6.08 ± 0.05^{A}	3.28 ± 0.04^{B}	3.27 ± 0.03^{B}	3.27 ± 0.03^{B}	3.26 ± 0.03^{B}
16	7.38 ± 0.05^{A}	7.29 ± 0.05^{A}	3.57 ± 0.04^{B}	3.57 ± 0.04^{B}	3.59 ± 0.04^{B}	3.57 ± 0.04^{B}
17	7.89 ± 0.05^{A}	7.82 ± 0.06^{A}	4.06 ± 0.05^{B}	4.07 ± 0.04^{B}	4.05 ± 0.04^{B}	4.09 ± 0.04^{B}
18	8.28 ± 0.06^{A}	8.24 ± 0.06^{A}	4.92 ± 0.05^{B}	4.87 ± 0.05^{B}	4.93 ± 0.05^{B}	4.88 ± 0.05^{B}
19	8.72 ± 0.06^{A}	8.67 ± 0.07^{A}	5.31 ± 0.06^{B}	4.91 ± 0.05^{C}	4.99 ± 0.05^{C}	4.87 ± 0.05^{C}
20	8.99 ± 0.06^{A}	8.37 ± 0.07^{B}	5.77 ± 0.06^{C}	5.52 ± 0.06^{D}	5.10 ± 0.05^{E}	4.98 ± 0.05^{E}
21	9.34 ± 0.06^{A}	8.54 ± 0.07^{B}	6.50 ± 0.07^{C}	5.80 ± 0.06^{D}	5.75 ± 0.05^{D}	5.12 ± 0.05^{E}
22	9.57 ± 0.07^{A}	8.80 ± 0.07^{B}	6.84 ± 0.07^{C}	6.43 ± 0.06^{D}	6.18 ± 0.05^{E}	5.72 ± 0.06^{F}
23	9.81 ± 0.07^{A}	9.01 ± 0.07^{B}	7.40 ± 0.07^{C}	7.10 ± 0.06^{D}	6.79 ± 0.05^{E}	6.45 ± 0.06^{F}
24	10.20 ± 0.07^{A}	9.32 ± 0.07^{B}	7.96 ± 0.07^{C}	7.69 ± 0.06^{D}	7.43 ± 0.06^{E}	7.01 ± 0.06^{F}
25	10.48 ± 0.07^{A}	9.55 ± 0.07^{B}	8.42 ± 0.07^{C}	8.21 ± 0.06^{D}	8.14 ± 0.06^{D}	7.75 ± 0.06^{E}
26	10.72 ± 0.07^{A}	9.82 ± 0.08^{B}	8.88 ± 0.07^{C}	8.63 ± 0.06^{D}	8.60 ± 0.06^{D}	8.31 ± 0.06^{E}
27	10.95 ± 0.08^{A}	10.18 ± 0.08^{B}	9.27 ± 0.08^{C}	9.03 ± 0.06^{D}	9.00 ± 0.06^{D}	8.78 ± 0.07^{E}
28	11.14 ± 0.08^{A}	10.41 ± 0.08^{B}	9.55 ± 0.08^{C}	9.30 ± 0.06^{D}	9.31 ± 0.06^{D}	9.14 ± 0.07^{D}
29	11.38 ± 0.08^{A}	10.76 ± 0.09^{B}	9.90 ± 0.08^{C}	9.72 ± 0.07^{CD}	9.73 ± 0.07^{CD}	9.57 ± 0.07^{D}
30	11.51 ± 0.08^{A}	10.96 ± 0.09^{B}	10.08 ± 0.08^{C}	9.90 ± 0.07^{CD}	9.96 ± 0.07^{CD}	9.80 ± 0.07^{D}
31	11.62 ± 0.08^{A}	11.15 ± 0.09^{B}	10.27 ± 0.08^{C}	10.09 ± 0.07^{CD}	10.12 ± 0.08^{CD}	10.01 ± 0.07^{D}
32	11.77 ± 0.08^{A}	11.46 ± 0.09^{B}	10.55 ± 0.09^{C}	10.42 ± 0.08^{C}	10.46 ± 0.08^{C}	10.34 ± 0.08^{C}

$^{A\text{-}F}$ Means within a row with no common superscripts differ significantly ($P \leq 0.01$).

[1] CON = Birds fed a standard commercial diet *ad libitum*; OATS = Birds fed a commercial diet through 18 wk and then oats from 19 through 26 wk; R17.0 = Birds restricted to 45% of the BW of the CON till 17.0 wk of age; R18.3 = Birds restricted to 45% of the BW of the CON till l8.3 wk of age; R19.6 = Birds restricted to 45% of the BW of the CON till 19.6 wk of age; R20.9 = Birds restricted to 45% of the BW of the CON till 20.9 wk of age.

TABLE 3. Effect of duration of body weight restriction on body weight of turkey breeder hens (mean ± SEM (cont'd.)

	Feeding regimens[1]					
Age (wks)	CON	OATS	R17.0	R18.3	R19.6	R20.9
	kg					
33	11.90 ± 0.09^{A}	11.78 ± 0.09^{A}	11.08 ± 0.08^{B}	10.90 ± 0.07^{BC}	10.99 ± 0.07^{BC}	10.81 ± 0.08^{C}
34	11.86 ± 0.08^{A}	11.78 ± 0.08^{A}	11.05 ± 0.07^{B}	10.90 ± 0.07^{B}	11.01 ± 0.07^{B}	10.83 ± 0.08^{B}
35	11.77 ± 0.09^{A}	11.70 ± 0.09^{A}	10.93 ± 0.08^{B}	10.85 ± 0.08^{B}	10.93 ± 0.08^{B}	10.70 ± 0.08^{B}
36	11.66 ± 0.09^{A}	11.60 ± 0.09^{A}	10.82 ± 0.08^{B}	10.79 ± 0.08^{BC}	10.83 ± 0.08^{B}	10.57 ± 0.08^{C}
37	11.56 ± 0.08^{A}	11.51 ± 0.09^{A}	10.76 ± 0.08^{B}	10.68 ± 0.08^{B}	10.71 ± 0.08^{B}	10.52 ± 0.08^{B}
38	11.46 ± 0.10^{A}	11.38 ± 0.09^{A}	10.73 ± 0.09^{B}	10.57 ± 0.09^{BC}	10.62 ± 0.09^{BC}	10.44 ± 0.09^{C}
39	11.33 ± 0.09^{A}	11.28 ± 0.09^{A}	10.61 ± 0.09^{B}	10.45 ± 0.09^{B}	10.52 ± 0.09^{B}	10.34 ± 0.10^{B}
40	11.30 ± 0.10^{A}	11.23 ± 0.09^{A}	10.58 ± 0.10^{B}	10.44 ± 0.09^{B}	10.51 ± 0.09^{B}	10.30 ± 0.10^{B}
43	11.12 ± 0.11^{A}	11.15 ± 0.10^{A}	10.58 ± 0.09^{B}	10.33 ± 0.10^{B}	10.55 ± 0.10^{B}	10.29 ± 0.11^{B}
46	11.20 ± 0.11^{A}	11.14 ± 0.10^{A}	10.52 ± 0.10^{BC}	10.38 ± 0.10^{BC}	10.58 ± 0.11^{B}	10.26 ± 0.12^{C}
49	11.29 ± 0.11^{A}	11.20 ± 0.11^{A}	10.66 ± 0.11^{B}	10.43 ± 0.10^{B}	10.69 ± 0.11^{B}	10.43 ± 0.12^{B}
52	11.35 ± 0.12^{A}	11.19 ± 0.11^{A}	10.71 ± 0.11^{B}	10.47 ± 0.10^{B}	10.77 ± 0.11^{B}	10.43 ± 0.14^{B}

[A-C] Means within a row with no common superscripts differ significantly ($P \leq 0.01$).

[1] CON = Birds fed a standard commercial diet *ad libitum*; OATS = Birds fed a commercial diet through 18 wk and then oats from 19 through 26 wk; R17.0 = Birds restricted to 45% of the BW of the CON till 17.0 wk of age; R18.3 = Birds restricted to 45% of the BW of the CON till l8.3 wk of age; R19.6 = Birds restricted to 45% of the BW of the CON till 19.6 wk of age; R20.9 = Birds restricted to 45% of the BW of the CON till 20.9 wk of age.

TABLE 4. Effect of duration of body weight restriction and prebreeder protein level on body weight changes (mean ± SEM)[1]

	Feeding regimens[2]						Protein content[3]	
Age (wk)	CON	OATS	R17.0	R18.3	R19.6	R20.9	15%	18%
	BW change (kg)							
6-31[4]	11.62 ± 0.08[A]	11.15 ± 0.09[B]	10.27 ± 0.08[C]	10.09 ± 0.07[CD]	10.12 ± 0.08[CD]	10.01 ± 0.07[D]	10.56 ± 0.05	10.53 ± 0.06
31-34[5]	0.18 ± 0.04[D]	0.47 ± 0.05[C]	0.54 ± 0.06[B]	0.66 ± 0.04[AB]	0.71 ± 0.04[A]	0.64 ± 0.05[AB]	0.55 ± 0.03	0.51 ± 0.03
34-44[6]	-0.71 ± 0.06[b]	-0.64 ± 0.06[ab]	-0.48 ± 0.05[a]	-0.54 ± 0.06[ab]	-0.49 ± 0.06[a]	-0.60 ± 0.06[ab]	-0.61 ± 0.03	-0.54 ± 0.04
44-52[7]	0.21 ± 0.04	0.10 ± 0.04	0.19 ± 0.04	0.14 ± 0.05	0.23 ± 0.05	0.26 ± 0.05	0.22 ± 0.02	0.15 ± 0.03

[a-b] Means within a row with no common superscripts differ significantly ($P \leq 0.05$).

[A-D] Means within a row with no common superscripts differ significantly ($P \leq 0.01$).

[1] Significant duration of restriction x dietary protein interaction for BW change from 44-52 wk of age ($P \leq 0.01$).

[2] CON = Birds fed a standard commercial diet *ad libitum*; OATS = Birds fed a commercial diet through 18 wk and then oats from 19 through 26 wk; R17.0 = Birds restricted to 45% of the BW of the CON till 17.0 wk of age; R18.3 = Birds restricted to 45% of the BW of the CON till l8.3 wk of age; R19.6 = Birds restricted to 45% of the BW of the CON till 19.6 wk of age; R20.9 = Birds restricted to 45% of the BW of the CON till 20.9 wk of age. Approximately 49 birds/treatment.

[3] Half of the birds were fed a 15% protein diet while the other half received a 18% protein diet from 27 to 31 wk of age. Approximately 147 birds/protein level.

[4] Growing period from 6 wk of age to photostimulation at 31 wk of age.

[5] From photostimulation to first egg.

[6] From first egg to lowest BW of breeder period.

[7] From lowest BW of breeder period to the end of the study.

TABLE 5. Interaction of duration of body weight restriction and prebreeder protein content on body weight changes from 44 to 52 weeks (mean ± SEM)

	Feeding regimens[1]					
Diet[2]	CON	OATS	R17.0	R18.3	R19.6	R20.9
	BW change (kg)					
15% Protein	0.18 ± 0.06[B]	0.16 ± 0.06[B]	0.18 ± 0.07[B]	0.12 ± 0.07[B]	0.43 ± 0.07[AX]	0.28 ± 0.06[AB]
18% Protein	0.24 ± 0.05[A]	0.20 ± 0.06[B]	0.19 ± 0.06[AB]	0.17 ± 0.07[AB]	0.03 ± 0.05[BY]	0.23 ± 0.07[A]

[A-B] Means within a row with no common superscripts differ significantly ($P \leq 0.01$).

[X-Y] Means within a column with no common superscripts differ significantly ($P \leq 0.01$).

[1] CON = Birds fed a standard commercial diet *ad libitum*; OATS = Birds fed a commercial diet through 18 wk and then oats from 19 through 26 wk; R17.0 = Birds restricted to 45% of the BW of the CON till 17.0 wk of age; R18.3 = Birds restricted to 45% of the BW of the CON till l8.3 wk of age; R19.6 = Birds restricted to 45% of the BW of the CON till 19.6 wk of age; R20.9 = Birds restricted to 45% of the BW of the CON till 20.9 wk of age. Approximately 49 birds/treatment.

[2] Half of the birds were fed a 15% protein diet while the other half received a 18% protein diet from 27 to 31 wk of age. Approximately 147 birds/protein level.

TABLE 6. Effect of duration of body weight restriction on coefficient of variation for body weight (mean ± SEM)

	Feeding regimens[1]					
Age (wk)	CON	OATS	R17.0	R18.3	R19.6	R20.9
	%					
6	8.29 ± 0.67	8.73 ± 0.66	8.67 ± 0.34	8.77 ± 0.51	8.83 ± 0.60	8.75 ± 0.42
8	9.12 ± 0.36	10.36 ± 0.60	10.66 ± 0.68	10.08 ± 0.79	10.27 ± 0.59	10.32 ± 0.39
10	10.36 ± 0.75	10.14 ± 0.35	11.88 ± 0.70	11.65 ± 1.20	12.19 ± 0.75	11.37 ± 0.99
12	8.84 ± 0.21^{b}	8.63 ± 0.40^{b}	11.17 ± 0.96^{ab}	10.63 ± 0.88^{ab}	11.91 ± 0.72^{a}	10.90 ± 1.20^{ab}
14	8.69 ± 0.40^{b}	8.51 ± 0.50^{b}	11.67 ± 1.06^{a}	11.15 ± 0.76^{ab}	10.33 ± 1.12^{ab}	10.64 ± 0.97^{ab}
16	7.57 ± 0.52^{B}	7.20 ± 0.46^{B}	12.86 ± 0.88^{A}	12.15 ± 0.97^{A}	11.20 ± 1.10^{A}	11.88 ± 1.24^{A}
18	6.96 ± 0.54^{B}	6.80 ± 0.47^{B}	11.82 ± 0.93^{A}	11.07 ± 1.06^{A}	10.08 ± 0.74^{A}	11.00 ± 1.03^{A}
20	6.90 ± 0.46^{B}	7.27 ± 0.57^{B}	11.05 ± 0.93^{A}	10.84 ± 1.17^{A}	9.99 ± 0.61^{A}	10.80 ± 1.15^{A}
22	5.55 ± 0.85^{C}	7.04 ± 0.51^{BC}	10.49 ± 0.81^{A}	9.60 ± 1.05^{AB}	9.39 ± 0.63^{AB}	11.12 ± 1.24^{A}
24	6.15 ± 0.44^{c}	6.74 ± 0.53^{bc}	8.92 ± 0.66^{ab}	7.60 ± 0.97^{abc}	7.83 ± 0.66^{abc}	9.29 ± 1.06^{a}
26	5.96 ± 0.48	7.06 ± 0.39	7.89 ± 0.86	6.67 ± 1.03	6.80 ± 0.76	7.35 ± 0.97
28	5.98 ± 0.46	7.07 ± 0.53	7.44 ± 0.91	6.57 ± 0.93	6.56 ± 0.75	6.96 ± 0.80
30	5.84 ± 0.40	7.04 ± 0.54	7.44 ± 0.92	6.48 ± 0.86	6.54 ± 0.68	7.04 ± 0.71
32	5.73 ± 0.43	6.68 ± 0.65	7.26 ± 0.93	6.74 ± 0.60	6.74 ± 0.59	6.96 ± 0.69
34	5.32 ± 0.37	4.98 ± 0.62	5.37 ± 0.54	5.39 ± 0.57	5.21 ± 0.69	6.07 ± 0.64
36	5.18 ± 0.50	5.22 ± 0.54	5.88 ± 0.57	5.67 ± 0.72	5.53 ± 0.79	6.24 ± 0.61
39	5.38 ± 0.38	5.31 ± 0.68	6.16 ± 0.79	6.51 ± 0.62	6.17 ± 0.72	6.85 ± 0.79
42	6.15 ± 0.66	5.60 ± 0.82	6.39 ± 0.88	6.84 ± 0.76	7.46 ± 0.80	7.18 ± 1.03
45	6.62 ± 0.69	6.45 ± 0.91	7.53 ± 1.20	6.71 ± 0.73	7.11 ± 0.83	7.48 ± 1.07
48	6.54 ± 0.77	6.24 ± 0.78	7.40 ± 0.47	7.24 ± 0.65	6.87 ± 0.94	7.91 ± 1.08
51	6.66 ± 1.00	6.37 ± 0.66	7.50 ± 0.65	7.07 ± 0.46	7.06 ± 0.99	8.59 ± 1.14

$^{A-C}$ Means within a row with no common superscripts differ significantly ($P \leq 0.01$).

$^{a-c}$ Means within a row with no common superscripts differ significantly ($P \leq 0.05$).

[1] CON = Birds fed a standard commercial diet *ad libitum*; OATS = Birds fed a commercial diet through 18 wk and then oats from 19 through 26 wk; R17.0 = Birds restricted to 45% of the BW of the CON till 17.0 wk of age; R18.3 = Birds restricted to 45% of the BW of the CON till l8.3 wk of age; R19.6 = Birds restricted to 45% of the BW of the CON till 19.6 wk of age; R20.9 = Birds restricted to 45% of the BW of the CON till 20.9 wk of age. Approximately 52 birds/feeding regimen remained at 51 wk of age.

TABLE 7. Effect of duration of body weight restriction on feed consumption and feed efficiency (mean ± SEM)

Age (wk)	CON	OATS	R17.0	R18.3	R19.6	R20.9
	Feeding regimens[1]					
	Total feed (kg/bird)					
6-16	19.9 ± 0.2^{A}	19.6 ± 0.2^{A}	10.2 ± 0.1^{B}	10.2 ± 0.1^{B}	10.3 ± 0.1^{B}	10.2 ± 0.1^{B}
17-31	27.8 ± 0.6	27.7 ± 0.6	28.9 ± 0.2	28.3 ± 0.3	27.9 ± 0.2	27.6 ± 0.3
32-53	38.9 ± 0.5	39.6 ± 0.5	38.6 ± 0.4	38.5 ± 0.5	39.5 ± 0.5	38.0 ± 0.5
6-31	47.7 ± 0.7^{A}	47.3 ± 0.7^{A}	39.1 ± 0.2^{B}	38.5 ± 0.3^{B}	38.2 ± 0.2^{B}	37.8 ± 0.3^{B}
6-53	86.7 ± 1.0^{A}	86.9 ± 0.8^{A}	77.6 ± 0.5^{B}	77.0 ± 0.7^{B}	77.7 ± 0.7^{B}	75.8 ± 0.5^{B}
17-37	38.1 ± 0.6	38.7 ± 0.5	39.9 ± 0.2	39.5 ± 0.3	39.2 ± 0.2	38.5 ± 0.3
	Feed/bird/day/kg BW (g)					
6-16	65.5 ± 0.7^{A}	65.2 ± 0.6^{A}	56.1 ± 0.4^{B}	56.0 ± 0.6^{B}	56.5 ± 0.9^{B}	56.4 ± 0.8^{B}
17-31	27.0 ± 0.3^{C}	28.3 ± 0.3^{B}	37.6 ± 0.2^{A}	37.9 ± 0.3^{A}	37.4 ± 0.3^{A}	37.9 ± 0.4^{A}
32-53	22.2 ± 0.3^{c}	22.8 ± 0.4^{bc}	23.5 ± 0.3^{ab}	23.8 ± 0.3^{ab}	24.0 ± 0.2^{a}	23.7 ± 0.2^{ab}
6-31	46.2 ± 0.3	46.7 ± 0.4	46.8 ± 0.2	47.0 ± 0.4	47.0 ± 0.4	47.1 ± 0.4
6-53	36.1 ± 0.2	36.6 ± 0.3	36.9 ± 0.2	37.1 ± 0.3	37.3 ± 0.3	37.2 ± 0.2
17-37	25.2 ± 0.1^{C}	26.7 ± 0.2^{B}	33.8 ± 0.2^{A}	34.2 ± 0.2^{A}	33.9 ± 0.2^{A}	34.1 ± 0.2^{A}
	Feed:gain ratio					
6-31	4.10^{B}	4.24^{A}	3.81^{C}	3.82^{C}	3.77^{C}	3.78^{C}

$^{A-C}$ Means within a row with no common superscripts differ significantly ($P \leq 0.01$).

$^{a-c}$ Means within a row with no common superscripts differ significantly ($P \leq 0.05$).

[1] CON = Birds fed a standard commercial diet *ad libitum*; OATS = Birds fed a commercial diet through 18 wk and then oats from 19 through 26 wk; R17.0 = Birds restricted to 45% of the BW of the CON till 17.0 wk of age; R18.3 = Birds restricted to 45% of the BW of the CON till l8.3 wk of age; R19.6 = Birds restricted to 45% of the BW of the CON till 19.6 wk of age; R20.9 = Birds restricted to 45% of the BW of the CON till 20.9 wk of age.

TABLE 8. Effect of prebreeder dietary protein content on feed consumption and feed efficiency (mean ± SEM)[1]

Age (wk)	Protein content[2]: 15%	18%
	Total feed (kg/bird)	
27-31	9.5 ± 0.2	9.6 ± 0.1
32-53	39.2 ± 0.3	38.5 ± 0.2
	Feed/bird/day (g)	
27-31	272.3 ± 4.9	273.5 ± 3.1
32-53	254.5 ± 2.1	250.1 ± 1.6
	Feed/bird/day/kg BW (g)	
27-31	27.3 ± 0.8	27.4 ± 0.7
32-53	23.5 ± 0.2	23.1 ± 0.2
	Feed:gain ratio	
6-31	3.92 ± 0.05	3.91 ± 0.04

[1] No significant differences ($P > 0.05$).

[2] Half of the birds were fed a 15% protein diet while the other half received a 18% protein diet from 27 to 31 wk of age.

TABLE 9. Effect of duration of body weight restriction on mortality and culling (mean ± SEM)

	Feeding regimens[1]					
Age (wk)	CON	OATS	R17.0	R18.3	R19.6	R20.9
	% Mortality					
6-31	2.50 ± 1.71	2.55 ± 1.77	2.46 ± 1.10	0.79 ± 0.79	0.83 ± 0.83	1.59 ± 1.56
6-53	4.92 ± 2.24	3.29 ± 1.66	4.09 ± 1.53	2.38 ± 2.30	1.63 ± 1.03	4.01 ± 2.28
	% Culling					
6-31[2]	0.00 ± 0.00^{B}	0.00 ± 0.00^{B}	11.39 ± 2.78^{A}	10.52 ± 3.59^{A}	12.10 ± 1.98^{A}	11.35 ± 1.54^{A}

$^{A-B}$ Means within a row with no common superscripts differ significantly ($P \leq 0.01$).

[1]CON = Birds fed a standard commercial diet *ad libitum*; OATS = Birds fed a commercial diet through 18 wk and then oats from 19 through 26 wk; R17.0 = Birds restricted to 45% of the BW of the CON till 17.0 wk of age; R18.3 = Birds restricted to 45% of the BW of the CON till l8.3 wk of age; R19.6 = Birds restricted to 45% of the BW of the CON till 19.6 wk of age; R20.9 = Birds restricted to 45% of the BW of the CON till 20.9 wk of age.

[2] Birds weighing less than 9.48 kg at photostimulation were culled.

TABLE 10. Effect of duration of body weight restriction and prebreeder protein level on the onset of sexual maturity (mean ± SEM)[1]

	Feeding regimens[2]						Protein content[3]	
Variable	CON	OATS	R17.0	R18.3	R19.6	R20.9	15%	18%
	Days							
First egg [4]	17.3 ± 0.3	17.2 ± 0.5	18.2 ± 0.4	17.2 ± 0.4	17.7 ± 0.5	17.5 ± 0.6	17.7 ± 0.2	17.3 ± 0.3
50% Production[5]	20.8 ± 0.3	20.8 ± 0.3	21.0 ± 0.5	20.5 ± 0.2	21.0 ± 0.6	21.3 ± 0.3	21.0 ± 0.2	20.8 ± 0.2

[1] No significant differences ($P > 0.05$).

[2] CON = Birds fed a standard commercial diet *ad libitum*; OATS = Birds fed a commercial diet through 18 wk and then oats from 19 through 26 wk; R17.0 = Birds restricted to 45% of the BW of the CON till 17.0 wk of age; R18.3 = Birds restricted to 45% of the BW of the CON till l8.3 wk of age; R19.6 = Birds restricted to 45% of the BW of the CON till 19.6 wk of age; R20.9 = Birds restricted to 45% of the BW of the CON till 20.9 wk of age.

[3] Half of the birds were fed a 15% protein diet while the other half received a 18% protein diet from 27 to 31 wk of age.

[4] Days post photostimulation until first egg was laid.

[5] Days post photostimulation until hens reached 50% production.

TABLE 11. Effect of duration of body weight restriction on abdominal fat pad weight (mean ± SEM)

		Feeding regimens[1]					
Age (wk)	n	CON	OATS	R17.0	R18.3	R19.6	R20.9
		(g)					
17	6	129.0 ± 16.8^{A}	159.9 ± 23.5^{A}	4.1 ± 2.3^{B}	2.4 ± 0.7^{B}	4.4 ± 3.0^{B}	5.4 ± 3.6^{B}
20	6	196.6 ± 19.6^{A}	176.2 ± 13.5^{A}	45.5 ± 7.8^{B}	20.5 ± 4.6^{BC}	17.0 ± 6.3^{BC}	10.8 ± 3.4^{C}
23	6	282.3 ± 16.7^{A}	236.8 ± 23.1^{B}	109.8 ± 18.3^{C}	79.6 ± 7.4^{CD}	77.1 ± 11.7^{CD}	51.3 ± 12.2^{D}
26	7	318.6 ± 22.0^{A}	243.2 ± 27.3^{B}	215.8 ± 13.1^{BC}	233.9 ± 11.3^{BC}	180.0 ± 16.5^{C}	179.0 ± 13.4^{C}
31	8	341.1 ± 17.2	308.8 ± 32.6	310.2 ± 16.3	288.5 ± 17.0	309.1 ± 20.9	276.4 ± 17.7
34	8	368.9 ± 12.9^{a}	274.7 ± 25.5^{b}	314.8 ± 17.2^{ab}	303.0 ± 19.6^{b}	274.4 ± 22.5^{b}	267.6 ± 18.1^{b}
37	10	319.7 ± 28.2^{a}	340.8 ± 16.7^{a}	229.9 ± 17.2^{b}	289.5 ± 27.0^{ab}	283.2 ± 14.2^{ab}	273.3 ± 19.6^{ab}
		(%) of BW					
17	6	1.75 ± 0.19^{A}	2.15 ± 0.28^{A}	0.09 ± 0.05^{B}	0.06 ± 0.02^{B}	0.09 ± 0.06^{B}	0.12 ± 0.07^{B}
20	6	2.25 ± 0.17^{A}	2.14 ± 0.13^{A}	0.82 ± 0.14^{B}	0.39 ± 0.08^{C}	0.32 ± 0.12^{C}	0.20 ± 0.06^{C}
23	6	2.89 ± 0.18^{A}	2.51 ± 0.18^{A}	1.47 ± 0.20^{B}	1.15 ± 0.09^{BC}	1.17 ± 0.18^{BC}	0.79 ± 0.17^{C}
26	7	3.00 ± 0.20^{a}	2.45 ± 0.25^{b}	2.31 ± 0.11^{b}	2.56 ± 0.13^{ab}	2.08 ± 0.17^{b}	2.11 ± 0.13^{b}
31	8	3.02 ± 0.15	2.86 ± 0.30	3.02 ± 0.15	2.88 ± 0.16	3.09 ± 0.18	2.78 ± 0.16
34	8	3.18 ± 0.10	2.45 ± 0.23	2.91 ± 0.15	2.88 ± 0.17	2.58 ± 0.19	2.60 ± 0.19
37	10	2.92 ± 0.23	3.08 ± 0.11	2.33 ± 0.18	2.85 ± 0.27	2.81 ± 0.12	2.71 ± 0.17

$^{A\text{-}D}$ Means within a row with no common superscripts differ significantly ($P \leq 0.01$).

$^{a\text{-}b}$ Means within a row with no common superscripts differ significantly ($P \leq 0.05$).

[1] CON = Birds fed a standard commercial diet *ad libitum*; OATS = Birds fed a commercial diet through 18 wk and then oats from 19 through 26 wk; R17.0 = Birds restricted to 45% of the BW of the CON till 17.0 wk of age; R18.3 = Birds restricted to 45% of the BW of the CON till l8.3 wk of age; R19.6 = Birds restricted to 45% of the BW of the CON till 19.6 wk of age; R20.9 = Birds restricted to 45% of the BW of the CON till 20.9 wk of age.

TABLE 12. Effect of duration of body weight restriction on breast muscle weight (mean ± SEM)

Age (wk)	n	CON	OATS	R17.0	R18.3	R19.6	R20.9
		Feeding regimens[1]					
		(kg)					
17	6	1.45 ± 0.10^{A}	1.55 ± 0.10^{A}	0.78 ± 0.04^{B}	0.74 ± 0.04^{B}	0.76 ± 0.06^{B}	0.69 ± 0.05^{B}
20	6	1.97 ± 0.12^{A}	1.88 ± 0.08^{A}	1.12 ± 0.06^{B}	1.01 ± 0.04^{B}	0.99 ± 0.07^{B}	1.01 ± 0.06^{B}
23	6	2.28 ± 0.09^{A}	1.95 ± 0.09^{B}	1.56 ± 0.06^{C}	1.48 ± 0.05^{CD}	1.30 ± 0.06^{DE}	1.20 ± 0.11^{E}
26	7	2.59 ± 0.09^{A}	2.18 ± 0.05^{B}	2.04 ± 0.06^{BC}	1.96 ± 0.08^{C}	1.90 ± 0.06^{CD}	1.75 ± 0.06^{D}
31	8	2.97 ± 0.15^{A}	2.89 ± 0.14^{AB}	2.63 ± 0.11^{BC}	2.55 ± 0.07^{C}	2.46 ± 0.05^{C}	2.52 ± 0.08^{C}
34	8	2.63 ± 0.11	2.69 ± 0.09	2.53 ± 0.06	2.53 ± 0.12	2.54 ± 0.06	2.42 ± 0.10
37	10	2.50 ± 0.07	2.54 ± 0.11	2.38 ± 0.08	2.41 ± 0.09	2.24 ± 0.05	2.27 ± 0.06
		(%) of BW					
17	6	19.78 ± 1.01^{AB}	21.13 ± 0.15^{A}	18.01 ± 0.54^{BC}	17.86 ± 0.50^{BC}	17.64 ± 0.62^{C}	16.57 ± 0.49^{C}
20	6	22.69 ± 1.00^{A}	22.91 ± 0.71^{A}	20.25 ± 0.56^{B}	19.60 ± 0.35^{B}	19.58 ± 0.48^{B}	19.85 ± 0.58^{B}
23	6	23.25 ± 0.14^{A}	21.68 ± 0.50^{AB}	21.32 ± 0.60^{B}	21.51 ± 0.57^{AB}	19.88 ± 0.38^{BC}	19.22 ± 0.93^{C}
26	7	24.28 ± 0.61^{A}	22.33 ± 0.89^{BC}	22.73 ± 0.52^{AB}	21.38 ± 0.61^{BC}	22.03 ± 0.40^{BC}	20.67 ± 0.36^{C}
31	8	26.20 ± 0.98	26.78 ± 1.00	25.55 ± 0.88	25.42 ± 0.73	24.64 ± 0.41	25.33 ± 0.26
34	8	22.83 ± 0.49	23.98 ± 0.50	23.49 ± 0.65	23.99 ± 0.65	23.91 ± 0.27	23.42 ± 0.68
37	10	22.98 ± 0.46	22.98 ± 0.63	23.86 ± 0.41	23.66 ± 0.73	22.26 ± 0.40	22.71 ± 0.46

[A-E] Means within a row with no common superscripts differ significantly ($P \leq 0.01$).

