EFFECTS OF FEEDING DIETS VARYING IN NUTRIENT DENSITY TO HY-LINE W-36 LAYING HENS ON PRODUCTION PERFORMANCE AND PROFITABILITY

BY

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THESIS

Submitted in partial fulfillment of the requirements
for the degree of Master of Science in Animal Sciences
in the Graduate College of the
University of Illinois at Urbana-Champaign, 2011

Urbana, Illinois

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Abstract

An experiment was conducted with 480 Hy-Line W-36 laying hens to determine whether feeding diets that varied in nutrient density would affect long-term egg production performance. At 18 wk of age, laying hens were weighed and randomly allocated to 6 replicate groups of 16 hens each (2 adjacent cages containing 8 hens per cage, 60.9 x 58.4 cm) per dietary treatment in a randomized complete block design. Placement within house and initial body weight were used as blocking criteria. The hens were fed 5 treatment diets formulated to contain 85, 90, 95, 100, and 105% of the energy and nutrient recommendations stated in the 2009 Hy-Line W-36 management guide. Production performance was measured for 52 wk from 18 to 70 wk of age. At 31 wk of age, hens fed the 85% Treatment experienced a post-peak decrease in egg production, with an average hen-day egg production of 65%. At 32 wk of age hen-day egg production for hens on the 85% Treatment was below 50%, with an average of 36%. At this time, hens fed the 85% Treatment were switched to the 100% Treatment (control) due to low egg production.

Over the course of the trial, a significant linear response to increasing nutrient density was seen for average hen-day egg production (18 to 70 wk of age), with Treatments 90 to 105% being 81.87, 81.28, 85.98, and 84.62%, respectively. From 18 to 70 wk of age, a significant linear response to increasing nutrient density was found for egg weight (g/egg), with Treatments 90 to 105% being 58.38, 59.15, 59.10, and 60.00g, respectively. Similarly, there was a significant linear increase in egg mass in response to increasing nutrient density, with Treatments 90 to 105% being 46.77, 47.35, 47.71, and 48.32 g egg/hen per day, respectively. A significant linear increase in feed intake due to increasing nutrient density occurred early in the production cycle and from 18 to 70 wk of age, an increase in nutrient density showed a significant linear response in improved feed efficiency (g egg/g feed), with Treatments 90 to 105% being 0.47, 0.48, 0.49, and 0.50, respectively. A significant linear response to increasing nutrient density was seen from 18 to 70 wk of age for Jumbo to Large and Medium to Small eggs. The majority of eggs produced throughout the trial (about 90%) were Extra Large, Large, and Medium sized eggs. On average, the 100 and 105% Treatments produced the most Jumbo to Large eggs, while diets of lower nutrient density produced more Medium to Small eggs. A significant linear response to increasing nutrient density was seen for body weight, with the 85% Treatment hens being the lightest and the 105% Treatment hens being the heaviest. At 70 wk of age a significant linear increase in nutrient density produced heavier fat pad weights, but no effect was noted for bone ash or bone breaking strength due to increasing nutrient density. Significant linear responses due to nutrient density were seen for income, feed cost, and return over feed cost. In general, as nutrient density increased, egg income and feed cost per hen increased, while return over feed cost decreased.

Overall, these results indicate that feeding Hy-Line W-36 hens diets formulated to contain lower nutrient density specifications (85% of control) than recommended may compromise production performance. Furthermore, increasing nutrient density in the diet of a laying hen will increase egg production, egg weight, and feed efficiency. However, these benefits do not take effect in early production and seem to be most effective in later stages of the production cycle; perhaps ‘priming’ the birds for better future production.

Dedication

This thesis is dedicated to my wonderful family, friends, and boyfriend Jay. Through their support and confidence in my abilities I was able to pursue and accomplish my goals.

Acknowledgments

I would first like to thank my advisor, Dr. Ken Koelkebeck, for allowing me the opportunity to be his graduate student, even though I joined the program having no poultry experience. I would like to express my appreciation to Dr. Carl Parsons for his advice and collaboration in this trial. I would like to thank Nancy David for always being available to help and answer my questions. I would also like to thank Dr. Ryan Dilger for assisting me with questions concerning the statistical analysis of data through SAS.

This thesis was made possible only by the help of many people. Pam Utterback, Chet Utterback, Doug Hilgendorf, Seth Gallivan, and the poultry farm staff, were essential to the set-up, labor, and hard work involved in the maintenance and data collection of this trial. The results of their efforts are presented in this document. A big thank you to my lab mates China Jacobs, Kelly Bland, Tara Davis, and Wes Walbaum. Thank you for your patience and hard work in feeding the hens, rain or shine, and in all the work involved with egg solids. Thank you Kelly, for helping me weigh and grade eggs every two weeks. China, thank you for the knowledge and experience you passed down to me. Thank you all for being great lab mates and friends.

Lastly, I would like to thank all the wonderful people at Hy-Line International. Dr. Neil O'Sullivan, Dr. Jesus Arango, and Dr. Kristjan Bregendahl, thank you all for all of your hard work and collaboration on this trial, and especially for always being available to answer my questions.

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Literature Review

THE LAYING HEN DIET

Introduction

Over the years, the management of the laying hen and composition of the diet fed have gone through many changes and alterations. This is because the diet fed to commercial laying hens can vary greatly, depending upon factors including the strain of bird, production goals, age, and weather conditions (Schaible and Patrick, 1980). Along with formulation, different feeding programs have been established to maximize efficiency and production. Since a laying hen draws upon the nutrients provided in its diet to produce eggs, the quality and formulation of the diet is of most importance to a producer, especially considering that 65 to 75% of the cost to produce eggs is due to feed costs (Bell and Weaver, 2002). Due to this fact, it has become increasingly important for producers to find a balance between feeding their birds on a least-cost basis as well as feeding the appropriate amounts of nutrients in the diet as the hen needs them throughout her lay cycle. This can be done through a phase feeding program, involving a pre-lay diet, and diets of different compositions to suit the stages of the hens lay cycle.

As stated in the 9th edition of Nutrient Requirements for Poultry (NRC, 1994), "Formulation of balanced diets is fundamental to economical poultry production, and this process depends on a knowledge of nutrient requirements of poultry". In essence, there are three main factors that an egg producer must be concerned with and they are; 1) the cost of feed, 2) the amount of egg production and quality of the eggs, and 3) the profit made. These three important elements all rely on proper composition of the diet. Singular changes in diet composition have been made to affect performance, but it is important to realize that ultimately, all nutrient levels in a diet act together. In order to formulate a proper laying hen diet, it is essential to have a thorough knowledge of each of the components involved and the sources from which they are derived.

Essential Dietary Components

The different components involved in a laying hen diet are all essential to, and have a direct effect on, bird health and egg production. The most important and basic components of a laying hen diet include energy, carbohydrates, protein and amino acids, fat, and vitamins and minerals. Not only must all of these nutrient sources be present in the diet, but they must also be present in certain amounts.

While energy is not a nutrient, it is an important factor in the diet of a laying hen, can be provided by carbohydrates, fat, and proteins, and is used in metabolism, maintenance, and egg production (NRC, 1994). A laying hen cannot digest cellulose, hemicellulose, or lignin, and must obtain energy from other carbohydrates. These include the polysaccharide starch, the disaccharides sucrose and maltose, and the monosaccharides glucose, fructose, mannose, and galactose (Young, 1976). Dietary carbohydrates are important sources of energy, and are commonly provided in the diet by cereal grains such as corn (NRC, 1994).

Poultry do not require protein, but rather the amino acids that make up protein (Hy-Line W-36, 2009). The needs for amino acids are numerous and include uses in building tissue protein, building enzyme systems, use as an energy source, fat and mineral translocation and storage, buffering and osmotic pressure, reproduction, oxygen transport, and more (Schaible and Patrick, 1980). Methionine is the first limiting amino acid for laying hens and lysine is the second limiting amino acid in most commercial diets (Schaible and Patrick, 1980). A third amino acid that may be limiting in a poultry diet is tryptophan (Schaible and Patrick, 1980). When an amino acid is limiting, the amount of it that is available determines the amount of protein that can be utilized. This is because all amino acids are required for tissue synthesis in certain amounts. If there is a shortage of certain amino acids, the others are wasted (Schaible and Patrick, 1980). Because of this, the amounts of limiting amino acids available are extremely important. These are also essential amino acids, meaning that the hen does not produce them and that they must be provided in the diet (Schaible and Patrick, 1980). There are twenty amino acids, of which thirteen are essential to poultry. These include phenylalanine, isoleucine, lysine, threonine, histidine, arginine, tryptophan, methionine, valine, leucine, and glycine. Nonessential amino acids, which can be synthesized in the body, include alanine, aspartic acid, cystine, cysteine, hydroxyproline, proline, serine, tyrosine, and glutamic acid (Schaible and Patrick, 1980; Young, 1976).

Minerals are the inorganic parts of feeds or tissues and are divided into macro (major) minerals and micro (minor) minerals (NRC, 1994). Minerals are required for skeletal formation, as cofactors of enzymes, and for maintenance of osmotic balance within the body (NRC, 1994). Macrominerals that are required in the diet of a laying hen include calcium, chloride, magnesium, phosphorus, potassium, and sodium. Two macrominerals that are particularly important in the diet of a laying hen are calcium and phosphorus. The amounts of calcium required in the diet for Leghorn-type laying hens, as recommended by the NRC (1994), are 4.06, 3.25, and 2.71% for 80, 100, or 120 grams of feed intake, respectively. The amounts of phosphorus required in the diet for Leghorn-type laying hens, as recommended by the NRC (1994), are 0.31, 0.25, and 0.21% for 80, 100, or 120 g of feed intake, respectively. Microminerals required in the diet include copper, iodine, iron, manganese, selenium, and zinc (NRC, 1994).

A vitamin can be defined as an organic compound that is a minute component of natural foods that is essential for the development of normal tissue and for health, growth, and maintenance (Young, 1976). When absent from the diet, or not properly absorbed or utilized, a deficiency can develop. Vitamins cannot be synthesized by an animal and therefore must be obtained in the diet. Vitamins are classified as fat-soluble, A, D, E, and K, and water-soluble (Young, 1976). Fat-soluble vitamins that are essential in the diet of a laying hen include A, D_3, E, and K. Water-soluble requirements include B_{12}, biotin, choline, folacin, niacin, pantothenic acid, pyridoxine, riboflavin, and thiamin (NRC, 1994).

Fats and oils can be a source of energy. Fat, in the form of linoleic acid, is required as 1.25, 1.0, or 0.83% of the diet based on feed intakes of 80, 100, or 120 g for leghorn-type laying hens (NRC, 1994), or 1,000 mg/hen/day for hens consuming 100 g of feed per day. Fats and oils are feed sources high in energy and can be added to a poultry diet to provide energy, and in turn improve productivity and efficiency. This is because oxidation of fats is an efficient way to obtain energy (NRC, 1994). The polyunsaturated acids, linolenic, linoleic, and arachidonic, have been designated as essential fatty acids for poultry (Schaible and Patrick, 1980).

The Hy-Line W-36 Laying Hen and Guidelines

The W-36 laying hen is a unique bird with special genetics. It is the most efficient laying hen in the world, having a low average daily feed intake of 91 g/day per bird, high livability at 97%, and excellent egg shell quality and strength (Hy-Line W-36, 2009). In contrast, while the Hy-Line W-98 and Hy-Line Brown both have excellent egg quality and 98% and 97% livability respectively, they are slightly larger birds than the W-36 and their average daily feed consumption is much greater (Hy-Line W-98, 2008; Hy-Line Brown, 2009). The W-98 average daily consumption is 98 g/bird/day, while the Hy-Line Brown is 107 g/bird/day (Hy-Line W-98, 2008; Hy-Line Brown, 2009). Furthermore, when compared to the Hy-Line 77, Bovan, or DeKalb Delta strains of laying hens, the Hy-Line W-36 can produce a gram of egg using about 5% less energy (Harms et al., 1999). These differences are drastic when considering diet formulation and profitability. When formulating a diet for the W-36 laying hen, the low feed intake is important to consider because, if the right amount of nutrients are not available, deficiencies can occur and decrease egg production. However, if the diet is balanced and takes into account feed intake, optimal egg production and profitability can be realized. Thus, the genetic and physical properties of the W-36 hen necessitate a different approach in management and diet formulation.

