Amino acid requirements of broiler breeders at peak production for egg mass, body weight, and fertility

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ABSTRACT Two trials were conducted to determine the amino acid and protein requirements of broiler breeders at peak production. In trial 1, 32-wk-old Cobb 500 broiler breeders with similar BW were selected to determine the digestible amino acid requirement for daily product output (g of egg mass + g of BW gain/b/d) and feed conversion (g of feed/g of product) for Met, Phe, Arg, Ile, Lys, and CP in a 42-d production study. In trial 2, 30-wk-old Cobb 500 broiler breeders were selected to determine the digestible requirement for Met, Lys, Ile, Arg, Cys, Val, Trp, and Thr in a 70-d production study. Breeders were given a corn-soy basal diet plus crystalline amino acids with 8 graded levels of amino acids (10 birds per level), representing 40 to 130% of the highest suggested requirements reported in the literature. All other amino acids were maintained at 100% of their suggested requirement level. All breeders were inseminated weekly and fertility was determined. A third trial consisted of 41-wk-old colostomized hens randomly assigned to 1 of 2 diets differing only in the amount of Ile. Urine was collected after a 6-wk feeding period. The average digestible requirements per breeder per day for both product and feed/product ratio from trials 1 and 2 for Met, Cys, TSAA, Phe, Phe + Tyr, Trp, Arg, Ile, Lys, Val, Thr, and CP were 424, 477, 901, 689, 997, 252, 1,026, 830, 916, 799, 613 mg/d, and 20.0 g/d, respectively. The ideal profile for digestible Met, Cys, TSAA, Phe, Phe + Tyr, Trp, Arg, Ile, Lys, Val, and Thr was 46, 52, 98, 76, 108, 28, 112.0, 91, 100.0, 87, and 67%, respectively. A significant decrease in fertility was noted with increasing levels of Ile and Lys. Urine pH was significantly more alkaline in hens fed the higher level of Ile. It is suggested that adequate dietary Lys and Ile should be provided for maximum hatching egg production but an excess may affect fertility.

Key words: amino acid, production requirement, broiler breeder hen, daily product output, fertility

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INTRODUCTION

Large variations are found in the amino acid and protein recommendations of Primary Breeders (i.e., Ross, Cobb-Vantress) for amino acid requirements for broiler breeder hens. Broiler breeders may potentially have more profound changes in BW, egg weight, and egg mass than a commercial egg-type laying hen: which enhances the need for developing amino acid requirement data. Amino acid requirements based on egg production data obtained in past research (Sakomura et al., 2011) may reflect egg production that would be less than optimum compared with the present higher producing breeder hen. A statistical reporting service recently reported that hatching egg production for the Cobb 500 breeder hen increased from 148 hatching eggs/hen housed in January 2005 to 157 hatching eggs/hen housed on Jan 2010 (AgriStats Inc., 2000–2010).

The Cobb-Vantress (2008) and Ross (2007) management guides place the total Lys requirements at 1,256 and 1,409 mg/bird per d, respectively. Fisher (1998) developed factorial amino acid requirements for breeders and suggested the Lys requirement was 1,121 mg/bird per d at 29 wk. The NRC (1994) suggests the dietary protein requirements for breeders is 19.5 g/bird per d; however, the poultry industry generally feeds breeders on a daily ME intake basis and the % protein remains at 15 to 16% regardless of intake. Because dietary energy prices are presently expensive, many producers have decided to decrease dietary ME levels and allocate more feed to the hens at each feeding during peak egg production. The daily protein intake for breeders in the industry ranges from 24 to 29 g and is clearly above the 19 g suggested by the NRC (1994). The industry continues to feed more protein and amino acid intake per day than suggested by the NRC (1994) because of concern of underfeeding for optimum hatching egg produc-

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tion and chick quality. Feeding breeders elevated levels of dietary amino acids and protein is a major reason for increased egg size. Research from Salas et al. (2010) suggests that breeders producing to their genetic potential for hatching eggs and egg mass may actually produce smaller eggs. Breeders producing smaller eggs may be able to partition more nutrients toward producing more total eggs. Overfeeding amino acids and CP to breeders in production may also elevate skeletal tissue protein deposition (Ekmay et al., 2011). An increase in skeletal protein deposition during egg production would increase the daily ME requirement for maintenance and decrease the amount of energy that would be partitioned for egg production. Previous research has also shown that high levels of dietary CP may negatively affect fertility and hatchability. Pearson and Herron (1982) reported that breeders consuming 27 g of protein per d produced an increased number of dead and deformed embryos and also reported a decrease in hatchability of fertile eggs compared with breeders consuming 23.1 g of protein/bird per d. Lopez and Leeson (1995) showed a decrease in fertility in hens fed high CP levels (16% vs. 10 to 14%). The objective of the study reported here was to determine the digestible amino acid requirement of each amino acid for product (egg mass plus BW change/d) and feed conversion (g of feed/ g product) for broiler breeder hens for the period around peak egg production.

MATERIALS AND METHODS

Main Trials

All procedures were carried out in accordance with Animal Use Protocol No. 03008 for the experiment, which was approved by the University of Arkansas Institutional Animal Care and Use Committee. Two similar trials were conducted to assess the amino acid requirements of broiler breeders. In trial 1, four hundred eighty 32-wk-old individually housed Cobb-Vantress sexually mature broiler breeders with similar BW (3,714 ± 172 g) were selected for a 42-d feeding study. In trial 2, six hundred forty 30-wk-old individually housed Cobb-Vantress sexually mature broiler breeders with similar BW (3,441 ± 293 g) were selected for a 70-d feeding study. Cages (47 cm high, 30.5 cm wide, 47 cm deep) were each equipped with an individual feeder and nipple drinker. Eighty breeders were given a corn-soy basal diet (Table 1) plus crystalline amino acids with 8 graded levels (10 breeders per level) of Met for trial 1, representing 40 to 130% of highest suggested digestible requirement (Tables 2 and 3) between NRC (1994) and Fisher (1998). All other amino acids were maintained at 100% of their suggested requirement level (Table 1). This experimental design was repeated with Lys, Phe, Ile, Arg, and digestible CP, respectively, to form trial 1. Trial 2 was used to determine the digestible amino acid requirement of Met, Lys, Ile, Arg, Cys, Val, Trp, and Thr, in an identical fashion to trial 1 (Table 2). The basal experimental diets (Tables 1 and 2) used to determine the digestible Met and Phe requirements also contained added Cys and Tyr, respectively. The added Cys and Tyr were at half of the requirement for TSAA and Phe plus Tyr of the highest suggested requirement between NRC (1994) or Fisher (1998). This was done to supply the requirement for the nonessential amino acid component for TSAA and Phe plus Tyr. The test Phe diet contained 0.24% digestible Tyr to provide the nonessential portion of the Phe-Tyr requirement. The test Met diet in trial 1 and 2 contained 0.204% digestible Cys. The test Cys diet in trial 2 contained 0.160% digestible Met (determined in trial 1) to determine the TSAA requirement. Glutamic acid was added to the basal diet containing 100% of essential amino acids to provide 80 to 140% of suggested CP requirement (NRC, 1994). The breeders were fed 154 g of feed (467 kcal of ME) daily, and each treatment contained 10 birds.

All eggs were recorded and weighed daily during the experimental period. A 2% acid insoluble ash marker (Celite, World Minerals Inc., Santa Barbara, CA) was added to basal diet (starch replaced all synthetic amino acids in basal diets) for trials 1 and 2 to determine digestible amino acids and digestible CP from the corn and soybean meal basal. The basal diet (with marker) was fed to 5 (trial 1) and 10 (trial 2) breeders, respectively, for 5 d, and excreta was collected on d 3 and 5 from each breeder. The excreta was mixed, freeze-dried, and the dried sample sent to the University of Arkansas Central Analytical Laboratory for amino acid analysis. The Cys and Met were determined according to AOAC (1990) 985.28, Trp was determined according to AOAC 988.15, and all other amino acids according to AOAC 982.30a. Regression analysis was performed to determine the requirements for egg production, egg weight, and BW gain based using the analyzed digestible amino acid values. The digestible CP was determined based on the composite digestible amino acid nitrogen from the basal ingredient protein and the nitrogen from added crystalline amino acids (considered 100% digestible) in Table 2. Glutamic acid was added to the CP test diet to provide different intakes of digestible CP. Samples were also analyzed for acid insoluble ash as described by Vogtmann et al. (1975).