[1] CON = Birds fed a standard commercial diet *ad libitum*; OATS = Birds fed a commercial diet through 18 wk and then oats from 19 through 26 wk; R17.0 = Birds restricted to 45% of the BW of the CON till 17.0 wk of age; R18.3 = Birds restricted to 45% of the BW of the CON till l8.3 wk of age; R19.6 = Birds restricted to 45% of the BW of the CON till 19.6 wk of age; R20.9 = Birds restricted to 45% of the BW of the CON till 20.9 wk of age.

TABLE 13. Effect of duration of body weight restriction on liver weight (mean ± SEM)

		Feeding regimens[1]					
Age (wk)	n	CON	OATS	R17.0	R18.3	R19.6	R20.9
		(g)					
17	6	144.0 ± 10.6	142.4 ± 10.7	134.5 ± 2.9	134.0 ± 7.2	142.8 ± 13.2	139.8 ± 9.0
20	6	99.4 ± 5.4	88.1 ± 4.5	103.9 ± 2.2	99.9 ± 6.7	109.5 ± 9.8	96.1 ± 5.9
23	6	130.7 ± 9.8^{BC}	110.4 ± 9.6^{C}	143.2 ± 10.8^{B}	133.4 ± 5.4^{BC}	144.1 ± 8.2^{B}	179.3 ± 4.5^{A}
26	7	127.0 ± 6.9^{B}	89.3 ± 6.3^{C}	128.1 ± 13.9^{B}	147.9 ± 7.1^{AB}	139.9 ± 16.5^{AB}	169.2 ± 12.5^{A}
31	8	92.2 ± 5.9	95.4 ± 6.1	101.7 ± 6.5	98.7 ± 4.9	95.8 ± 3.5	96.9 ± 4.2
34	8	125.8 ± 6.5	128.7 ± 7.2	135.4 ± 9.2	125.7 ± 10.7	132.7 ± 6.4	116.2 ± 7.1
37	10	128.8 ± 5.1^{a}	136.5 ± 5.1^{a}	102.8 ± 4.1^{b}	123.9 ± 7.0^{a}	120.1 ± 6.3^{ab}	124.2 ± 7.4^{a}
		(%) of BW					
17	6	1.97 ± 0.13^{B}	1.93 ± 0.09^{B}	3.13 ± 0.12^{A}	3.27 ± 0.14^{A}	3.32 ± 0.30^{A}	3.37 ± 0.27^{A}
20	6	1.15 ± 0.05^{B}	1.07 ± 0.06^{B}	1.89 ± 0.07^{A}	1.93 ± 0.11^{A}	2.16 ± 0.11^{A}	1.89 ± 0.05^{A}
23	6	1.33 ± 0.08^{C}	1.22 ± 0.06^{C}	1.96 ± 0.13^{B}	1.94 ± 0.08^{B}	2.21 ± 0.15^{B}	2.91 ± 0.10^{A}
26	7	1.19 ± 0.06^{C}	0.91 ± 0.05^{D}	1.41 ± 0.11^{BC}	1.61 ± 0.07^{B}	1.62 ± 0.14^{B}	2.01 ± 0.16^{A}
31	8	0.82 ± 0.05	0.88 ± 0.05	0.99 ± 0.05	0.99 ± 0.05	0.96 ± 0.03	0.98 ± 0.05
34	8	1.09 ± 0.06	1.15 ± 0.06	1.25 ± 0.07	1.19 ± 0.08	1.25 ± 0.06	1.12 ± 0.05
37	10	1.18 ± 0.04	1.24 ± 0.05	1.04 ± 0.04	1.22 ± 0.07	1.16 ± 0.07	1.24 ± 0.08

$^{A\text{-}D}$ Means within a row with no common superscripts differ significantly ($P \leq 0.01$).

$^{a\text{-}b}$ Means within a row with no common superscripts differ significantly ($P \leq 0.05$).

[1] CON = Birds fed a standard commercial diet *ad libitum*; OATS = Birds fed a commercial diet through 18 wk and then oats from 19 through 26 wk; R17.0 = Birds restricted to 45% of the BW of the CON till 17.0 wk of age; R18.3 = Birds restricted to 45% of the BW of the CON till l8.3 wk of age; R19.6 = Birds restricted to 45% of the BW of the CON till 19.6 wk of age; R20.9 = Birds restricted to 45% of the BW of the CON till 20.9 wk of age.

TABLE 14. Effect of duration of body weight restriction on gizzard weight (mean ± SEM)

		Feeding regimens[1]					
Age (wk)		CON	OATS	R17.0	R18.3	R19.6	R20.9
	n	(g)					
17	6	127.9 ± 10.6	103.2 ± 8.5	117.6 ± 9.1	113.0 ± 5.9	129.1 ± 8.6	122.8 ± 10.2
20	6	113.1 ± 3.5	113.2 ± 6.5	120.9 ± 7.1	124.4 ± 6.5	118.7 ± 8.8	126.5 ± 4.2
23	6	103.0 ± 3.7^{D}	193.2 ± 5.1^{A}	112.5 ± 3.8^{CD}	123.2 ± 4.6^{BC}	126.6 ± 4.3^{BC}	138.3 ± 7.7^{B}
26	7	107.8 ± 3.9^{B}	216.9 ± 12.3^{A}	108.8 ± 5.6^{B}	109.3 ± 3.6^{B}	116.9 ± 4.8^{B}	111.5 ± 1.6^{B}
31	8	113.2 ± 4.4^{B}	130.2 ± 4.5^{A}	94.9 ± 4.3^{C}	102.2 ± 4.4^{BC}	104.3 ± 3.7^{BC}	100.3 ± 4.2^{BC}
34	8	119.7 ± 9.2	123.7 ± 5.5	99.6 ± 4.9	102.2 ± 3.6	102.2 ± 7.8	102.5 ± 9.8
37	10	114.2 ± 5.7	128.4 ± 8.0	103.5 ± 5.5	103.0 ± 7.4	116.5 ± 6.1	107.1 ± 5.5
		(%) of BW					
17	6	1.94 ± 0.25^{B}	1.42 ± 0.15^{B}	2.71 ± 0.09^{A}	2.76 ± 0.14^{A}	3.03 ± 0.25^{A}	2.96 ± 0.28^{A}
20	6	1.31 ± 0.08^{B}	1.39 ± 0.11^{B}	2.20 ± 0.13^{A}	2.42 ± 0.15^{A}	2.44 ± 0.29^{A}	2.52 ± 0.14^{A}
23	6	1.05 ± 0.02^{E}	2.16 ± 0.09^{AB}	1.54 ± 0.05^{D}	1.79 ± 0.05^{C}	1.95 ± 0.11^{BC}	2.24 ± 0.11^{A}
26	7	1.02 ± 0.05^{C}	2.22 ± 0.15^{A}	1.21 ± 0.07^{B}	1.19 ± 0.03^{BC}	1.36 ± 0.06^{B}	1.32 ± 0.04^{B}
31	8	1.00 ± 0.04^{B}	1.22 ± 0.06^{A}	0.93 ± 0.05^{B}	1.02 ± 0.05^{B}	1.05 ± 0.04^{B}	1.01 ± 0.05^{B}
34	8	1.03 ± 0.08	1.10 ± 0.05	0.92 ± 0.05	0.98 ± 0.04	0.96 ± 0.07	1.00 ± 0.10
37	10	1.06 ± 0.07	1.16 ± 0.06	1.04 ± 0.05	1.01 ± 0.06	1.16 ± 0.07	1.07 ± 0.05

$^{A-E}$ Means within a row with no common superscripts differ significantly ($P \leq 0.01$).

[1] CON = Birds fed a standard commercial diet *ad libitum*; OATS = Birds fed a commercial diet through 18 wk and then oats from 19 through 26 wk; R17.0 = Birds restricted to 45% of the BW of the CON till 17.0 wk of age; R18.3 = Birds restricted to 45% of the BW of the CON till l8.3 wk of age; R19.6 = Birds restricted to 45% of the BW of the CON till 19.6 wk of age; R20.9 = Birds restricted to 45% of the BW of the CON till 20.9 wk of age.

TABLE 15. Effect of duration of body weight restriction on whole body composition (mean ± SEM)[1]

Age (wk)	n	CON	OATS	R17.0	R18.3	R19.6	R20.9
		Feeding regimens[2]					
		% Protein					
31	8	47.65 ± 1.74	46.51 ± 1.01	46.35 ± 1.32	48.30 ± 0.90	46.71 ± 0.96	44.92 ± 1.28
34	8	45.18 ± 1.67	48.62 ± 1.49	45.36 ± 0.92	44.92 ± 0.59	46.67 ± 0.52	46.01 ± 1.15
37	10	48.18 ± 1.42	47.80 ± 1.38	49.06 ± 1.21	48.60 ± 2.02	45.73 ± 1.09	47.82 ± 1.72
		% Fat					
31	8	18.16 ± 0.80	19.26 ± 0.72	18.69 ± 0.77	19.02 ± 0.62	18.88 ± 0.45	19.50 ± 0.73
34	8	20.59 ± 1.19	18.24 ± 0.68	19.80 ± 0.70	19.23 ± 0.68	18.83 ± 0.66	19.39 ± 1.24
37	10	19.77 ± 0.92	18.97 ± 0.72	19.09 ± 0.46	19.47 ± 1.12	20.05 ± 0.82	19.89 ± 0.76
		% Ash					
31	8	6.60 ± 0.50	6.05 ± 0.46	6.03 ± 0.20	5.52 ± 0.43	5.70 ± 0.43	6.11 ± 0.29
34	8	6.86 ± 0.40	7.35 ± 0.24	6.37 ± 0.37	6.04 ± 0.27	6.17 ± 0.25	7.12 ± 0.31
37	10	6.98 ± 0.29	7.17 ± 0.39	7.32 ± 0.24	7.16 ± 0.32	7.13 ± 0.15	7.12 ± 0.20
		% Dry Matter					
31	8	45.62 ± 1.10	45.38 ± 0.83	43.92 ± 1.06	44.88 ± 0.70	45.44 ± 0.63	45.76 ± 0.59
34	8	47.53 ± 1.19	43.84 ± 0.92	46.99 ± 1.04	46.05 ± 0.67	44.83 ± 0.65	46.56 ± 1.28
37	10	45.33 ± 1.16	43.95 ± 1.14	45.85 ± 0.69	46.97 ± 1.30	45.91 ± 0.55	46.16 ± 1.13

[1] No significant differences ($P > 0.05$).

[2] CON = Birds fed a standard commercial diet *ad libitum*; OATS = Birds fed a commercial diet through 18 wk and then oats from 19 through 26 wk; R17.0 = Birds restricted to 45% of the BW of the CON till 17.0 wk of age; R18.3 = Birds restricted to 45% of the BW of the CON till l8.3 wk of age; R19.6 = Birds restricted to 45% of the BW of the CON till 19.6 wk of age; R20.9 = Birds restricted to 45% of the BW of the CON till 20.9 wk of age.

TABLE 16. Effect of prebreeder dietary protein content on abdominal fat pad weight (mean ± SEM)[1]

	Protein content[2]	
Age (wk)	15%	18%
	(g)	
31	311.15 ± 12.07	300.61 ± 12.51
34	311.19 ± 13.48	289.04 ± 12.10
37	279.22 ± 14.49	300.28 ± 11.74
	% of BW	
31	3.01 ± 0.10	2.88 ± 0.11
34	2.82 ± 0.11	2.71 ± 0.11
37	2.68 ± 0.12	2.90 ± 0.10

[1] No significant differences ($P > 0.05$).

[2] Half of the birds were fed a 15% protein diet while the other half received a 18% protein diet from 27 to 31 wk of age.

TABLE 17. Effect of prebreeder dietary protein content on breast muscle weight (mean ± SEM)[1]

	Protein content [2]	
Age (wk)	15%	18%
	(kg)	
31	2.63 ± 0.06	2.71 ± 0.08
34	2.57 ± 0.05	2.54 ± 0.06
37	2.41 ± 0.05	2.34 ± 0.05
	% of BW	
31	25.43 ± 0.42	25.87 ± 0.47
34	23.43 ± 0.32	23.81 ± 0.32
37	23.21 ± 0.33	22.91 ± 0.29

[1] No significant differences ($P > 0.05$).

[2] Half of the birds were fed a 15% protein diet while the other half received a 18% protein diet from 27 to 31 wk of age.

TABLE 18. Effect of prebreeder dietary protein content on liver weight (mean ± SEM)[1]

Age (wk)	Protein content[2] 15%	18%
	(g)	
31	95.69 ± 2.36	97.80 ± 3.41
34	127.76 ± 4.90	127.05 ± 4.21
37	124.32 ± 3.94	120.98 ± 3.66
	% of BW	
31	0.93 ± 0.03	0.94 ± 0.03
34	1.16 ± 0.04	1.19 ± 0.03
37	1.20 ± 0.04	1.17 ± 0.03

[1] No significant differences ($P > 0.05$).

[2] Half of the birds were fed a 15% protein diet while the other half received a 18% protein diet from 27 to 31 wk of age.

TABLE 19. Effect of prebreeder dietary protein content on gizzard weight (mean ± SEM)[1]

	Protein content [2]	
Age (wk)	15%	18%
	(g)	
31	109.11 ± 3.17	106.08 ± 3.48
34	114.05 ± 4.75	102.10 ± 3.59
37	114.76 ± 4.33	109.27 ± 3.37
	% of BW	
31	1.06 ± 0.03	1.02 ± 0.03
34	1.04 ± 0.04	0.96 ± 0.03
37	1.11 ± 0.04	1.06 ± 0.03

[1] No significant differences ($P > 0.05$).

[2] Half of the birds were fed a 15% protein diet while the other half received a 18% protein diet from 27 to 31 wk of age.

TABLE 20. Effect of prebreeder dietary protein content on whole body carcass composition (mean ± SEM)[1]

	Protein content [2]	
Age (wk)	15%	18%
	% Protein	
31	47.23 ± 0.77	46.31 ± 0.63
34	45.64 ± 0.60	46.64 ± 0.71
37	48.20 ± 0.85	47.53 ± 0.87
	% Fat	
31	19.01 ± 0.37	18.83 ± 0.41
34	19.96 ± 0.58	18.71 ± 0.39
37	19.38 ± 0.43	19.70 ± 0.50
	% Ash	
31	6.03 ± 0.25	5.98 ± 0.21
34	6.58 ± 0.16	6.53 ± 0.22
37	7.15 ± 0.15	7.15 ± 0.16
	% Dry Matter	
31	44.98 ± 0.48	45.35 ± 0.48
34	46.22 ± 0.61	45.65 ± 0.59
37	45.25 ± 0.63	46.14 ± 0.55

[1] No significant differences (*P* > 0.05).

[2] Half of the birds were fed a 15% protein diet while the other half received a 18% protein diet from 27 to 31 wk of age.

TABLE 21. Effect of duration of body weight restriction on shank and keel length (mean ± SEM)

Age (wk)	n	CON	OATS	R17.0	R18.3	R19.6	R20.9
		Feeding regimens[1]					
		Shank length (mm)					
17	6	132.9 ± 1.6[A]	134.2 ± 2.0[A]	126.6 ± 0.8[B]	127.2 ± 0.6[B]	125.7 ± 1.2[B]	128.9 ± 1.5[B]
20	6	132.8 ± 1.8[a]	132.9 ± 1.3[a]	129.0 ± 2.2[ab]	128.2 ± 1.2[ab]	126.1 ± 2.1[b]	131.1 ± 1.4[ab]
23	6	130.9 ± 1.3	131.7 ± 1.7	127.0 ± 1.2	129.4 ± 0.5	131.6 ± 1.1	129.4 ± 1.5
26	7	131.4 ± 0.5[b]	136.5 ± 1.2[a]	132.3 ± 1.5[b]	131.4 ± 0.4[b]	129.4 ± 2.1[b]	132.2 ± 1.4[b]
31	8	134.2 ± 1.4	130.1 ± 1.6	131.4 ± 0.9	131.4 ± 1.2	130.1 ± 0.6	130.1 ± 1.2
34	8	131.7 ± 0.9	133.0 ± 1.2	130.8 ± 1.3	127.2 ± 1.5	128.5 ± 1.4	129.1 ± 1.7
37	10	133.1 ± 1.3[A]	134.1 ± 1.3[A]	128.4 ± 0.5[B]	128.7 ± 1.2[B]	130.0 ± 0.7[B]	129.3 ± 1.5[B]
		Keel length (cm)					
17	6	15.8 ± 0.3[A]	15.8 ± 0.2[A]	13.9 ± 0.2[B]	13.9 ± 0.2[B]	13.9 ± 0.3[B]	13.8 ± 0.3[B]
20	6	16.9 ± 0.2[A]	17.1 ± 0.2[A]	15.4 ± 0.3[B]	15.4 ± 0.2[B]	14.9 ± 0.2[B]	15.1 ± 0.3[B]
23	6	17.3 ± 0.2[A]	17.0 ± 0.2[AB]	16.1 ± 0.2[DC]	16.5 ± 0.1[BC]	16.4 ± 0.1[BC]	15.6 ± 0.5[D]
26	7	17.7 ± 0.2	17.6 ± 0.1	17.2 ± 0.2	17.3 ± 0.2	17.3 ± 0.2	16.9 ± 0.3
31	8	18.2 ± 0.2[a]	17.9 ± 0.2[ab]	17.4 ± 0.2[b]	17.8 ± 0.2[ab]	17.8 ± 0.2[ab]	17.4 ± 0.2[b]
34	8	18.2 ± 0.2[A]	17.6 ± 0.1[BC]	17.6 ± 0.2[BC]	17.2 ± 0.1[C]	17.9 ± 0.1[AB]	17.4 ± 0.2[BC]
37	10	17.8 ± 0.2	17.7 ± 0.1	17.5 ± 0.2	17.5 ± 0.1	17.5 ± 0.2	17.4 ± 0.1

[A-D] Means within a row with no common superscripts differ significantly ($P \leq 0.01$).

[a-b] Means within a row with no common superscripts differ significantly ($P \leq 0.05$).

[1] CON = Birds fed a standard commercial diet *ad libitum*; OATS = Birds fed a commercial diet through 18 wk and then oats from 19 through 26 wk; R17.0 = Birds restricted to 45% of the BW of the CON till 17.0 wk of age; R18.3 = Birds restricted to 45% of the BW of the CON till l8.3 wk of age; R19.6 = Birds restricted to 45% of the BW of the CON till 19.6 wk of age; R20.9 = Birds restricted to 45% of the BW of the CON till 20.9 wk of age.

TABLE 22. Effect of prebreeder dietary protein content on shank and keel length (mean ± SEM)

	Protein content [1]	
Age (wk)	15%	18%
	Shank length (mm)	
31	132.0 ± 0.7	130.5 ± 0.7
34	130.3 ± 0.8	129.8 ± 0.9
37	131.6 ± 0.7[a]	129.6 ± 0.8[b]
	Keel length (cm)	
31	17.7 ± 0.1	17.7 ± 0.1
34	17.7 ± 0.1	17.6 ± 0.1
37	17.5 ± 0.1	17.6 ± 0.1

[a,b] Means within a row with no common superscripts differ significantly ($P \leq 0.05$).

[1] Half of the birds were fed a 15% protein diet while the other half received a 18% protein diet from 27 to 31 wk of age.

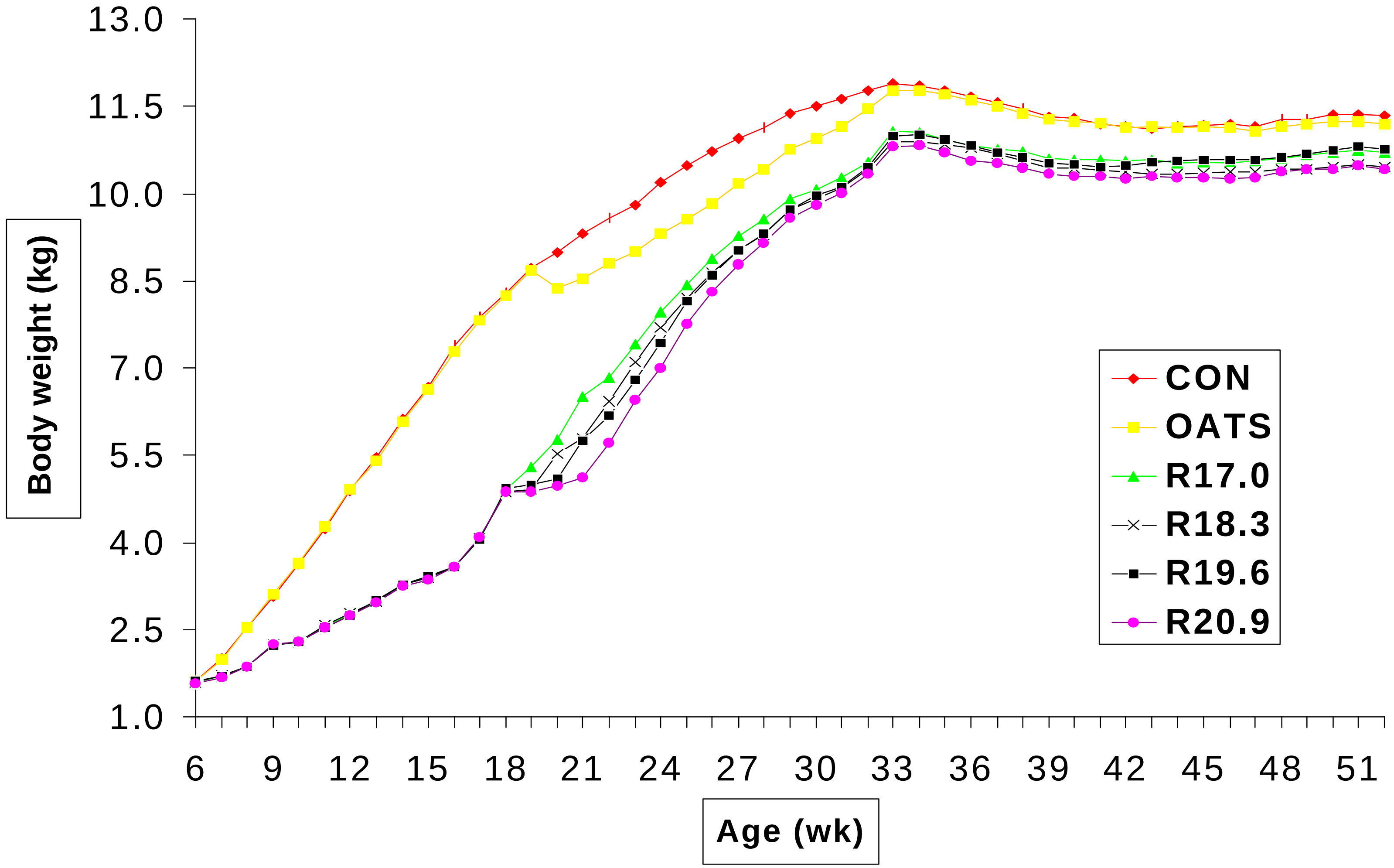

Figure 1. Body weights of turkey breeder hens either fed *ad libitum* or restricted to 45% of the body weight of the full-fed control at 16 wk of age and maintained on restriction until either 17.0, 18.3, 19.6, or 20.9 wk of age

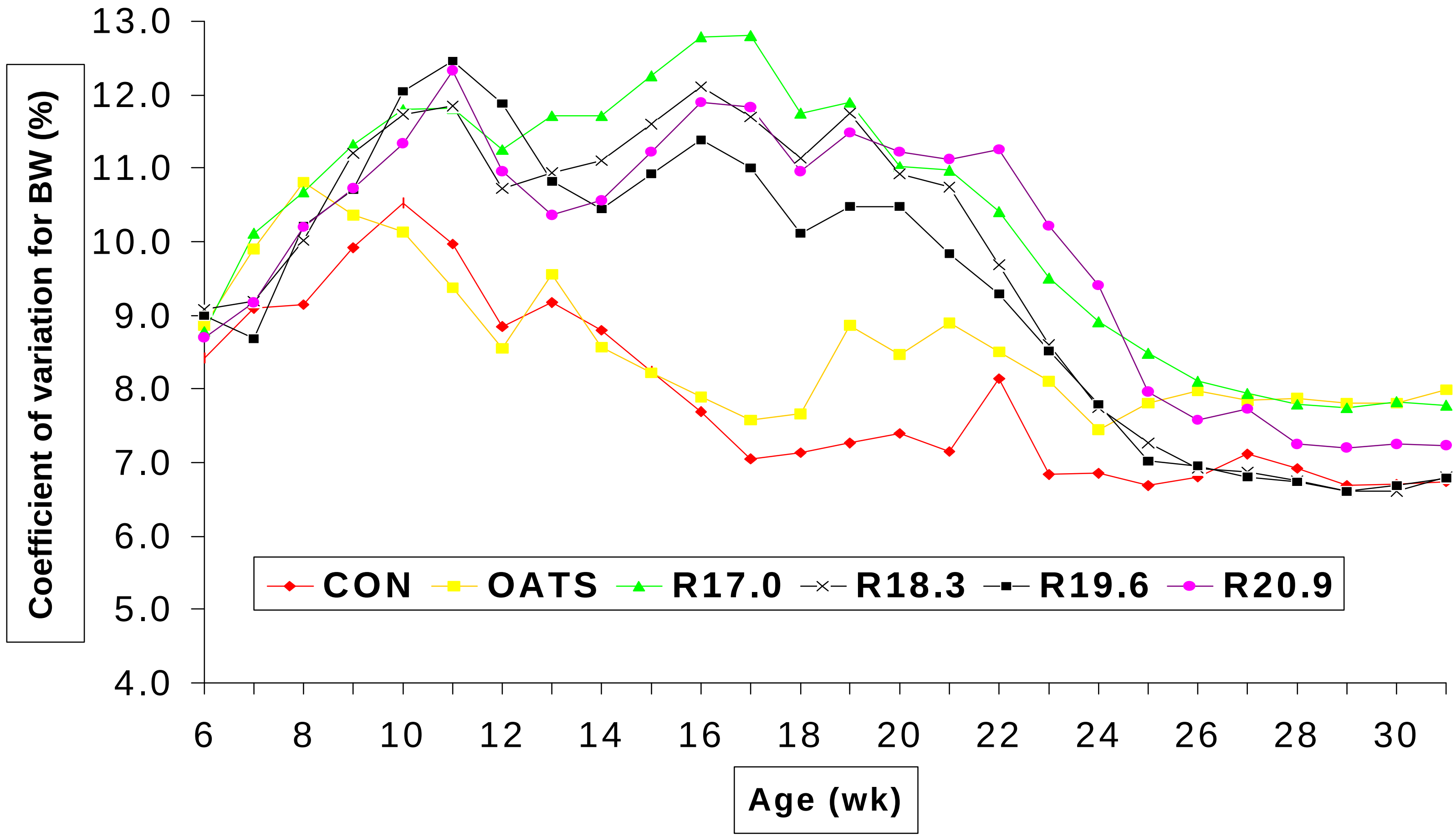

Figure 2. Coefficient of variation for body weight of turkey breeder hens either fed *ad libitum* or restricted to 45% of t body weight of the full-fed control at 16 wk of age and maintained on restriction until either 17.0, 18.3, 19.6, or 20.9 wk of

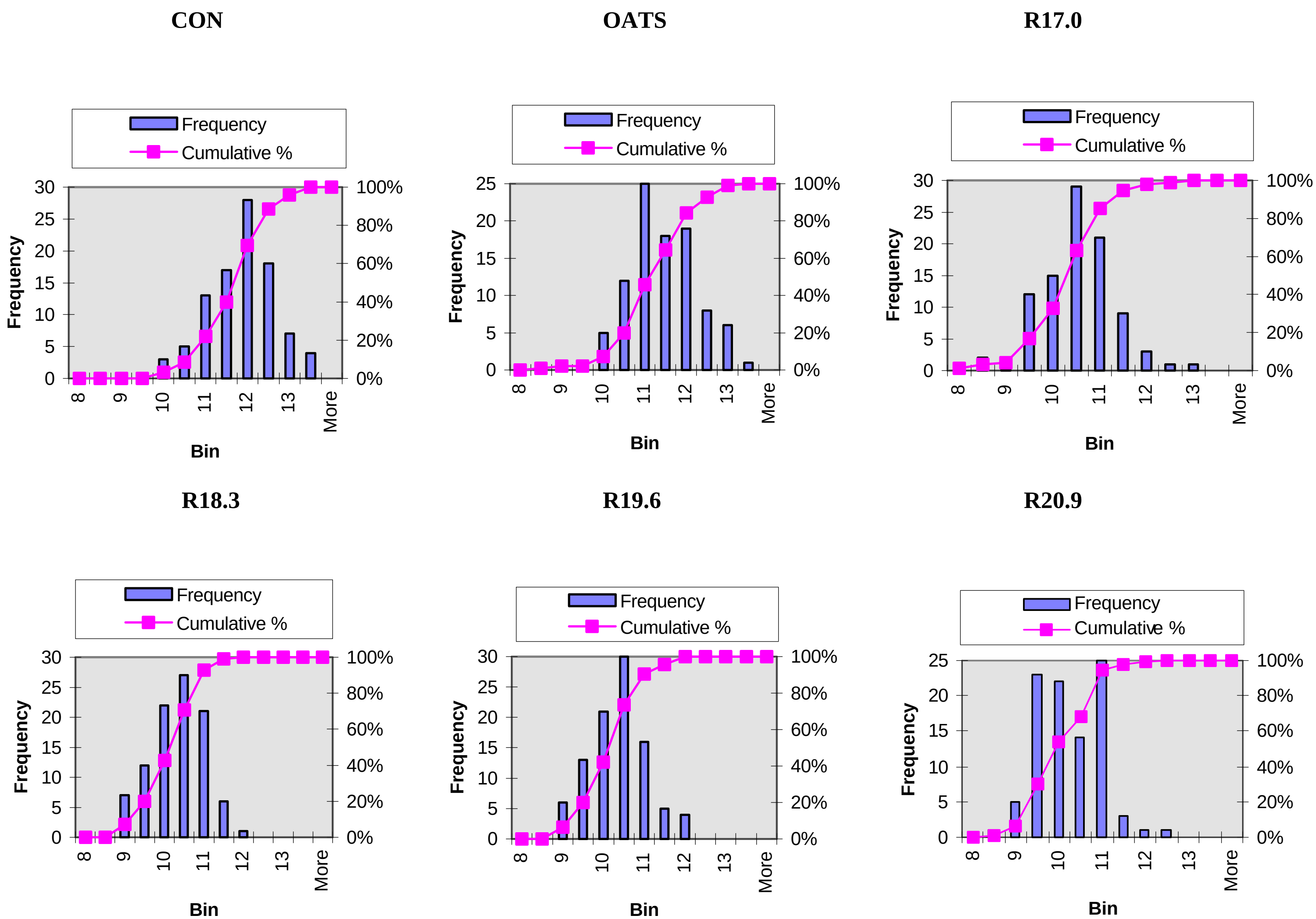

Figure 3. Histogram for body weight distribution of turkey breeder hens at 31 wk of age either fed *ad libitum* or restricted to 45% of the body weight of the full-fed control (CON) at 16 wk of age and maintained on restriction until either 17.0 (R17.0), 18.3 (R18.3), 19.6 (R19.6), or 20.9 (R20.9) wk of age. Plain white oats were fed from 19 through 26 wk of age (OATS).