The suggested diet program for the W-36 involves feeding for observed feed intake and desired production (Hy-Line W-36, 2009). Phase feeding is done to provide proper amounts of nutrients at different life stages of the laying hen. When the hen is younger, she requires nutrients in higher densities, as the hen ages, egg production decreases and less nutrients are needed for maintenance and production. It is recommended that diets be formulated by amino acid basis with no crude protein minimums. The content of all amino acids should be considered in order to avoid deficiencies. Furthermore, these requirements should be based off of a digestible amino acid basis rather than total, due to the fact that 10-15% of dietary amino acids are not digested. Formulating the diet in this way is more accurate, can decrease safety margins, and produces more economical diets (Hy-Line W-36, 2009).

STUDIES IN MANIPULATING NUTRIENTS IN THE LAYING HEN DIET TO INFLUENCE PERFORMANCE

Introduction

As the poultry industry has grown, so has the need for producers to increase the efficiency of their birds, the quality of their product, and decrease the costs involved. Diet formulation and nutrition have an important influence on the health and production capacity of laying hens. Certain nutrients, such as calcium and phosphorous, are especially critical to egg production, since these two nutrients are needed to form the egg shell. Other important factors of interest in the laying hen diet are protein and energy. Altering the amounts of these dietary nutrients can have a negative or positive impact on layer egg production and egg quality. For example, the amount of energy in a diet has a direct influence on feed intake and feed efficiency. Roland (2010) stated that selecting an incorrect energy level for a diet could adversely affect cost by up to 0.5 cents per dozen eggs. This is of great importance to producers, who aim to cut feed costs and increase profits. In order to do so, energy levels in the diet must be appropriate. Egg size can be affected by the amount of energy, total fat, crude protein, methionine, cystine, and linoleic acid in the diet and the intake of these nutrients by the hen (Hy-Line W-36, 2009). Levels of these nutrients can be manipulated at certain points in the lay cycle to increase egg sizes, decrease them, or to keep them constant. For years past, and even today, nutritionists cannot agree on the nutrient amounts required by hens. It is because of this disagreement that research has been used to find answers; to find ways to improve and modify existing diets and requirements.

Altering Amounts of Protein and Amino Acids

According to the NRC (1994), a Leghorn-type laying hen requires 18.8, 15.0, or 12.5% crude protein in the diet for feed intakes of 80, 100, or 120 g/hen/day, respectively. Technically, laying hens do not have a requirement for crude protein. However, enough crude protein needs to be available in the diet to provide a supply of nonessential amino acids (NRC, 1994). Specific indispensible amino acids have their own requirements.

In looking at specific amino acids, Harms et al. (1998) ran an experiment testing the influence of methionine on the egg production of 480 Hy-Line W-36 laying hens starting at 20 wk of age. Twelve experimental diets were fed for 8 wk. The diets consisted of two different levels of protein (12.7 and 15%), two different levels of energy (2772 and 3080 kcal ME/kg), and three different levels of methionine (0.250, 0.275, and 0.300%). It was found that egg output and weight increased as methionine intake increased, feed intake increased with increased methionine content and decreased with increased energy content. Egg production was greatest for the 15% protein diet, daily energy intake increased as methionine intake increased along with increased egg production, and kcal of energy required to produce a gram of egg decreased as egg production increased. These results indicate that both methionine and energy influence feed intake, that the intake of methionine controls egg output, and that hens consume energy to meet the requirement for egg output. In a similar trial to the previously mentioned, Harms et al. (1999) determined whether the need for energy and methionine could be satisfied by one feed with a constant energy:methionine ratio. Two experiments were run with Hy-Line W-36 laying hens. In the first experiment 640 hens were diets of four different ratios, 1:1.03, 1:1.09, 1:1.15, and 1:1.49 kcal:mg MET (control) from 18 to 36 wk of age. The second experiment was the same, except the hens were fed six diets with ratios of 1:1.0, 1:1.1, 1:1.2, 1:1.3, 1:1.4, and 1:1.5 kcal:mg Met from 21 to 36 wk of age. The results of this trial were similar to results found in the previous trial by Harms et al. (1998). It was found that a hen consumes energy to support the amount of eggs laid and that a higher intake of methionine is necessary for maximum egg weight. These reports document that the energy:methionine ratio is important. The proper ratio can result in a lower feed cost. These different studies also show the importance of protein (specifically amino acids such as methionine) in egg production, and the influence of nutrients (energy and amino acids) upon one another in the diet.

By taking advantage of the laying hens' tendency to adjust feed intake, trials were designed so that diets were only offered during times when hens most utilized nutrients for egg production; early morning or afternoon. Keshavarz (1998) used this concept by testing whether the daily requirements for calcium, phosphorous, and protein could be reduced. This was done by only providing hens feed during the time of day when those nutrients were most needed for egg production. Albumen proteins are synthesized in the morning, while the egg shell is formed in the afternoon and evening. Therefore, hens may have a higher protein requirement in the morning and higher calcium requirement in the afternoon. With phosphorous kept at adequate levels, egg production and shell quality could be maintained regardless of the time that phosphorous was provided. However, providing adequate calcium levels only in the afternoons and adequate protein levels only in the mornings failed to maintain satisfactory egg production. Focusing on protein, Khajali et al. (2008) studied the effect of feeding reduced protein diets with a constant total sulfur amino acid to lysine ratio on production and egg quality. They found that low protein could maintain performance and egg quality for the first 8 months of production, yet after this point, performance and egg quality could no longer be sustained. Therefore, it was concluded that layer performance could remain satisfactory when feeding reduced protein diets only in the short-term; however, long-term feeding of these diets reduced performance during later stages of production. Considering these trials, there is potential for analysis of feed costs and profitability. Safely decreasing certain dietary factors for periods of time or feeding nutrients only at critical points of the day could decrease feed costs, due to the fact that producers would be able to purchase smaller amounts of certain feed ingredients. Unfortunately, these studies were not entirely successful or practical, nor did they cover any economic data or discuss the possibilities of reduced feed costs for producers.

Gunawardana et al. (2009) documented that, when testing dietary energy, protein, and enzyme levels over a 12 wk trial, increasing dietary protein would increase feed intake to provide energy needed for increased egg production cause by increased protein while, as dietary energy increased, feed intake would decrease. One thousand nine hundred and twenty molted birds at 87 wk of age, in phase two of their second cycle, were fed diets of four different energy levels (2,791, 2,857, 2,923, and 2,989 kcal/kg of ME) and two different protein levels (15.5 and 16.1%). Hens fed high-protein diets had significantly higher egg weights than hens fed low protein diets. These results are consistent with those found by Parsons et al. (1993), Keshavarz (1995), Leeson (1989), and Sohail et al. (2003). Conversely, dietary energy had no influence on average egg weight. However, this conflicts with results found by Wu et al. (2005), who found that egg weight linearly increased with increasing dietary energy.

Altering Amounts of Energy

Since laying hens will eat to meet their energy needs, feed intake is influenced by the amount of energy present in the diet (Harms et al., 1998). Nutrient requirements for Leghorn-type laying hens, reported by the NRC (1994), are based off of a metabolizable energy concentration of approximately 2,900 kcal/kg. Wu et al. (2005) saw this effect, among others, when they ran a trial testing the effect of dietary energy on the performance of two strains of laying hens. Four different energy levels were fed to Bovans White and Dekalb White laying hens over the first lay phase (21 wk of age). There was a significant linear response in feed intake to dietary energy levels. As energy was increased in the diet, feed intake decreased. This effect varied between strains of laying hens. The Dekalb White hens had significantly lower feed intakes than the Bovans White hens. However, the decrease in feed intake in relation to energy was similar between strains. Other factors including egg production and egg mass differed among the strains, with the Bovans White having significantly higher egg production and mass at all four energy levels. Yet, it was found that dietary energy intake does not have a significant effect on egg production or egg mass. Latshaw et al. (1990) performed a similar study as Wu et al. (2005) and found similar results. Both Latshaw et al. (1990) and Gunawardana et al. (2009) also found that as dietary energy increased feed intake would decrease.

Experiments have shown that metabolizable energy levels around 3000 to 3100 kcal per kg of diet can give the most economical results due to the fact that the higher energy ration improves the efficiency of feed utilization when compared to lower energy diets (Young, 1976). This improved efficiency usually offsets the higher cost of the high energy feed. Decreasing the metabolizable energy of 110 kcal/kg of diet can increase consumption per hen by about 3.5 to 4%. If a high energy diet is no more than 3% more expensive than a diet of lower energy, the high energy diet will be the economical choice due to the feed cost per dozen eggs (Young, 1976).

Altering Amounts of Minerals

Calcium and phosphorus are important dietary components needed for egg production. Yet, the amounts required for the laying hen have been debated. According to the NRC (1994), a Leghorn-type laying hen requires 4.06, 3.25, or 2.71% calcium in the diet for feed intakes of 80, 100, or 120 g/hen/day, respectively. For nonphytate phosphorus, requirements are 0.31, 0.25, and 0.21% for an 80, 100, or 120 g feed intake. Davidson and Boyne (1969) reported that, for a modern hybrid hen with high production characteristics, recommended amounts of calcium ranged from 2.25, to 2.8, to 4.0%. Due to the disagreement on the value, Davidson and Boyne (1969) ran two experiments to determine a minimum calcium requirement for maximum production. In the first experiment, 350 Thornber 606 pullets at 19 wk of age were fed nine experimental diets for 6 months. These were combinations of calcium concentrations of 2, 3, or 4% and phosphorus concentrations of 0.5, 0.7, and 0.9%. This was to determine whether different levels of phosphorus would have an effect on the calcium requirement. However, different levels of phosphorus did not affect the calcium requirement. Knowing this, in experiment two, 264 hens were fed four different diets with a calcium concentration of 2.3, 2.6, 3.0, or 3.3% and phosphorus kept at 0.6% for all diets for 32 wk. In both experiments, lower levels of calcium caused lower production and reduced feed intake. Reduced feed intake in diets with higher calcium concentrations was seen by Clunies et al. (1992). With increased calcium there was an increase in shell thickness, weight, and resistance to cracking. Phosphorus did not affect these parameters. In Experiment 1, it was found that, with a phosphorus level of 0.55%, the calcium requirement was between 1.7 and 2.8%. In Experiment 2, it was found that the optimal concentration of calcium was 2.6%. There was no significant improvement in egg production above 2.6%. This requirement decreased as production levels of the hens decreased with age.

In another experiment, Reichmann and Connor (1977) also tested the influence of calcium and phosphorus on laying hen production. Six hundred and forty Rochedale 440 pullets at 22 wk of age were given treatments with 4.5, 6.0, 8.0, 10.7, or 14.2 g/kg of phosphorus and 24.0, 32.0, 42.7, or 56.9 g/kg of calcium for 16 wk. In contrast to the study conducted by Davidson and Boyne (1969), the treatments did not affect egg numbers, feed consumption, feed efficiency, body weight, or mortality. Increased calcium in the diet significantly increased egg specific gravity and radius strength and decreased egg weight. Increasing phosphorus from 4.5 to 6.0 g/kg increased egg specific gravity and decreased with higher amounts. Maximum egg specific gravity and egg weight occurred with 42.7 and 32.0 g/kg of dietary calcium respectively. Maximum shell strength was seen with 6.0 g/kg of dietary phosphorus. Insufficient dietary calcium can compromise egg shell strength and thickness, decrease egg production, and cause depletion of calcium in the bones and bone fragility. High phosphorus can also decrease egg production and/or compromise shell quality. This study found that increased calcium can improve shell quality. However, increased calcium can also decrease egg numbers, egg weight, and decrease feed consumption. This study only saw a decrease in egg weight with increased calcium. However, by these results, it can be concluded that increasing calcium to improve shell quality can cause a decrease in production. This enforces how essential it is to maintain an appropriate balance of nutrients, particularly calcium and phosphorus, in the laying hen diet.

Boorman and Gunaratne (2001) conducted two experiments using sixty ISA-Brown pullets at 20 wk of age to evaluate the importance of phosphorus in egg shell production, strength, and quality. In experiment one, the birds were laying at peak production and fed diets deficient or slightly excessive in phosphorus, while in experiment two, the birds were laying past peak production and fed diets with a large amount of excess phosphorus. It was found that phosphorus deficient diets or ones with a moderate excess of phosphorus had little effect on measures of egg production, shell production, body weight, and food intake. In Experiment 2, similar results were seen, with the exception that the largest amount of excess phosphorus seemed to decrease egg weight and increase feed intake.