Fertility was determined 4 times from the second to sixth week for both trials. Artificial insemination was conducted every Tuesday, and the eggs were collected every Thursday through Monday to determine fertility and hatchability. Fertility was calculated as the ratio of fertile eggs to total eggs, and hatchability was calculated as the ratio of hatched eggs to fertile eggs. Fifty million cells per insemination were used for optimum comparison based on measuring the sperm concentration before insemination using the Hyperion Micro-Reader I (Hyperion Inc., Miami, FL). The requisite dilution (mL) of the raw semen was determined by optical density (**OD**) and semen concentration conversion (provided by the conversion table in Hyperion Micro-Reader I) to obtain 50 million sperm per insemination. The OD

Table 1. Basal diet formulation for production studies for trials 1 and 2[1]

Item	Value			
Ingredient (%)				
Corn	60.46			
Soybean meal	4.34			
Starch	10.743			
Limestone	6.8			
Dicalcium phosphate	2.22			
Choline-60	0.07			
Ethoxyquin	0.02			
Poultry fat	2			
Propionic acid	0.05			
Salt	0.43			
Mineral premix[2]	0.1			
Vitamin premix[3]	0.2			
Sodium bicarbonate	1.3			
Cys[4]	0.14			
His	0.069			
Leu	0.22			
Tyr	0.192			
Val[5]	0.28			
Trp[6]	0.095			
Glu	10.27			
Calculated (% unless otherwise indicated)				
CP	15			
ME (kcal/kg)	3,031			
Ca	3.04			
P, total	0.59			
Met	0.13			
Lys	0.29			
Ile	0.34			
Arg	0.38			
Phe	0.34			
Cys	0.29			
Val	0.61			
Thr	0.26			
Trp	0.24			
	Trial 1		Trial 2	
Analyzed (%)	Total	Digestible[7]	Total	Digestible[7]
CP	16.1	14.6	—	—
Met	0.14	0.13	0.12	0.11
Lys	0.26	0.21	0.30	0.24
Ile	0.26	0.22	0.23	0.20
Arg	0.35	0.31	0.34	0.30
Phe	0.32	0.29	—	—
Cys	—	—	0.29	0.24 (0.10[8])
Val	—	—	0.64	0.54 (0.26[8])
Thr	—	—	0.22	0.18
Trp	—	—	0.19	0.16 (0.065[8])

[1]All amino acids except for the test amino acid were maintained at 100% of NRC (1994) or Fisher (1998).

[2]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.

[3]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.

[4]Added Cys omitted from Cys test basal diet (trial 2).

[5]Added Val omitted from Val test basal diet (trial 2).

[6]Added Trp omitted from Trp test basal diet (trial 2).

[7]%Digestible amino acids (% total amino acids × experimentally determined amino acid digestibility coefficients).

[8]Amount in basal diet without synthetic amino acid.

was determined by adding 10 μL of raw semen to 1.99 mL of 3% sodium citrate and analyzed by a Hyperion Micro-Reader I to obtain OD.

The digestible amino acid requirements in trials 1 and 2 were determined for daily product output (EM + BW gain/d), which was defined as daily egg mass (**EM**) plus average BW change (the total weight change divided by total days). Egg mass was calculated as the average egg weight multiplied by average hen day egg production. The average feed consumption divided by the product was defined as feed/product ratio (feed/EM + BW gain). The results of the experiment were subjected to ANOVA as a randomized factor design with a single serving as a replicate. The treatment fac-

Table 2. Basal diet formulation for CP requirement studies[1]

Item	%	
Ingredient		
Corn	60.20	
Soybean meal	7.00	
Starch	15.56	
Limestone	6.80	
Dicalcium phosphate	2.22	
Choline-60	0.07	
Ethoxyquin	0.02	
Poultry fat	2.00	
Propionic acid	0.05	
Salt	0.43	
Mineral premix[2]	0.10	
Vitamin premix[3]	0.20	
Sodium bicarbonate	1.50	
Lys	0.54	
Arg	0.30	
Ile	0.27	
Phe	0.11	
Met	0.17	
Thr	0.21	
Cys	0.11	
His	0.04	
Leu	0.13	
Tyr	0.11	
Val	0.24	
Cellulose	1.56	
Trp	0.08	
Calculated		
CP	11	
ME (kcal/kg)	3,016	
Ca	3.05	
P, total	0.60	
Met	0.32	
Lys	0.91	
Ile	0.67	
Arg	0.77	
Phe	0.51	
Leu	0.98	
Val	0.63	
His	0.27	
Thr	0.51	
Trp	0.16	
Cys	0.28	
Tyr	0.39	
CP	11.9	
Analyzed (%)	Total	Digestible[4]
Met	0.33	0.32
Lys	0.77	0.73
Ile	0.59	0.55
Arg	0.77	0.72
Phe	0.50	0.46
Leu	0.98	0.91
Val	0.63	0.58
His	0.27	0.24
Thr	0.52	0.47
Trp	0.17	0.16
Cys	0.26	0.24
Tyr	0.43	0.39
CP	11.9	10.7

[1]All amino acids were maintained at 100% of NRC (1994) or Fisher (1998).

[2]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.

[3]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.

[4]%Digestible amino acids (% total amino acids × experimentally determined amino acid digestibility coefficients).

tor was dietary digestible amino acid or CP intake. All statements of significance are based on an error $P > F$ of less than 0.05. The polynomial models were fitted to treatment means of the experimental data by means of regression procedure of SAS (SAS Institute Inc., Cary, NC). Amino acid requirements were calculated as 95% of the asymptote from the polynomial regression analysis.

The polynomial regression model was described by the following equation:

$$Y = a + bx + cx^2,$$

where x = amino acid content of treatment 1 to 8, a = intercept, b = coefficient for the linear slope, and c = coefficient for the quadratic slope.

Urine pH

After the completion of the main trials, a pilot study was conducted to investigate an observation found in the main trial. Twelve 41-wk-old colostomized (3,843 ± 336 g) broiler breeders (Manangi et al., 2007) were randomly assigned to 1 of 2 diets. The first diet was a standard Ile diet (800 mg/bird per d, diet 6, trial 2) and the second was a low Ile diet (300 mg/bird per d, diet 1, trial 2). Prior to the test period, hens had been fed a standard Breeder I diet (Cobb Vantress, 2008). After 6 wk, urine samples were collected twice a day (AM and PM) over a 3-d period. Urine pH was determined using an Orion 420A pH meter (Thermo Scientific, Waltham, MA).

RESULTS

Trial 1

Using the regression equation for product (g/bird per d) vs. Met intake (mg/bird per d) to determine the 95% asymptote, the digestible Met requirement was determined to be 409 mg/bird per d for optimal product, and the requirement for optimal feed conversion was determined to be 436 mg/bird per d (Tables 4, 5, and 6; Figure 1). No significant linear or quadratic relationships for fertility were determined. The requirement for digestible Phe using the same methods as for Met was determined to be 689 mg/bird per d for optimal product and optimal feed conversion (Tables 4, 5, and 6; Figure 2). As with Met, no significant linear or quadratic trends were observed for dietary Phe affecting fertility. The requirement for digestible Arg was determined to be 1,101 mg/bird per d for optimal product, whereas it was determined that 922 mg/bird per d was required for optimal feed conversion. No significant linear trends were observed for dietary Arg affecting fertility.

The digestible Ile requirement was determined to be 826 mg/bird per d for optimal product and 846 mg/bird per d for optimal feed conversion (Tables 4, 5, and

Table 3. Test synthetic amino acid (%) added to basal diet of trial 1 (wk 32 to 38) and trial 2 (wk 30 to 40) to form a complete test diet, and total digestible amino acid daily intake (mg/d) in test diets for trial 1 and trial 2[1]

