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An Examination of the P Requirements of Broiler Breeders for Performance, Progeny Quality and P Balance 1. Non-phytate Phosphorus

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Abstract: A 40-wk study was performed to assess the effects of reduced dietary Non-Phytate Phosphorus (NPP) on broiler breeder performance, progeny quality and P balance. Seven hundred Cobb 500 chicks were reared according to Cobb guidelines (Cobb-Vantress, 2005) and transferred to a production house at 21 wk. At 24 wk, 285 birds were switched over to one of five experimental diets (5 groups of 57) that differed only in NPP. Phosphorus levels ranged from 0.2% to 0.4% NPP in 0.05% increments; and corresponded to a daily intake of 288, 360, 432, 504 and 576 mg at peak. Production performance, egg quality, breeder and progeny skeletal quality, hatchability, progeny weight and P retention were monitored throughout the experimental period. Results show that total egg production, egg number, age at sexual maturity and egg weight were not negatively effected by lowering NPP levels to 0.20% (288 mg/day). Shell quality, though statistically impacted by NPP level, remained at high levels for all treatments (above 1.081). Reproductively, reduced dietary NPP did not negatively impact hatchability or subsequent progeny performance. Day old progeny wt and progeny bone quality were not significantly different from the breeders fed different NPP intake. Breeder tibia ash and relative strength was impaired at 0.20% NPP. The % total P (TP) retention showed a negative linear response with increasing dietary NPP, although absolute P retained increased with increasing dietary NPP. The amount of P deposited into the egg was not different among the treatment groups. Results appear to indicate that 360 mg NPP/day at peak (0.25% NPP) is sufficient for breeder hen performance, progeny 1 d wt and progeny skeletal quality. Breeder hens are able to maintain their performance by mobilizing bone reserves to meet the demands of egg formation and utilize dietary sources to replenish these reserves.

Key words: Breeder, non-phytate phosphorus, performance

INTRODUCTION

Unlike laying hens, the eggs from broiler breeders must fulfill the requirements of the embryo and subsequent chick for optimal growth. The P requirements of the breeder hen cannot be completely accounted for by the amount deposited into the egg. Phosphorus loss due to bone mobilization also accounts for a portion of the overall hen P requirement. The broiler breeder hen endogenous P loss, however, is difficult to quantify. NRC (1994) suggests the daily NPP requirement for layers or breeders is 250 mg/100 g of feed per hen or 0.25%. The P needs of broiler breeder hens for production and progeny performance have not been well investigated; as such, it is common for industry to feed up to 600 mg NPP/day. Previous studies have shown evidence that increasing P intake above 0.4% available P confers no additional benefit to production but very little research has been conducted with lower NPP breeder diets. Triyuwanta and Nys (1992) showed that increasing available P to amounts as high as 1% in dwarf broiler breeders did not improve egg production, egg weight, fertility, hatchability and hatching weight. Chandramoni *et al.* (1998) showed that egg production, shell weight, SWUSA and egg content did not improve with available P above 0.32% in caged layers; while Keshavarz (2000) found no differences in egg production in layer hens fed low levels (0.15-0.25%) of NPP. Although a major objective for feeding optimum levels of dietary NPP to breeders is to produce high quality chicks, the effects of parental P intake on subsequent progeny performance has received only marginal attention. Triyuwanta and Nys (1992) showed that feeding dwarf breeders a diet containing 1.0% available P significantly increased the bone ash and bone strength of day-old chicks compared to feeding 0.2% available P but did not improve 2-wk progeny wt or 7-wk progeny wt. Plumstead *et al.* (2007) reported that breeders fed 0.1% NPP (with and without added phytase) produced more eggs per hen housed compared to feeding breeders higher (0.37%) levels of NPP equivalents. Plumstead *et al.* (2007) reported a decrease in fertility when breeders were fed equivalent NPP levels below 0.37% but an increase in chicks per hen housed. Previous studies with broilers and commercial layers have shown an increase in the total amount of P excreted with increasing dietary P intakes (Leske and Coon, 1999; Chandramoni *et al.*, 1998). The environmental concerns of P runoff have added extra incentive into investigating reduced P intakes. The present study will investigate the impact of lowered NPP intake on production performance, progeny performance and P balance.