Some early experiments were conducted which documented that laying hens could alter their feed consumption to meet their dietary needs. Holcombe et al. (1975) found that young hens exhibited the ability to discriminate between high and low levels of calcium in the diet. When offered two diets, hens would increase consumption of the diet higher in calcium content. Holcombe et al. (1976) repeated this study using phosphorus and obtained similar results; hens would regulate their phosphorus intake when given the choice of diets varying in phosphorus levels.

The studies above suggest that calcium and phosphorus play a crucial role in egg production and can be detrimental if offered in excess or if deficient. The correct balance needs to be met to obtain optimal egg production.

Altering Nutrient Density

Armed with the knowledge of the fact that laying hens can adjust their feed intakes, trials were conducted to discover the implications of this behavior with changes in the nutrient densities of all components of the layer diet and how these changes influenced egg production and quality. Using Shaver White laying hens from 19 to 67 wk of age, Leeson et al. (2001) showed that the diet density could be lowered by 10% without affecting egg production or egg weight; however egg mass was significantly reduced when the density was lowered by 15%. Yet, the 10% reduction in energy and nutrient density resulted in a 20% increase in feed intake (from about 100 g/d to about 120 g/d; with the highest reported daily feed consumption being 130 g/d). Unfortunately, Leeson et al. (2001) did not report the diet's purchase price or egg incomes, but, because of the increased feed consumption, the purchase price of the low-density diet would have to be at least 80% of that of the control diet to maintain or improve profits. Wu et al. (2005; 2007) and Gunawardana et al. (2008) both conducted nutrient density trials with the conclusion that, due to the variability of egg and nutrient prices and the lack of a set price, there could be no fixed ideal levels in the diet for optimal profits.

Research has been carried out looking at different dietary factors surrounding the main theme of changing the density of nutrients in the diet and observing the effects on egg production, egg quality, and possibly economics. Yet, many of these studies have looked at changing the amounts of only certain elements of the diet rather than altering the whole nutrient density of the diet proportionally or have only studied through certain phases of the lay cycle. Furthermore, many did not take economic data into consideration; a main factor of importance to an egg producer. In the following trial, the effects of nutrient density on egg production and economics were taken into account over a complete lay cycle.

The hypothesis of this study is that laying hens can respond to less expensive, low-density diets, by increasing feed intake and thereby maintaining energy and nutrient consumption to meet the needs for maximal egg production such that overall egg profits are improved.

It is expected that the hens will attempt to change their feed intake proportionally to the changes in diet nutrient density to maintain energy and nutrient intake and, therefore, egg production and egg weight. However, the W-36 has a relatively limited capacity for increasing its feed intake (especially in hot weather). Therefore, egg production and egg weight may be reduced, decreasing overall returns due to decreased feed intake and lower egg production.

Therefore, the objective of this thesis is to determine the effects of feeding diets of five different nutrient densities to Hy-Line W-36 hens on measurements of long-term egg production performance and economic effects.

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Chapter 2

Effects of Feeding Diets Varying in Nutrient Density to Hy-Line W-36 Laying Hens on Production Performance and Profitability

Abstract

An experiment was conducted with 480 Hy-Line W-36 laying hens to determine whether feeding diets that varied in nutrient density would affect long-term egg production performance. At 18 wk of age, laying hens were weighed and randomly allocated to 6 replicate groups of 16 hens each (2 adjacent cages containing 8 hens per cage, 60.9 x 58.4 cm) per dietary treatment in a randomized complete block design. Placement within house and initial body weight were used as blocking criteria. The hens were fed 5 treatment diets formulated to contain 85, 90, 95, 100, and 105% of the energy and nutrient recommendations stated in the 2009 Hy-Line W-36 management guide. Production performance was measured for 52 wk from 18 to 70 wk of age. At 31 wk of age, hens fed the 85% Treatment experienced a post-peak decrease in egg production, with an average hen-day egg production of 65%. At 32 wk of age hen-day egg production for hens on the 85% Treatment was below 50%, with an average of 36%. At this time, hens fed the 85% Treatment were switched to the 100% Treatment (control) due to low egg production.

Over the course of the trial, a significant linear response to increasing nutrient density was seen for average hen-day egg production (18 to 70 wk of age), with Treatments 90 to 105% being 81.87, 81.28, 85.98, and 84.62%, respectively. From 18 to 70 wk of age, a significant linear response to increasing nutrient density was found for egg weight (g/egg), with Treatments 90 to 105% being 58.38, 59.15, 59.10, and 60.00g, respectively. Similarly, there was a significant linear increase in egg mass in response to increasing nutrient density, with Treatments 90 to 105% being 46.77, 47.35, 47.71, and 48.32 g egg/hen per day, respectively. A significant

linear increase in feed intake due to increasing nutrient density occurred early in the production cycle and from 18 to 70 wk of age, an increase in nutrient density showed a significant linear response in improved feed efficiency (g egg/g feed), with Treatments 90 to 105% being 0.47, 0.48, 0.49, and 0.50, respectively. A significant linear response to increasing nutrient density was seen from 18 to 70 wk of age for Jumbo to Large and Medium to Small eggs. The majority of eggs produced throughout the trial (about 90%) were Extra Large, Large, and Medium sized eggs. On average, the 100 and 105% Treatments produced the most Jumbo to Large eggs, while diets of lower nutrient density produced more Medium to Small eggs. A significant linear response to increasing nutrient density was seen for body weight, with the 85% Treatment hens being the lightest and the 105% Treatment hens being the heaviest. At 70 wk of age a significant linear increase in nutrient density produced heavier fat pad weights, but no effect was noted for bone ash or bone breaking strength due to increasing nutrient density. Significant linear responses due to nutrient density were seen for income, feed cost, and return over feed cost. In general, as nutrient density increased, egg income and feed cost per hen increased, while return over feed cost decreased.

Overall, these results indicate that feeding Hy-Line W-36 hens diets formulated to contain lower nutrient density specifications (85% of control) than recommended may compromise production performance. Furthermore, increasing nutrient density in the diet of a laying hen will increase egg production, egg weight, and feed efficiency. However, these benefits do not take effect in early production and seem to be most effective in later stages of the production cycle; perhaps ‘priming’ the birds for better future production.

Introduction

Outside the Midwest United States, high-energy feed ingredients such as corn grain and vegetable oil are relatively expensive, meaning that low-energy diets are often fed. While low-energy diets may not appear to supply sufficient energy to laying hens, hens can regulate their feed intake rate to maintain energy intake (Harms et al., 1998; Leeson et. al., 2001). In this way, hens will consume more of a low-energy diet than of a high-energy diet, thus ensuring that the calories consumed are similar with either diet. Accordingly, the percentage of nutrients, such as amino acids or phosphorous, can be lower in a low-energy diet than in a high-energy diet, yet still ensure adequate nutrient consumption due to the changes in feed intake. However, other research has suggested that hens are not accurate in adjusting feed intakes (Morris, 1968). Yet, low-density diets are attractive to producers outside the Midwest due to their lower purchase price and, often, mainly low-density commercial laying-hen diets are available from independent feed mills.

Modern strains of laying hens, such as the Hy-Line W-36, only have a limited capability to increase their feed intake to ensure adequate energy and nutrient intake. This is due to the characteristic low feed intake and increased feed efficiency of the strain of bird (Hy-Line W-36, 2009). While low density diets are less expensive to purchase, they will not ensure optimal egg production if hens do not adjust their feed intake. If hens do not have the capacity to increase their feed intake in order to consume enough of the nutrients they require, egg production can suffer. This may result in reduced returns due to decreases in egg incomes stemming from reductions in egg numbers and/or egg weights. On the other hand, the purchase price of low-density diets can be substantially lower than high-density diets and, if effective in maintaining long-term egg production and egg weight, can result in increased returns for the producer. Thus, feeding low-density nutrient diets to laying hens may result in improved returns due to a lower cost of those diets. However, it has been shown that the increased efficiency of birds fed on high density diets can offset the higher cost of the feed (Young, 1976).

Given this background, the hypothesis of this study is that laying hens can respond to less expensive, low-density diets, by increasing feed intake and thereby maintaining energy and nutrient consumption to meet the needs for maximal egg production such that overall returns are improved. Therefore, the objectives of this study were to measure egg production and economic effects of feeding diets of five different nutrient densities, formulated to 85, 90, 95, 100, and 105% of the energy and nutrient recommendations in the 2009-2011 Hy-Line W-36 management guide.

Materials and Methods

All animal care procedures were approved by the university Institutional Animal Care and Use Committee. An experiment was conducted using 480 Hy-Line W-36 Single Comb White Leghorn hens from 18 to 70 wk of age. The chicks were transported to the poultry research farm at 1 d of age and were brooded and reared on the floor in a grow-out building until 17 wk of age, upon which they were moved to a fan-ventilated cage laying-hen facility of commercial design. At this time, they were fed a pre-lay diet ad libitum and allowed to acclimate for a 1-wk period. This diet contained 17.0% CP, 2,951 kcal/kg of ME_n, 2.5% Ca, and 0.48% available P. At 18 wk of age all hens were weighed and assigned to treatments in a randomized complete block design with location within house and initial body weight as blocking criteria. Hens were housed 8 per cage (60.9 x 58.4 cm; 69 in^2/hen) to simulate industry practices[1] and 2 adjacent cages of 16 hens served as the experimental unit. Six replicate groups of 16 hens were each randomly assigned to each of the five treatment diets. All hens were fed the experimental diets from 18 to 70 wk of age. At 31 wk of age, hens fed the 85% Treatment experienced a post-peak decrease in egg production, with an average hen-day egg production of 65%. At 32 wk of age hen-day egg production for hens on the 85% Treatment was below 50%, with an average of 36%. At this time, hens fed the 85% Treatment were switched to the 100% Treatment (control) due to low egg production.

Hens were managed according to the guidelines in the 2009 Hy-Line W-36 management guide and had free access to feed and water at all times. The control diet was formulated to meet or exceed recommended energy and nutrient levels in the 2009 Hy-Line W-36 management guide, and the other dietary treatments were created by changing the energy and nutrient densities of the control diet (100%) to 85, 90, 95, and 105%, respectively (Tables 2.1 to 2.3). All diets were formulated on a least-cost basis using corn grain, soybean meal, wheat middlings, corn distiller's dried grains with solubles, and/or soybean hulls, to mimic industry practices, using feed-ingredient prices from a local commercial feed mill. The experimental diets were fed in phases. Phase 1 diets were fed from 18 to 25 wk of age (Table 2.1), phase 2 diets were fed from 26 to 31 wk of age (Table 2.2), and phase 3 diets were fed from 32 to 70 wk of age (Table 2.3). This phase feeding was done to maximize egg production and egg weights to equal that which is published in the 2009 Hy-Line W-36 management guide. All hens were weighed at the

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[1] Hens housed at lower densities (i.e., 7 hens per cage; 79 in^2/hen) will exhibit a different feed-consumption rate and behavior and results from housing in this manner may therefore not be applicable to the industry (Bell and Weaver, 2002).

beginning of the trial at 18 wk of age, when switched from Phase 1 to Phase 2 and Phase 2 to Phase 3 diets, and at the conclusion of the trial at 70 wk of age.

Egg Production Performance

Egg production and mortality were recorded daily, whereas feed consumption was measured every 2 wk as feed disappearance. Eggs were collected over a 48-hr period and weighed every 2 wk for determination of egg weight and egg grades.