	Amino acid level							
Item	1	2	3	4	5	6	7	8
Trial 1								
% added to basal								
Ile	0	0.05	0.09	0.14	0.19	0.23	0.28	0.33
Met	0	0.03	0.05	0.08	0.10	0.13	0.15	0.18
Arg	0	0.06	0.12	0.18	0.23	0.29	0.35	0.41
Lys	0	0.07	0.15	0.22	0.30	0.37	0.44	0.52
Phe	0	0.02	0.05	0.07	0.10	0.12	0.15	0.17
CP (Glu)	0	1.66	3.33	4.99	6.65	8.31	9.97	11.63
Trial 2								
Arg	0	0.15	0.23	0.3	0.38	0.46	0.53	0.61
Ile	0	0.1	0.16	0.21	0.27	0.32	0.38	0.43
Lys	0	0.25	0.31	0.37	0.42	0.48	0.54	0.60
Met	0	0.06	0.1	0.13	0.16	0.19	0.22	0.25
Thr	0	0.07	0.12	0.16	0.21	0.26	0.3	0.35
Trp	0	0.03	0.05	0.06	0.08	0.10	0.11	0.13
Val	0	0.06	0.11	0.17	0.22	0.28	0.36	0.4
Cys	0	0.02	0.04	0.06	0.08	0.11	0.13	0.15
Trial 1								
Total digestible intake (mg/d)								
Ile	344.5	421.5	483.1	560.1	637.1	698.7	775.7	852.7
Met	198.2	244.4	275.2	321.4	352.2	398.4	429.2	475.4
Arg	478.9	571.3	663.7	756.1	833.1	925.5	1,017.9	1,110.3
Lys	325.2	433	556.2	664	787.2	895	1,002.8	1,126
Phe	446.6	477.4	523.6	554.4	600.6	631.4	677.6	708.4
CP	1,694	1,848	2,002	2,156	2,310	2,464	2,618	2,772
Trial 2								
Arg	467.1	698.1	821.3	929.1	1,052.3	1,175.5	1,283.3	1,406.5
Ile	301.9	455.9	548.3	625.3	717.7	794.7	887.1	964.1
Lys	369.6	535.9	625.2	714.6	803.9	893.2	982.5	1,071.8
Met	168.3	260.7	322.3	368.5	414.7	460.9	507.1	553.3
Thr	272.5	380.3	457.3	518.9	595.9	672.9	734.5	811.5
Trp	88.1	135.8	160.5	185.1	209.7	234.4	259	283.7
Val	398	490.4	567.4	659.8	736.8	829.2	952.4	1014
Cys	313.4	344.2	375	405.8	436.6	482.8	513.6	544.4

[1]Each row represents the experimental range for one amino acid and is independent of the other rows. All amino acids except for the test amino acid are maintained at 100% of NRC (1994) and Fisher (1998).

6; Figure 3). The highest fertility of 93.92% was observed with 354 mg of digestible Ile/bird per d (level 1). Dietary Ile intake produced a significant negative linear trend and a significant negative quadratic trend. The digestible Lys requirement was determined to be 909 mg/bird per d for optimal product and 926 mg/bird per d for optimal feed conversion (Tables 4, 5, and 6; Figure 4). The highest fertility of 87.52% was observed (Table 7) with an intake of 370 mg of digestible Lys/bird per d (level 1). As with Ile, a significant negative

Table 4. Eggs per hen housed of broiler breeders fed various amino acid levels

	Amino acid level								
Item	1	2	3	4	5	6	7	8	SEM
Trial 1									
Phe	31.5[ab]	30.3[ab]	32.8[ab]	34.3[a]	31.1[ab]	28.4[b]	29.4[ab]	33.8[ab]	2.00
Met	31.5[a]	32.1[a]	33.4[a]	34.9[a]	33.4[a]	35.2[a]	34.0[a]	30.8[a]	1.62
Arg	32.4[a]	34.2[a]	33.7[a]	29.8[a]	36.1[a]	35.1[a]	35.6[a]	33.1[a]	2.27
CP	30.5[c]	37.8[ab]	34.6[bc]	37.9[ab]	32.3[bc]	42.8[a]	32.4[bc]	33.1[bc]	2.31
Ile	28.7[c]	30.0[bc]	37.5[a]	34.6[abc]	31.5[bc]	31.7[abc]	29.8[bc]	35.1[ab]	2.06
Lys	32.3[b]	32.1[b]	33.5[ab]	32.4[b]	38.5[a]	28.5[b]	30.2[b]	31.6[b]	1.93
Trial 2									
Arg	41.3[b]	42.2[ab]	48.1[a]	44.6[ab]	42.4[ab]	41.5[b]	45.4[ab]	44.1[ab]	2.32
Ile	22.9[c]	37.7[b]	41.7[ab]	42.0[ab]	38.7[ab]	40.5[ab]	42.3[ab]	45.6[a]	3.04
Lys	32.7[c]	33.2[bc]	44.7[a]	39.7[ab]	44.9[a]	43.5[a]	44.7[a]	40.5[a]	2.42
Met	28.1[b]	39.0[a]	44.6[a]	43.1[a]	38.8[a]	43.9[a]	43.9[a]	40.6[a]	2.57
Thr	33.9[c]	41.6[ab]	38.6[bc]	42.4[ab]	41.9[ab]	44.1[ab]	47.3[a]	44.9[a]	2.25
Trp	29.1[c]	37.2[ab]	36.7[b]	40.1[ab]	34.7[bc]	44.0[a]	39.6[ab]	41.4[ab]	2.83
Val	36.2[a]	39.9[a]	41.7[a]	42.4[a]	42.2[a]	40.7[a]	42.8[a]	42.8[a]	2.81
Cys	42.1[a]	41.2[a]	41.2[a]	43.7[a]	42.0[a]	44.2[a]	41.7[a]	44.0[a]	2.93

[a–c]Means within a row that do not share a common letter are significantly different ($P < 0.05$).

Table 5. Body weight change (g) of broiler breeders fed various amino acid levels over the length of the feeding study for trial 1 (wk 32 to 38) and trial 2 (wk 30 to 40)

	Amino acid level								
Amino acid	1	2	3	4	5	6	7	8	SEM
Trial 1									
Phe	205.56[ab]	173.5[b]	256.9[ab]	224.1[ab]	313.2[a]	194.22[ab]	307.8[a]	215.6[ab]	44.88
Met	−51.3[b]	133.9[a]	132.7[a]	194.5[a]	239.5[a]	188[a]	98.5[ab]	175.3[a]	58.44
Arg	203.0[ab]	294.0[a]	216.4[ab]	183.6[bc]	76.5[cd]	62.9[d]	45.5[d]	113.0[bcd]	38.31
CP	214.3[a]	135.1[ab]	115.5[ab]	168.2[ab]	89.44[b]	146[ab]	77.6[b]	126.0[ab]	36.19
Ile	−103.5[a]	151.67[b]	172.0[b]	254.5[b]	302.7[b]	226.0[b]	259.0[b]	166.5[b]	63.67
Lys	−94.1[b]	82.5[a]	162.9[a]	203[a]	154.5[a]	172.2[a]	186.5[a]	130.9[a]	55.71
Trial 2									
Arg	540.4[a]	543.7[a]	632.3[a]	592.5[a]	777.3[a]	591.5[a]	492.7[a]	603[a]	103.5
Ile	−152.6[c]	502.3[ab]	698.4[ab]	342.0[b]	523.6[ab]	591.5[ab]	825.8[a]	636.6[ab]	130.0
Lys	−115.2[c]	395.7[b]	604.1[ab]	645.8[ab]	738.6[a]	591.5[ab]	750.1[ab]	607.3[ab]	121.9
Met	−234.5[c]	439.1[b]	466.4[b]	448.9[b]	717.7[ab]	591.5[b]	594.5[ab]	953.3[a]	132.7
Thr	−123.5[b]	544.5[a]	527.9[a]	616.5[a]	667.0[a]	591.5[a]	591.4[a]	626.4[a]	119.7
Trp	321.8[bc]	407.6[abc]	244.0[c]	566.1[abc]	744.0[a]	591.5[ab]	700.6[a]	714.8[a]	123.7
Val	−293.5[b]	38.7[b]	633.5[a]	581.8[a]	547.9[a]	591.5[a]	483.6[a]	777.9[a]	130.1
Cys	389.6[bcd]	324.2[d]	626.3[abcd]	324.8[cd]	804.2[a]	591.5[abc]	703.8[ab]	628.6[abcd]	125.1

[a–d]Means within a row that do not share a common letter are significantly different ($P < 0.05$).

linear and quadratic trend for fertility was determined with increasing dietary Lys intake. Finally, the digestible CP requirement was determined to be 20,881 mg for optimal product and 19,350 mg for optimal feed conversion (Tables 4, 5, and 6; Figure 5). There was no significant linear or quadratic trend of digestible CP affecting fertility.