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Table 1: Composition (%) of rearing diets and nutrient contents

Ingredient	Pullet starter (0-4 wk)	Pullet grower (4-20 wk)	Prebreeder (20-25 wk)
Corn	61.70	61.70	66.90
Soybean meal	26.80	15.40	20.40
Wheat middlings	7.71	19.00	7.09
Dicalcium phosphate	1.83	1.74	1.80
Ground limestone	0.69	0.72	1.62
Termin-8[1]	0.30	0.30	0.30
Sodium chloride	0.29	0.31	0.08
Poultry fat	0.25	0.50	1.67
L-Lysine HCl	0.10		
Alimet-MHA, liquid[2]	0.10	0.07	0.19
Choline Cl-70%	0.09	0.07	0.09
Mineral premix[3]	0.06	0.06	0.06
Copper sulphate	0.05	0.05	0.05
Vitamin premix[4]	0.04	0.04	0.05
Ethoxyquin	0.01		
Nutrient			
ME (kcal/kg)	2870.00	2820.00	2920.00
CP, calculated	19.00	15.20	16.20
CP, analyzed[5]	18.69	15.44	16.00
Crude fat	2.82	3.27	4.15
Calcium	0.95	0.90	1.55
Total phosphorous	0.74	0.75	0.64
Avail. phosphorous	0.45	0.45	0.41

[1]Mold inhibitor (Anitox Corp).
[2]Methione Hydroxy Analog; Novus International, Inc, St. Louis, MO
[3]Mineral mix provided per kilogram of complete diet: Cu, 18 mg; I, 1.1 mg; Fe, 80 mg; Mn, 150 mg; Zn, 125 mg; Se, 0.25 mg.
[4]Vitamin mix provided per kilogram of complete diet: vitamin A, 10, 000 IU; vitamin D_3, 3, 000 IU; vitamin E, 100 IU; vitamin K_3, 3 mg; vitamin B_{12}, 0.03 mg; riboflavin, 8 mg; niacin, 60 mg; pantothenic acid, 18 mg; folic acid, 1 mg; pyridoxine HCl, 6 mg; thiamine HCl, 3 mg; biotin, 0.2 mg.
[5]Corrected to 90% DM

MATERIALS AND METHODS

Stock and management: A flock of Cobb 500 pullets were raised in 2.38 m x 1.83 m floor pens from day old utilizing the Cobb Breeder Management Guide (Cobb-Vantress, 2005) as a reference for all management conditions. The compositions of the diets utilized throughout the rearing period are shown in Table 1. Diets did not differ between treatments. The starter diet was fed from 0-4 wk of age, the grower diet was fed from 4 wk until 20 wk, the prebreeder was fed from 20 wk until 25 wk and experimental diets from 25 wk through termination. The flock was fed *ad libitum* for the first 2 wk. From 2-4 wk, all birds were fed restricted amounts of feed every day. Feed allocation was based on breeder recommended guidelines to reach target BW. Birds were weighed weekly by pen in order to adjust feed allocation to ensure target BW was met. At 21 wk, 300 birds were transferred to a production house and individually caged. Cages (47 cm high, 30.5 cm wide, 47 cm deep) were each equipped with an individual feeder and nipple drinker; birds were fed individually and provided with free access to water at all times. At 24 wk, all birds were put on an everyday feeding system and 285 breeders were randomly assigned to one of five experimental diets (5 groups of 57 individual breeders) that differed only in the level of NPP. Each breeder was considered a replicate. Composition of experimental diets is shown in Table 2. Phosphorus levels ranged from 0.2-0.4% NPP in 0.05% increments and corresponded to a daily intake of 288, 360, 432, 504 and 576 mg at peak intake. Calcium level was formulated to 3.25% for all experimental diets. Mean $CaCO_3$ particle size was 3489.7 microns and solubility was 38.5% (Shell and Bone Builder SBB, ILC Resources, Des Moines, Iowa). Solubility was determined using the method of Zhang and Coon (1997a). Dietary P was provided by feed grade dicalcium phosphate-18.5% P (PCS Sales, Inc., Northbrook, Illinois).