When hens were 26 wk of age and every 4 wk thereafter, a maximum of 30 eggs per replicate laid in a 48-hr period were collected and transported to Hy-Line International in Dallas Center, Iowa, for determination of shell breaking strength, albumen height, Haugh units, and weights of egg components (eggshell, yolk, and albumen). Haugh units were calculated in the same way as Wu et al. (2007). Eggs collected from a second 24-hr period when hens were 26 wk of age, and every 8 wk thereafter, were weighed and percent solids were measured at the University of Illinois. Seven eggs per replicate were collected 6 times at 31, 38, 46, 54, 62, and 69 wk of age and percent yolk, yolk solids, albumen solids, and whole egg solids were determined. Egg solids procedures were performed similarly to Wu et al. 2005. Each egg was weighed and broken into a cup. The yolk was then separated from the albumen and each component was mixed separately. A set of three fiberglass microwave pads were weighed and 3 g of yolk sample was applied in between the first and second pad. The pads were weighed again and micro-waved for 5 min at 80% power. Afterwards, the pads were weighed a final time. The same procedure was repeated for the albumen. The albumen samples were micro-waved for 5 min at 100% power. Samples were micro-waved in a 1.60 kW GE microwave with 120/60 Hz. This process for both yolk and albumen samples was repeated for each of the seven egg samples from each replicate. Whole solids were calculated from the yolk and albumen solids values obtained from the procedures above.

After one week into the experiment, 8 hens from an extra cage were weighed and euthanized by CO_2 asphyxiation, after which the fat pad was collected and weighed. Left-side tibias, humeri, and femurs were collected, stripped of soft and connective tissues, and dry-ashed for 24 hr, after which the ash (mineral) content and percentage bone ash was calculated. The right-side tibias, humeri, and femurs were used for flexural testing, measured according to Alexander et al. (2008) using an Instron Universal Testing Machine (Instron, Canton, MA) equipped with a 10-kN load cell and configured for 3-point bending tests. Load applied at both yield and failure were determined using software (Series IX, v 8.08.00 software, Instron). The bones were placed on upright supports spaced 3 cm apart and the crosshead applied pressure to the bone equidistant between the 2 uprights. At the end of the study, all hens were weighed and 3 hens from each replicate with a body weight close to the mean body weight within the replicate were euthanized for measures of fat-pad weight and bone strength as described previously, with the exception that femurs were not used and only left-side tibias and humeri were dry-ashed and right-side tibias and humeri were used for flexural testing.

Economics were evaluated as the income over feed cost, calculated from the cost of feeding the hens and the price obtained for the eggs. Egg income was calculated every two weeks when eggs were graded. A ratio of the total number of eggs laid in two weeks over the total number of eggs laid over two consecutive days of collection was used to provide an estimate of the number of eggs laid in each USDA size category over two weeks per hen. The percent of jumbo, extra large, large, medium, and small eggs laid over two consecutive days were multiplied by their respective Urner-Barry Midwest 5-day average price quote (prices for a dozen eggs from August 2009 to August 2011) and added together. This figure was multiplied by the ratio described above. Feed costs were calculated by multiplying the cost of each diet (based on the local price of feed ingredients, from August 2009 to August 2011, in \$/g of feed) by the total amount of feed consumed in a two week period on a per hen basis. To obtain feed costs, the cost of feed was divided by pounds of feed purchased to find the cost of feed per pound. Next, feed costs by ton were calculated by multiplying the feed cost per pound by 2,000 pounds. To calculate feed cost per gram, feed cost per pound was divided by 454 g. The feed costs per ton for Treatments 85 to 105% for phase one were \$279.80, \$307.00, \$341.20, \$376.48, and \$410.10, respectively. Feed costs per ton for Treatments 85 to 105% for phase two were \$248.20, \$266.60, \$295.10, \$326.90, and \$359.70, respectively. Feed costs per ton for Treatments 85 to 105% for phase three were \$256.68, \$266.20, \$296.12, and \$327.48, respectively. The 85% Treatment was not fed during phase three due to the hens being removed from the treatment and switched to the 100% Treatment (control) at 32 wk of age. Return over feed cost was calculated by subtracting feed costs from egg income and expressing this figure in \$/hen.

Statistical Analysis

The experimental design was a randomized complete block design with location within house and initial body weight as blocking criteria. Data were analyzed by ANOVA using the GLM procedure of SAS (SAS, 2008) with dietary treatment and block as independent variables (Steel and Torrie, 1980). Treatment effects were evaluated using linear and quadratic orthogonal polynomial contrasts. P-values ≤ 0.05 were considered significant. Data for mortality was transformed using square-root transformation.

Results

There were no significant differences seen in mortality due to nutrient density of diet. Average mortality over the length of the trial for all replicates was 1.35%.

At 31 wk of age, hens fed the 85% Treatment experienced a post-peak decrease in egg production, with an average hen-day egg production of 65%. At 32 wk of age hen-day egg production for hens on the 85% Treatment was below 50%, with an average of 36% (Figure 2.1). At this time, hens fed the 85% Treatment were switched to the 100% Treatment (control) due to low egg production. After being switched to the control treatment, hens previously fed the 85% Treatment had an average hen-day egg production of 68% at 33 wk of age. After two weeks, at 34 wk of age, the hens had recovered and caught up with hens fed the other experimental treatments, having an average hen-day egg production of 92%. Production data for the 85% Treatment was not statistically analyzed for data from 32 to 70 and 18 to 70 wk of age.

A significant linear response to increasing nutrient density was seen in hen-day egg production from 26 to 31, 32 to 70, and 18 to 70 wk of age (Table 2.4). The 100 and 105% Treatments showed higher egg production than the 85, 90, and 95% Treatments from 32 to 70 and 18 to 70 wk of age. In addition, egg production of the hens fed the control diet (100%) was the highest for all phases and over the entire experiment. These differences could be seen starting at 26 wk of age. A quadratic response of egg production to increasing nutrient density was also seen from 26 to 31 wk of age. Figure 2.1 depicts the hen-day egg production for the entire laying cycle. At the end of 31 wk of age, egg production for hens fed the 85% Treatment had dropped below 40%. Therefore, they were switched to the 100% Treatment (control) and egg production promptly recovered. Figure 2.2 depicts hen-day egg production of hens fed the 90, 95, 100, and

105% Treatments from 58 to 70 wk of age, when average in-house high and low temperatures were 30.8°C (87.4°F) and 25.3°C (77.5°F), respectively.

There was a significant linear increase in egg weight by 1 to 2 g from 18 to 25, 26 to 31, 32 to 70, and 18 to 70 wk of age (Table 2.5). From 18 to 25 and 26 to 31 wk of age, the 85% Treatment produced the lightest eggs, while the 90 and 95% Treatments produced eggs of similar weight, and the 100 and 105% Treatments produced the heaviest eggs. A quadratic response was seen from 26 to 31 wk of age, with hens fed the 85% Treatment having the lowest egg weights and hens fed the 105% Treatment having the highest egg weights. Overall (18 to 70 wk of age), the 90% Treatment produced the lightest eggs, the 95 and 100% Treatments produced similarly, and the 105% Treatment produced the heaviest eggs.

A significant linear response to increasing nutrient density was seen from 26 to 31 and 32 to 70 wk of age for Jumbo to Large and Medium to Small eggs. A significant linear response to increasing nutrient density was seen from 18 to 70 wk of age for Jumbo to Large, Medium to Small, and PeeWee to No Grade eggs. No quadratic responses were seen in response to increasing nutrient density (Table 2.6). The majority of eggs produced throughout the trial (about 90%) were Extra Large, Large, and Medium sized eggs. On average, the 100 and 105% Treatments produced the most Jumbo to Large eggs, while diets of lower nutrient density produced more Medium to Small eggs. PeeWee and Jumbo eggs only occurred in the beginning of the lay cycle (18 to 25 wk of age). No Grades were due to egg damage and were unable to be analyzed for grade size.

There was a significant linear increase in egg mass (g egg/hen per day) in response to increasing nutrient density from 18 to 25, 26 to 31, 32 to 70 and 18 to 70 wk of age. (Table 2.7). A quadratic response to increasing nutrient density was seen from 26 to 31 wk of age. In general, egg mass was highest for hens fed the 105% Treatment and decreased linearly with the 85 and 90% Treatments having the least.

Figure 2.3 depicts feed intake for hens fed the 85% Treatment and the 100% Treatment (control). This shows that feed intake dropped at 32 wk of age but increased back to its original level by 34 wk of age when the hens were switched to the 100% Treatment. An increase in dietary nutrient density showed a significant linear response in increased feed intake when hens were switched to the control (Table 2.8). Hens fed the 85% Treatment consumed the most feed from 18 to 25 wk of age and the 90% Treatment consumed the most feed from 26 to 31 wk of age (Table 2.8). From 26 to 31 wk of age there was a significant quadratic response in feed intake in response to nutrient density, with the 85 and 105% Treatments consuming less feed than Treatments 90 through 100%. Birds adjusted feed intake to nutrient density early in the lay cycle, from 18 to 25 and 26 to 31 wk of age, while failing to do so throughout the majority of the trial and lay cycle (32 to 70 wk of age). Figure 2.4 depicts the decline in feed intake during the last 12 wk of the experiment when in-house temperatures were high. This data show that hens fed the 90 and 95% Treatments consumed slightly less feed than those fed the 100 and 105% Treatments.

An increase in nutrient density showed a significant linear response in improved feed efficiency (g egg/g feed) for 18 to 25, 26 to 31, 32 to 70 and 18 to 70 wk of age (Table 2.9). As expected, the 105% Treatment had the best feed efficiency across 18 to 25, 26 to 31, 32 to 70 and 18 to 70 wk of age, with a peak from 26 to 31 wk of age of 0.56 g egg/g feed. A quadratic response was seen from 26 to 31 wk of age.

Body weight of hens increased significantly with an increase in nutrient density (Table 2.10; Figure 2.5). Significant linear responses to an increase in nutrient density were seen from

26 to 31, 32 to 70 wk of age, and when a final weight was taken at the end of the trial. When weights were recorded at 26, 32, and 70 wk of age, hens fed the 85% Treatment were the lightest, with hens fed Treatments 90 to 105% each being heavier than the next.

For egg quality measurements, significant linear responses in egg quality due to nutrient density were seen for egg weight from 26 to 31 wk of age, 32 to 70 wk of age, and overall (26 to 70 wk of age) and color of shell from 26 to 70 wk of age (Table 2.11). No significant linear responses were seen for breaking strength, albumen height, yolk weight, or Haugh units. Significant quadratic responses to increasing nutrient density were seen for yolk weight from 26 to 31 wk of age and albumen height, color of shell, and haugh units from 26 to 31, 32 to 70 and 26 to 70 wk of age.

The effect of diets varying in nutrient density on percent yolk and egg solids is depicted in Table 2.12. The only responses noted were a linear response to increasing nutrient density for percent egg yolk and whole solids from 26 to 31 wk of age. As nutrient density increased, percent of egg yolk decreased. No other significant responses were seen.

There was a significant linear effect of nutrient density of diet on the fat pad weight of laying hens (Table 2.13). As nutrient density increased, the fat pad weight increased.

There were no significant differences seen in bone ash (Table 2.14) or bone breaking strength (Table 2.15) due to nutrient density of diet.

Significant linear responses due to increasing nutrient density were seen for feed cost from 18 to 25, 26 to 31, 32 to 70 wk of age and overall (Table 2.16). Quadratic responses were seen from 32 to 70 wk of age and overall. Significant linear responses due to increasing nutrient density were seen for income from 18 to 25, 26 to 31, 32 to 70 and 18 to 70 wk of age. A significant quadratic response was seen from 26 to 31 wk of age. Significant linear responses due to increasing nutrient density were seen for return over feed cost from 18 to 25, 26 to 31, 32 to 70, and 18 to 70 wk of age. No quadratic responses were seen. In general, as nutrient density increased, income and feed cost increased, while return over feed cost decreased.

Discussion

Proper laying hen nutrition can be effective in allowing hens to reach optimal production, increase egg quality, and allow producers to reach their profit goals. Ways to alter the nutrient composition in the laying hen diet have been extensively explored, and past research to achieve these goals have included altering amounts of amino acids and protein (Harms et al. 1998, 1999; Keshavarz, 1998; Khajali et al., 2008), altering energy content (Latshaw et al., 1990; Wu et al., 2005; Gunawardana et al., 2009), or altering mineral content (Davidson and Boyne, 1969; Reichmann and Connor, 1977; Clunies et al. 1992) in the diet. Through studies involving protein, it was found that the amount of amino acids present in the diet can influence feed intake, egg production, and egg weight. Increasing protein in the diet would increase these parameters. When experimenting with energy content, it was found that hens will adjust their feed intake to the amount of energy present in a diet; that increasing energy will decrease feed intake. In looking at minerals, it was found that calcium positively influences egg quality and strength, and that high levels of phosphorous and/or calcium can decrease feed intake and possibly egg production and egg quality.