Trial 2

Utilizing the regression equation for product (g/bird per d) vs. Met intake (mg/bird per d) to determine the 95% asymptote, the digestible Met requirements were determined to be 425 mg/bird per d for optimal product and 427 mg/bird per d for optimal feed conversion (Tables 4, 5, and 6; Figure 1). The digestible Arg requirements were 1,060 mg/bird per d for optimal product and 1,032 mg/bird per d for optimal feed conversion (Tables 4, 5, and 6; Figure 6). The digestible Ile requirements were determined to be 829 mg/bird per d for optimal product and 820 mg/bird per d for optimal feed conversion (Tables 4, 5, and 6; Figure 3). The digestible Lys requirements were 919 mg/bird per d for optimal product and 911 mg/bird per d for optimal feed conversion (Tables 4, 5, and 6; Figure 4). The digestible Cys requirement for optimal product was determined to be 468 mg/bird per d and for optimal feed conversion determined to be 485 mg/bird per d (Tables 4, 5, and 6; Figure 7). The digestible Val requirement was 786 mg/bird per d for optimal product and 811 mg/bird per d for optimal feed conversion (Tables 4, 5, and 6; Figure 8). The requirement for digestible tryptophan was 243 mg/bird per d for optimal product and 261 mg/bird per d for optimal feed conversion (Tables 4, 5, and 6; Figure 9). Finally, the digestible Thr requirement was determined to be 613 mg/bird per d for both optimal product and optimal feed conversion (Tables 4, 5, and 6; Figure 10).

Table 6. Mean egg weights (g) for broiler breeders fed various amino acid levels in trial 1 (wk 32 to 38) and trial 2 (wk 30 to 40)

	Amino acid level								
Item	1	2	3	4	5	6	7	8	SEM
Trial 1									
Phe	61.68[d]	60.66[e]	61.44[d]	62.09[cd]	62.73[bc]	61.71[d]	63.82[a]	62.86[b]	0.27
Met	59.54[e]	62.15[bc]	60.74[d]	62.35[b]	61.46[cd]	61.68[bc]	62.16[bc]	63.59[a]	0.26
Arg	61.31[bc]	61.93[ab]	60.54[d]	62.58[a]	61.1[cd]	60.92[cd]	60.82[cd]	62.13[a]	0.27
CP	62.17[b]	64.08[a]	60.88[c]	61.94[b]	62.25[b]	60.38[c]	64.09[a]	62.57[b]	0.25
Ile	59.62[c]	61.87[b]	61.93[b]	62.12[b]	63.38[a]	63.59[a]	63.17[a]	62.06[b]	0.26
Lys	57.22[e]	60.78[c]	59.5[d]	61.79[b]	63.18[a]	62.08[b]	63.68[a]	61.94[b]	0.25
Trial 2									
Arg	60.79[a]	57.49[f]	58.66[de]	57.19[f]	59.17[cd]	60.16[b]	58.52[e]	59.31[c]	0.20
Ile	58.90[c]	57.07[e]	58.28[d]	59.83[b]	61.08[a]	60.16[b]	61.08[a]	60.25[b]	0.21
Lys	55.89[f]	57.79[e]	60.46[b]	58.89[cd]	59.36[c]	60.16[b]	58.58[d]	62.22[a]	0.22
Met	55.27[e]	56.53[d]	60.36[a]	59.65[b]	59.50[b]	60.16[a]	59.52[b]	58.48[c]	0.21
Thr	57.93[d]	60.09[b]	61.32[a]	61.00[a]	59.47[c]	60.16[b]	58.02[d]	58.25[d]	0.20
Trp	58.08[d]	60.04[c]	62.45[a]	61.99[a]	60.38[c]	60.16[c]	61.27[b]	61.29[b]	0.25
Val	57.76[d]	59.51[c]	59.93[bc]	61.03[a]	61.01[a]	60.16[b]	60.84[a]	60.87[a]	0.22
Cys	59.50[e]	58.12[f]	62.61[a]	60.25[cd]	60.60[bcd]	60.16[d]	60.94[b]	60.62[bc]	0.20

[a–f]Means within a row that do not share a common letter are significantly different ($P < 0.05$).

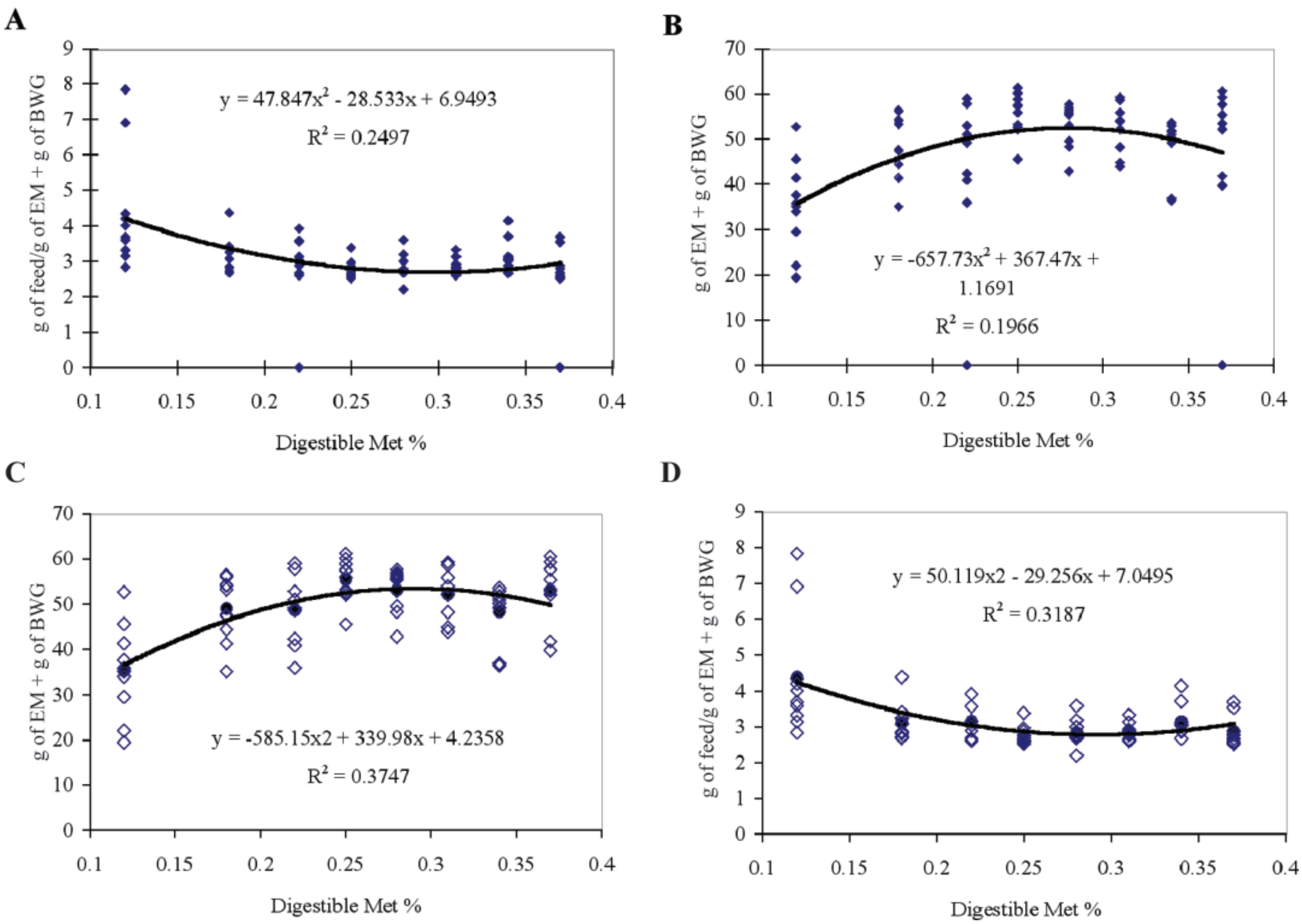

Figure 1. The polynomial response of digestible Met for daily grams of feed/gram of egg mass (EM) + grams of BW gain (BWG; A) and grams of EM + grams of BWG (B) for broiler breeders for trial 1; daily grams of EM + grams of BWG (C) and grams of feed/gram of EM + grams of BWG (D) for trial 2. Color version available in the online PDF.