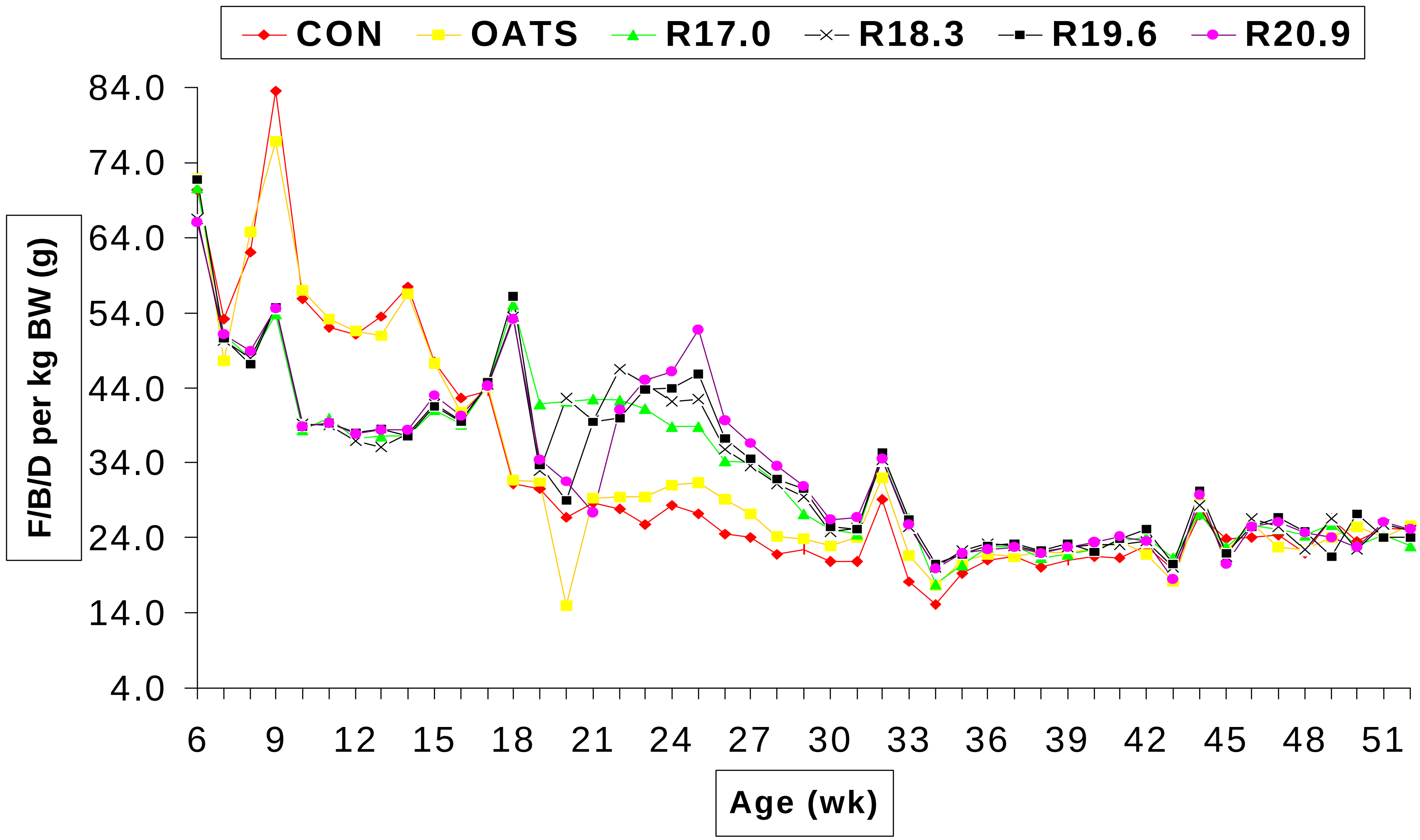

Figure 4. Feed consumption in feed per bird per day per kg body weight for turkey breeder hens either fed *ad libitum* or restricted to 45% of the body weight of the full-fed control at 16 wk of age and maintained on restriction until either 17.0, 18.3, 19.6, or 20.9 wk of age

CHAPTER II

Effect of Duration of Feed Restriction and Prebreeder Protein Content of Feed on Reproductive Performance of Commercial Large White Turkey Breeder Hens

ABSTRACT

The effect of duration of feed restriction and dietary prebreeder protein content on subsequent reproductive performance of commercial Large White Nicholas turkey breeder hens was investigated. The treatments were as follows: a) a control group fed standard commercial diets for *ad libitum* consumption (CON); b) a second group like (a) but fed plain white oats from 19 through 26 wk (OATS). In contrast, the four remaining treatments groups were feed restricted from 6 wk of age (WOA) to achieve body weights 45% less than the full-fed CON at 16 WOA. This level of restriction was maintained until either 17.0 (R17.0), 18.3 (R18.3), 19.6 (R19.6), or 20.9 (R20.9) WOA. Thereafter, feed allocations were gradually increased attempting to raise BW to a predetermined target of 10.8 kg at photostimulation. A protein treatment (18 *versus* 15%) was superimposed from 27 to 31 WOA. Total egg production did not differ significantly among treatments. The R18.3 treatment obtained the highest peak production ($P < 0.05$). However, all four restriction treatments demonstrated low laying persistency. Duration of restriction did not significantly reduce the number of large yellow follicles. Proportions of multiple follicle sets increased as prebreeder protein level increased. Restriction treatments did not affect initial egg weight, specific gravity, egg weight loss, shell conductance, fertility, or hatchability, but poult weight was significantly reduced. In conclusion, feed restriction improved peak egg production, but persistency was low. Prebreeder protein level may affect follicular proliferation. Oat feeding was the simplest feeding method and gave equivalent reproductive performance.

(*Key words*: turkey breeder hens, feed restriction, reproductive performance, egg production, poult quality

INTRODUCTION

Improvements in BW and conformation of commercial broiler and turkey populations have been extensive (Buss, 1989). Progress, however, has not been without substantial losses in reproductive fitness (McCartney *et al.*, 1968; Nestor, 1985). Genetic selection for growth in meat-type poultry is associated with poor egg production (Siegel and Dunnington, 1985) attributed to the negative correlation between egg production and BW (Cook *et al*., 1962; Clayton, 1971; Nestor, 1971; Arthur and Abplanalp, 1975; Nestor *et al*., 1980; Anthony *et al*., 1991; Nestor and Noble, 1995).

Inheritance which favors rapid protein anabolism also favors rapid formation and deposition of an ovarian follicular precursor lipoprotein (Jaap, 1969). Increased synthesis of lipoprotein in the liver leads to an increase in number and size of ovarian follicles in broiler breeders (Van Middelkoop, 1971; Zelenka *et al*., 1986; Yu *et al*., 1992), turkeys (Nestor *et al*., 1970; 1980; Bacon *et al*.,1972; Hocking 1992a,b), and ducks (Hocking, 1990). As a result, multiple hierarchies with two or more follicles of similar size develop, culminating in multiple ovulations, erratic ovipositions, and defective eggs with inferior egg shell quality (Hocking *et al*., 1987; Decuypere *et al*., 1994). Jaap and Muir (1968) were among the first to summarize these deleterious effects in a condition known as erratic oviposition and defective egg syndrome (EODES). However, research has shown that this apparent disturbance in harmony between ovarian and oviduct function (Jaap, 1969) can be restored, within limits, through the implementation of feed restriction programs in broiler breeders (Hocking *et al*., 1987; Hocking, 1994a). These programs are designed to manipulate the bird's inherent genotype to make her act more like a well synchronized, well performing egg-type chicken (Robinson *et al*., 1993a).

The reproductive lifespan of broiler breeders that have been diet-restricted is longer and more productive than that of hens fed *ad libitum* (Iqbal *et al*., 1997). Broiler breeders are routinely feed restricted beginning at an early age and often throughout the entire breeding period (Costa, 1981) to prevent or manage the problems associated with increased appetite and propensity for obesity in these birds (Siegel and Dunnington, 1985; Renema *et al*., 1994). Feed restriction has been shown to improve egg production, fertility and hatchability in broiler breeders (Costa, 1981; Wilson and Harms, 1986; Yu *et al*., 1992; Robinson *et al*., 1993a).

In turkeys, results of body weight restriction on reproduction are often more variable and less conclusive (Hester and Stevens, 1990; Renema *et al*., 1994; Crouch *et al*., 1997). Although some restriction programs have improved egg production in the past (Balloun, 1974; McCartney *et al*., 1977; Miles and Leeson, 1990), the vast majority of studies have either shown no beneficial effects (Potter and Leighton, 1973; Voitle and Harms, 1978; Owings and Sell, 1980; Ferket and Moran, 1986; Renema *et al*., 1995) or significantly impaired reproduction (Touchburn *et al*., 1968, Jones *et al*., 1976; Krueger *et al*., 1978).

Recently, Renema *et al*. (1995) used Hybrid male-line turkey breeder hens that are selected almost exclusively for growth characteristics as a model to study the physiological effects of feed restriction. Results indicated that restrictions in BW of 10 or 20% did not significantly affect egg production. In contrast, Hocking (1992a) showed significant improvements in settable egg production and hatchability in a small strain of caged BUT turkeys using a severe (40%) feed restriction program until point of lay. The author concluded that only drastic BW reductions were able to synchronize ovarian and oviduct function. Klein-Hessling (1994) implemented BW reductions of 15, 30, or 45% at 16 WOA upon which all treatments were gradually returned to *ad libitum* consumption prior to egg production. Only a BW reduction of 45% at 16 WOA was able to bring about significant improvements in egg production and hatchability. The improvements in egg production were, however, not associated with a significant reduction in large (> 10 mm in diameter) yellow follicles as postulated by Hocking (1992a). Subsequently, Klein-Hessling *et al*. (1995) outlined crucial elements in the development of a successful feed restriction program for turkeys. If restriction is too severe, and is continued too near the time of photostimulation, reproductive performance will be impaired. In addition, there is an interaction between feed restriction and time of year (Crouch *et al*., 1997) and changes in the feeding program pointing towards the necessity of establishing a minimum target BW for photostimulation have to be made accordingly.

In the past, commercial turkey nutritionists have historically fed prebreeder diets with a protein content ranging from 10-17% (Halloran and Wilgus, 1982). This wide variation indicates the lack of real solid direction for feeding breeder replacements and the lack of monitoring the effects of growth rate on subsequent egg production (Hulet *et al*., 1993). Data concerning the effect of dietary protein on BW gain during the last few wk prior to photostimulation and on subsequent reproductive performance of severely restricted modern turkey breeder hens is scarce. Noll *et al*. (1993) reported significantly improved egg production when a 18% protein diet was fed from 28 to 33 or following 30 WOA. Conversely, in *ad libitum* fed breeders, different levels of prebreeder protein did not affect BW, feed consumption, body composition, egg production, fertility or hatchability (Grimes *et al*., 1989). These results are in accordance with the reports by Mitchell *et al*. (1962), Voitle *et al*. (1973), and Cherms *et al*. (1976), while Meyer *et al*. (1980) reported beneficial effects when the protein content was increased.

The present study investigates the effect of length of time of restriction during the growing and holding period on subsequent reproductive performance of commercial Large White turkey breeder hens. In addition, the influence of dietary prebreeder protein content was also studied.

MATERIALS AND METHODS

Stock and Husbandry

Day old Nicholas Turkey poults (Line 700) were raised following commercial standard practices until 6 WOA. Feed and water were provided for *ad libitum* consumption. At this time, birds were wing-banded and randomly assigned to one of 36 floor pens with 20 birds each. Details on diet ingredients, diet composition and a sequential outline of the diets used in each treatment is shown previously (Table 1 and 2, Chapter I). All poults were provided continuous light on Day 1. Subsequently, the photoperiod was gradually reduced to 14 h of light (L):10 h darkness (D) at 2 WOA and remained unchanged until 17 WOA. At 18, 22, and 26 WOA, the day length was reduced to 8L:16D, 7L:17D, and 6L:18D, respectively. The breeder flock was moved into a laying house at 31 WOA on January 23, 1996. Each pen was approximately 4.0 m x 3.6 m in size and contained four nest boxes to accommodate 12 birds. Birds were initially exposed to a 13.5L:10.5D photoperiod at 31WOA which was increased to 14L:10D at first egg, and extended to 15L:9D at peak egg production. Additional increments of stimulatory light were added in the morning (15 min every two wk) until a 17.5L:6.5D photoperiod was reached at the end of the study.

During the laying period feed and water were available *ad libitum*. Hens were artificially inseminated (AI) with semen from feed restricted Nicholas males. Semen was obtained by applying the massage technique as described by Burrows and Quinn (1939). After the pooled semen sample had been macroscopically examined for contamination, all hens were inseminated within 1 h after semen collection. The first and second AI were performed on day 14 and 17 post photostimulation (McIntyre *et al*., 1982). Thereafter, AI was continued on a weekly basis in the late afternoon. Eggs were collected at least 7 times a day and then stored and accumulated in an egg cooler at approximately 13 C and 75 % relative humidity until setting occurred. Hens that showed behavioral signs of broodiness or were difficult to inseminate were placed in broody coops (120 cm x 76 cm; wired floor; standing 70 cm above the ground) for three consecutive days and then returned to the pen. Eggs from a production week (Monday-Sunday) were set on following Monday afternoon in commercial Natureform Incubators (Jacksonville, FL 322181) and pedigree hatched. After 24 days of incubation at 37.5 C and approximately 60% relative humidity, eggs were transferred into a hatcher operating at 37.2 C and approximately 70% relative humidity. Eggs that failed to hatch were broken open and macroscopically examined to determine true fertility and stage of embryonic development at death. A total of seven different categories, derived from Phillips and Williams (1944) were used to summarize the breakouts. The definitions were as follows:

1) Early dead (ED): d 1-2; development stops before blood formation
2) Week 1 (W1): d 3-7; blood islands form, fully pigmented eyes
3) Week 2 (W2): d 8-14; legs differentiate into limb parts, plumage visible and covers all parts of body
4) Week 3 (W3): d 15-21; toe nail visible, eyes closed, down partially pigmented
5) Week 4 (W4): d 22-25; nostrils appear open, down elongates and thickens and becomes fully pigmented, fluid absorbed and shoulder up, tucking position 3/4 of yolk sac inside, down is yellow
6) Int. pip (IP): d 26; yolk sac inside body, beak penetrates air cell
7) Ext. pip (EP): d 27; embryo breaks shell but not yet hatched

Experimental Procedures

The experimental treatments were initiated at 6 WOA by dividing all hens equally among six grower feeding regimens. The first two treatment groups served as controls and were as follows: a) a control group fed standard commercial diets for *ad libitum* consumption (CON); b) a second control group that was fed standard commercial diets through 18 wk, followed by plain white oats from 19 through 26 WOA (OATS) and then the same standard commercial diet for *ad libitum* consumption as in the CON until photostimulation. In contrast, the 4 remaining grower treatment groups were physically feed restricted on a skip-a-day basis beginning at 6 WOA in order to achieve body weights 45% less than the full-fed CON group at 16 WOA. These birds remained feed restricted until either 17.0 (R17.0), 18.3 (R18.3), 19.6 (R19.6), or 20.9 (R20.9) WOA. After these ages, feed allocations in the restriction treatments were gradually increased in order to increase BW to a predetermined minimum target of 10.8 kg at photostimulation. At 27 WOA, an additional dietary protein treatment was superimposed on the previous treatments. Half of the birds were fed a 15% protein diet, while the other half received an 18% protein diet. The composition of the diets is shown elsewhere (Chapter I).

Measurements

Eight randomly selected birds were sacrificed at photostimulation (31 WOA) and at first egg (34 WOA) followed by 10 birds per treatment at peak egg production (37 WOA). The abdominal cavity was opened and the weight of the ovary and oviduct was recorded. The data were expressed on an absolute as well as on a percentage of BW basis. The same birds were used to study ovarian follicular development. Large yellow follicles (> 10 mm in diameter) from each hen were sorted by size into groups of follicles differing by less than 1 g in weight or 1 mm in diameter to assess the potential for multiple ovulations by calculating the proportion of multiple follicle sets for each hen and treatment (Hocking, 1992a,b; Renema *et al.*, 1994).

Laying records were kept throughout the 20 wk production cycle. Data were calculated for percentage hen-housed production, total number of eggs produced per hen, as well as hen-day production. The proportion of broody and/or out of production hens were calculated weekly for each treatment. Eggs were classified as either settable eggs (> 75g and good shell quality) or as eggs not suitable for incubation. Nonsettable eggs included double yolked, misshaped, cracked, or soft shelled eggs.

Percentage egg weight loss (Christensen and McCorcle, 1982), shell conductance (Tulett, 1981), and conductance constant (Ar and Rahn, 1987) were determined each wk based on three randomly selected eggs per pen. Egg component characteristics were determined bi-weekly for albumen, yolk and shell weight (including membrane) on a wet and dry weight basis for effects of feeding regimen only. All eggs laid on Tuesdays and Wednesdays were used to determine average egg specific gravity (Voisey and Hamilton, 1977; Hamilton, 1982) and individual egg weights.

True fertility, hatchability, and viability were determined based on residue break-outs after each hatch was pulled. Hatchability was defined as the number of successful hatches obtained from the total number of eggs that were set. In contrast, viability was defined as the number of live poults obtained from the total number of fertile eggs. Classification of embryonic mortality was expressed as proportion of eggs that did not hatch. The weight of three poults from each pen was recorded immediately after hatch to determine average poult weight. Blood glucose concentrations were measured at hatch with a glucometer (ACCU-Chek II, Boehringer Mannheim Diagnostics, Indianapolis, IN 46250) as described by Christensen *et al*. (1991).

Statistical Analysis

The data were subjected to analysis of variance using General Linear Models procedures (SAS Institute, 1988). There were six feeding regimens (first independent variable) and two dietary treatments (second independent variable). Tests for significance were made for the main effects and the corresponding interaction. The experimental unit was the pen. Average number of settable eggs per breeder hen and percentage hen housed production were analyzed at five wk intervals. All percentage data were transformed using an arc sine square root transformation prior to analysis. The differences among main effect means for treatments were partitioned using Duncan's multiple range test. Statements of statistical significance were based upon $P \leq 0.05$ unless otherwise stated.

RESULTS AND DISCUSSION

Table 1 shows the effect of duration of restriction and prebreeder protein content on oviduct weight. There were no significant differences at either first egg or at peak production. This is in agreement with Renema *et al*. (1995) who restricted male-line hens to either 80 or 90 % of the BW of a full-fed control until point of lay. In contrast, Melnychuk *et al*.(1997) studied the degree of synchronous ovary and oviduct development at the time of photostimulation between male- and female-line turkey hens. While the oviduct of female-line birds reached maturity 3 d before the ovary, they matured simultaneously in male-line hens. This lack of synchronization could contribute to a loss in egg production early in lay (Van Middelkoop, 1971; Hocking *et al*., 1987; Hocking, 1993; Decuypere *et al*., 1994). Increasing the dietary protein content from 15 to 18% did not significantly hasten oviduct proliferation at either of the two sampling times whether expressed in g or as proportion of BW (Table 1).

Assessment on ovarian development began at the time of photostimulation. Follicular proliferation, as indicated by growth of yellow follicles, was barely detectable at photostimulation. The ovaries were still very small with an average weight of approximately 4.2 g across feeding regimens (Table 2). There was no effect of feed restriction on ovary weight at 31, 34, or 37 WOA, and adding 3 % dietary protein to the diet did not alter this response (Table 2). However, there was a significant duration of restriction x dietary protein interaction at 34 WOA (Table 3). When birds were fed the 18% protein diet, the ovary associated with the R17.0 treatment was significantly smaller than ovaries from any other treatment. This response was not seen when the 15 % protein diet was fed. Average ovary weight across feeding regimens was highest at the time of first egg (181.8 g) and declined at the time of peak egg production (169.2 g). This response is in agreement with previous reports (Renema *et al*., 1995; Melnychuk *et al*., 1997).

Table 4 shows the effect of feed restriction and prebreeder dietary protein on the number of large yellow follicles and the proportion of multiple follicle sets. Feed restriction in meat-type poultry improves egg production by reducing the number of large yellow follicles and the proportion of multiple follicle sets, culminating in an improvement of settable egg production (Hocking *et al*., 1987; Katanbaf *et al*., 1989; Hocking, 1992a,b; Robinson *et al*., 1993a). While there was no significant main effect for length of time of restriction on the number of follicles at either 34 or 37 WOA, there was a significant duration of restriction x dietary protein interaction at 34 WOA (Table 5). Among birds fed the 15% protein diet, the CON group had significantly more large yellow follicles than the hens in the R18.3 and R19.6 treatment. No significant differences existed among feeding regimens at the 18% protein level. The follicle number decreased with increasing age of the hen. These results agree with Klein-Hessling (1994) using BUT hens restricted to either 15, 30, or 45% of the BW of the *ad libitum* fed hens at 16 WOA. The R20.9 treatment had significantly more multiple follicle sets than the CON and the R17.0 group at 34 WOA (Table 4). Overall, the proportion of multiple follicle groups declined as the laying cycle progressed and, thus, this observation is in agreement with the effect of hen age on number of large yellow follicles.

Numerous reports have argued that a linear relationship exists between BW and the number of large yellow follicles at first egg when feed restriction is continued until point of lay, (Hocking, 1990, 1992a,b, 1994a,b; Hocking and Whitehead, 1990; Hocking *et al*., 1992). This relationship was derived from a broiler breeder study suggesting that when feed restriction was terminated before 14 WOA, then there was no effect on the number of large yellow follicles at the time of photostimulation (Hocking *et al*., 1989). Renema *et al*. (1995) restricted male-line turkey hens to either 80 or 90% of the BW of control hens until point of lay. The number of large yellow follicles as well as the proportion of multiple follicle groups was not significantly different among treatments at sexual maturity. Hocking (1992a, 1994a,b) suggested that restrictions had to be substantial to reduce follicle number and the response was more effective in smaller strains. Maximum egg production in turkeys is achieved when the ovary does not have more than nine or 10 large yellow follicles at the same time (Hocking *et al*., 1987). The necessary BW for a male-line hen to achieve this follicle number was predicted to be not more than 6.8 kg at photostimulation (Hocking, 1992b). In practical terms, this is would be equivalent to a BW reduction of approximately 40% of the weight of an *ad libitum* fed control at the time of lighting. Based on observations made in our own trial, it is highly unlikely that these birds will lay with any persistency after such a severe restriction.

Initial studies on feed restriction of broiler breeders (Hocking *et al*., 1989), turkeys (Hocking, 1992a,b), and ducks (Hocking, 1990) were confounded by degree of restriction, length of time of restriction, BW at first egg, and feed intake. Later, Hocking (1993) conducted a study in broiler breeders to delineated these relationships. The results showed that there was no effect of age at restriction (15 to 18 compared with 19 to 22 WOA) on the number of large yellow follicles, contradicting earlier conclusions (Hocking, 1993). Furthermore, strains with larger BW had more follicles than strains with smaller BW when exposed to the same degree of restriction, thus confirming the effect of BW on follicle count reported in previous studies. In treatments with birds of similar BW and different feed intake, those with the higher feed intake had a larger number of yellow follicles. The conclusion was later substantiated in other studies as well (Robinson *et al*.,1993b; Hocking, 1994a,b). Finally, the analysis confirmed previous observations indicating that fatness independent of body weight was not associated with the number of large ovarian follicles (Hocking *et al*., 1987, 1989; Hocking, 1990, 1992a,b; Renema *et al*., 1995) and, therefore, fatness does not explain why feed restriction improves egg production in turkeys and broiler breeders (Hocking, 1994a).

The results from the present study with regard to the number of large yellow follicles and the proportions of multiple follicles seem to be in full agreement with the conclusions drawn by Hocking (1993, 1994a,b). For example, the birds in the four quantitative restriction treatments weighed almost 1.5 kg less at photostimulation than the full-fed CON, yet they did not have a significantly lower follicle count at first egg or peak production. All birds in the quantitative restriction treatments had more feed available on a per kg BW basis than the CON (Chapter 1) . A significant reduction in follicle number in this study as well as in a previous study (Klein-Hessling, 1994) did not occur because the effect of reduced BW on follicle number was compensated by a significantly higher feed intake of the restricted hens at the same time.

An increase in prebreeder protein content was not associated with an increase in number of large yellow follicles (Table 4). However, the 18% crude protein diet caused a significant increase in the proportion of multiple follicle sets at 37 WOA. This is the first report indicating that follicular proliferation can be influenced by dietary protein.

Table 6 shows the influence of duration of restriction and prebreeder dietary protein content on percent floor and defective egg production. The proportion of floor eggs in this study was very high and varied between 23 and 38%. No efforts were made to train the hens to use the nests at the beginning of the laying cycle. Body weight restriction during the prebreeder period had no significant effects on these measurements. This is in agreement with Renema *et al*.(1995) for total number of nonsettable eggs but disagrees with numerous other studies in turkeys

(Hocking *et al*., 1988; Hocking, 1992a,b; Hocking *et al*., 1992) and broiler breeders (Van Middelkoop, 1971; Whitehead and Hocking, 1988; Yu *et al*., 1992; Robinson *et al*., 1993a,b).

Feeding an 18 % crude protein diet from 27-31 WOA decreased percentage misshaped eggs compared to birds provided 15 % crude protein. There was a significant duration of restriction x dietary protein interaction for the proportion of double yolked eggs (Table 7). While duration of BW restriction generally had no effect in birds provided the 18% crude protein, restriction increased the number of double-yolked eggs in the R18.3 and the R19.6 treatment at the 15% crude protein level. However, the number of double-yolked eggs in this study accounted for only a very small proportion of eggs laid.

The number of settable eggs and hen-housed egg production during a 20 wk laying cycle was not affected by body weight restriction or dietary protein (Table 8). When production was analyzed by wk, the R18.3 treatment had a significantly higher peak production during the second and third wk of lay (Figure 1). Similarly, this treatment obtained the highest production during the first 10 wk of lay ($P < 0.06$). The higher peak production of the R18.3 treatment closely resembled the results from a previous trial in which hens restricted to 45 % at 16 WOA performed significantly better than birds under less severe restrictions (Klein-Hessling, 1994). This observation has been confirmed by Hocking *et al*. (1994), Crouch *et al*. (1997) and recently in field trials by Douglas and Wojcinski (1997). Essentially the same results were obtained for percentage hen-housed production (Table 8). The CON, OATS, R17.0, R18.3, R19.6, and R20.9 treatment averaged 61.4, 66.5, 66.0, 66.2, 58.0, and 61.4 % egg production, respectively. Increasing the dietary protein content from 15 to 18 % did not affect egg production (Table 9). Average settable egg production for the 15 and 18 % protein diet amounted to 89.0 and 88.1 eggs per bird, respectively and there was no interaction for this variable. According to Meyer *et al*. (1980) egg production increased with increased prebreeder protein level until the diets contained 14 % protein. No further increase in egg production resulted from a 17 % protein prebreeder diet. However, Noll *et al*. (1993) reported significantly improved egg production when a 18 % protein diet was fed from 28 to 33 or following 30 WOA. Similarly, work with broiler breeders has also indicated positive responses to higher prebreeder protein diets (Cave, 1984; Brake *et al*., 1985).

During the latter part of the second half of the production cycle all four quantitative restriction treatments and the CON were unable to sustain high levels of egg production (Figure 1). This was particularly pronounced in the R19.6 and the R20.9 groups, while the birds on oats demonstrated superior persistency. After 20 wk of lay, production for this treatment was still at a remarkable rate of 60.4 %. The drop in egg production in the quantitatively restricted groups was related to the occurrence of broodiness and "out-of-lay" breeder hens over time (Figure 2). The low performance of the severely restricted hens of the R20.9 treatment was caused by a significant (wk 19 and 20) increase in broody and out-of-lay hens during the second part of the laying cycle. After 20 wk of production, 3.7, 7.4, 19.2, 20.0, 18.7, and 27.8 % of the birds in the CON, OATS, R17.0, R18.3, R19.6, and the R20.9 treatment were out of production. However, the relationships reversed for the quantitative restriction treatments when egg production was presented on a hen-day basis, except for the R19.6 treatment (Figure 3). The R18.3 treatment had a significantly higher hen-day egg production from 1through 5 and from 1 through 10 wk of lay than the *ad libitum* fed control. Although percent hen-housed egg production was significantly lower for the R20.9 treatment, it was statistically not discernible on a percent hen-day basis. The superior persistency of the OATS treatment was unexpected. Whether this response is a consequence of oat feeding *per se*, proper BW, or BW gain prior to photostimulation, and/or a combination of the these factors is currently still elusive. There is, however, strong evidence in the field that a certain BW must be obtained prior to photostimulation to support long term egg production (Hulet *et al*., 1993; Crouch *et al*., 1997). The effect of protein on broody and out-of-lay breeder hens was not significant (6.1 versus 5.9%).