The objective of the present study was to determine the effects of feeding diets of five different nutrient densities to Hy-Line W-36 hens on measurements of long-term egg production performance and economic effects. Significant linear responses to increasing nutrient density were only seen for feed intake from 18 to 25 and 26 to 31 wk of age. Hens altered their feed intake in response to nutrient density only in the early stages of the lay cycle, perhaps adjusting to the nutrient balance of the feed. Overall, hens did not alter feed intake throughout the majority of the trial (32 to 70 wk of age) as was hypothesized. Significant linear effects due to increasing nutrient density were seen for most parameters measured, including hen-day egg production, egg weight, egg mass, and feed efficiency. Data for hen-day egg production show that hens fed Treatment diets 2 and 3 (90 and 95% of control) laid fewer eggs than those fed Treatment diets 4 and 5 (100 and 105% of control).

Leeson et al. (2001) found that, as long as nutrient balance is maintained in low density diets, diets with an ME_n as low as 2465 kcal/kg and CP as low as 15.2% can be adequate to support a full cycle of production. However, hens fed the 85% Treatment were fed an ME_n content of 2750 and CP content of 19.66% for phase one (18 to 25 wk of age) and 2700 ME_n and 18.63% CP in phase two (26-31 wk of age). As can be seen, hens fed the 85% Treatment never reached the energy and protein limits established by Leeson et al. (2001). However, Leeson et al. (2001) did not use W-36 laying hens in his trial, so it is possible that the Shaver White hens could tolerate lower amounts of nutrients and continue to produce eggs at sufficient levels. In a study conducted by Harms and Russell (1998), Hy-Line W-36 hens were fed diets deficient in various amino acids from 29 to 37 wk of age. When fed deficient diets, egg production, egg weight, egg content, feed intake, and body weight all decreased. Egg production on deficient diets reached as low as 41.2%. This is consistent with the effects of deficiency seen in hens fed the 85% Treatment. The trial by Harms and Russell (1998) was conducted around the same age when hens fed the 85% Treatment had decreased egg production due to deficiencies in the diet. Also similar to the results in the trial conducted by Harms and Russell (1998), even though hens fed the 85% Treatment were deficient and suffered a decrease in egg production, once fed a diet with sufficient nutrients (control), performance was restored within a couple weeks.

It is hypothesized that energy and certain nutrients, especially calcium and phosphorus, were not supplied and/or consumed in adequate amounts to support the egg production of hens fed the 85% Treatment. However, a solid reason for why the 85% Treatment egg production dropped is unknown. In the early stages of the lay cycle, young hens have different nutrient requirements than older hens, and usually need higher nutrient concentrations due to low feed intake (NRC, 1994). It can be concluded that the 85% Treatment did not offer enough nutrients or energy for a young bird to be able to reach production in the first two phases and that the W-36 laying hen does not have the capacity to increase its intake when fed a diet of low nutrient density. This caused performance to suffer.

Egg production, egg weight, egg mass, and feed efficiency all increased in response to increased nutrient density. Lesson et al. (2001) saw similar results in Experiment 2, when birds fed diets with the lowest nutrient density produced the fewest eggs. Their results were significant in the third diet phase of the lay cycle starting at Week 35. Lesson et al. (2001) also saw a trend in reduced egg size when diet nutrient density was reduced. However, their results showed small effects and were only significant at isolated measurements. Lesson et al. (2001) similarly reported that a decline in nutrient density showed a decline in feed efficiency. As Young (1976) stated, higher energy diets can improve feed efficiency. This agrees with the results seen in this trial. In the present study, body weight was also greatly affected by nutrient density, with hens fed a higher density diet being heavier. Body weights of laying hens were lighter than normally expected in the W-36 laying hen possibly due to the fact that the birds for this trial were floor-raised. However, this did not inhibit their start of lay, peak production, growth, or overall production. This is with the exception of the 85% Treatment. Even though the birds were switched to the control diet, by 32 wk of age, they had the lowest average body weight. Not many significant differences were seen in the quality or components of eggs in response to nutrient density. Therefore, the greatest benefits and effects of nutrient density on the laying hen are apparent and active in the production of and size of the egg produced, as well as the feed efficiency of the hens.

Compared to three other strains of hens, the Hy-Line W-36 had the highest percentage of whole egg solids and the percentage of egg solids was hardly influenced by egg size, except for when eggs reached Jumbo size (Ahn et al., 1997). Whole egg, white, and yolk solids values for the Hy-Line W-36 were 24.52, 11.99, and 50.89%, respectively. These values for whole egg, white, and yolk solids found by Ahn et al. (1997) are fairly consistent with values found in this trial. Whole egg solid values from 26 to 70 wk of age for Treatments 90 to 105% were 25.11, 25.19, 24.99, and 24.51%, respectively. White solids values from 26 to 70 wk of age for Treatments 90 to 105% were 13.53, 13.44, 13.49, and 12.76%, respectively. Yolk solid values from 26 to 70 wk of age for Treatments 90 to 105% were 50.26, 50.34, 50.18, and 50.38%, respectively.

According to Anderson (2007), out of 8 other strains of laying hens raised in battery type cages, the W-36 had the lowest average feed cost per hen of $6.73. The average egg income per hen was also the lowest at $18.94. Feed costs from 18 to 70 wk of age were higher than costs seen by Anderson (2007), with the cost per hen for Treatments 90 to 105% being 10.60, 11.06, 12.41, and 13.52 $/hen, respectively. The average income for Treatments 90 to 105% from 18 to 70 wk of age was 21.55, 21.71, 22.90, and 22.93 $/hen, respectively. These incomes are slightly higher than those found by Anderson (2007). However, fluctuating egg prices and the price of feedstuffs can alter these results. Return over feed cost in $/hen was lowest for hens fed the 105% Treatment and there was a significant linear decrease in return over feed cost due to increasing nutrient density for Treatments 90 to 105% with returns being 10.96, 10.65, 10.49, and 9.41 $/hen, respectively, from 18 to 70 wk of age. These results indicate that, even though hens fed higher density diets had improved feed efficiency and produced more eggs of larger sizes, the income from these did not offset the costs of the high density diets, and return over feed cost was greater from hens fed lower density diets.

While this trial shared some similar results with that of Lesson et. al. (2001), it is important to take note that Lesson et al. (2001) used Shaver White Layers rather than Hy-Line W-36 laying hens. Lesson et al. (2001) had issues with the Shaver White hens over-consuming feed, which is more unlikely to occur with the W-36 (Anderson, 2007). The Hy-Line W-36 has a lower feed intake in comparison to other strains of laying hens.

In summary, these results indicate that increasing nutrient density in the diet of a laying hen will increase egg production, egg weight, egg mass, feed efficiency, body weight, income, and feed cost, as well as decrease return over feed cost. Furthermore, many of these benefits did not take effect in early production and seem to be most effective in later stages of the lay cycle; perhaps ‘priming’ the birds for better future production. As hypothesized, hens were not able to adjust their feed intakes and the lowest density diet was unable to support egg production.

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Tables

Table 2.1. Composition of the experimental diets fed during phase 1[1] of the laying cycle

	Nutrient Density[2]				
Ingredient	85%	90%	95%	100%	105%
Corn	53.46	51.44	45.59	41.75	35.50
Soybean meal	25.70	27.70	30.73	33.88	37.14
Pork meal (50% CP)	5.00	5.00	5.00	5.00	5.00
Corn DDGS	4.28	2.00	2.00	-	-
Soybean oil	0.48	2.15	4.29	6.25	8.48
$CaCO_3$[3]	9.26	9.66	10.13	10.61	11.16
Dicalcium phosphate	0.93	1.08	1.24	1.44	1.59
Salt	0.30	0.34	0.36	0.39	0.42
Vitamin mix[4]	0.20	0.20	0.20	0.20	0.20
Mineral mix[5]	0.15	0.15	0.15	0.15	0.15
DL-Methionine	0.19	0.23	0.25	0.28	0.31
Cyromazine	0.05	0.05	0.05	0.05	0.05
Calculated analysis:					
CP	19.66	19.89	20.87	21.56	22.62
Lysine	1.03	1.07	1.14	1.20	1.28
Methionine	0.49	0.53	0.56	0.59	0.63
Met + Cys	0.81	0.83	0.88	0.91	0.96
Crude fat, %	3.49	4.84	6.80	8.41	10.44
ME_n, kcal/kg	2750	2817	2884	2950	3017
Ca, %	4.24	4.43	4.65	4.88	5.13
Nonphytate P, %	0.53	0.55	0.58	0.61	0.64
Sodium, %	0.19	0.20	0.21	0.22	0.23

[1] Phase 1 treatment diets were fed from 18 to 25 wk of age.

[2] Percentage of recommended nutrient density.

[3] 65% of $CaCO_3$ was supplied in particle sizes over 0.14 mm.

[4] Provided per kilogram of diet: vitamin A from vitamin A acetate, 4,400IU; cholecalciferol, 1,000 IU; vitamin E from α-tocopheryl acetate, 11 IU; vitamin B_{12} 0.011 mg; riboflavin, 4.4 mg; d-panthothenic acid, 10 mg; niacin, 22 mg; menadione sodium bisulfate complex, 2.33 mg.

[5] Provided per kilogram of diet: manganese, 75 mg from manganese oxide; iron, 75 mg from iron sulfate; zinc, 75 mg from zinc oxide; copper, 5 mg from copper sulfate; iodine, 0.76 mg from ethylene diamine dihydroiodide; selenium, 0.1 mg from sodium selenite.

Table 2.2. Composition of the experimental diets fed during phase 2[1] of the laying cycle

	Nutrient Density[2]				
Ingredient	85%	90%	95%	100%	105%
Corn	51.68	57.07	54.45	50.65	45.07
Soybean meal	21.77	23.05	25.66	28.71	31.46
Pork meal (50% CP)	3.81	5.00	5.00	5.00	5.00
Corn DDGS	7.50	4.23	2.00	-	-
Soybean oil	-	0.17	1.88	3.84	5.96
$CaCO_3$[3]	8.59	8.80	9.20	9.63	10.18
Dicalcium phosphate	0.85	0.83	0.98	1.18	1.29
Salt	0.26	0.28	0.21	0.34	0.37
Vitamin mix[4]	0.20	0.20	0.20	0.20	0.20
Mineral mix[5]	0.15	0.15	0.15	0.15	0.15
DL-Methionine	0.14	0.17	0.22	0.24	0.27
Cyromazine	0.05	0.05	0.05	0.05	0.05
Calculated analysis:					
CP	18.63	18.67	19.15	19.80	20.68
Lysine	0.95	0.97	1.02	1.08	1.14
Methionine	0.42	0.46	0.50	0.53	0.57
Met + Cys	0.74	0.76	0.80	0.83	0.87
Crude fat, %	3.34	3.28	4.66	6.29	8.22
ME_n, kcal/kg	2711	2777	2844	2910	2977
Ca, %	3.86	4.04	4.23	4.44	4.68
Nonphytate P, %	0.48	0.51	0.53	0.56	0.58
Sodium, %	0.17	0.18	0.15	0.20	0.21

[1] Phase 2 treatment diets were fed from 26 to 31 wk of age.

[2] Percentage of recommended nutrient density.

[3] 65% of $CaCO_3$ was supplied in particle sizes over 0.14 mm.

[4] Provided per kilogram of diet: vitamin A from vitamin A acetate, 4,400IU; cholecalciferol, 1,000 IU; vitamin E from α-tocopheryl acetate, 11 IU; vitamin B_{12} 0.011 mg; riboflavin, 4.4 mg; d-panthothenic acid, 10 mg; niacin, 22 mg; menadione sodium bisulfate complex, 2.33 mg.

[5] Provided per kilogram of diet: manganese, 75 mg from manganese oxide; iron, 75 mg from iron sulfate; zinc, 75 mg from zinc oxide; copper, 5 mg from copper sulfate; iodine, 0.76 mg from ethylene diamine dihydroiodide; selenium, 0.1 mg from sodium selenite.