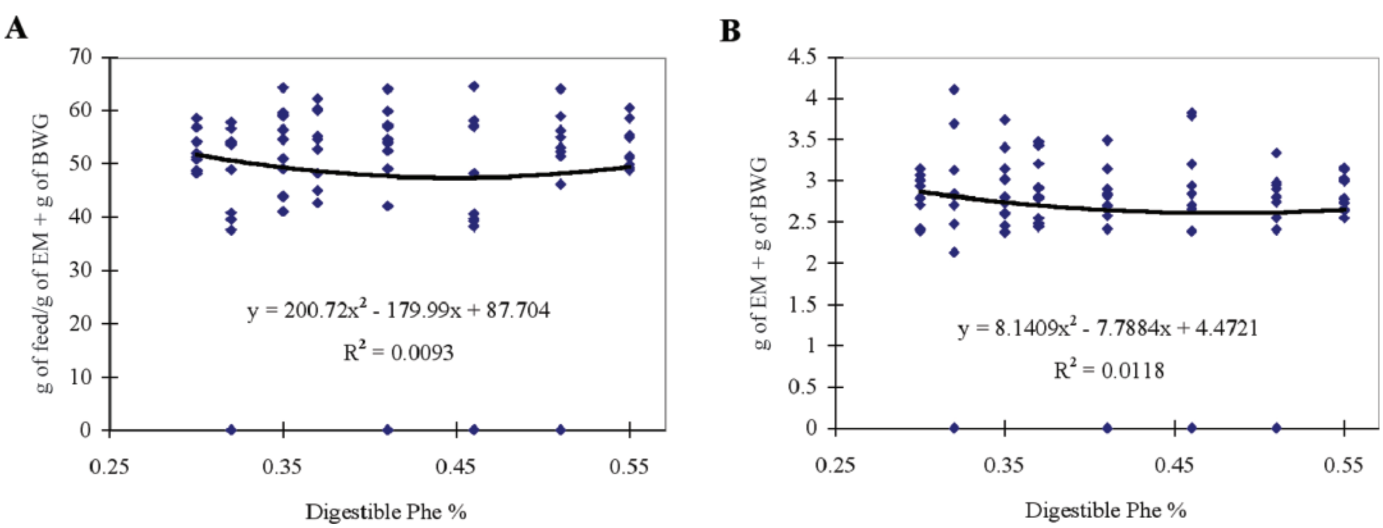

Figure 2. The polynomial response of digestible Phe for daily grams of feed/gram of egg mass (EM) + grams of BW gain (BWG; A) and grams of EM + grams of BWG (B) for broiler breeders for trial 1. Color version available in the online PDF.

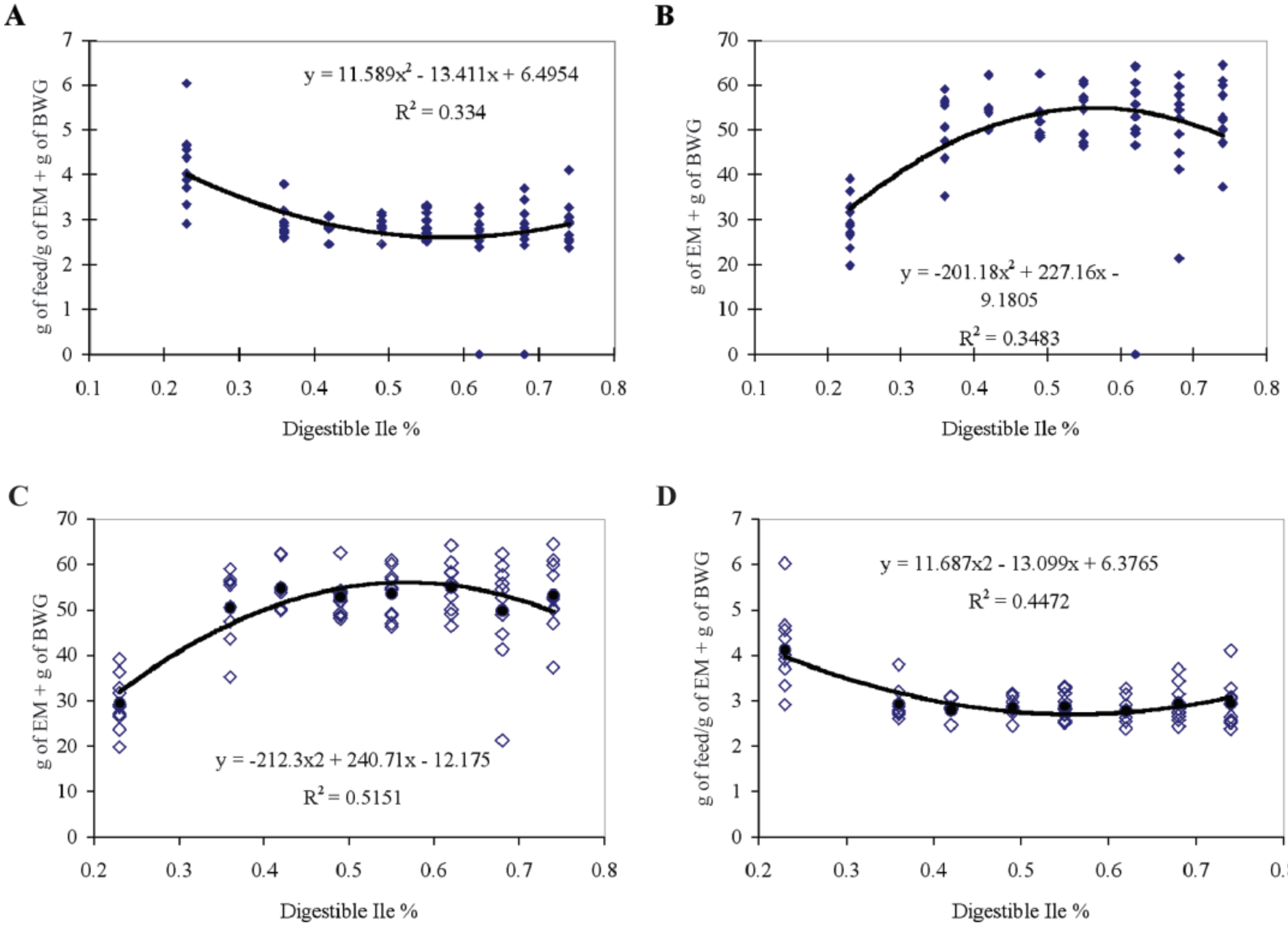

Figure 3. The polynomial response of digestible Ile for daily grams of feed/gram of egg mass (EM) + grams of BW gain (BWG; A) and grams of EM + grams of BWG (B) for broiler breeders for trial 1; daily grams of EM + grams of BWG (C) and grams of feed/gram of EM + grams of BWG (D) for trial 2. Color version available in the online PDF.

Urine pH

Urine pH in hens fed a standard Ile diet was significantly higher than hens fed the low Ile diet (Table 8). No effects were determined for time of day or collection day.

DISCUSSION

Dietary amino acid requirements for broiler breeders (NRC, 1994) have been made based primarily on empirical data. A factorial approach for developing amino acid requirements should provide an opportunity to suggest requirements for changing genetic lines with different hatching egg output and different BW. The factorial equation used most often is from Fisher (1998):

$$R_{aai} = aE + bW^n \pm c\Delta W,$$

where “R_{aai} = amino acid intake requirement, milligrams per bird per day; aE = the requirement for egg production as a function of E, grams of egg output per day; bW^n = tissue replacement for maintenance as a function of body or tissue weight; and $c\Delta W$ = the requirement for tissue growth as a function of weight change, grams per day” (Fisher, 1998). The present study determined the broiler breeder requirements for optimal egg mass and BW gain at a time period near peak production. The sum of average daily egg mass plus average daily BW gain was termed product. The requirements for daily egg mass production and BW change were considered together.

The initial BW for trial 1 were 3,714 ± 172 g and the initial BW for trial 2 were 3,441 ± 293 g. The present study discusses digestible amino acid requirements; however, most published reports only use total amino acid requirements (Table 9). The digestible amino acid requirements presented here tend to be between the available amino acid recommendations of Fisher (1998) and total amino acid recommendations of the NRC (1994; Table 10). The NRC recommendations have been adjusted in the present study to an 87% digestibility for comparative purposes. Fisher (1998) reported the digestible Lys requirements for egg production at 893 mg/bird per d based on the Reading model, which includes corrections for flock variability, whereas the NRC (1994) suggested requirement for digestible Lys

Table 7. Average fertility (%) of hatching eggs from broiler breeders fed various amino acid levels for trial 1 (wk 32 to 38) and trial 2 (wk 30 to 40)