According to Whitehead (1989), the principles involved in turkey prebreeder nutrition differ considerably from those in broiler breeders. *Ad libitum* fed commercial Large White turkey breeder hens show a characteristic decrease in feed consumption commencing during the black-out period (Hocking, 1992b; Klein-Hessling, 1994; Krueger, 1996; Chapter 1). From this time on, feed intake will not recover until after peak egg production. Similarly, BW decreases as soon as egg production begins (Cherms *et al.*, 1976; Krueger, 1982; Lilburn and Nestor, 1993). It has proved to be very difficult to encourage even restricted turkeys to increase feed consumption by nutritional means during this period (Whitehead, 1989). In contrast, previous research suggested that turkey diets for *ad libitum* fed hens should be designed to produce and maintain a heavier BW at least 2 wk prior to the onset of egg production to assure sufficient accumulation of body reserves to sustain egg production (Krueger, 1980; Waibel, 1981; Robel, 1984). However, no evidence exists to prove that BW maintenance, by itself, could maintain egg production (Hulet *et al*., 1993). Similarly, the fact that even good producing turkey hens will lose BW seems to indicate that maintenance of BW is not the primary stimulus for maintaining egg production, but rather a normal physiological response in egg producing turkeys (Whitehead, 1989). Nonetheless, based on the present data, it appears that there is a minimum threshold BW below which breeder hens are unable to sustain egg production.

Marther and Harms (1982) grouped turkey laying hens according to daily food intake into high intake or low intake treatments. They found no significant differences in egg production although the amount of protein, sulfur amino acids, lysine, phosphorus, calcium, and metabolizable energy consumed differed significantly. Likewise, Cherms *et al*. (1976) reported no significant improvements in egg production when daily intake of protein was increased from 35 to 50 g. In the past, nutritionists have fed prebreeder diets with protein contents ranging between 10 and 17 % (Halloran and Wilgus, 1982). This wide variation indicates that the nutritional needs for feeding breeder replacements are not well defined. In addition, research has yet to determine the effect of growth rate on egg production (Hulet *et al*., 1993). In fact, knowledge about the optimum BW at photostimulation in *ad libitum* and, certainly, in feed restricted turkey breeder hens is virtually non existent. Whitehead (1989) suggested marginally lower point-of-lay BW's in *ad libitum* fed breeder hens have not generally been associated with poorer reproductive performance. Similarly, correlation coefficients between egg numbers and BW at 33 or 43 WOA or the weight loss between 33 and 43 WOA were not significant (Herron and Whitehead, 1985). Taken together, it seems plausible that there may be a threshold for BW gain for initiation of persistent egg production but also a threshold for BW loss during production. Within limits, this BW loss may be part of a normal physiological response in turkeys but beyond a threshold weight loss, egg production may be severely compromised or even cease completely.

Table 10 presents the effect of feeding regimen and prebreeder dietary protein content on average egg weight. No significant feeding regimen effects were found for average egg weight over the 20 wk production period. The result confirms previous observations (Klein-Hessling, 1994; Crouch *et al*., 1997; Douglas and Wojcinski, 1997), but is inconsistent with the observations made by Hocking (1992a) and Renema *et al*. (1995) who reported significantly reduced egg weights for birds either fed low protein or hens that were restricted to 80% of the BW of the full-fed control.

Eggs from restricted hens during the first two wk of the laying cycle were not significantly smaller than those from their full-fed counter parts (Figure 4). Average egg weight across all six feeding regimens was approximately 92 g per egg. Egg weight increased with hen age ($P < .001$) which is in agreement with numerous other studies (Lerner *et al*., 1993; Reidy *et al*., 1994; Applegate and Lilburn, 1996). Dietary protein did not affect egg weight (Table 10) and there were no significant interactions. Similar results were reported by Meyer *et al*. (1980) and Noll *et al*. (1993).

Body weight restriction and prebreeder dietary protein level had no effect on egg quality (Table 10), thus confirming the results by Meyer *et al*. (1980). In contrast, Klein-Hessling (1994) and Renema *et al*. (1995) reported significantly improved specific gravity for eggs from restricted hens. Egg shell conductance was similar to those shown by Christensen *et al*. (1993) who reported that turkeys specifically selected for growth (F-line) had an eggshell conductance of 20 mg H_20/day per mm Hg and a conductance constant of 6.1. Similarly, egg weight loss as a proportion of initial egg weight averaged 10.4% from zero to 24 days of incubation which is in agreement with other studies (Christensen and McCorkle, 1982; French, 1993; Lerner *et al*., 1993). These results suggest that feed restriction does not alter the functional properties of the egg shell, nor adversely affect essential gas exchange, or embryonic metabolism.

Fertility and hatchability were not affected by BW restriction or dietary protein level (Table 11). True fertility averaged approximately 97% across feeding regimens. Mean hatchability and viability amounted to approximately 80 and 83%, respectively. There were no interactions. Similar results were found by Grimes *et al*. (1989) and Noll *et al*. (1993). Fertility has generally not been affected by restriction treatments (Hester and Stevens, 1990). However, the results with respect to hatchability differ from those obtained in a previous trial (Klein-Hessling, 1994) as well as those reported by Hocking (1992a). Both studies used BUT breeding stock and indicated significantly better hatchability for eggs laid by feed restricted dams. In contrast, Ferket and Moran (1986), Owings and Sell (1980), and Krueger *et al*. (1978) were not able to detect improvements in hatchability.

Assessment of poult quality is of utmost importance in validating major changes in breeder management systems. Blood glucose levels were not affected by treatments in the present experiment (Table 11). In contrast, Christensen and Krueger (1993) reported significantly increased blood glucose levels in poults from restricted dams at hatching as well as between strains of turkeys. With the exception of the R18.3 treatment group, poult weight was not affected by BW restriction or dietary protein level (Table 11; Figure 5). Mortality by age of embryonic development was not influenced by either BW restriction or dietary protein content (Table 12). The result contradicts with a previous trial on restriction (Klein-Hessling, 1994). Embryos from restricted BUT dams had significantly lower mortality during wk 4 of incubation than embryos from *ad libitum* fed hens. The differences might be strain related.

Shell, albumen, and yolk weights were compared on a percent wet and dry weight basis in Table 13. The OATS and the R19.6 treatment had a significantly lower dry shell weight than the R17.0 and the R20.9 treatment. Conversely, percentage wet albumen weight was significantly lower in the CON group than in any other treatment. However, the lower albumen content was subsequently compensated for by a higher yolk fraction. During the 20 wk production period egg weight, dry albumen, and dry yolk weight increased 16.0, 11.9, and 35.2%, respectively. A similar 3:1 ratio for egg yolk and albumen proportions was reported by Applegate and Lilburn (1996) suggesting that feed restriction did not change the ratios between these variables throughout the course of the experiment. Dry shell weight decreased significantly over time which is in accordance with Reidy *et al*. (1994).

The current results conflict with a previous BUT study (Klein-Hessling, 1994), although the BW restrictions in this study were more severe than intended (51 versus 45%). Klein-Hessling *et al*. (1995) outlined crucial elements in the development of a successful feed restriction program for turkeys. If restriction is too severe and is continued too near to the time of photostimulation, then egg production will be depressed. This might become a particular problem during the summer when high environmental temperatures reduce feed intake and interfere with BW gain to achieve a necessary minimum target BW. Defining and achieving a target BW for photostimulation is important for any turkey feed restriction program. Initial results from field trials on quantitative feed restriction of female turkey breeder hens at a primary breeding company are encouraging and suggest that this management regimen is feasible and of significant economic value (Douglas and Wojcinski, 1997). Considering the work necessary to restrict BW, feeding oats was the simplest treatment to implement. It resulted in high egg production and excellent persistency.

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TABLE 1. Effect of duration of body weight restriction and prebreeder protein level on oviduct weight at first egg and peak egg production (mean ± SEM)[1]

	Feeding regimens[2]						Protein content[3]	
Age (wk)	CON	OATS	R17.0	R18.3	R19.6	R20.9	15%	18%
	(g)						(g)	
34	108.2 ± 5.7	109.2 ± 4.0	107.0 ± 6.9	113.4 ± 5.5	110.1 ± 8.7	100.1 ± 3.1	109.0 ± 3.9	107.0 ± 2.7
37	112.0 ± 5.9	116.3 ± 4.8	108.0 ± 5.3	114.5 ± 4.9	109.3 ± 4.3	109.3 ± 4.3	114.3 ± 3.1	109.9 ± 2.7
	% of BW						% of BW	
34	0.9 ± 0.1	1.0 ± 0.1	1.0 ± 0.1	1.1 ± 0.1	1.0 ± 0.1	1.0 ± 0.1	1.0 ± 0.1	1.0 ± 0.1
37	1.0 ± 0.1	1.0 ± 0.1	1.1 ± 0.1	1.1 ± 0.1	1.1 ± 0.1	1.1 ± 0.1	1.1 ± 0.1	1.1 ± 0.1

[1] No significant differences ($P > 0.05$). Mean values are based on 8 and 10 birds/feeding regimen and 18 and 30 birds/protein level at 34 and 37 wk of age, respectively.

[2] CON = Birds fed a standard commercial diet *ad libitum*; OATS = Birds fed a commercial diet through 18 wk and then oats from 19 through 26 wk; R17.0 = Birds restricted to 45% of the BW of the CON till 17.0 wk of age; R18.3 = Birds restricted to 45% of the BW of the CON till l8.3 wk of age; R19.6 = Birds restricted to 45% of the BW of the CON till 19.6 wk of age; R20.9 = Birds restricted to 45% of the BW of the CON till 20.9 wk of age.

[3] Half of the birds were fed a 15% protein diet while the other half received a 18% protein diet from 27 to 31 wk of age.

TABLE 2. Effect of duration of body weight restriction and prebreeder protein level on ovary weight at age of photostimulation, first egg and peak egg production (mean ± SEM)[1]

	Feeding regimens[2]						Protein content[3]	
Age (wk)	CON	OATS	R17.0	R18.3	R19.6	R20.9	15%	18%
	(g)						(g)	
31	4.0 ± 0.6	3.7 ± 0.5	4.5 ± 0.5	3.9 ± 0.2	4.4 ± 0.6	4.5 ± 0.5	3.8 ± 0.2	4.5 ± 0.3
34	192.4 ± 8.9	186.0 ± 9.3	171.6 ± 13.7	176.0 ± 12.3	179.7 ± 12.5	178.8 ± 7.8	180.0 ± 6.2	180.4 ± 6.4
37	203.8 ± 20.5	175.4 ± 11.0	156.7 ± 5.9	157.3 ± 7.2	157.4 ± 9.1	164.5 ± 13.5	166.1 ± 8.6	173.0 ± 6.0
	% of BW						% of BW	
31	0.04 ± 0.005	0.03 ± 0.004	0.04 ± 0.006	0.04 ± 0.002	0.04 ± 0.006	0.04 ± 0.005	0.04 ± 0.002	0.04 ± 0.003
34	1.6 ± 0.1	1.7 ± 0.1	1.6 ± 0.1	1.7 ± 0.1	1.7 ± 0.1	1.7 ± 0.1	1.7 ± 0.1	1.7 ± 0.1
37	1.9 ± 0.2	1.6 ± 0.1	1.6 ± 0.1	1.5 ± 0.1	1.6 ± 0.1	1.6 ± 0.1	1.6 ± 0.1	1.7 ± 0.1

[1] No significant main effect differences at 31 and 37 wk of age ($P > 0.05$). However, there was a significant duration of restriction x dietary protein interaction for % ovary weight at 34 wk of age ($P \leq 0.01$). Mean values are based on 8 and 10 birds/feeding regimen and 18 and 30 birds/protein level from 31-34 and at 37 wk of age, respectively.

[2] CON = Birds fed a standard commercial diet *ad libitum*; OATS = Birds fed a commercial diet through 18 wk and then oats from 19 through 26 wk; R17.0 = Birds restricted to 45% of the BW of the CON till 17.0 wk of age; R18.3 = Birds restricted to 45% of the BW of the CON till l8.3 wk of age; R19.6 = Birds restricted to 45% of the BW of the CON till 19.6 wk of age; R20.9 = Birds restricted to 45% of the BW of the CON till 20.9 wk of age.

[3] Half of the birds were fed a 15% protein diet while the other half received a 18% protein diet from 27 to 31 wk of age.

TABLE 3. Interaction of duration of body weight restriction and prebreeder protein level on ovary weight at 34 weeks (mean ± SEM)

	Feeding regimens[1]					
Diet[2]	CON	OATS	R17.0	R18.3	R19.6	R20.9
	(g)					
15% Protein	189.2 ± 12.4	175.4 ± 10.9	206.0 ± 3.5^{X}	166.9 ± 17.4	160.2 ± 17.1	187.9 ± 20.3
18% Protein	198.8 ± 14.3^{A}	196.6 ± 14.4^{A}	137.2 ± 8.3^{BY}	191.1 ± 14.6^{A}	199.2 ± 13.4^{A}	173.3 ± 5.1^{A}
	% of body weight					
15% Protein	1.63 ± 0.11	1.60 ± 0.08	1.89 ± 0.02^{X}	1.55 ± 0.19	1.50 ± 0.16	1.76 ± 0.17
18% Protein	1.67 ± 0.01^{A}	1.72 ± 0.14^{A}	1.28 ± 0.06^{BY}	1.93 ± 0.11^{A}	1.89 ± 0.14^{A}	1.72 ± 0.07^{A}

$^{A-B}$ Means within a row with no common superscripts differ significantly ($P \leq 0.01$).

$^{X-Y}$ Means within a column with no common superscripts differ significantly ($P \leq 0.01$).

[1] CON = Birds fed a standard commercial diet *ad libitum*; OATS = Birds fed a commercial diet through 18 wk and then oats from 19 through 26 wk; R17.0 = Birds restricted to 45% of the BW of the CON till 17.0 wk of age; R18.3 = Birds restricted to 45% of the BW of the CON till l8.3 wk of age; R19.6 = Birds restricted to 45% of the BW of the CON till 19.6 wk of age; R20.9 = Birds restricted to 45% of the BW of the CON till 20.9 wk of age.

[2] Half of the birds were fed a 15% protein diet while the other half received a 18% protein diet from 27 to 31 wk of age.

TABLE 4. Effect of duration of body weight restriction and prebreeder protein level on number of large yellow follicles and on the incidence of multiple follicle groups at first egg and peak egg production (mean ± SEM)[1]

	Feeding regimens[2]						Protein content[3]	
Age (wk)	CON	OATS	R17.0	R18.3	R19.6	R20.9	15%	18%
	No. of follicles [4]						No. of follicles [4]	
34	12.9 ± 1.1	13.1 ± 0.3	12.5 ± 0.5	11.6 ± 0.5	12.0 ± 0.5	12.6 ± 0.5	12.7 ± 0.3	12.2 ± 0.4
37	11.7 ± 0.7	11.3 ± 0.5	10.0 ± 0.6	10.8 ± 0.6	10.7 ± 0.5	11.4 ± 0.7	10.9 ± 0.3	11.1 ± 0.4
	% multiple follicle groups [5]						% multiple follicle groups [5]	
34 [3]	39.1 ± 7.3^{b}	44.8 ± 6.8^{ab}	39.9 ± 6.5^{b}	46.3 ± 4.5^{ab}	43.1 ± 9.2^{ab}	59.2 ± 4.7^{a}	42.1 ± 3.4	48.9 ± 4.3
37	26.6 ± 7.2	27.6 ± 6.1	20.6 ± 5.3	32.8 ± 7.4	19.9 ± 3.7	26.8 ± 6.5	18.9 ± 3.0^{A}	33.1 ± 3.6^{B}
	% multiple follicle groups [4]						% multiple follicle groups [4]	
34	37.3 ± 4.8	31.2 ± 3.5	25.4 ± 4.1	31.2 ± 6.0	36.3 ± 7.4	30.2 ± 4.9	30.4 ± 2.9	33.7 ± 3.2
37	31.8 ± 4.3	23.0 ± 5.0	20.6 ± 3.8	28.2 ± 4.8	32.9 ± 4.7	32.9 ± 6.4	27.0 ± 2.8	29.7 ± 2.8

a-b Means within a row with no common superscripts differ significantly (*P* ≤ 0.05).

A-B Means within a row with no common superscripts differ significantly (*P* ≤ 0.01).

[1] Significant duration of restriction x dietary protein interaction for number of follicles at 34 wk of age (*P* ≤ 0.01). Mean values are based on 8 and 10 birds/feeding regimen and 18 and 30 birds/protein level at 34 and 37 wk of age, respectively.

[2] CON = Birds fed a standard commercial diet *ad libitum*; OATS = Birds fed a commercial diet through 18 wk and then oats from 19 through 26 wk; R17.0 = Birds restricted to 45% of the BW of the CON till 17.0 wk of age; R18.3 = Birds restricted to 45% of the BW of the CON till l8.3 wk of age; R19.6 = Birds restricted to 45% of the BW of the CON till 19.6 wk of age; R20.9 = Birds restricted to 45% of the BW of the CON till 20.9 wk of age.

[3] Half of the birds were fed a 15% protein diet while the other half received a 18% protein diet from 27 to 31 wk of age.

[4] Classified on diameter basis.

[5] Classified on weight basis.

TABLE 5. Interaction of duration of body weight restriction and prebreeder protein level on ovarian follicle count at 34 weeks (mean ± SEM)

	Feeding regimens[1]					
Diet[2]	CON	OATS	R17.0	R18.3	R19.6	R20.9
	No. of follicles [3]					
15% Protein	14.4 ± 0.9[a]	13.0 ± 0.4[ab]	13.3 ± 0.6[ab]	11.2 ± 0.5[b]	11.3 ± 0.6[b]	13.0 ± 0.6[ab]
18% Protein	10.3 ± 1.8	13.3 ± 0.7	11.8 ± 0.8	12.3 ± 0.8	12.8 ± 0.8	12.4 ± 0.7

[a-b] Means within a row with no common superscripts differ significantly ($P \leq 0.05$).

[1] CON = Birds fed a standard commercial diet *ad libitum*; OATS = Birds fed a commercial diet through 18 wk and then oats from 19 through 26 wk; R17.0 = Birds restricted to 45% of the BW of the CON till 17.0 wk of age; R18.3 = Birds restricted to 45% of the BW of the CON till l8.3 wk of age; R19.6 = Birds restricted to 45% of the BW of the CON till 19.6 wk of age; R20.9 = Birds restricted to 45% of the BW of the CON till 20.9 wk of age.

[2] Half of the birds were fed a 15% protein diet while the other half received a 18% protein diet from 27 to 31 wk of age.

[3] Classified on diameter basis.

TABLE 6. Effect of duration of body weight restriction and prebreeder protein level on floor and non - settable egg production (mean ± SEM)

	Feeding regimens[1]						Protein content[2]	
Variable	CON	OATS	R17.0	R18.3	R19.6	R20.9	15%	18%
	% incidence						% incidence	
Floor eggs	23.8 ± 4.9	26.1 ± 6.7	29.9 ± 2.8	35.6 ± 8.3	38.6 ± 4.7	36.5 ± 9.7	32.1 ± 3.9	31.3 ± 3.7
D. yolked eggs[3]	0.1 ± 0.1	0.2 ± 0.1	0.2 ± 0.1	0.3 ± 0.1	0.3 ± 0.1	0.2 ± 0.1	0.3 ± 0.1	0.2 ± 0.1
Misshaped eggs	0.8 ± 0.2	1.4 ± 0.6	1.1 ± 0.2	0.8 ± 0.2	1.0 ± 0.2	1.0 ± 0.4	1.4 ± 0.2[A]	0.7 ± 0.1[B]
Soft shelled eggs	2.5 ± 1.3	2.2 ± 0.9	0.9 ± 0.2	1.0 ± 0.4	1.9 ± 0.6	2.1 ± 0.5	1.3 ± 0.2	2.3 ± 0.5
Cracked eggs	4.4 ± 0.8	4.0 ± 0.8	3.2 ± 0.4	3.1 ± 0.4	5.9 ± 1.3	4.2 ± 0.6	3.8 ± 0.3	4.5 ± 0.6

[A-B] Means within a row with no common superscripts differ significantly ($P \leq 0.01$).

[1] CON = Birds fed a standard commercial diet *ad libitum*; OATS = Birds fed a commercial diet through 18 wk and then oats from 19 through 26 wk; R17.0 = Birds restricted to 45% of the BW of the CON till 17.0 wk of age; R18.3 = Birds restricted to 45% of the BW of the CON till l8.3 wk of age; R19.6 = Birds restricted to 45% of the BW of the CON till 19.6 wk of age; R20.9 = Birds restricted to 45% of the BW of the CON till 20.9 wk of age.

[2] Half of the birds were fed a 15% protein diet while the other half received a 18% protein diet from 27 to 31 wk of age.

TABLE 7. Interaction of duration of body weight restriction and prebreeder protein level on double-yolked eggs (mean ± SEM)

Diet[2]	Feeding regimens[1]					
	CON	OATS	R17.0	R18.3	R19.6	R20.9
	% incidence					
15% Protein	0.00 ± 0.00[bx]	0.22 ± 0.12[ab]	0.13 ± 0.08[b]	0.43 ± 0.03[a]	0.44 ± 0.19[a]	0.36 ± 0.13[ab]
18% Protein	0.27 ± 0.03[y]	0.21 ± 0.08	0.19 ± 0.14	0.19 ± 0.09	0.25 ± 0.12	0.05 ± 0.04

[a-b] Means within a row with no common superscripts differ significantly ($P \leq 0.05$).

[x-y] Means within a column with no common superscripts differ significantly ($P \leq 0.01$).

[1] CON = Birds fed a standard commercial diet *ad libitum*; OATS = Birds fed a commercial diet through 18 wk and then oats from 19 through 26 wk; R17.0 = Birds restricted to 45% of the BW of the CON till 17.0 wk of age; R18.3 = Birds restricted to 45% of the BW of the CON till l8.3 wk of age; R19.6 = Birds restricted to 45% of the BW of the CON till 19.6 wk of age; R20.9 = Birds restricted to 45% of the BW of the CON till 20.9 wk of age.

[2] Half of the birds were fed a 15% protein diet while the other half received a 18% protein diet from 27 to 31 wk of age.

TABLE 8. Effect of duration of body weight restriction on egg production (mean ± SEM)

Week	CON	OATS	R17.0	R18.3	R19.6	R20.9	Probability
	Feeding regimens[1]						
	Avg settable eggs/hen						
1 - 5	22.2 ± 0.6	23.3 ± 0.6	24.4 ± 0.6	25.6 ± 1.1	22.5 ± 1.3	24.0 ± 0.7	($P < 0.08$).
6 - 10	22.9 ± 0.8[bc]	24.6 ± 0.7[ab]	25.3 ± 0.4[a]	25.1 ± 0.3[ab]	22.2 ± 1.7[c]	24.0 ± 0.7[abc]	($P < 0.05$).
11 - 15	21.3 ± 0.8	23.5 ± 0.6	22.7 ± 0.8	22.5 ± 1.3	19.5 ± 0.9	21.0 ± 1.2	($P < 0.26$).
16 - 20	19.5 ± 0.8	21.9 ± 0.8	19.7 ± 0.7	19.1 ± 1.2	16.5 ± 1.4	16.7 ± 1.8	($P < 0.15$).
1 - 10	45.0 ± 1.4[b]	47.7 ± 1.1[ab]	49.6 ± 0.6[a]	50.8 ± 1.3[a]	44.8 ± 2.9[b]	48.0 ± 1.3[ab]	($P < 0.06$).
11 - 20	40.8 ± 1.5	45.5 ± 1.3	42.5 ± 1.4	41.6 ± 2.1	36.0 ± 2.1	37.7 ± 2.9	($P < 0.16$).
1 - 20	85.9 ± 2.5	93.2 ± 1.8	92.2 ± 1.4	92.6 ± 2.5	81.0 ± 4.8	85.8 ± 3.7	($P < 0.13$).
	% HH production						
1 - 5	63.3 ± 1.6	66.5 ± 1.7	69.8 ± 1.6	73.2 ± 3.0	64.3 ± 3.7	68.5 ± 2.0	($P < 0.07$).
6 - 10	65.4 ± 2.3	70.1 ± 2.0	72.2 ± 1.2	71.8 ± 1.0	63.4 ± 3.9	68.5 ± 2.1	($P < 0.07$).
11 - 15	60.9 ± 2.3	67.1 ± 1.7	64.9 ± 2.2	64.4 ± 3.6	55.8 ± 2.6	60.1 ± 3.3	($P < 0.26$).
16 - 20	55.6 ± 2.2	62.5 ± 2.4	56.4 ± 1.9	54.7 ± 3.5	47.3 ± 4.0	47.7 ± 5.3	($P < 0.15$).
1 - 10	64.3 ± 1.9[b]	68.2 ± 1.6[ab]	70.9 ± 0.8[a]	72.5 ± 1.8[a]	63.9 ± 4.1[b]	68.5 ± 1.9[ab]	($P < 0.06$).
11 - 20	58.2 ± 2.1	64.8 ± 1.8	60.6 ± 1.9	59.6 ± 3.0	51.6 ± 3.0	53.9 ± 4.1	($P < 0.16$).
1 - 20	61.4 ± 1.8	66.5 ± 1.3	66.0 ± 1.0	66.2 ± 1.8	58.0 ± 3.5	61.4 ± 2.6	($P < 0.13$).

[a-c] Means within a row with no common superscripts differ significantly ($P \leq 0.06$).

[1] CON = Birds fed a standard commercial diet *ad libitum*; OATS = Birds fed a commercial diet through 18 wk and then oats from 19 through 26 wk; R17.0 = Birds restricted to 45% of the BW of the CON till 17.0 wk of age; R18.3 = Birds restricted to 45% of the BW of the CON till l8.3 wk of age; R19.6 = Birds restricted to 45% of the BW of the CON till 19.6 wk of age; R20.9 = Birds restricted to 45% of the BW of the CON till 20.9 wk of age.

TABLE 9. Effect of prebreeder protein level on egg production (mean ± SEM)[1]

	Protein content [1]	
Week	15%	18%
	Avg. settable eggs/hen	
1-5	23.5 ± 0.4	23.8 ± 0.7
6-10	24.2 ± 0.6	23.8 ± 0.5
11-15	22.0 ± 0.6	21.5 ± 0.6
16-20	19.1 ± 0.8	18.8 ± 0.7
1-10	47.7 ± 0.9	47.6 ± 1.1
11-20	41.1 ± 1.4	40.3 ± 1.2
1-20	89.0 ± 1.9	88.1 ± 2.0
	% HH production	
1-5	67.3 ± 1.1	68.0 ± 1.9
6-10	69.1 ± 1.7	68 0 ± 1.5
11-15	62.9 ± 1.8	61.6 ± 1.6
16-20	54.5 ± 2.4	53.6 ± 2.1
1-10	68.1 ± 1.3	68.0 ± 1.6
11-20	58.7 ± 1.9	57.6 ± 1.8
1-20	63.6 ± 1.4	62.9 ± 1.4

[1] No significant differences ($P > 0.05$).

[2] Half of the birds were fed a 15% protein diet while the other half received a 18% protein diet from 27 to 31 wk of age.

TABLE 10. Effect of duration of body weight restriction and prebreeder protein level on egg weight and egg shell quality traits (mean ± SEM)[1]

	Feeding regimens[2]						Protein content[3]	
Variable	CON	OATS	R17.0	R18.3	R19.6	R20.9	15%	18%
Egg weight (g)	92.4± 0.2	92.9± 0.2	92.0± 0.2	91.0± 0.2	92.6± 0.2	91.5± 0.2	92.3± 0.1	91.9± 0.1
Spec. gravity [4]	1.083± 0.001	1.082± 0.001	1.083± 0.001	1.083± 0.001	1.082± 0.001	1.083± 0.001	1.083± 0.001	1.083± 0.001
% wt. Loss[5]	10.4± 0.1	10.4± 0.3	10.5± 0.2	10.6± 0.2	10.4± 0.3	10.2± 0.1	10.5± 0.1	10.3± 0.1
Shell conduct.[6]	20.7± 0.3	20.7± 0.5	20.8± 0.6	20.7± 0.6	20.8± 0.6	20.1± 0.2	20.9± 0.3	20.4± 0.3
Conduct. const.[7]	6.2± 0.1	6.2± 0.2	6.3± 0.1	6.3± 0.1	6.2± 0.2	6.1± 0.1	6.3± 0.1	6.2± 0.1

[1] No significant differences ($P > 0.05$).

[2] CON = Birds fed a standard commercial diet *ad libitum*; OATS = Birds fed a commercial diet through 18 wk and then oats from 19 through 26 wk; R17.0 = Birds restricted to 45% until 17.0 wk of age; R18.3 = Birds restricted to 45% until l8.3 wk of age; R19.6 = Birds restricted to 45% until 19.6 wk of age; R20.9 = Birds restricted to 45% until 20.9 wk of age.

[3] Half of the birds were fed a 15% protein diet while the other half received a 18% protein diet from 27 to 31 wk of age.

[4] Specific gravity.

[5] Percentage egg weight loss from zero to twenty-four days of incubation.

[6] Shell conductance; mg H_2O/d/torr.

[7] Shell conductance/egg weight (g) x 28.

TABLE 11. Effect of duration of body weight restriction and prebreeder protein level on fertility, hatchability and poult characteristics (mean ± SEM)

	Feeding regimens[1]						Protein content[2]	
Variable	CON	OATS	R17.0	R18.3	R19.6	R20.9	15%	18%
	% incidence						% incidence	
Fertility	96.5 ± 0.6	97.0 ± 0.2	96.2 ± 1.3	97.4 ± 0.4	97.4 ± 0.4	97.7 ± 0.5	96.8 ± 0.4	97.2 ± 0.3
Hatchability [3]	82.4 ± 0.9	79.9 ± 0.5	80.2 ± 1.4	81.7 ± 0.7	81.3 ± 1.4	80.8 ± 1.5	80.9 ± 0.8	81.2 ± 0.5
Viability[4]	85.4 ± 0.6	82.3 ± 0.6	83.4 ± 1.2	83.9 ± 0.6	83.4 ± 1.3	82.7 ± 1.3	83.6 ± 0.7	83.5 ± 0.5
	g or mg/dl						g or mg/dl	
Poult weight	64.5 ± 0.6[a]	64.0 ± 0.5[a]	64.0 ± 0.6[a]	62.2 ± 0.4[b]	64.4 ± 0.6[a]	63.3 ± 0.5[ab]	65.3 ± 0.3	66.9 ± 0.4
Blood glucose [5]	253.1 ± 2.5	252.2 ± 3.1	253.9 ± 3.2	253.2 ± 3.8	254.1 ± 3.4	252.1 ± 3.6	252.3 ± 1.7	253.9 ± 1.9

[a-b] Means within a row with no common superscripts differ significantly ($P \leq 0.01$).