Table 2.3. Composition of the experimental diets fed during phase 3[1] of the laying cycle

	Nutrient Density[2]			
Ingredient	90%	95%	100%	105%
Corn	57.43	59.96	55.55	53.15
Soybean meal	17.24	20.04	22.34	25.13
Pork meal (50% CP)	5.00	5.00	5.00	5.00
Corn DDGS	5.08	3.41	2.91	-
Soybean oil	-	0.70	2.64	4.43
$CaCO_3$[3]	8.93	9.33	9.78	10.27
Dicalcium phosphate	0.53	0.71	0.88	1.05
Salt	0.25	0.28	0.31	0.35
Vitamin mix[4]	0.20	0.20	0.20	0.20
Mineral mix[5]	0.15	0.15	0.15	0.15
DL-Methionine	0.14	0.16	0.18	0.23
Cyromazine	0.05	0.05	0.05	0.05
Calculated analysis:				
CP	16.94	17.28	17.90	18.31
Lysine	0.84	0.88	0.93	0.98
Methionine	0.40	0.43	0.45	0.50
Met + Cys	0.68	0.71	0.74	0.77
Crude fat, %	3.34	3.79	5.52	6.92
ME_n, kcal/kg	2757	2824	2890	2957
Ca, %	4.02	4.21	4.42	4.65
Nonphytate P, %	0.46	0.48	0.51	0.53
Sodium, %	0.17	0.18	0.19	0.20

[1] Phase 3 treatment diets were fed from 32 to 70 wk of age. Treatment 1 is not shown because hens on this treatment were switched to Treatment 4 at 32 wk of age.

[2] Percentage of recommended nutrient density.

[3] 65% of $CaCO_3$ was supplied in particle sizes over 0.14 mm.

[4] Provided per kilogram of diet: vitamin A from vitamin A acetate, 4,400IU; cholecalciferol, 1,000 IU; vitamin E from α-tocopheryl acetate, 11 IU; vitamin B_{12} 0.011 mg; riboflavin, 4.4 mg; d-panthothenic acid, 10 mg; niacin, 22 mg; menadione sodium bisulfate complex, 2.33 mg.

[5] Provided per kilogram of diet: manganese, 75 mg from manganese oxide; iron, 75 mg from iron sulfate; zinc, 75 mg from zinc oxide; copper, 5 mg from copper sulfate; iodine, 0.76 mg from ethylene diamine dihydroiodide; selenium, 0.1 mg from sodium selenite.

Table 2.4. Effect of feeding diets varying in nutrient density on hen-day egg production (%)[1]

Age, weeks[3]	Nutrient density[2]					Pooled SEM	*P*-value	
	85%	90%	95%	100%	105%		Linear	Quadratic
18 to 25	60.6	62.2	63.0	65.0	62.6	1.307	0.109	0.174
26 to 31	89.1	92.9	94.4	97.2	94.3	1.196	0.001	0.015
32 to 70	-----	84.3	83.1	88.6	87.7	1.135	0.007	0.888
18 to 70	-----	81.9	81.3	86.0	84.6	1.007	0.012	0.707

[1] Data are means of 6 replicate groups of 16 hens each.

[2] Percentage of recommended nutrient density.

[3] At 32 wk of age, hens fed the 85% Treatment were switched to the 100% Treatment (control). Therefore, data from hens on the 85% Treatment were omitted from analysis of 32 to 70 and 18 to 70 wk of age.

Table 2.5. Effect of feeding diets varying in nutrient density on egg weight (g/egg) [1]

Age, weeks[3]	Nutrient density[2]					Pooled SEM	*P*-value	
	85%	90%	95%	100%	105%		Linear	Quadratic
18 to 25	50.4	50.9	51.0	51.6	51.3	0.333	0.024	0.370
26 to 31	54.1	55.9	56.2	56.8	57.2	0.295	<0.001	0.039
32 to 70	-----	60.4	61.3	61.0	62.2	0.386	0.007	0.796
18 to 70	-----	58.4	59.2	59.1	60.0	0.344	0.008	0.885

[1] Data are means of 6 replicate groups of 16 hens each.

[2] Percentage of recommended nutrient density.

[3] At 32 wk of age, hens fed the 85% Treatment were switched to the 100% Treatment (control). Therefore, data from hens on the 85% Treatment were omitted from analysis of 32 to 70 and 18 to 70 wk of age.

Table 2.6. Effect of feeding diets varying in nutrient density on egg size (%)[1]

		Nutrient density[2]						*P*-value	
Age, weeks[3]	Egg size	85%	90%	95%	100%	105%	Pooled SEM	Linear	Quadratic
18 to 25	Jumbo to Large	10.23	11.60	11.69	17.11	11.59	2.103	0.230	0.297
	Medium to Small	86.37	85.21	85.11	79.61	86.29	2.154	0.408	0.217
	PeeWee and No Grade	3.40	3.19	3.20	3.29	2.11	0.608	0.211	0.429
26 to 31	Jumbo to Large	19.57	37.18	37.91	48.17	48.68	3.832	<0.001	0.101
	Medium to Small	78.96	60.48	60.80	49.66	50.75	3.848	<0.001	0.069
	PeeWee and No Grade	1.47	2.34	1.29	2.17	0.57	0.567	0.281	0.172
32 to 70	Jumbo to Large	-----	76.07	80.54	80.43	87.13	2.725	0.016	0.688
	Medium to Small	-----	22.20	17.97	18.42	11.64	2.764	0.023	0.651
	PeeWee and No Grade	-----	1.74	1.50	1.16	1.24	0.252	0.127	0.537
18 to70	Jumbo to Large	-----	61.54	64.54	67.28	71.46	2.618	0.014	0.825
	Medium to Small	-----	36.43	33.74	31.13	27.27	2.586	0.020	0.823
	PeeWee and No Grade	-----	2.03	1.72	1.59	1.29	0.226	0.033	0.997

[1] Data are means of 6 replicate groups of 16 hens each.

[2] Percentage of recommended nutrient density.

[3] At 32 wk of age hens fed the 85% Treatment were switched to the 100% Treatment (control). Therefore, data from the hens on the 85% Treatment were omitted from analysis of 32 to 70 and 18 to70 wk of age.

Table 2.7. Effect of feeding diets varying in nutrient density on egg mass (g egg/hen per day)[1]

	Nutrient density[2]						*P*-value	
Age, weeks[3]	85%	90%	95%	100%	105%	Pooled SEM	Linear	Quadratic
18 to 25	33.7	33.9	33.9	34.3	34.2	0.202	0.042	0.618
26 to 31	51.2	52.9	53.2	53.8	54.2	0.280	<0.001	0.034
32 to 70	-----	48.5	49.3	49.6	50.4	0.324	0.001	0.968
18 to 70	-----	46.8	47.4	47.7	48.3	0.291	0.002	0.980

[1] Data are means of 6 replicate groups of 16 hens each.

[2] Percentage of recommended nutrient density.

[3] At 32 wk of age, hens fed the 85% Treatment were switched to the 100% Treatment (control). Therefore, data from hens on the 85% Treatment were omitted from analysis of 32 to 70 and 18 to 70 wk of age.

Table 2.8. Effect of feeding diets varying in nutrient density on feed intake (g/hen/day)[1]

	Nutrient density[2]						P-value	
Age, weeks[3]	85%	90%	95%	100%	105%	Pooled SEM	Linear	Quadratic
18 to 25	83.6	83.4	82.2	83.5	81.6	0.565	0.043	0.707
26 to 31	92.7	97.6	96.7	97.4	95.4	0.634	0.017	<0.001
32 to 70	-----	103.9	102.8	103.8	102.9	0.444	0.275	0.772
18 to 70	-----	100.1	98.9	99.9	98.7	0.446	0.164	0.974

[1] Data are means of 6 replicate groups of 16 hens each.

[2] Percentage of recommended nutrient density.

[3] At 32 wk of age, hens fed the 85% Treatment were switched to the 100% Treatment (control). Therefore, data from hens on the 85% Treatment were omitted from analysis of 32 to 70 and 18 to 70 wk of age.

Table 2.9. Effect of feeding diets varying in nutrient density on feed efficiency (g egg/g feed)[1]

	Nutrient density[2]						*P*-value	
Age, weeks[3]	85%	90%	95%	100%	105%	Pooled SEM	Linear	Quadratic
18 to 25	0.387	0.388	0.395	0.397	0.403	0.003	0.001	0.699
26 to 31	0.555	0.543	0.550	0.552	0.568	0.004	0.021	0.005
32 to 70	-----	0.482	0.492	0.493	0.503	0.004	0.002	1.000
18 to 70	-----	0.473	0.482	0.487	0.495	0.004	0.006	1.000

[1] Data are means of 6 replicate groups of 16 hens each.

[2] Percentage of recommended nutrient density.

[3] At 32 wk of age, hens fed the 85% Treatment were switched to the 100% Treatment (control). Therefore, data from hens on the 85% Treatment were omitted from analysis of 32 to 70 and 18 to 70 wk of age.

Table 2.10. Effect of feeding diets varying in nutrient density on body weight (g/hen)[1]

	Nutrient density[2]						*P*-value	
Age, weeks[3]	85%	90%	95%	100%	105%	Pooled SEM	Linear	Quadratic
18	1156	1157	1157	1157	1169	12.754	0.527	0.670
26	1423	1426	1453	1492	1516	16.078	<0.001	0.379
32	1241	1489	1497	1562	1578	19.094	0.001	0.844
70	-----	1637	1696	1743	1794	18.350	<0.001	0.820

[1] Data are means of 6 replicate groups of 16 hens each.

[2] Percentage of recommended nutrient density.

[3] At 32 wk of age, hens fed the 85% Treatment were switched to the 100% Treatment (control). Therefore, data from hens on the 85% Treatment were omitted from analysis of 32 to 70 and 18 to 70 wk of age.

Table 2.11. Effect of feeding diets varying in nutrient density on egg quality[1]

		Nutrient density[2]						*P*-value	
Age, weeks[3]	Quality Measure[4]	85%	90%	95%	100%	105%	Pooled SEM	Linear	Quadratic
26 to 31[5]	Breaking strength (kg)	4293	4274	4371	4317	4291	62.970	0.845	0.494
	Egg weight (g)	54.5	55.1	55.4	55.7	56.0	0.296	0.009	0.610
	Albumen height (mm)	7.9	8.0	7.7	7.9	8.1	0.081	0.571	0.036
	Shell color	9.1	9.7	10.0	10.0	9.1	0.313	0.709	0.010
	Yolk weight (g)	13.8	14.0	14.2	14.1	14.0	0.092	0.143	0.015
	Haugh units (units)	90.2	90.7	88.7	89.6	90.6	0.435	0.836	0.023
32 to 70[6]	Breaking strength (kg)	-----	3890	3742	3769	3826	76.941	0.640	0.203
	Egg weight (g)	-----	60.0	60.6	60.6	61.9	0.459	0.014	0.469
	Albumen height (mm)	-----	7.3	7.0	7.1	7.2	0.071	0.507	0.034
	Shell color	-----	9.0	9.0	9.1	8.4	0.161	0.069	0.039
	Yolk weight (g)	-----	16.9	17.4	17.2	17.4	0.160	0.136	0.354
	Haugh units (units)	-----	84.8	82.9	83.3	83.4	0.461	0.071	0.046
26 to 70	Breaking strength (kg)	-----	3976	3896	3886	3992	73.518	0.605	0.443
	Egg weight (g)	-----	59.0	59.4	59.6	60.7	0.412	0.011	0.416
	Albumen height (mm)	-----	7.4	7.2	7.3	7.4	0.064	0.645	0.013
	Shell color	-----	9.1	9.2	9.297	8.6	0.154	0.046	0.019
	Yolk weight (g)	-----	16.3	16.6	16.5	16.6	0.141	0.174	0.451
	Haugh units (units)	-----	86.0	84.2	84.5	84.8	0.421	0.103	0.025

[1] Data are means of 6 replicate groups of 16 hens each. A maximum of 30 eggs for each replicate were measured for egg quality.

[2] Percentage of recommended nutrient density.

[3] At 32 wk of age, hens fed the 85% Treatment were switched to the 100% Treatment (control). Therefore, data from hens on the 85% Treatment were omitted from analysis of 32 to 70 and 18 to 70 wk of age.

[4] Measurements taken once every 4 wk. No measurements were taken from 18 to 25 wk of age.

[5] Values are averages of two sampling periods taken at 26 and 30 wk of age.

[6] Values are averages of nine sampling periods taken at 34, 38, 42, 46, 50, 59, 62, 66, and 70 wk of age.