	Amino acid level										
Item	1	2	3	4	5	6	7	8	Pooled SEM	Linear	Quadratic
Trial 1											
Phe	72.15^{ab}	67.32^{b}	67.95^{b}	85.41^{a}	75.33^{ab}	78.02^{ab}	71.85^{ab}	73.54^{ab}	5.69	0.5294	0.5034
Met	79.63^{ab}	76.12^{ab}	68.96^{b}	84.78^{a}	76.11^{ab}	85.88^{a}	79.79^{ab}	81.58^{ab}	9.36	0.3282	0.6359
Arg	67.68^{b}	60^{b}	88.51^{a}	88.14^{a}	84.71^{a}	89.23^{a}	85.88^{a}	69.66^{b}	4.2	0.3819	0.0642
CP	78^{abcd}	81.57^{abcd}	90.51^{a}	76.42^{bcd}	87.59^{ab}	82.69^{abc}	69.88^{d}	71.45^{cd}	8.26	0.2424	0.1406
Ile	93.92^{a}	91.57^{a}	92.87^{a}	85.64^{ab}	80.35^{b}	82.79^{ab}	67.37^{c}	65.87^{c}	4.87	0.0005	0.0014
Lys	87.25^{a}	82.35^{ab}	78.87^{abc}	83.59^{a}	82.79^{a}	67.22^{c}	66.07^{c}	69.64^{bc}	5.01	0.0084	0.0418
Trial 2											
Arg	53.22^{abc}	44.27^{c}	49.87^{abc}	45.51^{bc}	41.74^{c}	61.21^{a}	62.07^{ab}	46.33^{bc}	6.11	0.1467	0.3216
Cys	45.79^{b}	49.15^{ab}	56.30^{ab}	57.02^{ab}	50.40^{ab}	61.21^{a}	47.48^{b}	49.63^{ab}	5.79	0.2816	0.0878
Ile	63.10^{a}	62.46^{ab}	57.84^{ab}	55.75^{ab}	48.63^{ab}	61.21^{a}	44.23^{b}	48.12^{b}	6.75	0.0381	0.0928
Lys	66.25^{ab}	69.99^{ab}	57.07^{a}	52.99^{ab}	56.60^{ab}	61.21^{ab}	55.38^{ab}	49.75^{b}	6.07	0.0691	0.1910
Met	54.23^{ab}	56.96^{ab}	62.10^{ab}	52.75^{ab}	55.95^{ab}	61.21^{a}	57.87^{ab}	47.23^{b}	6.13	0.9942	0.3731
Thr	49.58^{ab}	48.16^{ab}	62.25^{ab}	54.74^{ab}	48.39^{b}	61.21^{a}	61.62^{ab}	64.26^{ab}	5.99	0.0171	0.0554
Trp	36.81^{b}	54.80^{ab}	52.96^{ab}	47.56^{ab}	40.53^{b}	61.21^{a}	44.69^{b}	37.34^{b}	6.42	0.3511	0.0156
Val	57.88^{a}	40.02^{c}	53.99^{abc}	61.36^{a}	56.20^{ab}	61.21^{a}	41.80^{bc}	58.71^{a}	5.15	0.4558	0.7154

[a–d]Means within a row that do not share a common letter are significantly different ($P < 0.05$).

is 666 mg/bird per d. The requirements determined for maximum product in the present study places the need of digestible Lys at 909 mg/bird per d (trial 1) and 919 mg/bird per d (trial 2) with an overall average requirement of 916 mg/bird per d across both trials for both optimal product and feed conversion. This value repre-

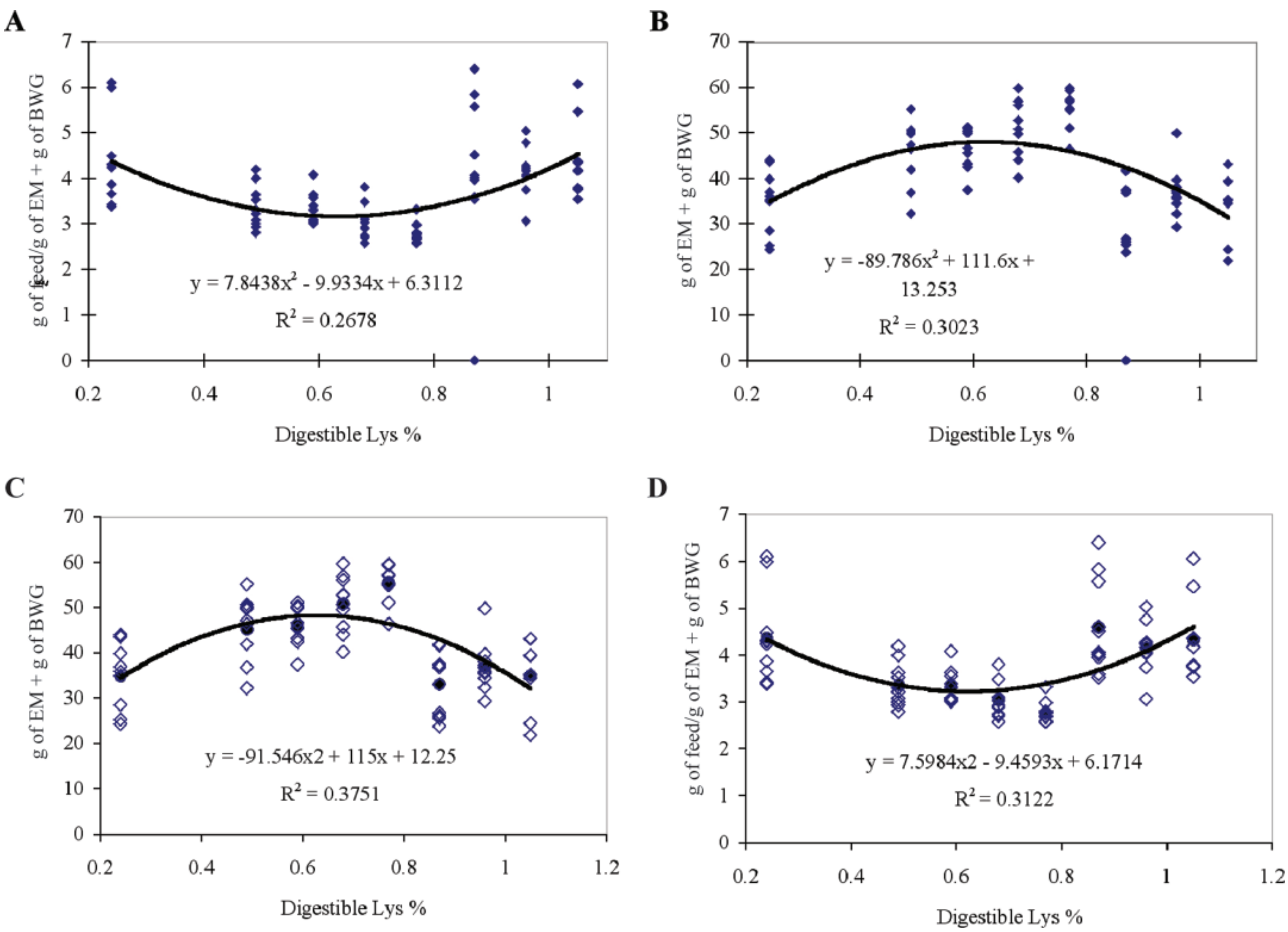

Figure 4. The polynomial response of digestible Lys for daily grams of feed/gram of egg mass (EM) + grams of BW gain (BWG; A) and grams of EM + grams of BWG (B) for broiler breeders for trial 1; daily grams of EM + grams of BWG (C) and grams of feed/gram of EM + grams of BWG (D) for trial 2. Color version available in the online PDF.

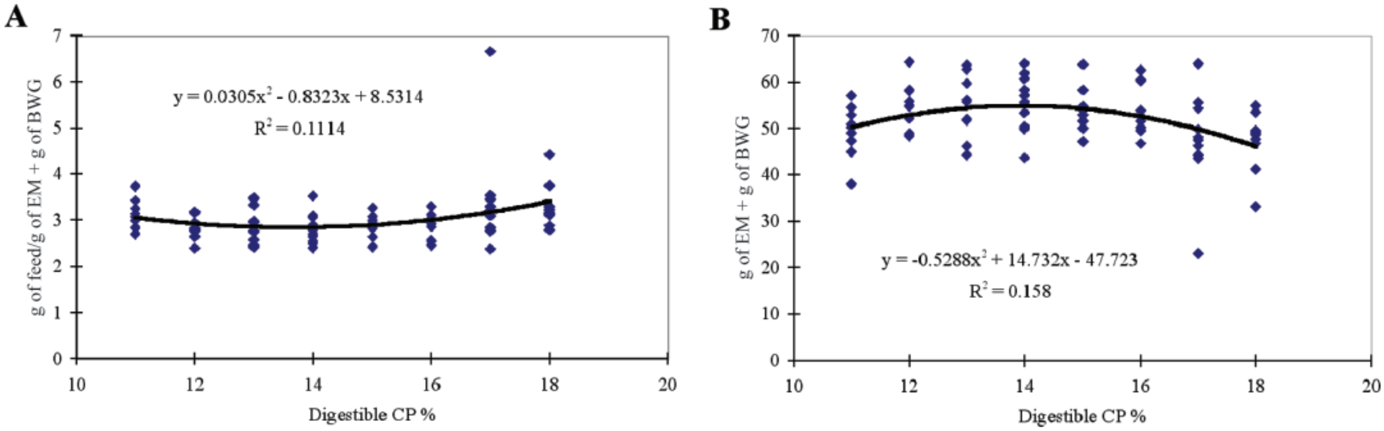

Figure 5. The polynomial response of digestible CP for daily grams of feed/gram of egg mass (EM) + grams of BW gain (BWG; A) and grams of EM + grams of BWG (B) for broiler breeders for trial 1. Color version available in the online PDF.