[1] CON = Birds fed a standard commercial diet *ad libitum*; OATS = Birds fed a commercial diet through 18 wk and then oats from 19 through 26 wk; R17.0 = Birds restricted to 45% of the BW of the CON till 17.0 wk of age; R18.3 = Birds restricted to 45% of the BW of the CON till l8.3 wk of age; R19.6 = Birds restricted to 45% of the BW of the CON till 19.6 wk of age; R20.9 = Birds restricted to 45% of the BW of the CON till 20.9 wk of age.

[2] Half of the birds were fed a 15% protein diet while the other half received a 18% protein diet from 27 to 31 wk of age.

[3] Hatchability is defined as the number of successful hatches obtained from the total number of eggs that were set.

[4] Viability is defined as the number of live poults obtained from the total number of fertile eggs.

[5] Blood glucose concentration of poults measured at hatch.

TABLE 12. Effect of duration of body weight restriction and prebreeder protein level on embryonic mortality (mean ± SEM)[1]

	Feeding regimens [2]						Protein content [3]	
Variable	CON	OATS	R17.0	R18.3	R19.6	R20.9	15%	18%
	% incidence						% incidence	
Early dead	4.2 ± 0.4	4.3 ± 0.4	4.6 ± 0.5	3.5 ± 0.5	3.8 ± 0.3	3.7 ± 0.4	4.1 ± 0.3	3.9 ± 0.2
Dead wk 1	1.4 ± 0.1	1.6 ± 0.4	1.3 ± 0.2	1.3 ± 0.1	1.5 ± 0.2	2.0 ± 0.3	1.6 ± 0.2	1.4 ± 0.1
Dead wk 2	0.3 ± 0.1	0.5 ± 0.1	0.5 ± 0.1	0.5 ± 0.1	0.5 ± 0.1	0.5 ± 0.2	0.4 ± 0.1	0.5 ± 0.1
Dead wk 3	0.8 ± 0.2	1.5 ± 0.2	1.5 ± 0.4	1.3 ± 0.1	1.3 ± 0.3	1.4 ± 0.3	1.2 ± 0.2	1.4 ± 0.2
Dead wk 4	3.2 ± 0.3	4.4 ± 0.5	3.5 ± 0.8	4.6 ± 0.4	3.9 ± 0.4	4.0 ± 0.5	3.8 ± 0.3	4.1 ± 0.3
Internal pip	0.4 ± 0.1	0.5 ± 0.1	0.6 ± 0.3	0.4 ± 0.1	0.5 ± 0.3	0.5 ± 0.1	0.4 ± 0.1	0.5 ± 0.1
External pip	3.6 ± 0.3	4.2 ± 0.4	3.8 ± 0.2	3.9 ± 0.2	4.5 ± 0.5	4.8 ± 0.4	4.3 ± 0.2	4.0 ± 0.2

[1] No significant differences ($P > 0.05$).

[2] CON = Birds fed a standard commercial diet *ad libitum*; OATS = Birds fed a commercial diet through 18 wk and then oats from 19 through 26 wk; R17.0 = Birds restricted to 45% of the BW of the CON till 17.0 wk of age; R18.3 = Birds restricted to 45% of the BW of the CON till l8.3 wk of age; R19.6 = Birds restricted to 45% of the BW of the CON till 19.6 wk of age; R20.9 = Birds restricted to 45% of the BW of the CON till 20.9 wk of age.

[3] Half of the birds were fed a 15% protein diet while the other half received a 18% protein diet from 27 to 31 wk of age.

TABLE 13. Effect of duration of body weight restriction on egg components of turkey hatching eggs (mean ± SEM)

	Feeding regimens[1]					
Variable[2]	CON	OATS	R17.0	R18.3	R19.6	R20.9
			Wet weight (%)			
Shell	12.5 ± 0.1	12.2 ± 0.1	12.3 ± 0.1	12.3 ± 0.1	12.2 ± 0.1	12.4 ± 0.1
Albumen	53.9 ± 0.3[b]	54.7 ± 0.3[a]	55.0 ± 0.3[a]	55.1 ± 0.2[a]	55.0 ± 0.2[a]	55.4 ± 0.3[a]
Yolk	29.3 ± 0.4[a]	28.8 ± 0.2[ab]	28.1 ± 0.3[bc]	28.3 ± 0.2[bc]	28.3 ± 0.2[bc]	27.8 ± 0.2[c]
			Dry weight (%)			
Shell	9.0 ± 0.1[ab]	8.9 ± 0.1[b]	9.1 ± 0.1[a]	9.0 ± 0.1[ab]	8.9 ± 0.1[b]	9.1 ± 0.1[a]
Albumen	6.5 ± 0.0[b]	6.6 ± 0.1[ab]	6.7 ± 0.0[a]	6.7 ± 0.0[a]	6.6 ± 0.1[a]	6.6 ± 0.1[ab]
Yolk	15.1 ± 0.1[a]	15.1 ± 0.1[a]	14.7 ± 0.1[b]	14.9 ± 0.1[ab]	14.8 ± 0.1[ab]	14.6 ± 0.1[b]

[a-c] Means within a row with no common superscripts differ significantly ($P \leq 0.05$).

[1] CON = Birds fed a standard commercial diet *ad libitum*; OATS = Birds fed a commercial diet through 18 wk and then oats from 19 through 26 wk; R17.0 = Birds restricted to 45% of the BW of the CON till 17.0 wk of age; R18.3 = Birds restricted to 45% of the BW of the CON till l8.3 wk of age; R19.6 = Birds restricted to 45% of the BW of the CON till 19.6 wk of age; R20.9 = Birds restricted to 45% of the BW of the CON till 20.9 wk of age.

[2] No significant differences in egg weight. Total number of eggs used was 528.

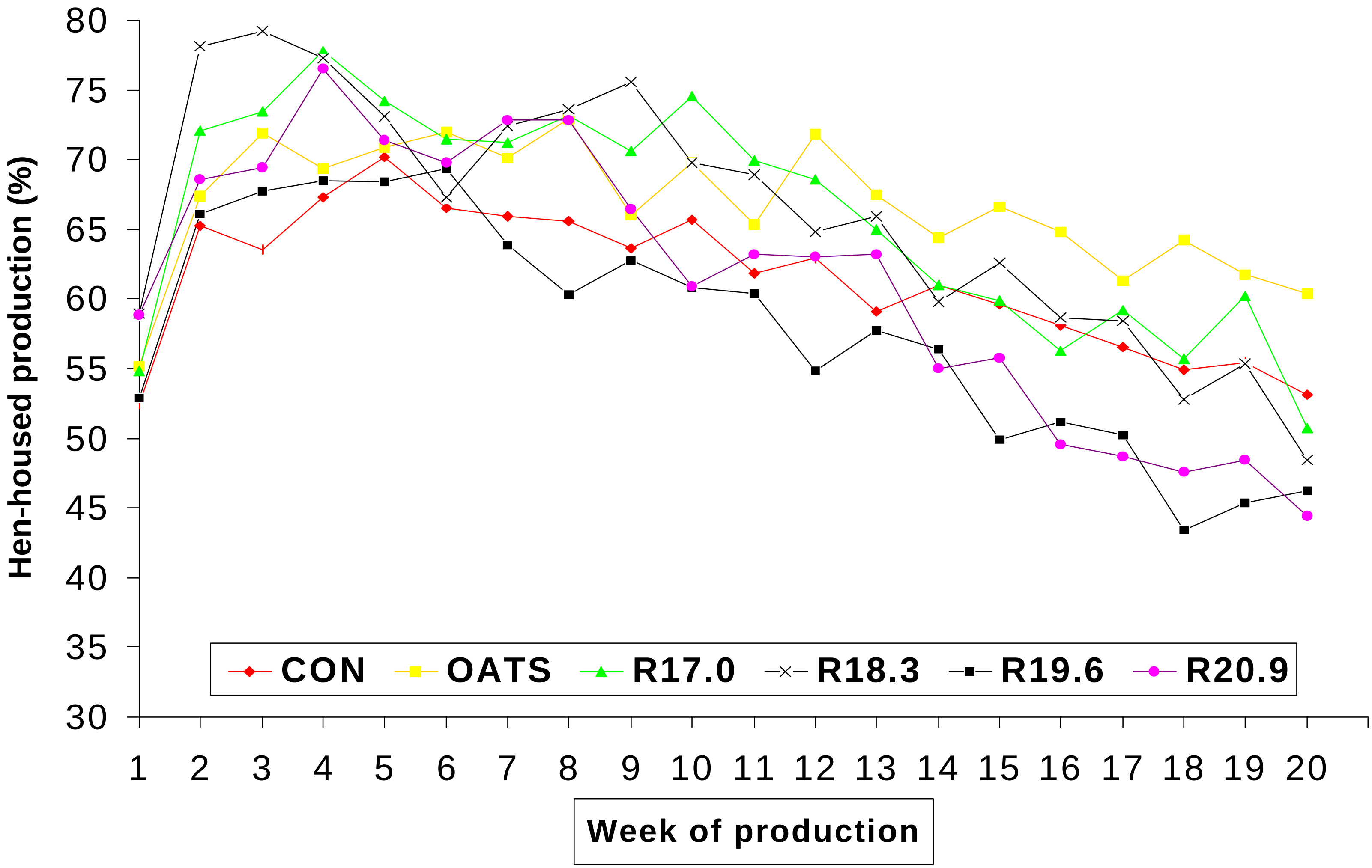

Figure 1. Percent hen-housed egg production of turkey breeder hens either fed *ad libitum* or restricted to 45% of the body weight of the full-fed control at 16 wk of age and maintained on restriction until either 17.0, 18.3, 19.6, or 20.9 wk of age

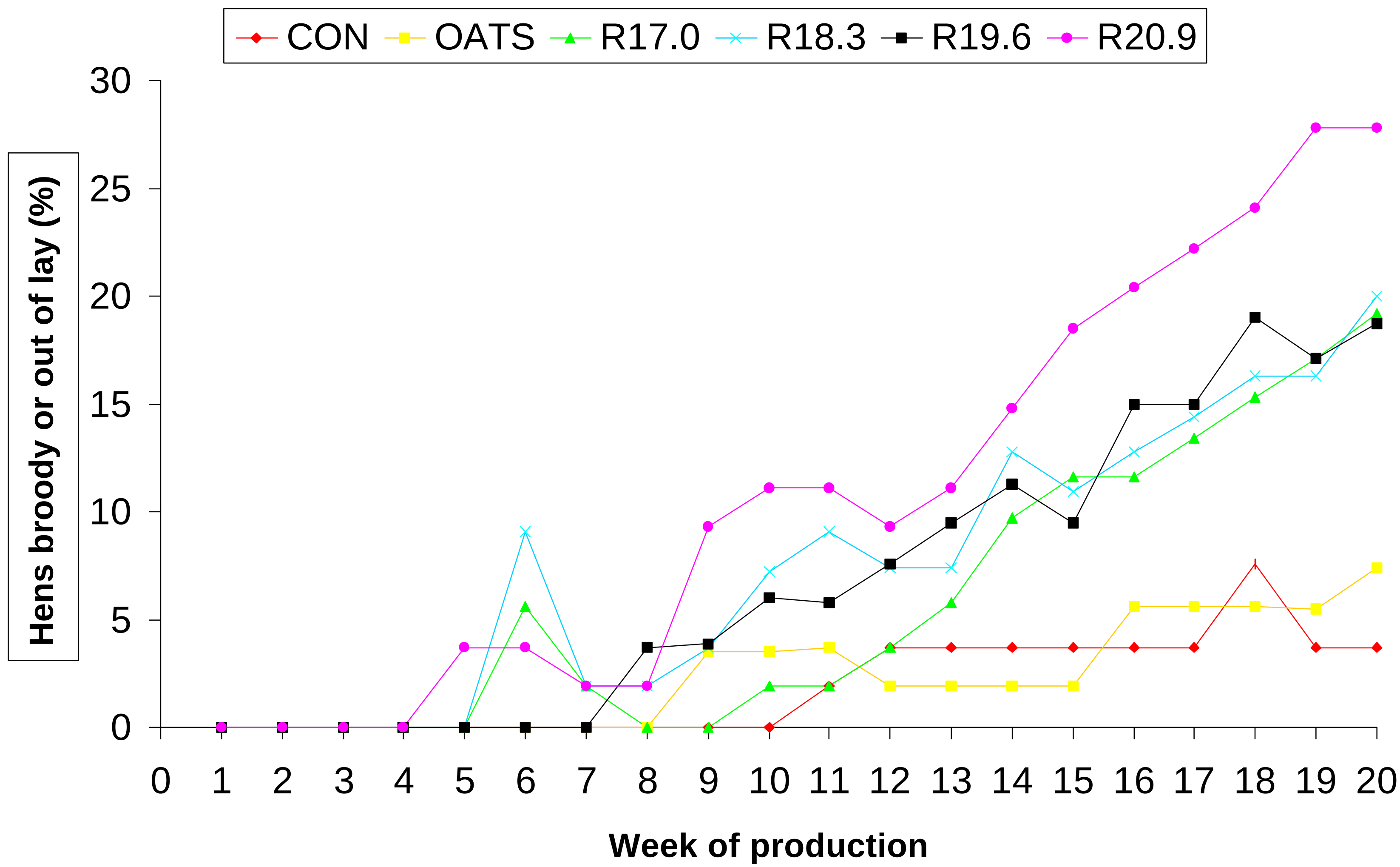

Figure 2. Percent broody or out-of-lay turkey breeder hens either fed *ad libitum* or restricted to 45% of the body weight of the full-fed control at 16 wk of age and maintained on restriction until either 17.0, 18.3, 19.6, or 20.9 wk of age

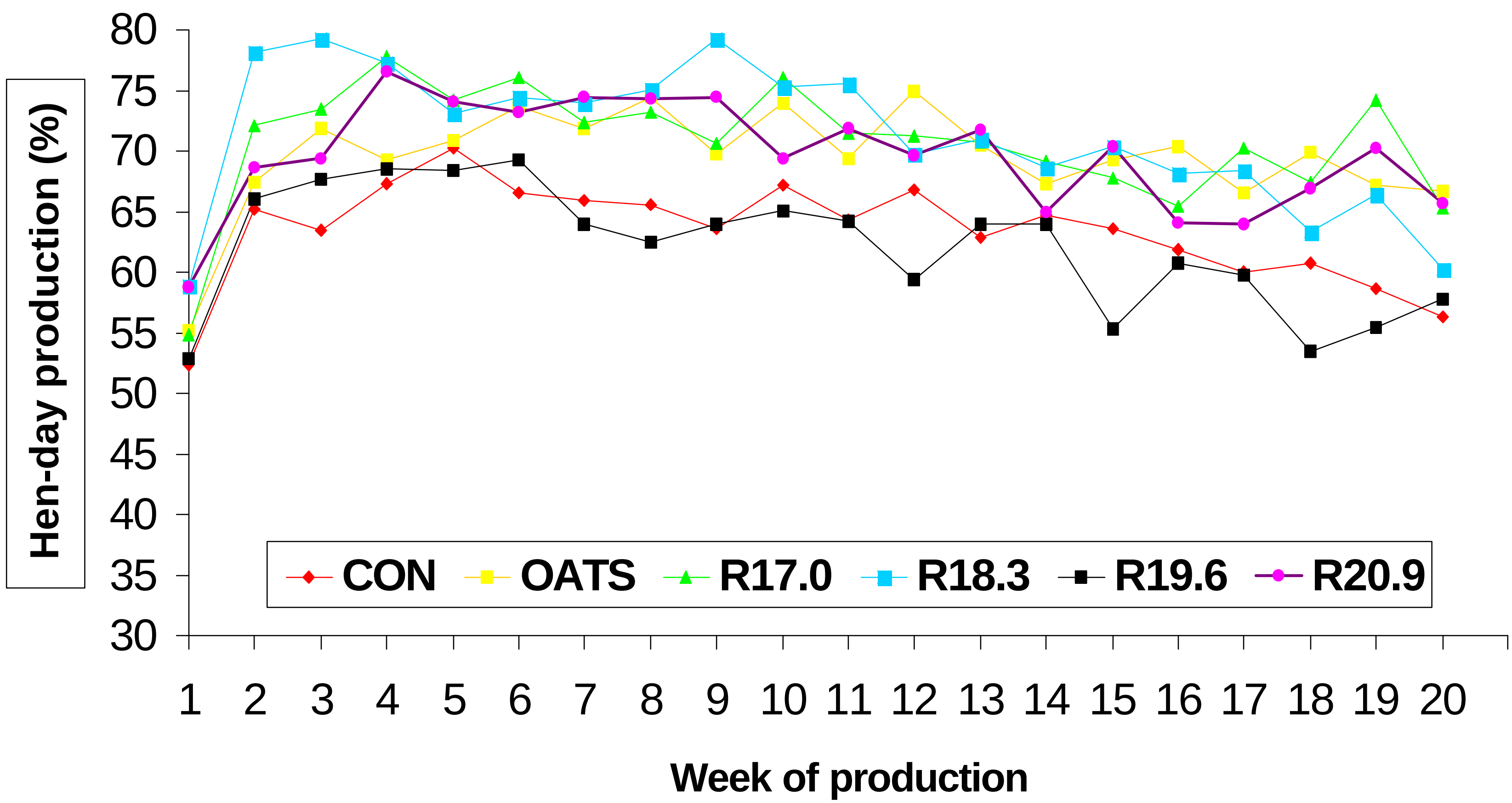

Figure 3. Percent hen-day egg production of turkey breeder hens either fed *ad libitum* or restricted to 45% of the body weight of the full fed control at 16 wk of age and maintained on restriction until either 17.0, 18.3, 19.6, or 20.9 wk of age

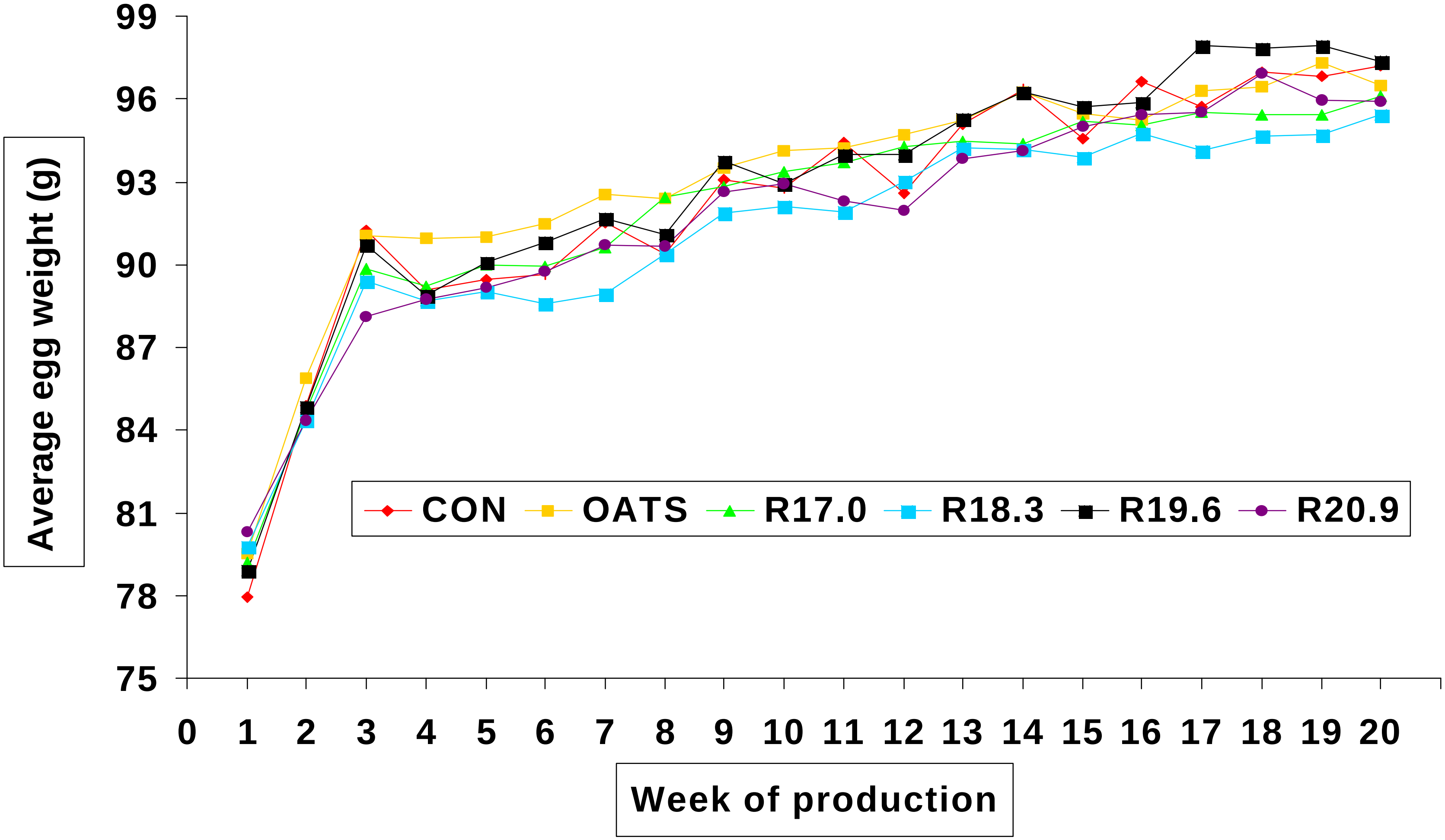

Figure 4. Average egg weight of turkey breeder hens either fed *ad libitum* or restricted to 45% of the body weight of the full-fed control at 16 wk of age and maintained on restriction until either 17.0, 18.3, 19.6, or 20.9 wk of age

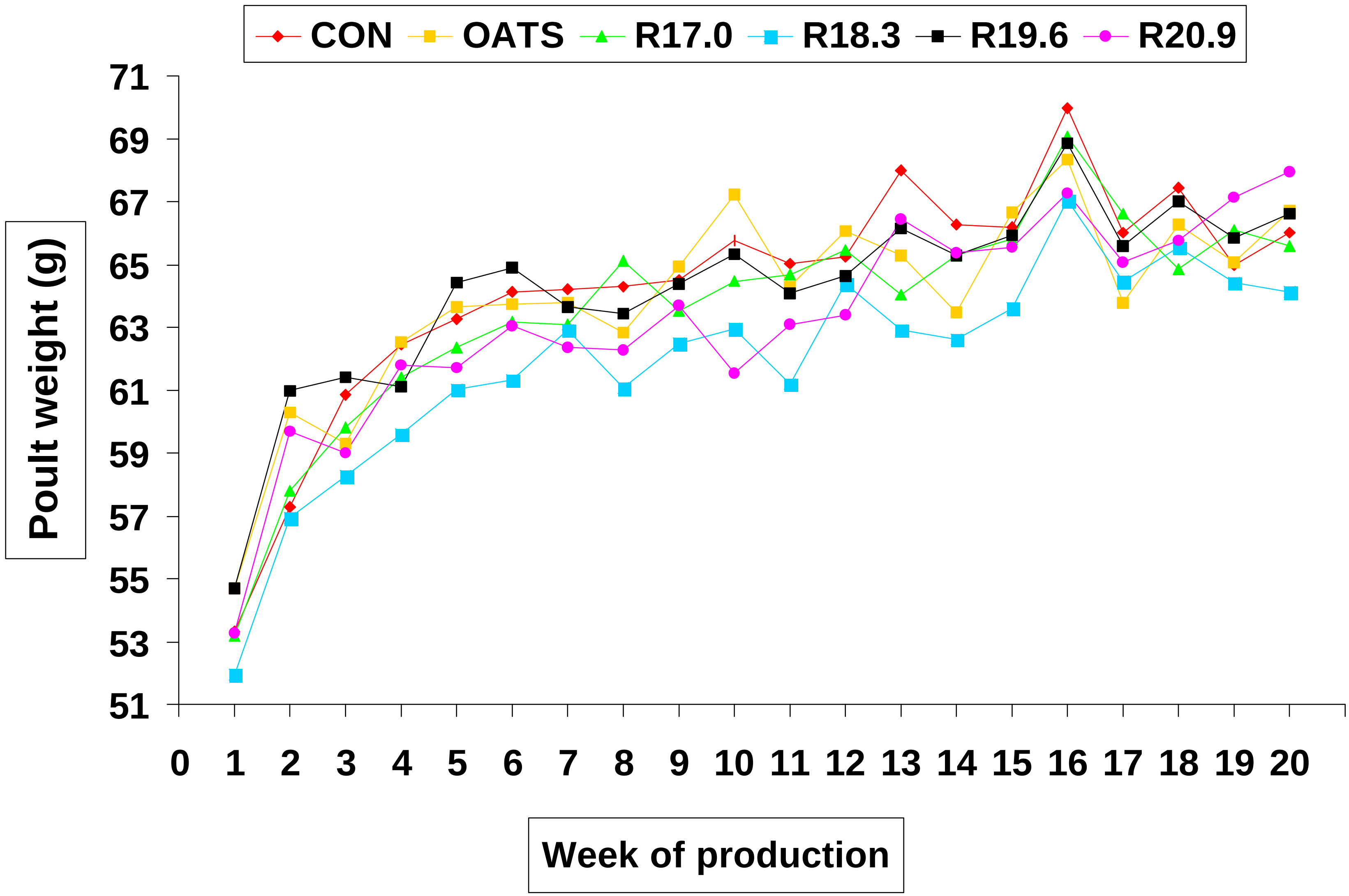

Figure 5. Average poult weight of turkey breeder hens either fed *ad libitum* or restricted to 45% of the body weight of the full-fed control at 16 wk of age and maintained on restriction until either 17.0, 18.3, 19.6, or 20.9 wk of age

CHAPTER III

Effect of Nesting Material on Reproductive Performance of Commercial Large White Turkey Breeder Hens

ABSTRACT

The effectiveness of a paper chip product was evaluated as an alternative nesting material for turkey breeder operations. Nicholas Large White turkey breeder hens were raised in floor pens covered with pine shavings. The birds were moved into a laying house using the same litter material. Each breeder pen contained four trapnests. Approximately 10 cm of one of the following litter materials was placed into the nests at 33 WOA: 1) all nests filled with shavings (S), 2) all nests filled with paper chips (P), and 3) two nests filled with shavings and two nests filled with paper chips (S/P). Litter was added as needed. Each treatment had 12 replications and data were collected for 20 wk of lay. A highly significant increase in floor eggs was observed for both P and S/P treatments. More eggs were broken in the S/P than in the S or P treatments ($P < 0.05$). Hens laying on S had highly significant improvements in settable egg production during the first 10 wk of lay. There were no differences in fertility, hatchability, poult weight, and blood glucose concentrations at hatch. In conclusion, turkey breeder hens can and do distinguish between nesting materials. Combinations of various types of nesting materials within the same breeder house should be avoided. P may be a poor substitute for conventional nesting materials.

(*Key words*: turkey breeder hens, nesting material, paper chips, floor eggs, egg production

INTRODUCTION

The search for alternative inexpensive nesting and bedding materials in all areas of commercial poultry production is increasing (Veltmann *et al*., 1984; Lien *et al*., 1992). The reasons are twofold. The first is that the availability of the "classical" softwood pine shavings is limited and, secondly, due to this shortage, high quality soft wood pine shavings are rather expensive (Benabdeljelil and Ayachi, 1996). Among the groups that demand and compete for large quantities of pine shavings are particle board manufacturers, as well as commercial steam generators (Malone, 1982). Many alternative nesting materials exist and have been tested with favorable results (Brake *et al*., 1992). However, high transportation cost exclude many potential products from being used for poultry bedding (Brake *et al*., 1993).

A qualitatively acceptable nesting material must be absorbent, dust-free, difficult to ingest, nontoxic to animals and personnel, inexpensive, easily shipped and received, continuously available, and durable (Brake *et al*, 1992; Brake *et al*., 1993). Good nesting material must prevent eggs from being broken during events associated with oviposition (Ruszler and Carson, 1974), movements of the birds in the nest, and should not interfere with mechanical egg collection systems. Moreover, microbial contamination should be minimized (SO *et al*., 1978; Brake, 1985).

Sources of potential nesting materials other than pine shavings include rice hulls (Dendy *et al*., 1968), rice straw (Andrews and McPherson, 1963) peanut shells (Ruszler and Carson, 1968; Lien *et al*., 1998), peat moss, corn cobs, sawdust (Chaloupka *et al*., 1967), wheat, barely, or oat straw (Andrews and McPerson, 1963), pine tree bark (Dick *et al*., 1976), hardwood bark (Brake *et al*., 1992), chopped kenaf (Brake *et al*., 1993), shredded and composted newspaper (Malone, 1982; Malone *et al*., 1983a), recycled paper chips (Lien *et al*., 1992), and particleboard residue (Hester *et al*., 1997). Malone *et al*. (1983b) reported that broilers consumed less paper-based litter material relative to saw dust or wood fibers. Moreover, coccidial lesions of birds on paper-based litter were lower as compared to broilers placed on sawdust.

The texture of a product has a significant effect on the moisture holding capacity of the material (Tilly *et al*., 1996). This feature is crucial in controlling high ammonia levels. For instance, pine shavings can absorb more moisture than hard wood bark (Brake *et al*., 1992). The particle size of litter material can also lead to an increased incidence of focal ulcerative dermatitis, or “breast buttons,” of poorly feathered skin over the keel of the breast of predominantly male turkeys (Tilly *et al*.,1996). Different litter types (Smith, 1956) and particle size (Martin *et al*., 1971) may affect carcass grade. Breast blisters and foot problems occur if the material is too large in size and has too many sharp edged corners. This is particularly a problem when unchopped corn cobs (Smith, 1956) and hardwood shavings are used or sometimes when straw is filled in (Tilly *et al*., 1996). Very little information is available concerning the effectiveness of these litter materials as potential nesting materials in breeder operations (Lien *et al*., 1998). Even less is known concerning the efficiency of some of these materials used in combination (Veltmann *et al*., 1984; Benabdeljelil and Ayachi, 1996).

The preference of the hen for various nesting materials depends on numerous factors and choosing a material with low bird acceptance can have far reaching consequences. For instance, many floor eggs get broken, and this may encourage egg eating. Those floor eggs that are salvaged are often contaminated and lead to reduced hatchability (Appleby, 1984). Perry *et al*. (1971) reported 30% floor eggs in a broiler breeder flock. Other researchers have observed levels ranging between 3 to 23% (Dorminey *et al*., 1970). This great variability suggests that many causal factors of floor laying are poorly understood or simply overlooked (Appleby, 1984). Hens in a flock typically establish a laying pattern at the onset of production (Hurnik *et al.*, 1973). Each hen has to learn to lay the eggs into a nest. Once the laying behavior is established it is difficult to change, even with a major effort (Appleby *et al.*, 1983).