Table 2.12. Effect of feeding diets varying in nutrient density on percent yolk and percent egg solids (%)[1]

Age, weeks[3]	Quality Measure[4]	Nutrient density[2] 85%	90%	95%	100%	105%	Pooled SEM	*P*-value Linear	Quadratic
26 to 31[5]	Yolk	30.64	28.6	29.2	29.0	28.7	0.347	0.005	0.054
	Yolk solids	49.77	49.8	50.0	49.9	49.3	0.170	0.166	0.053
	White solids	12.41	12.5	12.5	12.6	12.7	0.102	0.086	0.880
	Whole solids	23.86	23.2	23.5	23.4	23.2	0.167	0.048	0.369
32 to 70[6]	Yolk	-----	32.1	32.4	31.9	31.8	0.272	0.197	0.437
	Yolk solids	-----	50.4	50.4	50.3	50.6	0.120	0.362	0.253
	White solids	-----	13.7	13.6	13.7	12.8	0.521	0.248	0.469
	Whole solids	-----	25.5	25.5	25.3	24.8	0.378	0.184	0.462
26 to70	Yolk	-----	31.5	31.9	31.4	31.2	0.264	0.265	0.348
	Yolk solids	-----	50.3	50.3	50.2	50.4	0.096	0.642	0.549
	White solids	-----	13.5	13.4	13.5	12.8	0.435	0.264	0.476
	Whole solids	-----	25.1	25.2	25.0	24.5	0.329	0.200	0.409

[1] Data are means of 6 replicate groups of 16 hens each. Egg solids were analyzed for 7 eggs for each replicate.

[2] Percentage of recommended nutrient density.

[3] At 32 wk of age, hens fed the 85% Treatment were switched to the 100% Treatment 4 (control). Therefore, data from hens on the 85% Treatment were omitted from analysis of 32 to 70 and 26 to70 wk of age.

[4] Measurements taken once every other month. No measurements were taken from 18 to 25 wk of age.

[5] Values are an average of one sampling period taken at 31 wk of age.

[6] Values are averages of five sampling periods taken at 38, 46, 54, 62, and 69 wk of age.

Table 2.13. Effect of feeding diets varying in nutrient density on fat pad weight (g/hen)

	Nutrient density[1]					*P*-value	
Age, weeks[2]	90%	95%	100%	105%	Pooled SEM	Linear	Quadratic
70[3]	93.5	97.4	114.6	116.5	6.392	0.009	0.880
% of BW[4]	5.5	5.8	6.4	6.7	0.273	0.005	0.967

[1] Percentage of recommended nutrient density.

[2] At 32 wk of age, hens fed the 85% Treatment were switched to the 100% Treatment (control). Therefore, data from hens on the 85% Treatment were omitted from analysis at 70 wk of age.

[3] At 70 wk of age, fat pad samples were taken from 3 birds from each replicate.

[4] Percent fat pad within average body weight of three hens from each replicate.

Table 2.14. Effect of feeding diets varying in nutrient density on bone ash (%)

		Nutrient density[1]					*P*-value	
Age, weeks[2]	Bone	90%	95%	100%	105%	Pooled SEM	Linear	Quadratic
70[3]	Tibia	55.7	55.3	57.8	55.8	0.949	0.490	0.394
	Humerus	60.5	59.3	58.6	58.9	0.947	0.222	0.455

[1] Percentage of recommended nutrient density.

[2] At 32 wk of age, hens fed the 85% Treatment were switched to the 100% Treatment (control). Therefore, data from hens on the 85% Treatment were omitted from analysis at 70 wk of age.

[3] At 70 wk of age, left tibia and humerus samples were taken and dry-ashed from 3 birds from each replicate.

Table 2.15. Effect of feeding diets varying in nutrient density on bone breaking strength (kg)

		Nutrient density[1]					*P*-value	
Age, weeks[2]	Bone	90%	95%	100%	105%	Pooled SEM	Linear	Quadratic
70[3]	Tibia	15.0	15.2	15.5	14.8	0.477	0.963	0.427
	Humerus	10.8	10.1	10.3	9.7	0.746	0.343	0.965

[1] Percentage of recommended nutrient density.

[2] At 32 wk of age, hens fed the 85% Treatment were switched to the 100% Treatment (control). Therefore, data from hens on the 85% Treatment were omitted from analysis at 70 wk of age.

[3] At 70 wk of age, right tibia and humerus samples were taken for flexural testing from 3 birds from each replicate.

Table 2.16. Effect of feeding diets varying in nutrient density on economics ($/hen/day)[1]

Age, weeks[3]	Nutrient density[2]					Pooled SEM	*P*-value	
	85%	90%	95%	100%	105%		Linear	Quadratic
	INCOME[4]							
18 to 25	2.11	2.18	2.22	2.31	2.24	0.047	0.016	0.170
26 to 31	2.41	2.65	2.71	2.84	2.82	0.053	<0.001	0.031
32 to 70	-----	16.73	16.77	17.74	17.87	0.197	0.002	0.829
18 to 70	-----	21.55	21.71	22.90	22.93	0.257	0.003	0.809
	FEED COST[5]							
18 to 25	1.44	1.58	1.73	1.94	2.07	0.012	<0.001	0.483
26 to 31	1.07	1.20	1.32	1.47	1.59	0.009	<0.001	0.881
32 to 70	-----	7.82	8.01	9.00	9.87	0.036	<0.001	<0.001
18 to 70	-----	10.60	11.06	12.41	13.52	0.054	<0.001	<0.001
	RETURN OVER FEED COST[6]							
18 to 25	0.66	0.60	0.50	0.37	0.17	0.043	<0.001	0.087
26 to 31	1.34	1.45	1.40	1.37	1.23	0.054	0.101	0.032
32 to 70	-----	8.91	8.76	8.74	8.01	0.201	0.009	0.170
18 to 70	-----	10.96	10.65	10.49	9.41	0.258	0.008	0.156

[1] Data are means of 6 replicate groups of 16 hens each.

[2] Percentage of recommended nutrient density.

[3] At 32 wk of age, hens fed the 85% Treatment were switched to the 100% Treatment (control). Therefore, data from hens on the 85% Treatment were omitted from analysis of 32 to 70 and 18 to 70 wk of age.

[4] Egg income was calculated every two weeks when eggs were graded. A ratio of the total number of eggs laid in two weeks over total number of eggs laid over two consecutive days was used to estimate the number of eggs laid in each size category over two weeks per hen. The percent of jumbo, extra large, large, medium, and small eggs laid over two days were multiplied by their respective Urner-Barry Midwest 5-day average price quote, added together, and multiplied by the ratio described above.

[5] Feed costs were calculated by multiplying the cost of each diet (based on the local price of feed ingredients in each diet in $/g of feed) by the

total amount of feed consumed in two weeks on a per hen basis.

[6] Return over feed cost was calculated by subtracting feed cost from egg income.

Figures

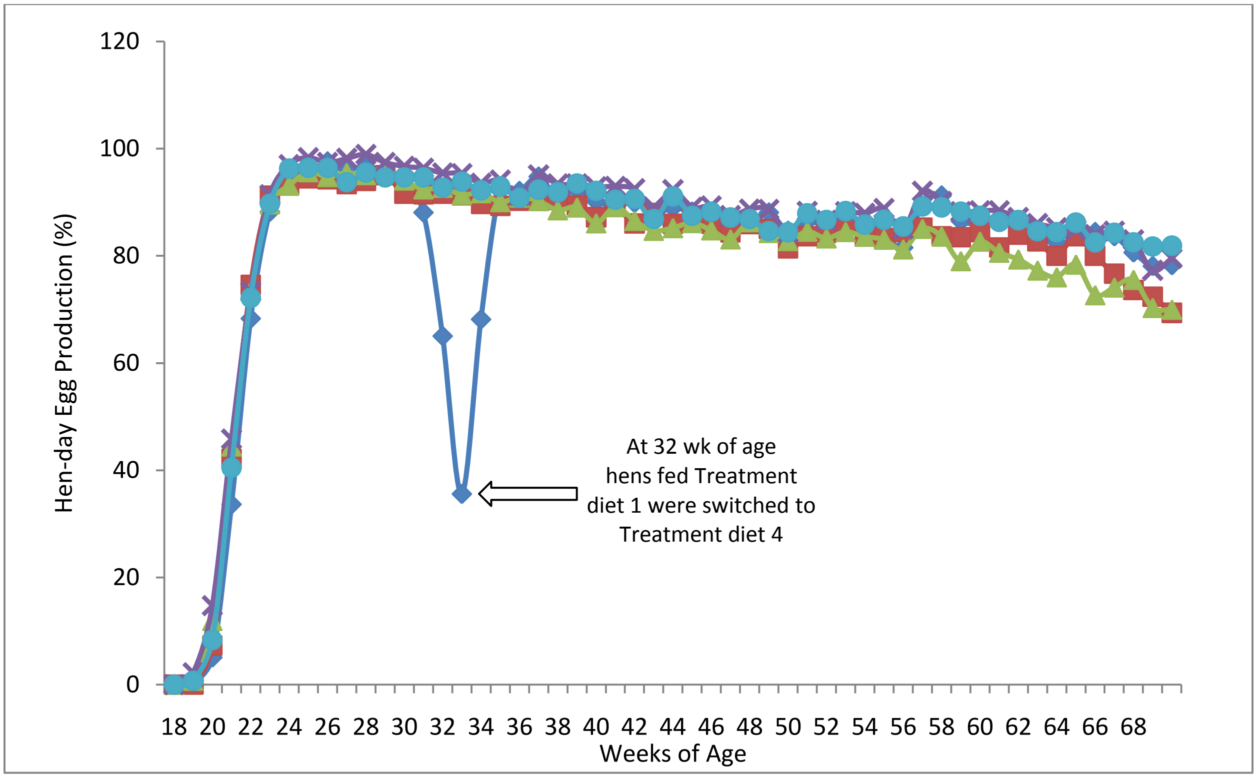

Figure 2.1. Weekly hen-day egg production of hens fed diets varying in nutrient density. Treatment diets were: 1) 85% (♦), 2) 90% (■), 3) 95% (▲), 4) 100% (×), and 5) 105% (•) of nutrient density of the control diet (100%), respectively. At 32 wk of age hens fed the 85% Treatment were taken off of this treatment and switched to the control (100%). Phase 1, 2, and 3 treatment diets were fed from 18 to 25, 26 to 31, and 32 to 70 wk of age, respectively.

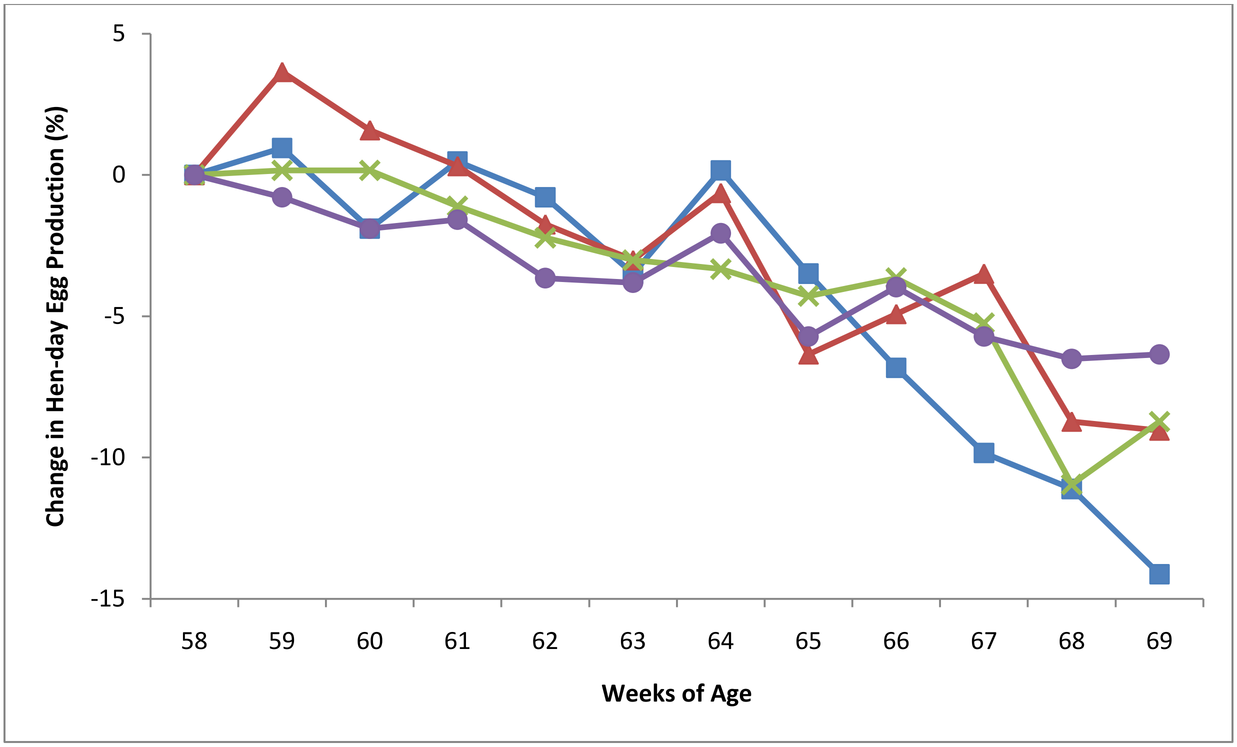

Figure 2.2. Weekly hen-day egg production of hens fed diets varying in nutrient density. Treatment diets were: 2) 90% (■), 3) 95% (▲), 4) 100% (×), and 5) 105% (•) of nutrient density of the control treatment (100%), respectively. The average high and low in-house temperatures for the last 12 wk of the trial were 30.8°C (87.4°F) and 25.3°C (77.5°F), respectively.