sents both egg mass and BW gain; therefore, it could be argued that Fisher's factorial available Lys requirement closely matches the 916 mg/bird per d presented in Table 9. Sakomura et al. (2011) proposed a factorial model that would correspond to a digestible Lys requirement of 670 mg/bird per d for a 4-kg breeder, which is similar to the NRC (1994) requirement. Soares et al. (1988) reported that 45- to 60-wk-old broiler breeders required 915 mg of total Lys/d when consuming 18.5 g of protein/d. Harms and Ivey (1992) placed the total Lys requirements for approximately 50-wk-old broiler breeders at 819 mg/bird per d for maximum egg mass

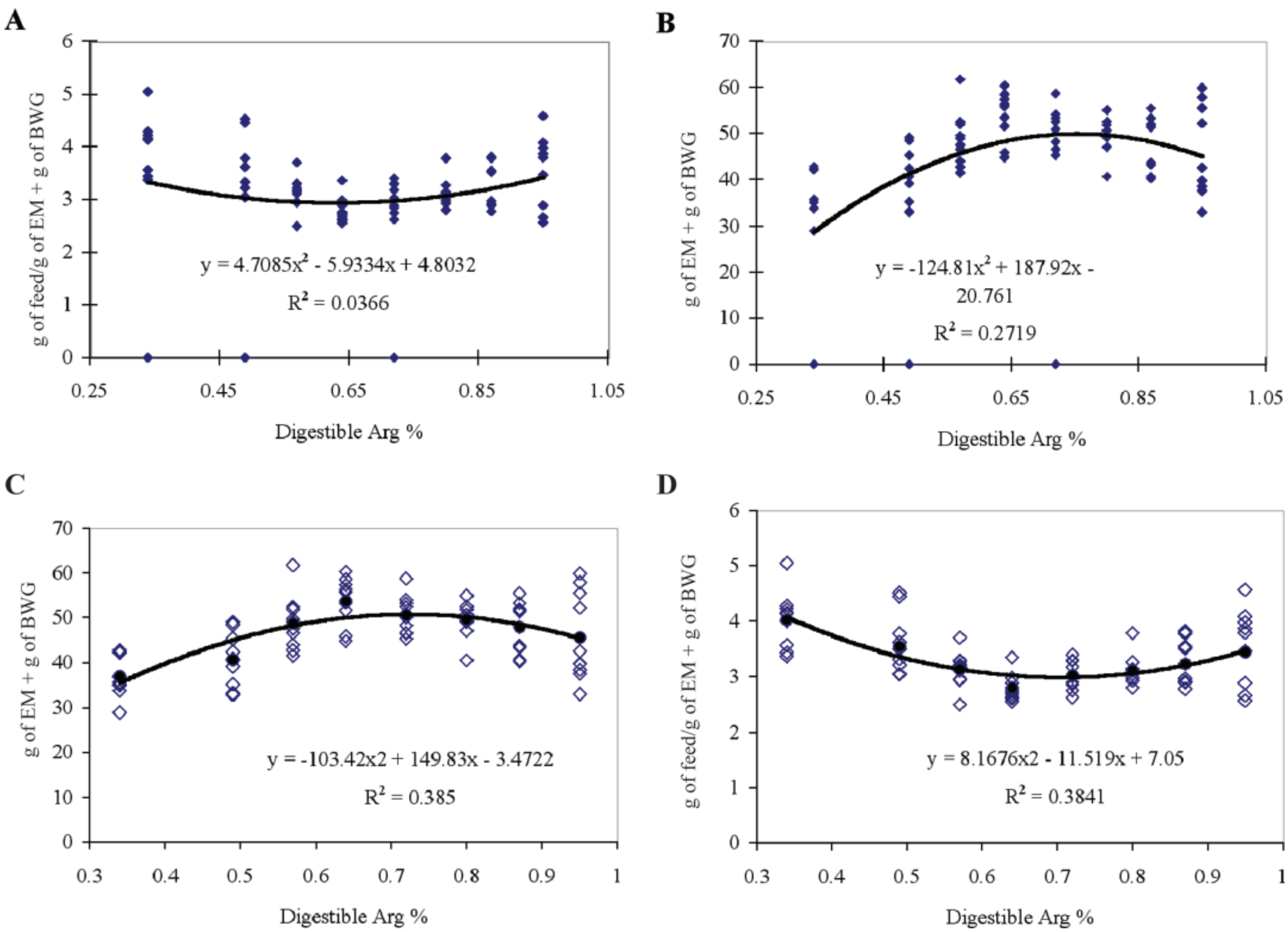

Figure 6. The polynomial response of digestible Arg for daily grams of feed/gram of egg mass (EM) + grams of BW gain (BWG; A) and grams of EM + grams of BWG (B) for broiler breeders for trial 1; daily grams of EM + grams of BWG (C) and grams of feed/gram of EM + grams of BWG (D) for trial 2. Color version available in the online PDF.

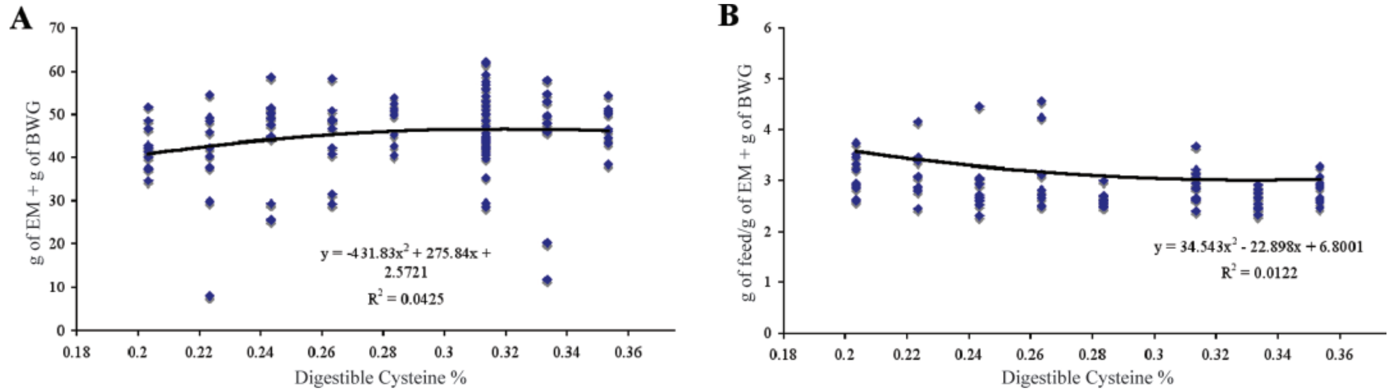

Figure 7. The polynomial response of digestible Cys for grams of egg mass (EM) + grams of BW gain (BWG; A) and daily grams of feed/gram of EM + grams of BWG (B) for broiler breeders for trial 2. Color version available in the online PDF.

when CP was fed at levels greater than 18.55 g. Harms and Russell (1995) revisited the total Lys requirements and suggested the requirement was 845 mg/d for maximum egg production, egg mass, and egg content. Recently, Fakhraei et al. (2010) reported a total Lys requirement of 1,012.5 mg/bird per d for 60+-wk-old broiler breeders. Fakhraei et al. (2010) recommendation adjusted to an assumed 87% digestibility provides 881 mg/bird per d and closely matches the overall average requirement of 916 mg/bird per d presented in Table 9. Although evidence suggests placing Lys requirements toward the high end of the ranges reported, there is concern over the negative impacts of high Lys levels. In the present study, a negative linear decrease in fertility was observed with increasing Lys levels, especially above 893 mg of Lys/d (Table 7). To detect differences in fertility in the present study, only 50 million sperm cells per insemination were used. Previous unpublished research (Keith Bramwell, University of Arkansas, Fayetteville, personal communication) has shown difficulty in assessing differences in fertility when sperm count per insemination was higher than 50 million. Fakhraei et al. (2010) did not observe a statistically significant decrease in hatch of fertile eggs with increasing total Lys levels; however, hatch of fertile eggs dropped from a high of 73.16% to a low of 58.80% when Lys was increased from 0.57 to 0.78%. The decrease in fertility in the present study due to high Lys intakes was also observed for Ile.