The objective of the current study was to evaluate the effectiveness of a paper chip product as an alternative nesting material for turkey hatching egg production. Of particular interest was the assessment of the response of turkey breeder hens given the choice to choose between two nesting materials offered at the same time.

MATERIALS AND METHODS

Stock and Husbandry

Nicholas Large White turkey breeder hens, *Line 700*, were obtained on day of hatch and placed in floor pens covered with pine shavings. Each pen was approximately 4.0 m x 3.6 m in size. The breeder hens were equally divided among six grower treatment groups. Quantitative feed restriction in four treatment groups began at six WOA and were aimed to achieve differences in BW of 45% less than the BW of the full-fed control (CON) at 16 WOA. This level of restriction was then maintained until either 17.0 (R17.0), 18.3 (R18.3), 19.6 (R 19.6), or 20.9 (R20.9) WOA upon which the birds were gradually released from restriction to obtain a predetermined minimum target BW considered necessary for photostimulation. The remaining treatment group (OATS) was fed and maintained in accordance with the primary breeder's BW recommendation and feeding instructions using plain white oats from 19 through 26 WOA to control BW gain. From 27 to 31 WOA, two additional dietary treatments were superimposed on all six feeding regimens. Half of the birds were fed a 15% protein diet while the other half received an 18% protein diet.

At 31 WOA, the hens were moved into a breeder house. The floors of the layer pens were covered with pine shavings. Reproductive activity was initiated by increasing the photoperiod from 6 h per day to 13.5 h per day at lighting. Day length was increased to 14 h per day at first egg, and extended to 15 h per day at peak egg production. Additional increments of stimulatory light were added in the morning (15 min every two wk) until a 17.5 h photoperiod was reached at the end of the study. During lay, all birds were provided feed and water for *ad libitum* consumption. Diet ingredients and the calculated analysis for the various rations used during the course of the study are reported elsewhere (Chapter 1). All hens were artificially inseminated on a weekly basis. Eggs were collected at least 7 times a day and classified as either settable or non settable eggs. Eggs suitable for incubation were stored according to standard commercial conditions and set on a weekly basis (Chapter 2).

Experimental Procedures

Each breeder pen contained four trapnests. Each nest was approximately 63.5 cm high, 71.1 cm deep, and 48.3 cm wide. The gate at the entrance of the nest was 32.4 cm wide and 36.2 cm high. A wooden platform was placed in front of the nest to reduce nest contamination and to improve nest acceptance. About 10 cm of litter material were placed into each nest at 33 WOA. Nests were cleaned routinely throughout the production period and litter was added as needed. All hens were divided among 36 pens and assigned to one of the following three treatments: 1) all nest boxes within a pen filled with standard commercial pine shavings (S); 2) all nest boxes within a pen filled with Canbrands (Canbrands International Ltd, Moncton, New Brunswick, Canada E1C 9T1) paper chips (P); and 3) two nest boxes within a pen filled with shavings while the remaining two were filled with paper chips (S/P). The arrangement of the nest material in the combination treatment (S/P) was altered within replicates to negate positional effects (Hurnik *et al*., 1973; Brake, 1985). Each treatment group was replicated 12 times and the birds were kept for a standard 20 wk production cycle.

Measurements

Egg production data were calculated for percentage hen-housed production as well as average egg production per hen. The proportion of broody and/or out-of-lay hens was calculated weekly for each treatment. Eggs were marked as floor or nest eggs and classified as either settable (> 75g and good shell quality) or non-settable. Non-settable eggs included double yolked, misshaped, cracked, or soft shelled eggs.

True fertility, hatchability, and viability were assessed based on residual break-outs after each hatch was pulled. Hatchability was defined as the number of successful hatches obtained from the total number of eggs that were set. In contrast, viability was defined as the number of live poults obtained from the total number of fertile eggs. Poult weights were determined immediately after hatch. Blood glucose concentrations at hatch were measured with a glucometer (ACCU-Chek II, Boehringer Mannheim Diagnostics, Indianapolis, IN 46250) as described by Christensen *et al*. (1991).

Statistical Analysis

The data for Chapter 3 were derived from a larger experiment described in Chapter 1 and 2. Nesting materials were randomly assigned to each treatment combination and the effects were analyzed by one-way analysis of variance. The variation among individual pens was used as the error term for percentage floor, cracked, misshaped, and soft shelled eggs as well as percentage egg production, fertility, hatchability, viability, poult weight, and blood glucose levels. All percentage data were transformed using arc sine square root transformation prior to analysis. The differences among main effect means for treatments were partitioned using the Duncan option of the General Linear Model Procedure (SAS, 1988). Statements of statistical significance were based upon $P \leq 0.05$ unless otherwise stated.

RESULTS AND DISCUSSION

Table 1 shows the effect of nesting material on the proportion of floor and non-settable eggs. Overall, the number of floor eggs encountered was very high. However, no efforts were made at the beginning of the laying cycle to train the hens to use the nests to be able to determine if the birds had a preference for one of the three nest material combinations. The data clearly indicates hens had a preference for using S as nesting material. The proportion of floor eggs laid in the S treatment was 18.2 and 17.0% lower than in the P and S/P treatment, respectively ($P < .01$). There was no statistical difference with regard to percentage floor eggs when P was either provided alone or in combination with S (38.2 versus 37.0%).

The proportion of floor eggs is usually the highest at the onset of lay and then declines as the laying cycle advances (Hurnik *et al*., 1973). Each hen has to learn to lay in a nest and most hens are consistent in laying either in nests or on the floor (Appleby and McRae, 1983). Once the laying behavior is established, it is difficult to change (Perry et al., 1971; Appleby, 1984). Among breeding stock, broiler breeders lay more floor eggs than layer breeders. Similarly, strain differences exist among broiler breeders (Hurnik *et al*., 1973) and turkeys (Kosin and Mun, 1960) and a relationship between BW and nest acceptance has been suggested (Appleby, 1984). However, the effect of rearing conditions is often overlooked in relation to laying behavior. The results from the present study may therefore suggest that the type of litter and nesting material being used in turkey breeder facilities should have very similar physical properties to the one used during the rearing and holding period.

Nesting material had no effect on the production of double-yolked, misshaped, or soft shelled eggs (Table 1). However, the amount of cracked eggs was significantly affected by nesting material. The S/P treatment showed a significantly higher number of broken eggs than either the S or P treatment alone. The present result is in disagreement with Siegel and Howes (1959) who compared five different nesting materials in a group of White Rock pullets and suggested that the type of nesting material had little influence on percentage clean or nest eggs, cracked or broken eggs, provided the nests were maintained properly. They noted that birds had a preference for certain nesting materials, but considered it doubtful that type of litter would be a factor if all nests within a pen contained the same nesting material. The results from the present study do not substantiate their hypothesis. First, the results from this study clearly show differences in proportions of floor eggs between treatments that either used only S or only P. Second, combining different nesting materials resulted in an increased incidence of cracked eggs. In contrast, Anthony *et al*. (1992) compared the effect of wood shavings, shredded newspaper, and cotton seed hulls in two lines of turkeys differing in mature BW. The results showed a significant increase in egg breakage with the shredded paper as well as with increased BW of the birds. However, no comparison was made to test different nest materials in the same pen. The authors suggested that the significant increase in percentage broken eggs for the large bodied strain was consistent with behavioral observations that indicated increased nesting activity in large bodied turkey lines prior to and following egg laying. Unfortunately, the paper did not mention if appropriate adjustments in nest size had been made to accommodate for the naturally larger nest size requirement of the bigger strain.

There was significantly lower production of settable eggs for hens provided nest boxes containing P or a combination of S/P during the early stages of the laying cycle (Table 2). From 6-10 wk of production, hens laying on P had statistically the same level of egg production as hens laying on S but birds given a choice (S/P) still had statistically the lowest performance.

As egg production declined during the second part of the laying cycle, the effect of nesting material on egg production was less prevalent (Figure 1). There was no significant difference in total egg production. Numeric differences of five eggs per hen housed favored the S over the S/P treatment. Average settable egg production amounted to 87.6, 91.5, and 86.5 eggs per hen for the P, S, and the S/P treatments, respectively. Comparable results for turkey breeder hens are virtually non existent. In broiler breeders, Brake (1985) obtained significantly higher egg production for eggs laid on S as compared to Astro Turf when the birds were allowed to choose. However, when the birds were provided nest boxes that were filled with either S or Astro Turf, no difference in egg production was noticed.

Figure 2 shows the effect of nesting material on the proportion of broody and out-of-lay hens over time. The graph represents a cumulative summary. The first broody peak occurred at six wk of lay. From 12 to 18 and from 18 to 20 wk of lay, the S/P treatment segregated from the S and P treatment. However, this numeric deviation was not significant. Across treatments, the proportion of hens that went out-of-lay increased from zero percent at four wk of lay to approximately 15% at 20 wk of lay.

Nesting material had no effect on fertility, hatchability, or viability (Table 3). Viability averaged 82.7, 83.7, and 84.1% for the P, S, and the S/P treatment, respectively. According to Brake (1985), viability was significantly improved when nest boxes were furnished with nest pads. However, the result could not be explained conclusively based on the level of microbial contamination since the bacterial count was not consistently different among eggs laid on either shavings and nest pads.

Poult quality was not affected by nesting material. Poult weight averaged 66.8, 65.4, and 66.9 g for the P, S, and the S/P treatment, respectively. Similarly, there were no differences in blood glucose concentrations at hatch.

In conclusion, the present data advises breeder personnel not to use several different nesting materials in a breeder house at the same time if the goal is to maximize egg production. Turkeys have the ability to differentiate between nesting materials and develop a preference for a particular material. P may be a poor substitute for conventional nesting materials.

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TABLE 1. Effect of nesting material on floor and non-settable egg production (mean ± SEM)

Variable	Nesting material[1]		
	Paper chips	Pine shavings	Paper chips/pine shavings
	% incidence		
Floor eggs	38.2 ± 3.9^{A}	20.0 ± 2.9^{B}	37.0 ± 5.0^{A}
Double yolked eggs	0.2 ± 0.0	0.2 ± 0.1	0.3 ± 0.1
Misshaped eggs	0.9 ± 0.2	0.9 ± 0.2	1.2 ± 0.3
Soft shelled eggs	1.3 ± 0.3	1.3 ± 0.5	2.7 ± 0.7
Cracked eggs	3.1 ± 0.3^{b}	3.7 ± 0.4^{b}	5.6 ± 0.8^{a}

$^{A-B}$ Means within a row with no common superscripts differ significantly ($P \le 0.01$).
$^{a-b}$ Means within a row with no common superscripts differ significantly ($P \le 0.05$).
[1] Paper chips = all 4 nest boxes in a pen were filled with paper chips only. Pine shavings = all 4 nest boxes in a pen were filled with pine shavings only. Paper chips/pine shavings = Two of the 4 nest boxes in a pen were filled with paper chips and 2 with pine shavings. Treatments started at 31 wk of age.

TABLE 2. Effect of nesting material on egg production (mean ±SEM)

Week	Paper chips	Pine shavings	Paper chips/ pine shavings
	Nesting material[1]		
		Avg. settable eggs/hen	
1 - 5	23.4 ± 0.5[b]	25.2 ± 0.2[a]	22.5 ± 0.8[b]
6 - 10	23.8 ± 0.5[ab]	25.3 ± 0.3[a]	22.9 ± 0.9[b]
11 - 15	21.5 ± 0.7	22.1 ± 0.1	21.8 ± 0.8
16 - 20	18.8 ± 1.0	18.7 ± 1.0	19.2 ± 0.9
1 - 10	47.1 ± 0.9[B]	50.5 ± 0.7[A]	45.3 ± 1.5[B]
11 - 20	40.3 ± 1.7	40.8 ± 1.6	41.0 ± 1.5
1 - 20	87.6 ± 2.2	91.5 ± 1.8	86.5 ± 2.9
		% HH production	
1 - 5	66.8 ± 1.3[b]	71.9 ± 1.4[a]	64.2 ± 2.1[b]
6 - 10	68.1 ± 1.6[ab]	72.3 ± 0.9[a]	65.4 ± 2.6[b]
11 - 15	61.3 ± 2.1	63.0 ± 1.9	62.3 ± 2.4
16 - 20	53.7 ± 3.0	53.4 ± 2.9	55.0 ± 2.4
1 - 10	67.4 ± 1.2[B]	72.1 ± 0.9[A]	64.8 ± 2.2[B]
11 - 20	57.5 ± 2.4	58.2 ± 2.3	58.6 ± 2.2
1 - 20	62.6 ± 1.6	65.4 ± 1.3	61.8 ± 2.1

[A-B] Means within a row with no common superscripts differ significantly ($P \leq 0.01$).

[a-b] Means within a row with no common superscripts differ significantly ($P \leq 0.05$).

[1] Paper chips = all 4 nest boxes in a pen were filled with paper chips only. Pine shavings = all 4 nest boxes in a pen were filled with pine shavings only. Paper chips/pine shavings = Two of the 4 nest boxes in a pen were filled with paper chips and 2 with pine shavings. Treatments started at 31 wk of age.

TABLE 3. Effect of nesting material on fertility, hatchability, and poult characteristics (mean ± SEM)[1]

	Nesting material[2]		
Variable	Paper chips	Pine shavings	Paper chips/pine shavings
		% incidence	
Fertility	97.2 ± 0.3	96.8 ± 0.7	97.2 ± 0.3
Hatchability[3]	80.3 ± 0.7	81.0 ± 0.9	81.8 ± 0.8
Viability[4]	82.7 ± 0.7	83.7 ± 0.7	84.1 ± 0.7
		g or mg/dl	
Poult weight	66.8 ± 0.4	65.4 ± 0.3	66.9 ± 0.5
Blood glucose[5]	254.1 ± 2.8	252.8 ± 1.8	252.4 ± 2.0

[1] No significant differences ($P > 0.05$).

[2] Paper chips = all 4 nest boxes in a pen were filled with paper chips only. Pine shavings = all 4 nest boxes in a pen were filled with pine shavings only. Paper chips/pine shavings = Two of the 4 nest boxes in a pen were filled with paper chips and 2 with pine shavings. Treatments started at 31 wk of age.

[3] Hatchability is defined as the number of successful hatches obtained from the total number of eggs that were set.

[4] Viability is defined as the number of live poults obtained from the total number of fertile eggs.

[5] Blood glucose concentration of poults measured at hatch.

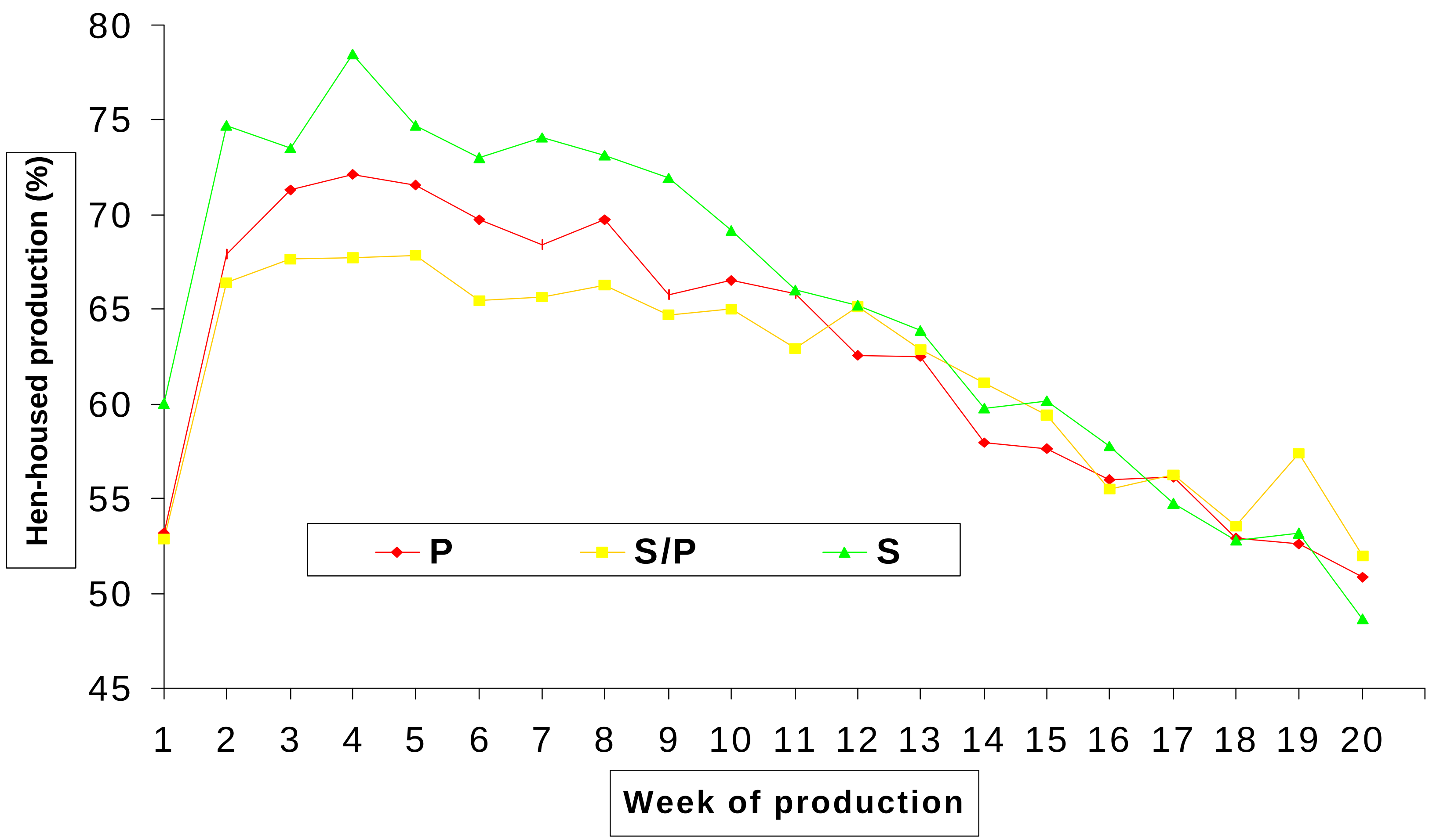

Figure 1. Effect of nesting material on percent hen-housed egg production of turkey breeder hens. Paper chips = all 4 nest boxes in a pen were filled with paper chips only (P). Pine shavings = all 4 nest boxes in a pen were filled with pine shavings only (S). Paper chips/pine shavings = Two of the 4 nest boxes in a pen were filled with paper chips and two with pine shavings (S/P).

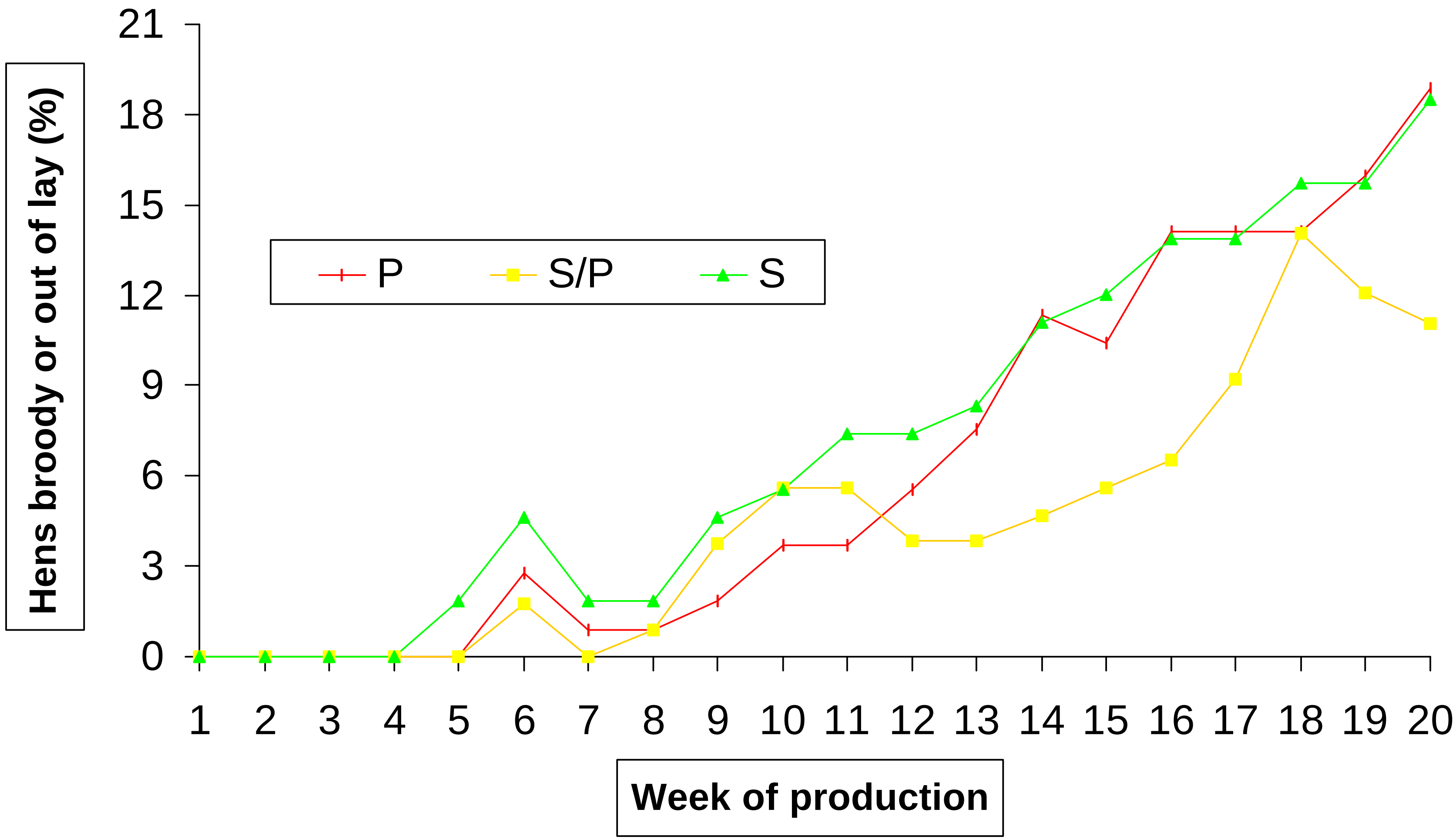

Figure 2. Effect of nesting material on percent broody or out-of-lay turkey breeder hens. Paper chips = all 4 nest boxes in a pen were filled with paper chips only (P). Pine shavings = all 4 nest boxes in a pen were filled with pine shavings only (S). Paper chips/pine shavings = Two of the 4 nest boxes in a pen were filled with paper chips and two with pine shavings (S/P).

GENERAL SYNTHESIS

I. Feed Restriction and Dietary Prebreeder Protein

Reproductive efficiency in meat-type poultry is relatively low. This causal relationship is based on a negative correlation between reproductive traits and growth characteristics. The broiler breeder industry has used feed restriction programs for many years with considerable success as a tool to minimize these undesirable and deleterious relationships. In fact, the rapid pace of genetic improvements in growth performance of broilers would not have been possible without this management innovation.

Research suggests that feed restriction improves egg production by reducing the number of large yellow follicles and the proportion of multiple follicle sets, which are associated with an improvement in settable egg production. While feed restriction of turkey breeder hens has been attempted many times, the results of earlier studies did not usually show consistent improvements in reproduction. Most of these studies were carried out with Broad Breasted Bronze turkeys. However, the modern-day commercial turkey has changed considerably and is thought to be more responsive to feed restriction than strains from the past (Hester and Stevens, 1990).

Indeed, in a previous trial, the present author compared the effect of a 15, 30, or 45% BW reduction in commercial BUT turkeys and reported significant improvements in egg production and hatchability only when a 45% restriction was implemented. It was hypothesized that the effectiveness of the feeding program could be further improved by determining the optimum length of time of restriction. This hypothesis provided the foundation for the design of the present study.

Nicholas turkey breeder hens were physically restricted beginning at 6 WOA to achieve body weights 45% less than the weight of *an ad libitum* fed control at 16 WOA. This level of restriction was maintained until either 17.0 (R17.0), 18.3 (R18.3), 19.6 (R19.6), or 20.9 (R20.9) WOA upon which the birds began realimentation. Feed allocation was gradual increased attempting to meet a predetermined minimum target BW considered necessary for photostimulation. A prebreeder dietary protein treatment was superimposed on the restriction treatments to accelerate BW gain during the period of *ad libitum* consumption. A second control group was fed plain white oats according to the primary breeder's recommendation and feeding instructions.

Feed restriction reduced feed consumption and improved feed efficiency significantly. After release from restriction, none of the quantitative restriction treatments met the minimum target BW for photostimulation. Flock uniformity, sexual maturity and body composition were similar at photostimulation. There were no differences in number of large yellow follicles. The higher prebreeder protein content was associated with a significant increase in proportions of multiple follicle groups and a concomitant decrease in soft shelled eggs. Settable egg production (1-20 wk) was not significantly improved by either feeding regimens or prebreeder protein content. However, numeric differences in egg production favored the R18.3, R17.0, and the OATS treatment. The former two treatments had statistically the highest production during the first 10 wk of lay. Quantitatively restricted birds exhibited low persistency in production during the second part of the laying cycle. The proportion of birds that ceased laying increased significantly with duration of restriction. There were no differences in egg shell quality traits, fertility, and hatchability, but poult weight was significantly reduced in the R18.3 treatment.

Scientific Implications

The present study did not reveal any significant differences in total production of settable eggs. This suggests that duration of restriction did not exert an effect within the parameters of this study. Similarly, regardless whether turkey breeder hens were restricted to 45% from 6-17 or 6-21 WOA, this did not have an impact on the number of large yellow follicles at photostimulation. Moreover, there were no significant differences between the four restriction treatments on one hand and the CON group on the other hand. These results are consistent with the observations made by Klein-Hessling (1994) who reduced BW by 45% at 16 WOA and did not find differences in follicle numbers between restricted and full-fed birds. Similarly, Renema *et al*. (1995) restricted male-line hens to either 80 or 90% of the BW of control birds until point of lay and noted no significant differences in follicle count. Taken together, these results are indicative that duration of restriction *per-se* does not affect yellow follicle numbers in turkeys. It is now clear that initial experiments (Hocking *et al*., 1987; Hocking, 1990, 1992a) investigating the effects of feed restriction on ovarian function gave rise to false interpretation and conclusions. Recently, these relationships have been delineated (Hocking, 1993; 1994a,b) and are now properly defined in broiler breeders, but not yet in turkeys. Contrary to previous results, there was no evidence for an effect of age at which the restriction was applied nor was there evidence for an effect of degree of restriction on follicle number. Instead, it is now known that feed intake during the period immediately prior to the onset of lay had a major influence on follicular maturation and was more important than BW *per se* (Hocking, 1993; Hocking, 1994a,b). Supporting evidence for this postulation can be derived from the results of the present study. Restricted birds, although substantially lighter at photostimulation, had significantly more feed available on a per kg BW basis and, consequently, follicle count did not differ. This suggests that the transition time in turkey breeders, beginning during the last few wk before photostimulation and extending until after the first broody peak, plays an equally important role to the pullet-layer transition time in broiler breeders.

The same observations can also be interpreted in a different way. Assuming that the degree of restriction and duration of restriction do not affect follicle number, then it should be possible to reduce the degree of restriction to a slightly higher feed intake in an effort to expose the birds to a slightly less stressful condition. As a result, the birds may be better predisposed to be able to cope with the impact of restriction and, perhaps, exhibit a better compensatory growth and, thus increasing the likelihood of achieving better uniformity and a yet to be defined optimum target BW. However, substantial BW restrictions would still be necessary so that there remains a substantial BW gain potential for the bird. In other words, the bird must be given the room to respond to increases in feed allowance with increases in BW (Klein-Hessling, 1994).

If feed consumption and, in particular, pattern of feed intake is so critical, then turkey breeder hens should be fed according to a carefully designed feeding program with controlled and stepwise increases in feed allowance and should never be released to *ad libitum* consumption immediately after release from restriction as suggested by Klein-Hessling (1994). This target oriented feed allocation may also shift nutrients to a later reproductive stage at which conventionally managed and well conditioned flocks may suffer potential performance due to insufficient nutrients resulting in excessive BW loss and a concomitant increase in broodiness.

Basic research on the impact of growth rate prior to photostimulation on subsequent reproductive performance is long overdue. For instance, a study designed to investigate the effects of BW development over time (i.e. gaining or losing 1.0 to 1.3 kg, or maintaining BW) during the last few wk prior to photostimulation (5 wk), would greatly aid in delineating the role of lighting BW, BW changes (rate of gain), feed consumption, pattern of feed intake on ovarian function, and settable egg production. In this regard, Klein-Hessling (1994) observed a significant positive correlation between the rate of gain prior to photostimulation and subsequent reproductive performance. It is, however, clear from the results of the present study that a minimum target BW must be achieved to improve persistency of lay. Furthermore, administration of anabolic steroids could be used to unveil the relevance of increased fleshing and accretion of lean tissue mass on reproductive performance.

More research needs to be conducted to explain the failure of recovery from restriction from a metabolic, physiological, and endocrine perspective. Presently, there is very little information regarding the nutrient requirements of feed restricted turkey breeder hens during restriction and following photostimulation. Energy, protein, nutrient density, energy protein ratios, and vitamin and mineral fortification may require repeated adjustments throughout the life of a restricted flock. Each of these factors alone or in combination may have an effect on recovery from restriction, subsequent rate of BW gain, ovarian function, and egg production.

What would be the effect if those birds that did not reach the target BW at photostimulation were kept separately and allowed to continue to grow until they would have met the target BW? What would their level of performance be? Their rate of gain would obviously be low but would it have physiological significance? What level of persistency would these birds display? In contrast, would it be more effective to separate severely under weight birds during the time of actual implementation of restriction and feed them on an *ad libitum* basis to allow them to meet the target BW? Would it not be better to select turkey breeder hens under a similar severe feed restriction regimen in the first place and to continue to breed those candidates that cope well with the impact of restriction and give superior reproductive performance?

An important question is how do we embark upon the fact that 10% of the flock in the quantitative restricted groups ceased egg production? Percent hen-day production of the quantitative restriction treatments was equivalent to the level of performance of the other treatments. Presently, it is unclear whether this cessation in egg production is a carry-over effect due to the implementation of the restriction treatments during the growing period, or the result of a nutritional deficiency. Have, for instance, the nutritional needs of restricted hens during the second half of the laying cycle fundamentally changed? Perhaps, an experiment involving choice feeding implemented before, during, or after photostimulation may be helpful in identifying nutritional needs. Force-feeding experiments could also be conducted on a small trial basis, while a closer look at biology of starvation and the theory of compensatory growth might reveal some important insights.