Production and reproductive performance: Production and reproductive performance, eggshell quality, parental and progeny skeletal structure were all monitored through 65 wk of age. Egg production was recorded daily and egg weights were recorded four days a week. All soft shelled, double yolk and cracked eggs were recorded. Eggs per Hen Day (EHD) were defined as Eggs per Hen Housed (EHH) corrected for mortality. Peak egg production was determined as a five day rolling average. Shell quality was determined by specific gravity twice a week using the flotation method (Bennett, 1992). Hens were artificially inseminated beginning at wk 35 and inseminations were repeated at approximately six-week intervals through wk 60. Twenty-five hens per NPP level were inseminated with 1 x 10^8 cells/50 µl and settable eggs were collected for a six-day period. Semen was collected from broiler breeder males using the abdominal massage method, as described by Burrows and Quinn (1937). Semen was pooled and sperm cell concentration determined using an IMV Micro-Reader I, using an optical density of 381 nm (King *et al*., 2000). Semen was diluted to 1 x 10^8 cells/50 µl using Beltsville Poultry Semen Extender (Continental Plastic Corp., Delavan, WI) to ensure all hens were inseminated with the same number and volume of sperm cells. The fertility and hatchability of fertile eggs were determined 5 times during the 40 wk study. All progeny not sacrificed at 1 d were placed in floor pens and fed a standard broiler starter diet. Progeny weight was recorded at day of hatch and again at 21 d. Progeny were sacrificed via CO_2 asphyxiation and tibia samples were collected at both 1 d and 21 d. Both tibia per bird were collected at 1 d and then pooled to two tibiae per replicate with a total of 50 replicates per treatment and used for analysis. Both 21 d tibia were also collected and pooled to two tibiae per replicate with a total of 10 replicates for analysis. Samples are representative of the entire insemination period. Samples of breeder hen tibia were collected at 45 wk and at 65 wk after CO_2 asphyxiation; 9 and 10 sample hens per treatment were utilized, respectively. Tibia for both progeny and breeders were stored at -20°C until analysis. Tibia were cut length-wise, oven dried and ashed in ceramic crucibles

Table 2: Composition (%) of experimental diets and nutrient contents

Ingredient	0.20% NPP	0.25% NPP	0.30% NPP	0.35% NPP	0.40% NPP
Corn	64.27	64.27	64.27	64.27	64.27
Soybean meal	23.795	23.795	23.795	23.795	23.795
Dicalcium phosphate	0.485	0.75644	1.02746	1.298475	1.569495
Limestone	8.102	8.102	8.102	8.102	8.102
Mold Curb[1]	0.05	0.05	0.05	0.05	0.05
Salt	0.345	0.345	0.345	0.345	0.345
Poultry fat	2.13	2.13	2.13	2.13	2.13
L-Lysine HCl	0.0735	0.0735	0.0735	0.0735	0.0735
Choline	0.0945	0.0945	0.0945	0.0945	0.0945
Mineral premix[2]	0.06	0.06	0.06	0.06	0.06
Copper sulphate	0.05	0.05	0.05	0.05	0.05
Vitamin premix[3]	0.1	0.1	0.1	0.1	0.1
Ethoxyquin	0.02	0.02	0.02	0.02	0.02
Nutrient					
ME_n (kcal/kg)	2915	2915	2915	2915	2915
CP (%) (calculated)	0.16	0.16	0.16	0.16	0.16
Lysine (%)	0.89	0.89	0.89	0.89	0.89
Methionine (%)	0.47	0.47	0.47	0.47	0.47
Crude fat (%)	4.185	4.185	4.185	4.185	4.185
Ca (%) (calculated)	3.25	3.25	3.25	3.25	3.25
Total P (%) (calculated)	0.398	0.4478	0.4975	0.5473	0.5971
Total P (%) (analyzed)	0.42	0.46	0.51	0.56	0.63
NPP (%) (analyzed)	0.21	0.24	0.32	0.35	0.42

[1]50% Propionic acid. Kemin Industries, Inc., Des Moines, Iowa.

[2]Provided per kg of diet: Mn, 180 mg; Zn, 150.6 mg; Fe, 20.16 mg; Cu, 2.04 mg; I, 1.26 mg; Se, 0.3 mg.