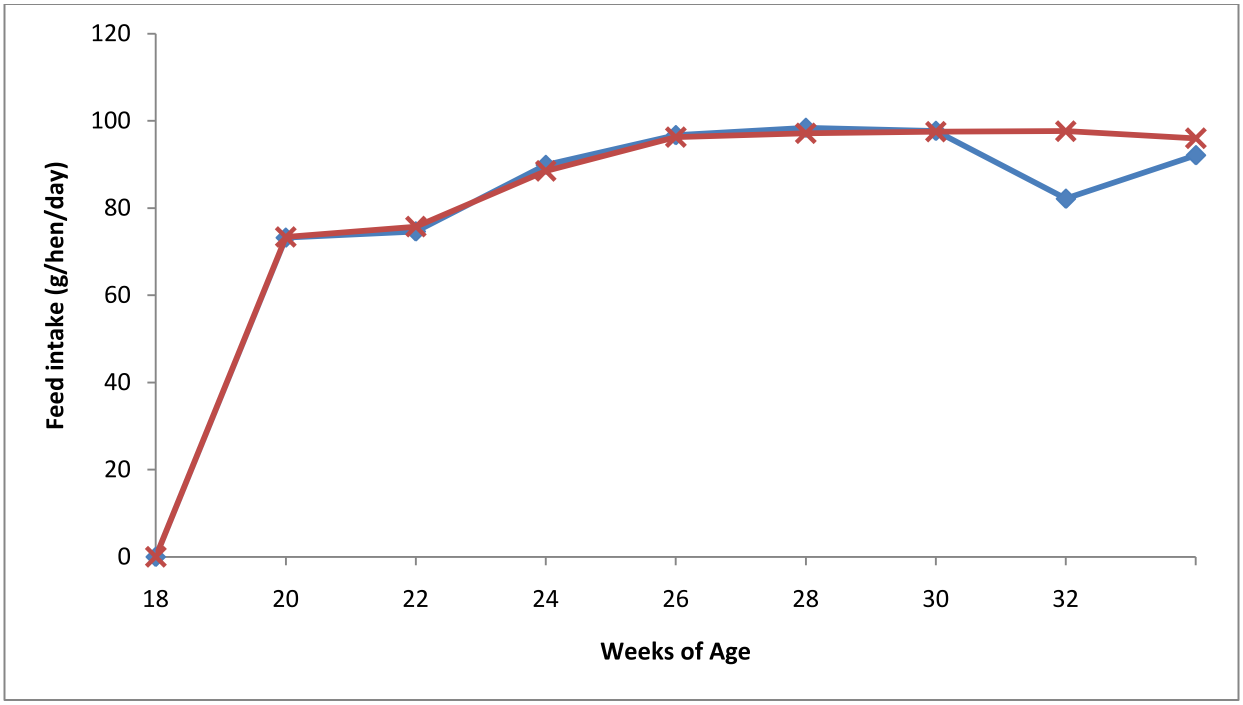

Figure 2.3. Feed intake of hens fed the 85% Treatment (♦) and the 100% Treatment (×). At 32 wk of age hens fed the 85% Treatment were taken off of this treatment and switched to the control (100%).

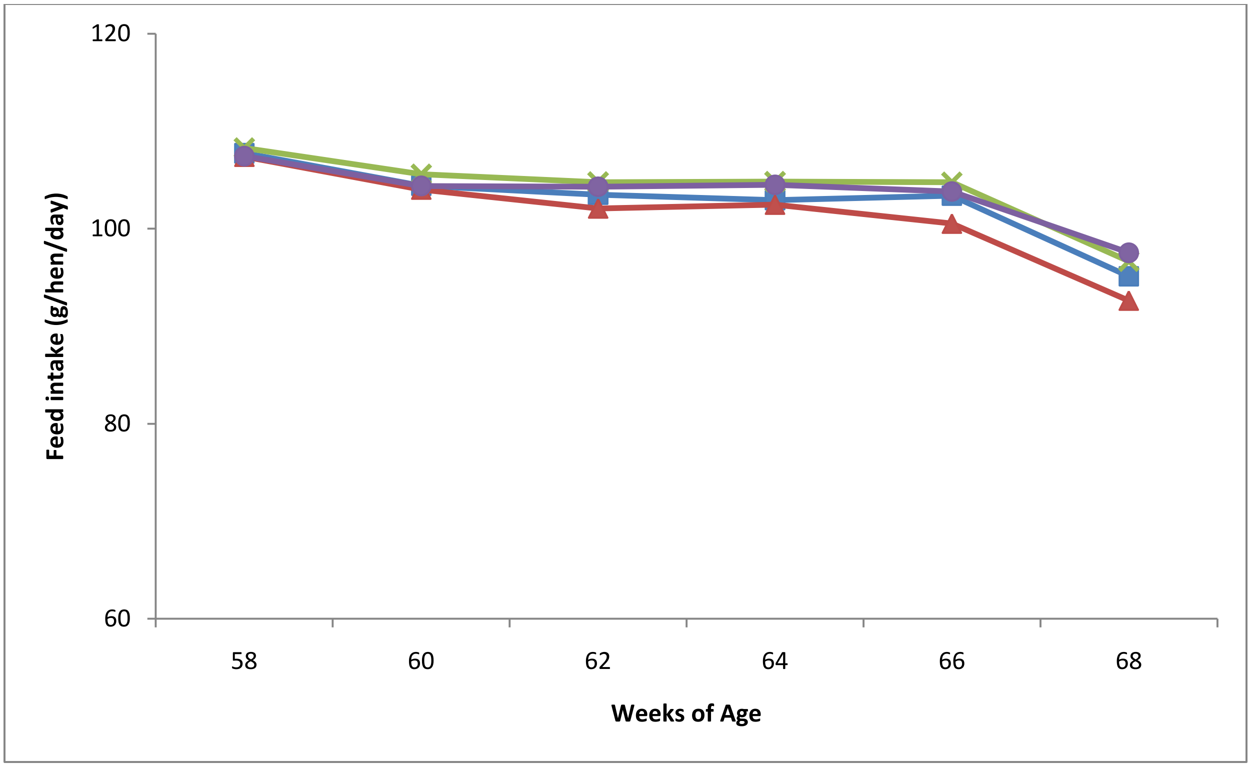

Figure 2.4. Feed intake of hens fed diets varying in nutrient density. Treatment diets were: 2) 90% (■), 3) 95% (▲), 4) 100% (×), and 5) 105% (•) of nutrient density of the control diet (100%), respectively. The average high and low in-house temperatures for the last 12 wk of the trial were 30.8°C (87.4°F) and 25.3°C (77.5°F), respectively.

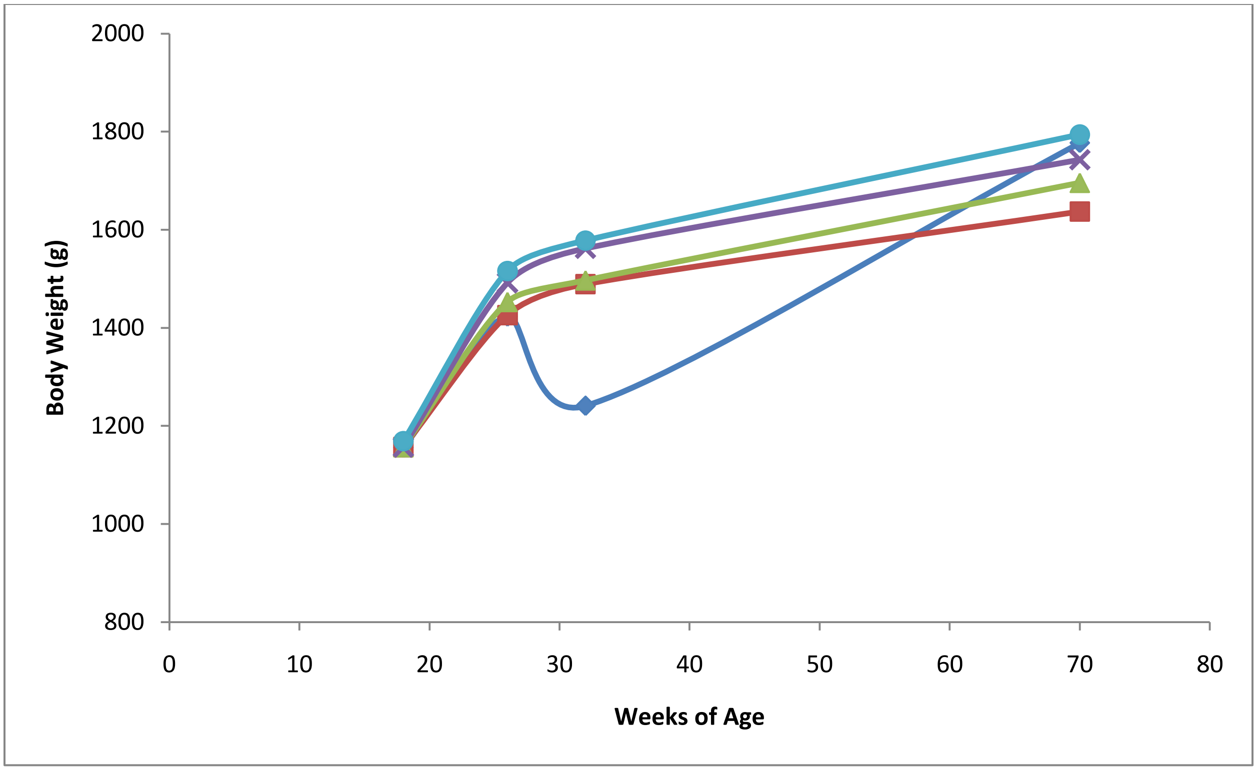

Figure 2.5. Body weights of hens fed diets varying in nutrient density. Treatment diets were: 1) 85% (♦), 2) 90% (■), 3) 95% (▲), 4) 100% (×), and 5) 105% (●) of nutrient density of the control (100%), respectively. At 32 wk of age, hens fed the 85% Treatment were switched to the control treatment (100%).

Vita

Suzette dePersio was born August 5, 1987 in Lake Forest, Illinois. She is the daughter of Mark and Cheryl dePersio. Suzette attended the University of Illinois at Champaign-Urbana from 2005-2009, where she earned her Bachelor's of Science degree. After receiving her B.S. degree, Suzette returned home to work at Cairo Animal Hospital for the summer. In August 2009, she began working on her Master's degree at the University of Illinois at Champaign-Urbana under Dr. Ken Koelkebeck, focusing her research on the effect of feeding low density diets to Hy-Line W-36 laying hens on production and profitability. Suzette was also involved in a trial evaluating feeding spray-dried bovine plasma to laying hens under heat stress conditions. Upon completion of her Master's of Science degree, Suzette will pursue admission into the University of Illinois College of Veterinary Medicine.