There is a considerable body of evidence suggesting that ovarian function changes with selection for high growth rates (Bacon *et al*., 1972). Several workers have reported that the reduction in BW of birds with the *dw* gene is associated with a decrease in number of large yellow follicles (Reddy and Siegel, 1976; Hocking *et al*., 1987). The *dw* gene mediates this effect through a reduction in the responsiveness to growth hormone (Brunside *et al*., 1991). Growth hormone (GH) is thought to act indirectly on growth through an increased activity of insulin-like growth factor-1 (IGF-1) either derived from the general circulation and/or via local production within the ovary (Hocking, 1994a,b). There does not appear to be a direct relationship between growth of different strains and plasma concentrations of IGF-1 (Goddard *et al*., 1988; Ballard *et al*., 1990). Slower growing strains have consistently higher plasma GH concentrations than large selected lines during the relatively rapid growth phase of the first 10 wk after hatching (Goddard *et al*., 1988; Anthony *et al*., 1990; Hocking *et al*., 1994). In turkeys, IGF-1 secretion varies with sex of the bird and changes as the animal matures (Bacon *et al*., 1993). Fasting or low dietary protein concentrations, which both result in decreased growth, have been shown to increase plasma GH (Scanes *et al*., 1981) and IGF-1 concentration (Hocking, 1994a,b). The avian IGF-1 gene is expressed in the ovary (Roberts *et al*., 1990) and the presence of a specific receptor in the granulosa cells has been demonstrated (Decuypere *et al*., 1994). IGF-1 has a mitogenic action *in vitro* on both granulosa and theca cells of hens (Roberts, 1991). Little is known about IGF-binding proteins. Nonetheless, IGF-1 potentiates basal progesteron (P_4) production and enhances LH stimulated P_4 production *in vitro* (Peddie *et al*., 1993). Furthermore, in *vivo* supplementation of IGF-1 changed the in vitro LH sensitivity of follicles. This resulted in an increased P_4 production in the F_3 follicle and a decreased P_4 production in the F_1 follicle (Huybrechts *et al.*, 1993) thereby interfering with the process of establishing a clear sequential hierarchy. Taken together, this implicates a possible role of IGF-1 *in vivo* in follicular development and maturation (Decuypere *et al*., 1994).

In vitro studies have shown that follicles from broiler breeders, in general, were more sensitive to gonadotropin stimulation than follicles from commercial layers (Armstrong, 1986). It was concluded that this observation could be related to the prevalence of multiple ovulation in *ad libitum* fed broiler breeders (Hocking, 1994a). Unfortunately, no endocrine profiles were taken in this particular study. However, the interaction of growth factors with steroid hormones and gonadotropins may be an important area for basic research into ovarian mechanisms and the possible role of positive and inhibitory feedback mechanisms involving the hypothalamus and pituitary should not be overlooked.

The reportedly increased sensitivity of feed restricted broiler breeders with regard to GnRH stimulation raises questions about our current lighting management practice. The activity of the hypothalamic-pituitary-gonadal-axis is normally controlled by the proportions of photo and scoto period within a 24 h day. The minimum day length required to stimulate gonadotropin release in chickens and turkeys is between 10 to 12 h (Sharp, 1989). In this particular study, restricted hens were initially stimulated with 13.5 h of light. It is at the onset of lay, that feed restriction exerts the strongest impact on follicular structure and egg production, but the GnRH stimulating effect of 13.5 h of stimulatory light may still be too strong and, perhaps, disrupt follicular hierarchy, and thus, reduce maximum settable egg production at this early stage in lay. Conversely, following peak production reproductive performance declines due to an insufficient recruitment of small white follicles into the yellow follicular hierarchy. If we could further reduce the photoperiod early at the beginning of the laying cycle, we may be able to continue to increase the photoperiod for a longer period of time during the later part of lay as currently practiced. This may help stimulating GnRH release, secretion of FSH, and recruitment of small white follicles into the hierarchy. Therefore, the interaction of feed restriction and lighting on ovarian function and subsequent egg production may warrant some interesting insight into ovarian regulation and requires further study.

Practical Implications

These results, together with the pool of available literature, suggest that BW control can be used to reduce feed cost significantly. Furthermore, there is sufficient evidence to suggest that feed restriction will lead to similar flock uniformity. Even birds restricted to 45% from 6-21 WOA can achieve a similar range in BW at a conventional lighting age under the condition that proper management provisions are made. The same principles, as outlined before, apply to managing sexual maturity and initial egg weight. Restriction will not impact on fertility. This is different from broiler breeders. However, turkey hens are artificially inseminated and mating behavior is not critical. In addition, most breeder operations use either a quantitative or qualitative feeding program to condition male turkey breeders. At the present time, the effect of restriction on hatchability is inconclusive. Hatchability was improved in two trials using BUT stock (Hocking, 1992b, Klein-Hessling, 1994), but either inconsistent (Crouch *et al*.,1997) or without effect (present study) in Nicholas stock. Effects of restriction on egg production need further study. Presently, there is a high risk that when feed restriction is too severe and continued for too long, a significant proportion of the birds in a flock will be substantially below a minimum target BW to achieve maximum reproductive performance due to poor persistency. However, strain differences may exist. Finally, poult weight, poult livability, and growth performance of progeny need more attention and these criteria should be included in any trial in the future to assure that this management practice does not lead to poor performing commercial turkeys.

Conclusion

This research leaves many questions unanswered and, therefore, provides a foundation for future inquiry. A multidisciplinary approach, comparing different strains, is necessary in order to obtain an understanding of the complex subject of feed restriction in turkey breeder hens.

II. Nesting Material

Nowadays, locating high quality, inexpensive nesting materials is a difficult task across the poultry industry. The classical pine shavings are rather scarce and there is a need to find appropriate substitution products. However, not only must each potential nesting material satisfy certain physical characteristics, good nest acceptance by the flock is of equal importance. Breeder hens establish a laying behavior at the onset of production. Once hens have decided where they want to lay their eggs, it is very difficult to change this behavior. As a result, the proportion of floor eggs increases. Furthermore, floor eggs usually exhibit a higher degree of microbial contamination than nest eggs. This may affect hatchability and may interfere with hatchery operation due to exploders. Finally, floor eggs tend to get broken more often and this may encourage egg eating.

The objective of the current study was to compare the effectiveness of traditional pine shavings with an industrial manufactured paper chip product as an alternative nesting material for turkey breeder operations. By providing both materials within one and the same pen, it would be possible to make indirect inferences about nest acceptance and preference for a particular nesting material.

Each breeder pen contained four trapnests. Nests were either filled with savings, paper chips, or a combination of the two products. Nesting material affected initial egg production and the proportion of floor and cracked eggs significantly.

Scientific Implications

The present study raises many questions about factors influencing nesting behavior. Obviously, more research is needed to elucidate the effects of color and texture of nesting materials on subsequent nest acceptance. In addition, a possibility of confounding can not be completely excluded. It may very well be that the type of litter material used during rearing and, consequently, the associated experience with that material, may have had an impact on acceptance rate later on during the laying cycle. An explanation for the significant decrease in initial egg production is not immediately evident. The physiological parameters established with regard to oviduct and ovarian function, fat pad, breast muscle weight, carcass composition data, etc. (data not shown) did not reveal any differences. At the present time, it can only be speculated that certain types of nest materials may trigger a stress response. This hypothesis should be tested during experimentation in the future.

Practical Implications

Substitution products for nesting materials should be chosen carefully. A product with low bird acceptance may not only increase the proportion of floor eggs, it can also significantly impact initial egg production. The results suggest that different types of nesting materials should not be used simultaneously in the same breeder house. Turkey breeder hens can and do distinguish between nesting materials and develop a preference for a particular product. Under the current conditions of the experiment, paper chips were a poor substitute for conventional soft wood pine shavings.

Conclusion

Little attention has been paid on influences of rearing conditions on subsequent nest acceptance and even fewer efforts have been dedicated to study factors affecting the ability of hens to use nests. Consequently, choosing a nesting material should be an integral part within the broader scope of other management considerations.

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APPENDIX A

ANALYSIS OF VARIANCE TABLES - CHAPTER I

Appendix A Table 1. Analysis of variance for body weight of feed restricted turkeys breeder hens at various ages

Age (wk)	Source of variation	df	Mean square	F-value	Probability
6	Restriction	5	0.028	1.390	0.226
	Error	730	0.020		
	Total	735			
17	Restriction	5	441.729	1668.880	0.001
	Error	689	0.265		
	Total	694			
18	Restriction	5	346.811	1088.730	0.001
	Error	687	0.319		
	Total	692			
19	Restriction	5	416.816	1083.730	0.001
	Error	686	0.385		
	Total	691			
20	Restriction	5	338.492	879.550	0.001
	Error	651	0.384		
	Total	656			
21	Restriction	5	316.006	740.080	0.001
	Error	651	0.427		
	Total	656			
22	Restriction	5	264.314	565.890	0.001
	Error	650	0.467		
	Total	655			
25	Restriction	5	110.899	254.110	0.001
	Error	613	0.436		
	Total	618			
28	Restriction	5	59.978	117.240	0.001
	Diet	1	0.061	0.120	0.731
	Restriction x Diet	5	0.164	0.320	0.900
	Error	563	0.512		
	Total	574			
31	Restriction	5	43.494	74.010	0.001
	Diet	1	0.135	0.230	0.632
	Restriction x Diet	5	0.421	0.720	0.612
	Error	560	0.588		
	Total	571			
34	Restriction	5	14.966	36.720	0.001
	Diet	1	0.017	0.040	0.836
	Restriction x Diet	5	0.150	0.370	0.870
	Error	417	0.408		
	Total	428			
37	Restriction	5	13.125	30.060	0.001
	Diet	1	0.005	0.010	0.912
	Restriction x Diet	5	0.342	0.780	0.562
	Error	369	0.437		
	Total	380			

Appendix A Table 1. Analysis of variance for body weight of feed restricted turkeys breeder hens at various ages (cont'd.)

Age (wk)	Source of variation	df	Mean square	F-value	Probability
40	Restriction	5	9.891	20.350	0.001
	Diet	1	0.031	0.060	0.802
	Restriction x Diet	5	0.415	0.850	0.512
	Error	309	0.486		
	Total	320			
43	Restriction	5	7.497	13.350	0.001
	Diet	1	0.095	0.170	0.681
	Restriction x Diet	5	0.532	0.950	0.451
	Error	303	0.562		
	Total	314			
46	Restriction	5	8.135	13.640	0.001
	Diet	1	0.001	0.000	0.988
	Restriction x Diet	5	0.610	1.020	0.405
	Error	301	0.596		
	Total	312			
49	Restriction	5	7.110	11.300	0.001
	Diet	1	0.004	0.010	0.935
	Restriction x Diet	5	0.808	1.280	0.271
	Error	301	0.629		
	Total	312			
52	Restriction	5	7.083	10.950	0.001
	Diet	1	0.082	0.130	0.722
	Restriction x Diet	5	1.682	1.600	0.256
	Error	300	0.647		
	Total	311			

Appendix A Table 2. Analysis of variance for body weight changes of feed restricted turkey breeder hens at various time intervals

Age (wk)	Source of variation	df	Mean square	F-value	Probability
31-34	Restriction	5	1.799	17.630	0.001
	Diet	1	0.099	0.970	0.324
	Restriction x Diet	5	0.106	1.040	0.393
	Error	285	0.102		
	Total	296			
34-44	Restriction	5	0.421	2.540	0.029
	Diet	1	0.239	1.440	0.231
	Restriction x Diet	5	0.105	0.640	0.672
	Error	280	0.167		
	Total	291			
44-52	Restriction	5	0.178	1.810	0.111
	Diet	1	0.499	5.080	0.025
	Restriction x Diet	5	0.369	3.770	0.003
	Error	280	0.098		
	Total	291			

Appendix A Table 3. Analysis of variance for coefficient of variation for body weight of feed restricted turkey breeder hens at various ages

Age (wk)	Source of variation	df	Mean square	F-value	Probability
6	Restriction	5	0.233	0.130	0.985
	Error	30	1.808		
	Total	35			
8	Restriction	5	1.698	0.820	0.546
	Error	30	2.073		
	Total	35			
10	Restriction	5	4.120	0.990	0.439
	Error	30	4.155		
	Total	35			
12	Restriction	5	10.441	2.710	0.039
	Error	30	3.857		
	Total	35			
14	Restriction	5	10.066	2.340	0.066
	Error	30	4.305		
	Total	35			
16	Restriction	5	36.185	7.300	0.001
	Error	30	4.958		
	Total	35			
18	Restriction	5	28.922	7.070	0.001
	Error	30	4.093		
	Total	35			
20	Restriction	5	21.369	4.780	0.003
	Error	30	4.469		
	Total	35			
22	Restriction	5	27.481	5.860	0.001
	Error	30	4.689		
	Total	35			
24	Restriction	5	8.819	2.590	0.046
	Error	30	3.401		
	Total	35			
26	Restriction	5	2.547	0.690	0.636
	Error	30	3.702		
	Total	35			
28	Restriction	5	1.543	0.420	0.829
	Diet	1	4.608	1.260	0.273
	Restriction x Diet	5	1.856	0.510	0.768
	Error	24	3.662		
	Total	35			
30	Restriction	5	1.896	0.590	0.708
	Diet	1	3.868	1.200	0.284
	Restriction x Diet	5	1.745	0.540	0.742
	Error	24	3.216		
	Total	35			

Appendix A Table 3. Analysis of variance for coefficient of variation for body weight of feed restricted turkey breeder hens at various ages (cont'd.)

Age (wk)	Source of variation	df	Mean square	F-value	Probability
32	Restriction	5	1.591	0.510	0.765
	Diet	1	1.075	0.340	0.572
	Restriction x Diet	5	1.364	0.430	0.815
	Error	24	3.139		
	Total	35			
34	Restriction	5	0.802	0.410	0.832
	Diet	1	0.012	0.010	0.939
	Restriction x Diet	5	2.179	1.110	0.412
	Error	24	1.956		
	Total	35			
36	Restriction	5	0.979	0.460	0.795
	Diet	1	0.016	0.010	0.932
	Restriction x Diet	5	2.179	1.030	0.449
	Error	24	2.110		
	Total	35			
39	Restriction	5	2.233	0.620	0.691
	Diet	1	0.751	0.210	0.659
	Restriction x Diet	5	0.320	0.880	0.527
	Error	24	3.627		
	Total	35			
42	Restriction	5	2.849	0.520	0.756
	Diet	1	0.031	0.010	0.942
	Restriction x Diet	5	5.227	0.950	0.489
	Error	24	5.480		
	Total	35			
45	Restriction	5	1.260	0.160	0.972
	Diet	1	1.440	0.180	0.679
	Restriction x Diet	5	6.882	0.870	0.535
	Error	24	7.933		
	Total	35			
48	Restriction	5	2.213	0.300	0.904
	Diet	1	0.050	0.010	0.937
	Restriction x Diet	5	1.813	0.240	0.934
	Error	24	7.469		
	Total	35			
51	Restriction	5	3.637	0.540	0.743
	Diet	1	0.483	0.070	0.794
	Restriction x Diet	5	5.492	0.810	0.566
	Error	24	6.745		
	Total	35			

Appendix A Table 4. Analysis of variance for feed consumption of feed restricted turkey breeder hens from 6-53 weeks

Variable	Source of variation	df	Mean square	F-value	Probability
kg/bird	Restriction	5	1.549×10^{8}	64.730	0.001
	Diet	1	7.162×10^{6}	2.990	0.114
	Restriction x Diet	5	1.877×10^{6}	0.780	0.584
	Error	24	2.393×10^{6}		
	Total	35			
Feed/bird/day	Restriction	5	1169.310	64.730	0.001
	Diet	1	54.060	2.990	0.114
	Restriction x Diet	5	14.172	0.780	0.584
	Error	24	18.065		
	Total	35			
Feed/bird/day/ kg BW	Restriction	5	1.293	2.050	0.157
	Diet	1	0.983	1.560	0.241
	Restriction x Diet	5	0.164	0.260	0.925
	Error	24	0.631		
	Total	35			

Appendix A Table 5. Analysis of variance for feed consumption of feed restricted turkey breeder hens from 6-31 weeks

Variable	Source of variation	df	Mean square	F-value	Probability
kg/bird	Restriction	5	1.345×10^8	85.240	0.001
	Diet	1	4.500×10^5	0.290	0.598
	Restriction x Diet	5	6.571×10^5	0.420	0.833
	Error	24	1.578×10^6		
	Total	35			
Feed/bird/day	Restriction	5	3050.716	85.240	0.001
	Diet	1	10.204	0.290	0.598
	Restriction x Diet	5	14.902	0.420	0.833
	Error	24	35.791		
	Total	35			
Feed/bird/day/ kg BW	Restriction	5	0.607	0.630	0.675
	Diet	1	0.788	0.820	0.373
	Restriction x Diet	5	0.379	0.400	0.847
	Error	24	0.956		
	Total	35			

Appendix A Table 6. Analysis of variance for feed consumption of feed restricted turkey breeder hens from 17-31 weeks

Variable	Source of variation	df	Mean square	F-value	Probability
kg/bird	Restriction	5	$1.35x10^6$	1.210	0.336
	Diet	1	$2.48x10^4$	0.020	0.882
	Restriction x Diet	5	$5.01x10^5$	0.450	0.809
	Error	24	$1.11x10^6$		
	Total	35			
Feed/bird/day/ kg BW	Restriction	5	$1.63x10^2$	330.1	0.001
	Diet	1	0.09	0.190	0.664
	Restriction x Diet	5	0.48	0.970	0.458
	Error	24	0.50		
	Total	35			

Appendix A Table 7. Analysis of variance for feed consumption of feed restricted turkey breeder hens from 17-37 weeks

Variable	Source of variation	df	Mean square	F-value	Probability
kg/bird	Restriction	5	$2.65x10^6$	3.040	0.034
	Diet	1	$1.39x10^4$	0.020	0.901
	Restriction x Diet	5	$5.63x10^5$	0.650	0.668
	Error	24	$8.73x10^5$		
	Total	35			
Feed/bird/day/ kg BW	Restriction	5	$1.05x10^2$	256.8	0.001
	Diet	1	0.02	0.040	0.847
	Restriction x Diet	5	0.15	0.370	0.860
	Error	24	0.41		
	Total	35			

Appendix A Table 8. Analysis of variance for feed consumption of feed restricted turkey breeder hens from 32-53 weeks

Variable	Source of variation	df	Mean square	F-value	Probability
kg/bird	Restriction	5	2.367×10^6	1.840	0.193
	Diet	1	4.022×10^6	3.130	0.107
	Restriction x Diet	5	9.022×10^5	0.700	0.634
	Error	24	1.283×10^6		
	Total	35			
Feed/bird/day	Restriction	5	99.372	1.840	0.193
	Diet	1	169.591	3.130	0.107
	Restriction x Diet	5	38.042	0.700	0.634
	Error	24	54.111		
	Total	35			
Feed/bird/day/ kg BW	Restriction	5	2.864	5.410	0.012
	Diet	1	1.283	2.420	0.151
	Restriction x Diet	5	0.095	0.180	0.965
	Error	24	0.530		
	Total	35			

Appendix A Table 9. Analysis of variance for feed conversion (feed:gain ratio) of feed restricted turkey breeder hens from 6-31 weeks

Age (wk)	Source of variation	df	Mean square	F-value	Probability
6-31	Restriction	5	0.245	80.990	0.001
	Diet	1	0.001	0.370	0.551
	Restriction x Diet	5	0.004	1.220	0.330
	Error	24	0.003		
	Total	35			

Appendix A Table 10. Analysis of variance for mortality[1] and culls[2] of feed restricted turkey breeder hens during various time periods

Age (wks)	Source of variation	df	Mean square	F-value	Probability
6-31[1]	Restriction	5	6.15×10^{-3}	0.410	0.834
	Diet	1	8.57×10^{-3}	0.580	0.455
	Restriction x Diet	5	1.68×10^{-2}	1.130	0.371
	Error	24	1.48×10^{-2}		
	Total	35			
6-53[1]	Restriction	5	1.29×10^{-2}	0.500	0.769
	Diet	1	7.73×10^{-4}	0.030	0.866
	Restriction x Diet	5	2.38×10^{-2}	0.930	0.548
	Error	24	2.56×10^{-2}		
	Total	35			
31[2]	Restriction	5	1.67×10^{-1}	8.880	0.002
	Diet	1	5.82×10^{-3}	0.310	0.590
	Restriction x Diet	5	4.44×10^{-3}	0.240	0.937
	Error	24	1.88×10^{-2}		
	Total	35			

Appendix A Table 11. Analysis of variance for feed restricted turkey breeder hens either broody or out-of-lay (%)

wk of lay	Source of variation	df	Mean square	F-value	Probability
19	Restriction	5	$1.48x10^{-3}$	4.240	0.025
	Diet	1	$3.46x10^{-6}$	0.010	0.923
	Restriction x Diet	5	$4.07x10^{-4}$	1.160	0.408
	Error	24	$3.15x10^{-4}$		
	Total	35			
20	Restriction	5	$1.38x10^{-3}$	3.790	0.035
	Diet	1	$6.08x10^{-5}$	0.170	0.691
	Restriction x Diet	5	$2.70x10^{-4}$	0.740	0.610
	Error	24	$3.64x10^{-4}$		
	Total	35			
1-20	Restriction	5	$2.75x10^{-4}$	1.910	0.180
	Diet	1	$1.03x10^{-5}$	0.070	0.795
	Restriction x Diet	5	$9.73x10^{-5}$	0.680	0.652
	Error	24	$9.73x10^{-5}$		
	Total	35			

Appendix A Table 12. Analysis of variance for onset of sexual maturity of feed restricted turkey breeder hens

Variable	Source of variation	df	Mean square	F-value	Probability
1st egg	Restriction	5	0.8667	0.710	0.628
	Diet	1	1.000	0.820	0.386
	Restriction x Diet	5	1.133	0.930	0.500
	Error	24	1.217		
	Total	35			
50 % egg production	Restriction	5	0.450	0.480	0.782
	Diet	1	0.250	0.270	0.616
	Restriction x Diet	5	0.450	0.480	0.782
	Error	24	0.933		
	Total	35			

Appendix A Table 13. Analysis of variance for fat pad weight of feed restricted turkey breeder hens at various ages

Age (wk)	Source of variation	df	Mean square	F-value	Probability
17 (g)	Restriction	5	27620.147	41.290	0.001
	Error	26	668.908		
	Total	31			
17 (%)	Restriction	5	$1.78x10^{-2}$	59.850	0.001
	Error	26	$2.98x10^{-4}$		
	Total	31			
20 (g)	Restriction	5	38537.326	70.260	0.001
	Error	28	548.504		
	Total	33			
20 (%)	Restriction	5	$1.26x10^{-2}$	30.710	0.001
	Error	28	$4.09x10^{-4}$		
	Total	33			
23 (g)	Restriction	5	53234.429	39.310	0.001
	Error	29	1354.283		
	Total	34			
23 (%)	Restriction	5	$6.26x10^{-3}$	18.290	0.001
	Error	29	$3.42x10^{-4}$		
	Total	34			
26 (g)	Restriction	5	18574.820	8.010	0.001
	Error	35	2319.890		
	Total	40			
26 (%)	Restriction	5	$8.17x10^{-4}$	3.580	0.010
	Error	35	$2.28x10^{-4}$		
	Total	40			
31 (g)	Restriction	5	3811.119	1.020	0.422
	Diet	1	1009.517	0.270	0.607
	Restriction x Diet	5	2714.998	0.730	0.609
	Error	36	3744.108		
	Total	47			
31 (%)	Restriction	5	$1.09x10^{-4}$	0.390	0.852
	Diet	1	$2.06x10^{-4}$	0.740	0.396
	Restriction x Diet	5	$1.84x10^{-4}$	0.660	0.656
	Error	36	$2.79x10^{-4}$		
	Total	47			
34 (g)	Restriction	5	9481.188	2.700	0.048
	Diet	1	2744.152	0.780	0.386
	Restriction x Diet	5	1045.810	0.300	0.909
	Error	36	3509.963		
	Total	47			
34 (%)	Restriction	5	$4.55x10^{-4}$	1.640	0.192
	Diet	1	$3.13x10^{-5}$	0.110	0.740
	Restriction x Diet	5	$5.28x10^{-5}$	0.190	0.963
	Error	36	$2.78x10^{-4}$		
	Total	47			

Appendix A Table 13. Analysis of variance for fat pad weight of feed restricted turkey breeder hens at various ages (cont'd.)

Age (wk)	Source of variation	df	Mean square	F-value	Probability
37 (g)	Restriction	5	14372.829	3.080	0.021
	Diet	1	4346.127	0.930	0.341
	Restriction x Diet	5	3405.437	0.730	0.606
	Error	48	4668.148		
	Total	59			
37 (%)	Restriction	5	$6.61x10^{-4}$	1.890	0.122
	Diet	1	$6.08x10^{-4}$	1.740	0.197
	Restriction x Diet	5	$2.82x10^{-4}$	0.800	0.554
	Error	48	$3.50x10^{-4}$		
	Total	59			

Appendix A Table 14. Analysis of variance for breast weight of feed restricted turkey breeder hens at various ages

Age (wk)	Source of variation	df	Mean square	F-value	Probability
17 (g)	Restriction	5	797222.494	47.050	0.001
	Error	26	16944.784		
	Total	31			
17 (%)	Restriction	5	2.27×10^{-3}	6.830	0.001
	Error	26	3.32×10^{-4}		
	Total	31			
20 (g)	Restriction	5	1147500.583	39.400	0.001
	Error	28	29123.249		
	Total	33			
20 (%)	Restriction	5	1.92×10^{-3}	6.000	0.001
	Error	28	3.19×10^{-4}		
	Total	33			
23 (g)	Restriction	5	1008891.378	29.910	0.001
	Error	30	33729.556		
	Total	35			
23 (%)	Restriction	5	1.87×10^{-3}	6.140	0.001
	Error	30	3.04×10^{-4}		
	Total	35			
26 (g)	Restriction	5	591498.100	18.500	0.001
	Error	36	31972.516		
	Total	41			
26 (%)	Restriction	5	1.53×10^{-3}	4.380	0.003
	Error	36	3.49×10^{-4}		
	Total	41			
31 (g)	Restriction	5	358822.375	4.290	0.004
	Diet	1	108908.809	1.300	0.261
	Restriction x Diet	5	137745.217	1.650	0.173
	Error	36	83611.413		
	Total	47			
31 (%)	Restriction	5	5.54×10^{-4}	0.990	0.435
	Diet	1	3.19×10^{-4}	0.570	0.454
	Restriction x Diet	5	1.19×10^{-3}	2.140	0.083
	Error	36	5.57×10^{-4}		
	Total	47			
34 (g)	Restriction	5	60116.117	0.790	0.572
	Diet	1	822.584	0.010	0.918
	Restriction x Diet	5	110703.107	1.450	0.249
	Error	35	76535.093		
	Total	46			
34 (%)	Restriction	5	1.80×10^{-4}	0.430	0.822
	Diet	1	4.79×10^{-5}	1.140	0.297
	Restriction x Diet	5	4.71×10^{-5}	1.130	0.378
	Error	35	4.19×10^{-4}		
	Total	46			

Appendix A Table 14. Analysis of variance for breast weight of feed restricted turkey breeder hens at various ages (cont'd.)

Age (wk)	Source of variation	df	Mean square	F-value	Probability
37 (g)	Restriction	5	155211.465	2.230	0.074
	Diet	1	11855.199	0.170	0.683
	Restriction x Diet	5	31599.052	0.450	0.808
	Error	48	69730.568		
	Total	59			
37 (%)	Restriction	5	$3.99x10^{-4}$	1.150	0.352
	Diet	1	$7.34x10^{-5}$	0.210	0.648
	Restriction x Diet	5	$3.30x10^{-4}$	0.960	0.459
	Error	48	$3.46x10^{-4}$		
	Total	59			

Appendix A Table 15. Analysis of variance for liver weight of feed restricted turkey breeder hens at various ages

Age (wk)	Source of variation	df	Mean square	F-value	Probability
17 (g)	Restriction	5	102.982	0.200	0.958
	Error	26	504.523		
	Total	31			
17 (%)	Restriction	5	2.41×10^{-3}	13.550	0.001
	Error	26	1.78×10^{-4}		
	Total	31			
20 (g)	Restriction	5	287.596	1.260	0.309
	Error	28	228.441		
	Total	33			
20 (%)	Restriction	5	1.83×10^{-3}	35.410	0.001
	Error	28	5.16×10^{-5}		
	Total	33			
23 (g)	Restriction	5	3099.445	7.360	0.001
	Error	30	420.928		
	Total	35			
23 (%)	Restriction	5	3.02×10^{-3}	36.990	0.001
	Error	30	8.16×10^{-5}		
	Total	35			
26 (g)	Restriction	5	4710.763	6.260	0.001
	Error	35	752.621		
	Total	40			
26 (%)	Restriction	5	1.74×10^{-3}	15.120	0.001
	Error	35	1.15×10^{-4}		
	Total	40			
31 (g)	Restriction	5	90.843	0.390	0.856
	Diet	1	41.311	0.180	0.678
	Restriction x Diet	5	183.888	0.780	0.571
	Error	36	235.727		
	Total	47			
31 (%)	Restriction	5	1.19×10^{-4}	2.380	0.057
	Diet	1	1.00×10^{-7}	0.000	0.965
	Restriction x Diet	5	6.60×10^{-5}	1.320	0.277
	Error	36	4.99×10^{-5}		
	Total	47			
34 (g)	Restriction	5	357.245	0.760	0.586
	Diet	1	130.182	0.280	0.603
	Restriction x Diet	5	919.113	1.960	0.124
	Error	36	468.061		
	Total	47			
34 (%)	Restriction	5	7.67×10^{-5}	1.030	0.423
	Diet	1	2.67×10^{-5}	0.360	0.556
	Restriction x Diet	5	1.04×10^{-5}	1.390	0.265
	Error	35	7.47×10^{-5}		
	Total	46			

Appendix A Table 15. Analysis of variance for liver weight of feed restricted turkey breeder hens at various ages (cont'd.)