[3]Provided per kg of diet: Vitamin A, 13200 IU; Vitamin E, 66 IU; Vitamin D_3, 4950 ICU; Niacin, 74.25 mg; D-panthothenic acid, 33 mg; Riboflavin, 19.8 mg; Pyridoxine, 5000 mg; Thiamine, 3.3 mg; Menadione, 3.3 mg; Folic acid, 3.3 mg; Biotin, 0.33 mg; Vitamin B_{12}, 0.0297

for 16 h at 600°C to determine bone ash percentage. Total Ca and P were determined by Inductively Couple Plasma Emission Mass Spectrometry (ICP-MS) as described by Leske and Coon (1999). Bone strength was determined on an Instron 4502 (Instron Co., Canton, Massachusetts) machine and reported as relative strength (breaking force divided by diameter). Phytic acid was determined by HPLC utilizing a Dionex AS7 anion-exchange column. Nitric acid was utilized as the eluent at a flow rate of 0.5 ml/min. Ferric nitrate was utilized for post-column derivatization and absorbance at 290 nm recorded. NPP was determined mathematically after subtracting phytate P from total P.

Phosphorus retention: A balance study was conducted at 52 wk to assess P retention. The very same experimental diets were mixed with 2% celite (acid insoluble marker). NPP intake was 260, 325, 390, 455, 520 mg day for the diets containing 0.20, 0.25, 0.30, 0.35 and 0.40% NPP, respectively. At the time of the retention study, 10 hens from each NPP level for a total of 50 hens were fed 130 g/day. Birds were fed the test diets and acclimated for 3 days; after which all excreta and eggs were collected during a 24-h test period. The total P retention percentage was defined as: (total P intake-total P excreted)/total P intake times 100. Egg P was not factored into the calculation of total P retention percentage.

Statistical analysis: Data was analyzed on JMP 7 (SAS Institute, Cary, North Carolina) and subjected to GLM to determine overall NPP effects, when effects were significant a Student's t test was performed to determine the differences between pairs and linear relationships. All statements of significance are based on testing at $p \leq 0.05$.

RESULTS

No statistical differences in eggs per hen housed, eggs per hen day and age at sexual maturity were found (Table 3). Peak production (85.7%) was highest for breeders fed diets containing 0.20% NPP. Eggs per hen housed (159 eggs) were highest for hens fed diets containing 0.25% NPP (360 mg/day at peak). Eggs per hen day (179) were highest for hens fed diets with 0.20% NPP (288 mg/day at peak). Hens fed diets with 0.20% NPP (288 mg/day at peak) reached sexual maturity the earliest at 189.6 days.

No statistical treatment effect on egg wt was found, however a significant treatment effect on specific gravity was determined (P = 0.0035). Specific gravity (1.0818) was significantly lower for hens fed diets with 0.35% NPP (504 mg/day at peak). Specific gravity ranged from 1.0823-1.0825 for all other treatments. Hens fed the 0.40% NPP diet produced the heaviest eggs (66.4 g) over the entire production period while breeders fed diets containing 0.30% NPP produced the smallest eggs (Table 3) but no significant NPP effect on egg weight was determined. No differences in hatchability were noted, but the highest hatch of fertile (91.5%) was for hens fed diets containing 0.35% NPP.

Table 3: Production and skeletal quality for broiler breeder hens fed graded levels of dietary NPP from 25-65 weeks of age[1]

	0.20% NPP	0.25% NPP	0.30% NPP	0.35% NPP	0.40% NPP	SEM	P-value
Age at sexual maturity (d)[2]	192.9	193.1	196.2	193.5	193.4	1.6	0.5823
Age of peak production (d)	230	226	230	235	227	NA	NA
Peak egg production (%)[3]	85.7	80.7	77.7	79.6	79.1	NA	NA
Eggs per hen housed	154	159.4	144.6	148.3	153.6	4.3	0.1391
Eggs per hen day[4]	179.3	172.5	167.4	179.1	168.6	6.1	0.4995
Egg weight (g)	64.3	65.3	64.2	64.6	66.4	0.7	0.14
Specific gravity	1.0825^{A}	1.0824^{A}	1.0824^{A}	1.0818^{B}	1.0823^{A}	0.00014	0.0035
Hatchability (%)[5]	85.3	86.1	87.7	91.5	85.3	4.5	0.8024
45 week Breeder tibial ash (%)[6]	47.8^{C}	52.8^{AB}	51.4^{B}	55.8^{A}	54.2^{AB}	1.1	<0.0001
45 week Breeder tibial relative strength[6,7]	6.42^{B}	8.23^{A}	7.88^{A}	8.34^{A}	7.89^{A}	0.51	0.0747
65 week Breeder tibial ash (%)[6]	48.2^{B}	51.9^{A}	52.6^{A}	52.1^{A}	54^{A}	1.0	0.0016

[1]Values are presented as means ± SEM for the entire 40-week production period.
[2]Defined as age at first egg.
[3]Peak production and age of peak production determined on a five-day rolling average.
[4]Defined as total eggs per hen corrected for mortality.
[5]n = 200 eggs over 5 inseminations.
[6]n = 9 replicates, 2 tibiae per replicate.
[7]n = 10 replicates, 2 tibiae per replicate. [7]Relative strength = max yield/diameter.
[A-B]Means within a row that do not share a letter are significantly different ($p \leq 0.05$)

Table 4: Broiler breeder progeny weight and tibia ash from hens (35-60 wk) fed graded levels of dietary NPP from 25-65 weeks of age[1]

	0.20%NPP	0.25% NPP	0.30% NPP	0.35% NPP	0.40% NPP	SEM	P-value
1-day progeny weight (g)	44.3	45.8	43.2	43.7	43.9	1.38	0.4943
1-day progeny tibial ash (%)[2]	37.0	38.7	38.5	38.9	39.5	1.0	0.3163

[1]Values are presented as means ± SEM for the entire 40-week production period. [2]n = 50 replicates, 2 tibiae per replicate

Table 5: Phosphorus retention, yolk P and tibia P in 52 wk-old broiler breeder hens fed graded levels of dietary NPP from 25-65 wk of age

Dietary NPP	Total feed P (mg)	Total excreta P (mg)	Excreta NPP (mg)	Total P retention (%)[1]	Total yolk P (mg)	Total tibia P (g)*
0.20%	554.3	388.8^{B}	246.3^{D}	33.8	112.0	0.91^{B}
0.25%	598	398.8^{B}	247.9^{CD}	38.2	91.9	0.93^{B}
0.30%	722.5	678.3^{A}	448.4^{AB}	24.5	99.8	0.88^{B}
0.35%	731.8	666.9^{A}	385.8^{BC}	24.5	100.3	1.14^{A}
0.40%	889.3	726.9^{A}	556.6^{A}	22.5	107.0	1.04^{AB}
SEM	NA	54.3	45.5	7.6	6.5	0.06
ANOVA (p-value)	NA	0.0001	0.0003	0.3563	0.2492	0.0415
Linear (p-value)	NA	<0.0001	<0.0001	0.1143	0.9427	0.0294

*45 week-old hens. [1]Retention defined as (intake-excretion)/intake x 100.
[A-D]Means within a column not sharing a letter are significantly different ($p<0.05$)

No NPP effects were noted for the mean 1 d progeny wt (Table 4) across all hatches (P = 0.4943). Breeders fed diets containing 0.25% NPP produced the largest mean 1 d progeny wt (45.8 g). There were no treatment effects on 1 d tibia % bone ash, however breeders fed 0.40% NPP (576 mg/day at peak) had a numerical higher % bone ash. The TP content of tibia for day-old chicks did not differ between breeder treatment groups.

A significant treatment effect was obtained for breeder tibia % bone ash (Table 3) for the 45 wk-old experimental breeder hens. Breeder hens fed 288 mg NPP intake had the lowest tibia % bone ash. The tibia bone ash percentage increased in breeders fed increasing NPP intake. Breeders fed 504 mg NPP/day had the highest tibia % bone ash (55.8%). The relative breaking strength of 45 wk-old tibia was lowest in hens fed 288 mg NPP/day but no differences were noted for tibia from breeders fed higher levels of NPP (P = 0.0747). The % bone ash for 65 wk-old breeders offered similar results to 45 wk bone strength results. The % bone ash was significantly lower in hens fed 288 mg NPP (48.2%) but no differences were noted for breeders fed higher levels of NPP. Total tibia P content was significantly lower from breeders fed NPP levels below 504 mg NPP/day (P = 0.0415).

Calculated values of feed TP and NPP were confirmed with analyzed values (Table 2). The range of TP in the feed was 554.3-889.3 mg. Total excreta P content was higher from breeders fed dietary NPP above 0.30% NPP (P = 0.0001): ranging from 388.8-726.9 mg for a 24 h collection. The % TP retention was not significantly different between treatments but was highest for breeders fed 0.25% NPP. The % TP retention did not show a significant linear response to increasing NPP. The excreta NPP content was significantly higher above 0.30% NPP to coincide with excreta TP content (P = 0.0003). The % NPP excreted was highest for breeders fed 0.4% NPP diets and it decreased as dietary NPP decreased (data not shown). Overall, there was a linear increase in excreta TP with increasing levels of dietary NPP ($P \leq 0.0001$). Egg TP remained constant at approximately 100 mg for all dietary NPP levels (P=0.2492).