Age (wk)	Source of variation	df	Mean square	F-value	Probability
37 (g)	Restriction	5	1232.024	3.330	0.015
	Diet	1	145.432	0.390	0.535
	Restriction x Diet	5	532.386	1.440	0.235
	Error	48	369.880		
	Total	59			
37 (%)	Restriction	5	$1.28x10^{-4}$	2.120	0.086
	Diet	1	$1.82x10^{-5}$	0.300	0.587
	Restriction x Diet	5	$1.07x10^{-4}$	1.780	0.144
	Error	48	$6.03x10^{-5}$		
	Total	59			

Appendix A Table 16. Analysis of variance for gizzard weight of feed restricted turkey breeder hens at various ages

Age (wk)	Source of variation	df	Mean square	F-value	Probability
17 (g)	Restriction	5	512.076	1.310	0.290
	Error	26	390.460		
	Total	31			
17 (%)	Restriction	5	$2.81x10^{-3}$	14.150	0.001
	Error	26	$1.98x10^{-4}$		
	Total	31			
20 (g)	Restriction	5	287.596	1.260	0.309
	Error	28	228.441		
	Total	33			
20 (%)	Restriction	5	$2.17x10^{-3}$	11.780	0.001
	Error	28	$1.85x10^{-4}$		
	Total	33			
23 (g)	Restriction	5	6131.864	39.74	0.001
	Error	30	420.928		
	Total	35			
23 (%)	Restriction	5	$1.85x10^{-3}$	37.770	0.001
	Error	30	$4.89x10^{-5}$		
	Total	35			
26 (g)	Restriction	5	13188.542	47.980	0.001
	Error	36	274.856		
	Total	41			
26 (%)	Restriction	5	$1.96x10^{-3}$	29.930	0.001
	Error	36	$6.55x10^{-5}$		
	Total	41			
31 (g)	Restriction	5	1286.114	9.000	0.001
	Diet	1	75.347	0.530	0.472
	Restriction x Diet	5	172.059	1.200	0.327
	Error	36	142.866		
	Total	47			
31 (%)	Restriction	5	$1.72x10^{-4}$	3.910	0.006
	Diet	1	$4.93x10^{-5}$	1.120	0.297
	Restriction x Diet	5	$5.86x10^{-5}$	1.330	0.273
	Error	36	$4.40x10^{-5}$		
	Total	47			
34 (g)	Restriction	5	603.410	1.510	0.227
	Diet	1	1077.093	2.700	0.115
	Restriction x Diet	5	265.765	0.670	0.654
	Error	36	399.568		
	Total	47			
34 (%)	Restriction	5	$6.25x10^{-5}$	0.690	0.635
	Diet	1	$9.76x10^{-5}$	1.08	0.310
	Restriction x Diet	5	$8.46x10^{-5}$	0.940	0.477
	Error	36	$9.03x10^{-5}$		
	Total	47			

Appendix A Table 16. Analysis of variance for gizzard weight of feed restricted turkey breeder hens (cont'd.)

Age (wk)	Source of variation	df	Mean square	F-value	Probability
37 (g)	Restriction	5	880.707	1.720	0.157
	Diet	1	544.031	1.060	0.310
	Restriction x Diet	5	257.539	0.500	0.772
	Error	48	511.866		
	Total	59			
37 (%)	Restriction	5	$9.86x10^{-5}$	0.950	0.464
	Diet	1	$8.69x10^{-5}$	0.830	0.368
	Restriction x Diet	5	$5.02x10^{-5}$	0.480	0.787
	Error	48	$6.41x10^{-5}$		
	Total	59			

Appendix A Table 17. Analysis of variance for shank length of feed restricted turkey breeder hens at various ages

Age (wk)	Source of variation	df	Mean square	F-value	Probability
17	Restriction	5	65.107	6.940	0.003
	Error	26	9.386		
	Total	31			
20	Restriction	5	41.084	2.490	0.055
	Error	28	16.513		
	Total	33			
23	Restriction	5	18.864	1.880	0.123
	Error	30	10.016		
	Total	35			
26	Restriction	5	38.823	3.520	0.011
	Error	36	11.019		
	Total	41			
31	Restriction	5	20.555	1.780	0.142
	Diet	1	29.619	2.570	0.1180
	Restriction x Diet	5	5.807	0.500	0.772
	Error	36	11.547		
	Total	47			
34	Restriction	5	29.825	1.751	0.165
	Diet	1	0.425	0.020	0.876
	Restriction x Diet	5	9.050	0.530	0.751
	Error	36	17.052		
	Total	47			
37	Restriction	5	48.190	5.050	0.001
	Diet	1	61.961	6.500	0.016
	Restriction x Diet	5	5.059	0.530	0.752
	Error	48	9.535		
	Total	59			

Appendix A Table 18. Analysis of variance for keel length of feed restricted turkey breeder hens at various ages

Age (wk)	Source of variation	df	Mean square	F-value	Probability
17	Restriction	5	4.927	12.870	0.001
	Error	26	0.383		
	Total	31			
20	Restriction	5	4.840	15.780	0.001
	Error	28	0.308		
	Total	33			
23	Restriction	5	2.297	6.190	0.001
	Error	30	0.371		
	Total	35			
26	Restriction	5	0.485	2.120	0.086
	Error	36	0.229		
	Total	41			
31	Restriction	5	0.729	2.960	0.025
	Diet	1	2.290×10^{-5}	0.000	0.992
	Restriction x Diet	5	0.094	0.380	0.858
	Error	36	0.246		
	Total	47			
34	Restriction	5	1.003	4.150	0.009
	Diet	1	0.026	0.110	0.747
	Restriction x Diet	5	0.241	0.990	0.445
	Error	35	0.242		
	Total	46			
37	Restriction	5	0.252	1.210	0.328
	Diet	1	0.009	0.040	0.834
	Restriction x Diet	5	0.240	1.150	0.356
	Error	48	0.209		
	Total	59			

Appendix A Table 19. Analysis of variance for whole body dry matter content (%) of feed restricted turkey breeder hens at various ages

Age (wk)	Source of variation	df	Mean square	F-value	Probability
31	Restriction	5	$1.06x10^{-4}$	0.150	0.979
	Diet	1	$1.00x10^{-8}$	0.000	0.997
	Restriction x Diet	5	$5.90x10^{-5}$	0.080	0.995
	Error	36	$7.27x10^{-4}$		
	Total	47			
34	Restriction	5	$1.73x10^{-3}$	1.950	0.129
	Diet	1	$4.51x10^{-4}$	0.510	0.484
	Restriction x Diet	5	$9.43x10^{-4}$	1.060	0.409
	Error	35	$8.87x10^{-4}$		
	Total	46			
37	Restriction	5	$1.14x10^{-3}$	1.220	0.319
	Diet	1	$2.24x10^{-3}$	2.410	0.130
	Restriction x Diet	5	$1.43x10^{-3}$	1.540	0.204
	Error	48	$9.30x10^{-4}$		
	Total	59			

Appendix A Table 20. Analysis of variance for whole body ash content (%) of feed restricted turkey breeder hens at various ages

Age (wk)	Source of variation	df	Mean square	F-value	Probability
31	Restriction	5	$3.35x10^{-4}$	0.530	0.754
	Diet	1	$3.65x10^{-5}$	0.060	0.813
	Restriction x Diet	5	$1.07x10^{-3}$	1.680	0.180
	Error	36	$6.36x10^{-4}$		
	Total	47			
34	Restriction	5	$5.70x10^{-4}$	1.590	0.206
	Diet	1	$2.75x10^{-5}$	0.080	0.784
	Restriction x Diet	5	$5.49x10^{-5}$	0.150	0.977
	Error	35	$3.58x10^{-4}$		
	Total	46			
37	Restriction	5	$1.29x10^{-4}$	0.420	0.834
	Diet	1	$1.11x10^{-4}$	0.360	0.554
	Restriction x Diet	5	$3.19x10^{-4}$	1.030	0.417
	Error	48	$3.10x10^{-4}$		
	Total	59			

Appendix A Table 21. Analysis of variance for whole body protein content (%) of feed restricted turkey breeder hens at various ages

Age (wk)	Source of variation	df	Mean square	F-value	Probability
31	Restriction	5	6.50×10^{-4}	0.630	0.679
	Diet	1	6.09×10^{-4}	0.590	0.451
	Restriction x Diet	5	1.09×10^{-3}	1.050	0.414
	Error	36	1.03×10^{-3}		
	Total	47			
34	Restriction	5	2.08×10^{-3}	2.140	0.100
	Diet	1	1.24×10^{-3}	1.280	0.271
	Restriction x Diet	5	4.04×10^{-4}	0.420	0.883
	Error	35	9.74×10^{-4}		
	Total	46			
37	Restriction	5	2.00×10^{-3}	0.760	0.588
	Diet	1	1.55×10^{-3}	0.590	0.450
	Restriction x Diet	5	3.62×10^{-3}	1.370	0.261
	Error	48	2.65×10^{-3}		
	Total	59			

Appendix A Table 22. Analysis of variance for whole body fat content (%) of feed restricted turkey breeder hens at various ages

Age (wk)	Source of variation	df	Mean square	F-value	Probability
31	Restriction	5	1.93×10^{-4}	0.510	0.766
	Diet	1	2.50×10^{-5}	0.070	0.800
	Restriction x Diet	5	5.45×10^{-4}	1.440	0.251
	Error	36	3.79×10^{-4}		
	Total	47			
34	Restriction	5	1.10×10^{-3}	1.050	0.416
	Diet	1	3.77×10^{-3}	3.590	0.072
	Restriction x Diet	5	4.73×10^{-4}	0.450	0.807
	Error	35	1.05×10^{-3}		
	Total	46			
37	Restriction	5	6.44×10^{-4}	0.570	0.723
	Diet	1	6.34×10^{-4}	0.560	0.460
	Restriction x Diet	5	1.79×10^{-3}	1.580	0.192
	Error	48	1.13×10^{-3}		
	Total	59			

APPENDIX B

ANALYSIS OF VARIANCE TABLES - CHAPTER II

Appendix B Table 1. Analysis of variance for oviduct weight of feed restricted turkey breeder hens at various ages

Age (wk)	Source of variation	df	Mean square	F-value	Probability
34 (g)	Restriction	5	411.181	1.630	0.193
	Diet	1	107.929	0.430	0.520
	Restriction x Diet	5	157.072	0.620	0.684
	Error	36	252.042		
	Total	47			
34 (%)	Restriction	5	$1.36x10^{-4}$	2.40	0.070
	Diet	1	$1.12x10^{-4}$	1.99	0.172
	Restriction x Diet	5	$2.01x10^{-5}$	0.360	0.873
	Error	34	$5.65x10^{-5}$		
	Total	45			
37 (g)	Restriction	5	59.903	0.210	0.958
	Diet	1	187.793	0.640	0.428
	Restriction x Diet	5	176.361	0.600	0.697
	Error	48	291.604		
	Total	59			
37 (%)	Restriction	5	$3.33x10^{-5}$	0.560	0.732
	Diet	1	$2.79x10^{-5}$	0.470	0.499
	Restriction x Diet	5	$2.36x10^{-5}$	0.390	0.849
	Error	48	$5.98x10^{-5}$		
	Total	59			

Appendix B Table 2. Analysis of variance for ovary weight of feed restricted turkey breeder hens at various ages

Age (wk)	Source of variation	df	Mean square	F-value	Probability
31(g)	Restriction	5	0.904	0.440	0.817
	Diet	1	5.693	2.780	0.105
	Restriction x Diet	5	0.701	0.340	0.884
	Error	35	2.050		
	Total	46			
31 (%)	Restriction	5	$1.15x10^{-5}$	1.110	0.371
	Diet	1	$2.09x10^{-5}$	2.030	0.164
	Restriction x Diet	5	$4.23x10^{-6}$	0.410	0.839
	Error	35	$1.03x10^{-5}$		
	Total	46			
34 (g)	Restriction	5	191.162	0.490	0.780
	Diet	1	226.522	0.580	0.455
	Restriction x Diet	5	1885.416	4.820	0.005
	Error	34	390.865		
	Total	45			
34 (%)	Restriction	5	$5.01x10^{-5}$	0.710	0.622
	Diet	1	$1.94x10^{-6}$	0.030	0.870
	Restriction x Diet	5	$2.88x10^{-4}$	4.090	0.010
	Error	34	$7.04x10^{-5}$		
	Total	45			
37 (g)	Restriction	5	2910.062	1.640	0.177
	Diet	1	519.197	0.290	0.592
	Restriction x Diet	5	903.075	0.510	0.767
	Error	46	1771.271		
	Total	57			
37 (%)	Restriction	5	$1.77x10^{-4}$	0.880	0.505
	Diet	1	$1.19x10^{-4}$	0.590	0.447
	Restriction x Diet	5	$1.59x10^{-4}$	0.790	0.566
	Error	46	$2.01x10^{-4}$		
	Total	57			

Appendix B Table 3. Analysis of variance for number of large yellow follicles of feed restricted turkey breeder hens at various ages

Age (wk)	Source of variation	df	Mean square	F-value	Probability
34	Restriction	5	5.05×10^{-2}	2.370	0.075
	Diet	1	6.96×10^{-2}	3.270	0.085
	Restriction x Diet	5	1.61×10^{-1}	7.550	0.003
	Error	35	6.36×10^{-2}		
	Total	46			
37	Restriction	5	8.27×10^{-2}	1.300	0.288
	Diet	1	8.95×10^{-2}	1.410	0.244
	Restriction x Diet	5	7.11×10^{-2}	1.120	0.370
	Error	46	6.36×10^{-2}		
	Total	57			

Appendix B Table 4. Analysis of variance for percentage multiple follicle groups calculated on either diameter[1] or weight[2] basis of feed restricted turkey breeder hens

Age (wk)	Source of variation	df	Mean square	F-value	Probability
34[1]	Restriction	5	0.579	0.210	0.955
	Diet	1	1.317	0.470	0.498
	Restriction x Diet	5	3.362	1.210	0.338
	Error	35	2.776		
	Total	46			
37[1]	Restriction	5	3.313	1.170	0.346
	Diet	1	4.106	1.450	0.238
	Restriction x Diet	5	2.885	1.020	0.423
	Error	46	2.833		
	Total	57			
34[2]	Restriction	5	4.556	2.660	0.005
	Diet	1	0.031	0.020	0.894
	Restriction x Diet	5	4.405	2.580	0.056
	Error	36	1.710		
	Total	47			
37[2]	Restriction	5	0.971	0.180	0.968
	Diet	1	45.235	8.350	0.007
	Restriction x Diet	5	4.008	0.740	0.599
	Error	46	5.414		
	Total	57			

Appendix B Table 5. Analysis of variance for percentage floor and non-settable egg production of feed restricted turkey breeder hens

Variable	Source of variation	df	Mean square	F-value	Probability
Floor eggs	Restriction	5	0.027	1.530	0.267
	Diet	1	0.002	0.090	0.769
	Restriction x Diet	5	0.025	1.420	0.298
	Error	24	0.017		
	Total	35			
Cracked eggs	Restriction	5	0.003	2.030	0.159
	Diet	1	0.002	1.450	0.256
	Restriction x Diet	5	0.002	0.930	0.501
	Error	24	0.002		
	Total	35			
Double yolked eggs	Restriction	5	$8.80x10^{-4}$	1.970	0.168
	Diet	1	$1.20x10^{-4}$	0.280	0.611
	Restriction x Diet	5	$1.65x10^{-3}$	3.730	0.036
	Error	24	$4.40x10^{-4}$		
	Total	35			
Misshaped eggs	Restriction	5	$4.30x10^{-4}$	0.650	0.671
	Diet	1	$1.22x10^{-2}$	18.180	0.002
	Restriction x Diet	5	$1.06x10^{-3}$	1.580	0.252
	Error	24	$6.70x10^{-4}$		
	Total	35			
Soft-shelled eggs	Restriction	5	$3.48x10^{-3}$	1.260	0.353
	Diet	1	$7.82x10^{-3}$	2.830	0.124
	Restriction x Diet	5	$3.16x10^{-3}$	1.140	0.400
	Error	24	$2.76x10^{-3}$		
	Total	35			

Appendix B Table 6. Analysis of variance for average egg production (eggs/hen housed) of feed restricted turkey breeder hens

Week	Source of variation	df	Mean square	F-value	Probability
2	Restriction	5	0.743	5.780	0.009
	Diet	1	0.453	3.530	0.089
	Restriction x Diet	5	0.392	3.050	0.063
	Error	24	0.129		
	Total	35			
3	Restriction	5	0.851	3.290	0.051
	Diet	1	0.164	0.630	0.445
	Restriction x Diet	5	0.149	0.570	0.721
	Error	24	0.259		
	Total	35			
1-5	Restriction	5	9.940	2.870	0.073
	Diet	1	0.594	0.170	0.687
	Restriction x Diet	5	4.573	1.320	0.330
	Error	24	3.457		
	Total	35			
6-10	Restriction	5	9.098	3.340	0.049
	Diet	1	1.314	0.480	0.503
	Restriction x Diet	5	1.286	0.470	0.789
	Error	24	2.722		
	Total	35			
11-15	Restriction	5	12.224	1.530	0.264
	Diet	1	1.859	0.230	0.640
	Restriction x Diet	5	2.787	0.350	0.871
	Error	24	7.979		
	Total	35			
16-20	Restriction	5	24.344	2.050	0.156
	Diet	1	0.812	0.070	0.799
	Restriction x Diet	5	2.124	0.180	0.964
	Error	24	11.855		
	Total	35			
1-10	Restriction	5	34.853	3.250	0.053
	Diet	1	0.082	0.010	0.932
	Restriction x Diet	5	7.618	0.710	0.629
	Error	24	10.708		
	Total	35			
11-20	Restriction	5	67.165	2.000	0.164
	Diet	1	5.127	0.150	0.704
	Restriction x Diet	5	6.702	0.200	0.955
	Error	24			
	Total	35			
1-20	Restriction	5	145.762	2.280	0.125
	Diet	1	6.767	0.110	0.752
	Restriction x Diet	5	15.922	0.250	0.931
	Error	24	63.936		
	Total	35			

Appendix B Table 7. Analysis of variance for percentage hen-housed egg production of feed restricted turkey breeder hens during various time intervals

Week	Source of variation	df	Mean square	F-value	Probability
1-5	Restriction	5	81.139	2.870	0.073
	Diet	1	4.848	4.848	0.687
	Restriction x Diet	5	37.331	1.320	0.329
	Error	24	28.223		
	Total	35			
6-10	Restriction	5	74.267	3.34	0.049
	Diet	1	10.726	0.480	0.503
	Restriction x Diet	5	10.499	0.470	0.789
	Error	24	22.220		
	Total	35			
11-15	Restriction	5	99.789	1.530	0.264
	Diet	1	15.175	0.230	0.640
	Restriction x Diet	5	22.749	0.350	0.871
	Error	24	65.125		
	Total	35			
16-20	Restriction	5	198.729	2.050	0.156
	Diet	1	6.626	0.070	0.799
	Restriction x Diet	5	17.343	0.180	0.964
	Error	24	96.772		
	Total	35			
1-10	Restriction	5	71.129	3.250	0.053
	Diet	1	0.168	0.010	0.932
	Restriction x Diet	5	15.547	0.710	0.629
	Error	24	21.853		
	Total	35			
11-20	Restriction	5	137.071	2.000	0.164
	Diet	1	10.464	0.150	0.704
	Restriction x Diet	5	13.677	0.200	0.955
	Error	24	68.556		
	Total	35			
1-20	Restriction	5	74.638	2.280	0.125
	Diet	1	3.452	0.110	0.752
	Restriction x Diet	5	8.124	0.250	0.931
	Error	24	32.620		
	Total	35			

Appendix B Table 8. Analysis of variance for average egg weight for eggs from feed restricted turkey breeder hens

Week	Source of variation	df	Mean square	F-value	Probability
1	Restriction	5	30.893	0.910	0.479
	Diet	1	10.228	0.300	0.585
	Restriction x Diet	5	19.237	0.560	0.727
	Error	153	34.087		
	Total	164			
2	Restriction	5	4.507	0.130	0.985
	Diet	1	16.822	0.500	0.482
	Restriction x Diet	5	38.294	1.130	0.346
	Error	177	33.868		
	Total	188			
1-20	Restriction	5	2.807	2.180	0.138
	Diet	1	0.789	0.610	0.452
	Restriction x Diet	5	2.762	2.140	0.143
	Error	24	1.288		
	Total	35			
1-20	Restriction	5	$1.69x10^{-6}$	1.540	0.263
	Diet	1	$5.70x10^{-7}$	0.520	0.487
	Restriction x Diet	5	$2.28x10^{-6}$	2.070	0.153
	Error	24	$1.10x10^{-6}$		
	Total	35			

Appendix B Table 9. Analysis of variance for egg shell quality traits of feed restricted turkey breeder hens

Variable	Source of variation	df	Mean square	F-value	Probability
Egg weight loss(%)	Restriction	5	$7.35x10^{-6}$	0.290	0.909
	Diet	1	$4.30x10^{-5}$	1.680	0.224
	Restriction x Diet	5	$8.82x10^{-6}$	0.350	0.874
	Error	24	$2.56x10^{-5}$		
	Total	35			
Shell conductance	Restriction	5	$6.72x10^{-5}$	0.350	0.874
	Diet	1	$4.41x10^{-4}$	2.270	0.163
	Restriction x Diet	5	$8.74x10^{-5}$	0.450	0.805
	Error	24	$1.94x10^{-4}$		
	Total	35			
Conductance constant	Restriction	5	0.027	0.290	0.906
	Diet	1	0.155	1.710	0.220
	Restriction x Diet	5	0.032	0.360	0.867
	Error	24	0.091		
	Total	35			

Appendix B Table 10. Analysis of variance for average fertility and hatchability (%) of feed restricted turkey breeder hens from 1-20 weeks

Variable	Source of variation	df	Mean square	F-value	Probability
Fertility	Restriction	5	$1.55x10^{-3}$	0.800	0.576
	Diet	1	$1.14x10^{-3}$	0.590	0.462
	Restriction x Diet	5	$3.21x10^{-3}$	1.660	0.232
	Error	24	$1.94x10^{-3}$		
	Total	35			
Hatchability of settable	Restriction	5	$8.90x10^{-4}$	1.080	0.426
	Diet	1	$4.67x10^{-5}$	0.060	0.8165
	Restriction x Diet	5	$1.08x10^{-3}$	1.310	0.334
	Error	24	$8.22x10^{-4}$		
	Total	35			
Viability	Restriction	5	$1.29x10^{-3}$	2.000	0.164
	Diet	1	$2.99x10^{-5}$	0.050	0.833
	Restriction x Diet	5	$1.26x10^{-3}$	1.960	0.170
	Error	24	$6.42x10^{-4}$		
	Total	35			

Appendix B Table 11. Analysis of variance for poult quality characteristics for offsprings of feed restricted turkey breeder hens

Variable	Source of variation	df	Mean square	F-value	Probability
Poult weight	Restriction	5	4.832	3.970	0.030
	Diet	1	0.486	0.400	0.542
	Restriction x Diet	5	2.755	2.260	0.128
	Error	24	1.219		
	Total	35			
Blood glucose concentration	Restriction	5	4.083	0.060	0.997
	Diet	1	21.380	0.320	0.585
	Restriction x Diet	5	105.620	1.580	0.252
	Error	24	66.969		
	Total	35			

Appendix B Table 12. Analysis of variance for embryonic mortality of offsprings of feed restricted turkey breeder hens

Variable	Source of variation	df	Mean square	F-value	Probability
Early dead	Restriction	5	6.60×10^{-5}	1.700	0.223
	Diet	1	6.27×10^{-6}	0.160	0.697
	Restriction x Diet	5	1.04×10^{-3}	2.670	0.089
	Error	24	3.89×10^{-4}		
	Total	35			
Dead wk 1	Restriction	5	4.91×10^{-4}	0.780	0.583
	Diet	1	8.07×10^{-4}	1.290	0.283
	Restriction x Diet	5	3.71×10^{-4}	0.590	0.707
	Error	24	6.26×10^{-4}		
	Total	35			
Dead wk 2	Restriction	5	2.66×10^{-4}	0.570	0.719
	Diet	1	3.14×10^{-4}	0.680	0.429
	Restriction x Diet	5	1.68×10^{-4}	0.360	0.862
	Error	24	4.63×10^{-4}		
	Total	35			
Dead wk 3	Restriction	5	7.44×10^{-4}	0.900	0.516
	Diet	1	3.31×10^{-4}	0.400	0.541
	Restriction x Diet	5	1.36×10^{-4}	1.650	0.233
	Error	24	8.25×10^{-4}		
	Total	35			
Dead wk 4	Restriction	5	1.16×10^{-3}	1.100	0.417
	Diet	1	4.86×10^{-4}	0.460	0.513
	Restriction x Diet	5	1.64×10^{-3}	1.550	0.260
	Error	24	1.06×10^{-3}		
	Total	35			
External pip	Restriction	5	8.40×10^{-4}	2.130	0.145
	Diet	1	5.79×10^{-4}	1.460	0.254
	Restriction x Diet	5	8.10×10^{-4}	2.050	0.157
	Error	24	3.95×10^{-4}		
	Total	35			

Appendix B Table 13. Analysis of variance for effects of duration of restriction on egg components (%) of feed restricted turkey breeder hens

Variable	Source of variation	df	Mean square	F-value	Probability
Wet shell	Restriction	5	3.98×10^{-4}	1.700	0.134
	Error	534	2.35×10^{-4}		
	Total	539			
Wet albumen	Restriction	5	2.21×10^{-3}	3.700	0.003
	Error	522	5.98×10^{-4}		
	Total	527			
Wet yolk	Restriction	5	2.76×10^{-3}	3.550	0.004
	Error	522	7.76×10^{-4}		
	Total	527			
Dry shell	Restriction	5	3.90×10^{-4}	2.480	0.031
	Error	534	1.57×10^{-4}		
	Total	539			
Dry albumen	Restriction	5	2.17×10^{-4}	2.200	0.053
	Error	522	9.88×10^{-5}		
	Total	527			
Dry yolk	Restriction	5	7.63×10^{-4}	2.720	0.020
	Error	522	2.81×10^{-4}		
	Total	527			

APPENDIX C

ANALYSIS OF VARIANCE TABLES - CHAPTER III

Appendix C Table 1. Analysis of variance for effects of nesting material on percentage floor and non-settable egg production of turkey breeder hens

Variable	Source of variation	df	Mean square	F-value	Probability
Floor eggs	Nest material	2	0.165	9.430	0.005
	Error	33	0.017		
	Total	35			
Cracked eggs	Nest material	2	0.010	6.380	0.016
	Error	33	0.002		
	Total	35			
Double yolked eggs	Nest material	2	$2.20x10^{-4}$	0.510	0.618
	Error	33	$4.40x10^{-4}$		
	Total	35			
Misshaped eggs	Nest material	2	$4.30x10^{-4}$	0.640	0.546
	Error	33	$6.70x10^{-4}$		
	Total	35			
Soft-shelled eggs	Nest material	2	$1.01x10^{-2}$	3.640	0.065
	Error	33	$2.76x10^{-3}$		
	Total	35			

Appendix C Table 2. Analysis of variance for effects of nesting material on average egg production (eggs/hen housed) of turkey breeder hens

Week	Source of variation	df	Mean square	F-value	Probability
1-5	Nest material	2	22.656	6.550	0.015
	Error	33	3.457		
	Total	35			
6-10	Nest material	2	17.604	6.470	0.016
	Error	33	2.722		
	Total	35			
11-15	Nest material	2	1.096	0.140	0.873
	Error	33	7.979		
	Total	35			
16-20	Nest material	2	0.960	0.080	0.923
	Error	33	11.855		
	Total	35			
1-10	Nest material	2	81.251	7.590	0.009
	Error	33	10.708		
	Total	35			
11-20	Nest material	2	1.905	0.060	0.945
	Error	33			
	Total	35			
1-20	Nest material	2	83.603	1.310	0.313
	Error	33	63.936		
	Total	35			

Appendix C Table 3. Analysis of variance for effects of nesting material on percentage hen-housed egg production of turkey breeder hens during various time intervals

Week	Source of variation	df	Mean square	F-value	Probability
1-5	Nest material	2	184.951	6.55	0.015
	Error	33	28.223		
	Total	35			
6-10	Nest material	2	143.702	6.470	0.016
	Error	33	22.220		
	Total	35			
11-15	Nest material	2	8.944	0.140	0.873
	Error	33	65.125		
	Total	35			
16-20	Nest material	2	7.838	0.080	0.923
	Error	33	96.772		
	Total	35			
1-10	Nest material	2	165.819	7.590	0.009
	Error	33	21.853		
	Total	35			
11-20	Nest material	2	3.887	0.060	0.945
	Error	33	68.556		
	Total	35			
1-20	Nest material	2	42.655	1.310	0.313
	Error	33	32.620		
	Total	35			

Appendix C Table 4. Analysis of variance for effects of nesting material on broody or out-of-lay (%) turkey breeder hens

Age (wk)	Source of variation	df	Mean square	F-value	Probability
1-20	Nest material	2	6.64×10^{-5}	0.460	0.643
	Error	33	9.73×10^{-5}		
	Total	35			

Appendix C Table 5. Analysis of variance for effects of nesting material on average fertility, hatchability, and poult quality from 1-20 weeks

Variable	Source of variation	df	Mean square	F-value	Probability
Fertility	Nest material	2	1.40×10^{-4}	0.070	0.931
	Error	33	1.94×10^{-3}		
	Total	35			
Hatch of settable eggs	Nest material	2	1.04×10^{-3}	1.260	0.324
	Error	33	8.22×10^{-4}		
	Total	35			
Viability	Nest material	2	1.18×10^{-3}	1.830	0.210
	Error	33	6.42×10^{-4}		
	Total	35			
Poult weight	Nest material	2	1.480	1.210	0.337
	Error	33	1.219		
	Total	35			
Blood glucose concentration	Nest material	2	9.026	0.130	0.876
	Error	33	66.969		
	Total	35			

VITA

Hermann Klein-Hessling was born on January 8, 1963 in Vreden, a rural community in the State of Nordrhein-Westfalen, Germany. He grew up on the family farm together with 5 brothers and one sister. After completing an apprenticeship in agriculture in 1981 he continued his educational career at a technical college where he received his degree as "Staatlich gepruefter Landwirt" in 1984. He obtained his university diploma from the Fachhochschule Osnabrueck in 1990 with special emphasis in animal production, crop science, and agricultural economics. In 1994, he earned a Master's Degree in Poultry Science from North Carolina State University under Dr. Vern L. Christensen.

Currently, he is a Ph.D. candidate at Virginia Polytechnic Institute and State University under the supervision of Dr. D. Mike Denbow in the Department of Animal and Poultry Sciences. He has a special interest in turkey breeder management, nutrition, incubation, reproductive physiology, commercial turkey production, and processing. He is currently a member of Gamma Sigma Delta Agricultural Honorary Society, the Poultry Science, and World's Poultry Science Association.