DISCUSSION

The P requirements of broiler breeder hens cannot be completely accounted for by the amount deposited into the egg. The amount of P in the egg is approximately 116 mg (111 mg in the yolk and 5 mg in the albumen; Romanoff and Romanoff, 1949). The mobilization of bone Ca for the formation of the egg shell also increases the overall P requirement for breeders because the bone P is also mobilized. However, the endogenous P loss is difficult to quantify and questions remain as to whether increasing dietary P prevents skeletal mobilization. Limited P balance research has been conducted with breeders on the effects of reduced P intake, Plumstead *et al.* (2007) showed that reducing P intake in broiler breeders improved total egg production. The research group reported a reduction in fertility, but an increase in total chicks produced per hen. The researchers did not evaluate the bone status of breeders or progeny. Several authors (Triyuwanta and Nys, 1992; Keshavarz, 2000; Boling *et al.*, 2000) have found no difference in egg production for breeder hens or laying hens fed 0.15% to 0.25%NPP. It appears from the results reported herein that lowering the NPP intake to 288 mg per day during a complete 40 wk production period did not produce detrimental effects on breeder production or progeny quality. Though no significant differences were noted, breeders that were fed the two lowest daily intakes of NPP produced the most eggs. In a separate study, lowering dietary NPP to 0.20% and feeding broiler breeders 288 mg NPP at peak did not negatively impact egg production through 40 wk of age (Ekmay and Coon, 2009a). However, lowering dietary NPP to 0.15% (216 mg/day at peak) significantly reduced egg production and increased mortality (Ekmay *et al.*, 2009b).

Progeny skeletal quality and weight from breeders fed 288 mg NPP at peak was equal to progeny of breeders fed higher levels of NPP. Though non-significant, day-old progeny wt was highest for breeders fed the two lowest NPP intakes. The tibia P content of 1 d chicks was similar across breeder treatments. Triyuwanta and Nys (1992) reported a statistical difference in progeny skeletal quality as determined by bone ash percentage and strength with dietary available P ranging from 0.2-1.0% in dwarf breeders. Observations reported herein show no differences in 1 d progeny bone ash percentage when breeder dietary NPP is increased from 0.2-0.4%. The sustained performance of the breeder hens fed the lower levels of NPP for the 40 wk production study appears to come at the expense of skeletal integrity. Breeder bone ash percentage at 45 and 65 wk was significantly lower for breeders fed diets containing 0.20% NPP: showing that the breeder was sacrificing her own skeletal integrity to maintain performance. The bone ash percentage was the highest for the breeders fed diets containing 0.35% NPP at 45 wk. Similarly, breeders fed diets containing 0.40% NPP had the highest bone ash at 65 wk of age, though no significant difference was seen above 0.25% NPP. Total tibia P reflected these same findings.

Two scenarios may explain the observed increase in % bone ash for breeders fed increasing dietary NPP. One possible mechanism is that the increased dietary NPP spares the need for mobilization. The second and more likely, scenario is that the increased dietary NPP aids in the replenishment of medullary bone reserves. Medullary bone does not provide the same strength as cortical and trabecular bone. This may explain the constant bone strength for breeders fed diets containing $\geq$0.25% NPP. Therefore, structural bone of breeders does not become significantly depleted when breeders are fed $\geq$0.25% NPP and the excess dietary NPP will be used for medullary bone formation. Overall, the % bone ash will increase in breeders fed $\geq$0.25% NPP but bone strength will remain relatively constant. The % bone ash of breeders at 65 wk seemed to equalize when breeders were fed $\geq$0.25% NPP and were higher compared to the % bone ash for breeders at 45 wk; this is probably due to the cumulative effects of circulating estrogen levels. Estrogen stimulates bone formation, with medullary bone predominantly laid down rather than structural bone in sexually mature hens: mineral content increases but structural strength does not (Whitehead, 2004, Beck and Hansen, 2004).

The present study demonstrates that decreasing dietary NPP does not impair a breeder hen's ability to deposit P into the egg. Results show that the amount of P deposited into the egg does not differ across treatments. Previous studies with breeders fed lower levels of P showed that hatchability and subsequent progeny quality do not differ and can be partly attributed to the breeders maintaining a constant P level in the egg (Ekmay *et al.*, 2009b).

Several authors (Leske and Coon, 1999; Plumstead *et al.*, 2007; Chandramoni *et al.*, 1998) have shown an improvement in the absolute amount of P retained with increased dietary P. However, the % TP retained diminished with increasing dietary P. The results reported in the present study follow this same trend. The % TP retention decreased with increasing P intake, however, a linear relationship could not be established. The strong linear response in excreta P for breeders fed increasing levels of dietary NPP indicate that once the P needs for egg formation are met; the excess is excreted through the kidneys. The amount of TP excreted in 31-wk old hens also increased linearly with increasing dietary NPP levels (Ekmay and Coon, 2009a). The diminished tibia P content for breeders fed diets containing $\leq$0.35% NPP in present study indicates that at least a portion of the P utilized for egg formation is supplied by bone reserves. A closer look at the linear relationships of excreta TP and tibia P, respectively, reveal a striking

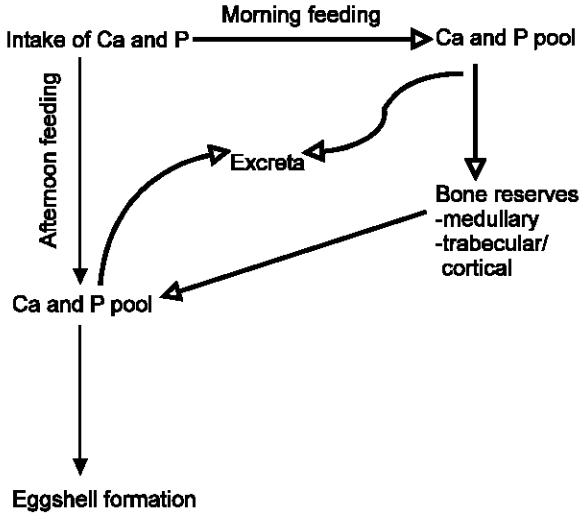

Fig. 1: Proposed model of Ca and P utilization in broiler breeder hens. Line thickness is indicative of extent of flow

similarity. It can be surmised that the excreta TP may in fact be coming from bone reserves when breeders were fed diets containing ≤0.35% NPP. The destination of dietary NPP remains unclear, however, results seem to indicate that a breeder hen will utilize bone reserves regardless of dietary P levels for egg formation. Dietary P is then utilized for the replenishment of bone reserves. Such a mechanism can be understood considering the timing of meals in typical broiler breeder production houses (Fig. 1). Utilizing bone markers to estimate bone deposition and re-sorption, Ekmay *et al.* (2009b) showed that there is a period of bone resorption followed by a period of deposition that repeats in a cyclic manner. Dietary NPP determines the extent of bone turnover. Most breeder hens are fed one meal early in the morning, whereas egg formation typically occurs overnight. Evidence has been presented that feeding in the late evening, or utilizing large particulate calcium, improves egg shell quality (Zhang and Coon, 1997b).

In summary, the present study shows that broiler breeder hens are able to maintain a high production level when fed diets containing levels of dietary NPP as low as 0.20% (288 mg/day at peak). Progeny hatch weight and skeletal quality was also maintained with lower levels of parental dietary NPP. Breeders will mobilize bone reserves to aid in egg formation and do not rely solely on dietary P even at adequate dietary levels. Increasing dietary NPP will serve in replenishing bone reserves, although the structural support may be impaired when breeders are fed diets containing ≤0.25% (360 mg/day at peak). The research reported herein shows that broiler breeders can be fed a daily intake of 360 mg NPP for maximum production, skeletal integrity and produce progeny with equal weight and skeletal quality as breeders fed 1.6 times more NPP. Increasing dietary NPP beyond a physiological threshold will increase the amount of P eliminated. Once the P needs of egg formation have been met through bone mobilization, dietary P will be utilized to replenish said bone reserves. The increased amount of excreta TP for breeders fed diets containing increasing dietary NPP would be of environmental and financial concern and serious considerations should be made at reducing dietary NPP inclusion.

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