In a typical poultry diet based on corn and soybean meal, Met is the first limiting amino acid, whereas Lys is second. Methionine requirements are usually considered in concert with Cys. Methionine can be converted to Cys with 100% efficiency; however, Cys can only spare about 50% of the total Met requirement. The conversion of Met to Cys is equal on an equimolar basis or is approximately 80% on a weight basis (Met molecular weight, 149.2; Cys molecular weight, 121.2) for both broilers and laying hens (Cao et al., 1995). Fisher (1998) reported the digestible Met requirement to be 372 mg/bird per d, whereas the NRC (1994) suggested the Met requirement for broiler breeders was 392 mg/bird per d. The results of the present study indicate the digestible Met requirement to be 409 mg/bird per d (trial 1) and 425 mg/bird per d (trial 2) for optimal product and an overall average of 424 mg/bird per d (Table 9), similar to the available Met recommendations of Fisher and the NRC. The simulated requirement for total Met using the response coefficients of Bowmaker and Gous (1991) for a 2.5-kg breeder producing 50 g of egg mass per day was reported to be 355 mg/d. Harms and Russell (1998) reported the total

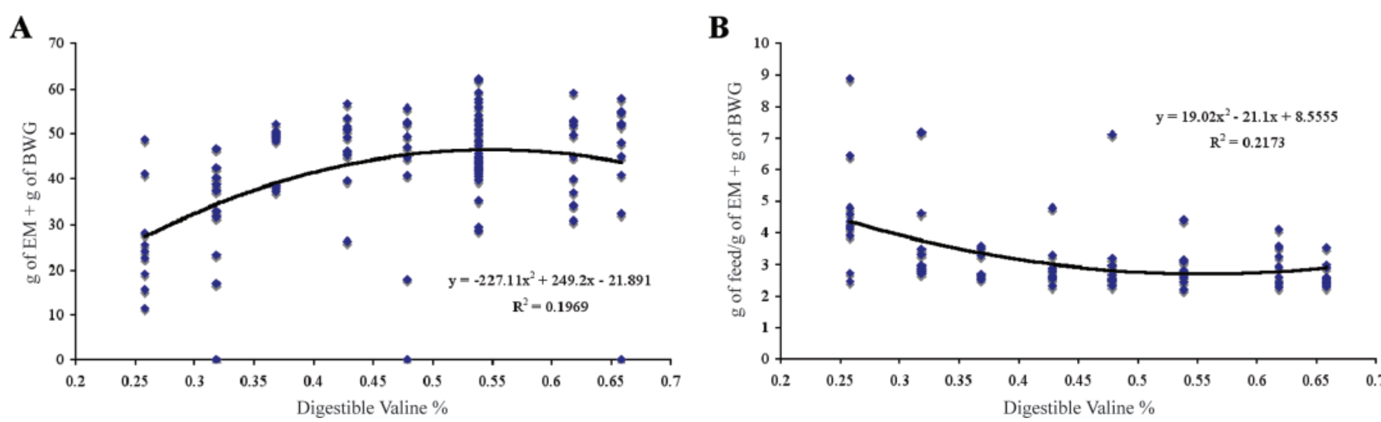

Figure 8. The polynomial response of digestible Val for grams of egg mass (EM) + grams of BW gain (BWG; A) and daily grams of feed/gram of EM + grams of BWG (B) for broiler breeders for trial 2. Color version available in the online PDF.

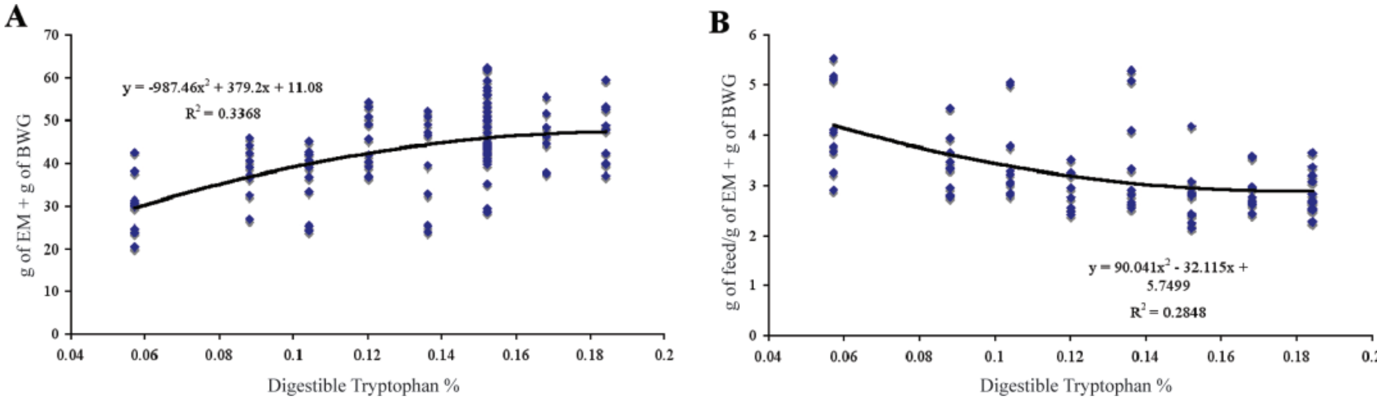

Figure 9. The polynomial response of digestible Trp for grams of egg mass (EM) + grams of BW gain (BWG; A) and daily grams of feed/gram of EM + grams of BWG (B) for broiler breeders for trial 2. Color version available in the online PDF.

Met requirement to be 344 mg/bird per d in broiler breeders from ages that ranged from 32 to 46 wk that are close to the recommendations by Fisher (1998). Bornstein et al. (1979) and Pearson and Herron (1981), however, recommended a much higher requirement at 570 mg/bird per d. The digestible Cys requirements in the present study were determined to be 468 mg/bird per d and an overall average of 477 mg/bird per d. Neither Fisher (1998) nor the NRC (1994) provided an estimate of the Cys requirement. Gomes et al. (2011) reported the digestible Met + Cys requirement to be 727 mg/bird per d in Cobb broiler breeders from 40 to 60 wk of age. Cave et al. (1990) suggested a higher total requirement of 528 mg of Met/d and 960 mg of TSAA/d due to an increase of 6 to 8% in egg mass output over previous studies. Wilson and Harms (1984) suggested the Met and TSAA requirement for breeders was 400 and 750 mg/d, respectively. However, Fisher (1998) reported the TSAA requirement at 621 mg/bird per d. The digestible Met + Cys (TSAA) requirement in this present study was determined to be 893 mg/bird per d (trial 1) and 912 mg/bird per d (trial 2) with an average for both trials of 902 mg/bird per d (Table 9). The present authors believe that the appropriate method for determining the Met requirement is to add dietary Cys equal to 50% of the TSAA requirement to the Met test diets to ensure the Met is being primarily used for methylation reactions and protein synthesis and not for transsulfuration reactions noted for Cys synthesis. Also, the present authors believe the appropriate method for determining the TSAA requirement is to determine the essential Met requirement in a separate study and then add the appropriate level of Met to the Cys test diets. The Cys requirement can then be evaluated for the nonessential amino acid functions and then the requirement for digestible Met and digestible Cys added together for the digestible TSAA requirement.

Very few studies exist assessing the Ile and Val requirements of broiler breeders. The NRC (1994) and Fisher (1998) place the digestible requirements of Ile at 740 and 598 mg/bird per d, respectively, which is a large discrepancy. The value reported in this present study for digestible Ile is in general agreement with the NRC (1994) recommendation; the present study places the digestible requirement of Ile at 826 mg/bird per d (trial 1) and 829 mg/bird per d (trial 2) for optimal product and an overall average of 830 mg/bird per d. Harms and Ivey (1992) reported that a total Ile intake of 625 mg/d along with 16.72 g of CP/d resulted in satisfactory performance, although they recommended 685 mg/bird per d and 17.51 g of CP/d. Beyond these

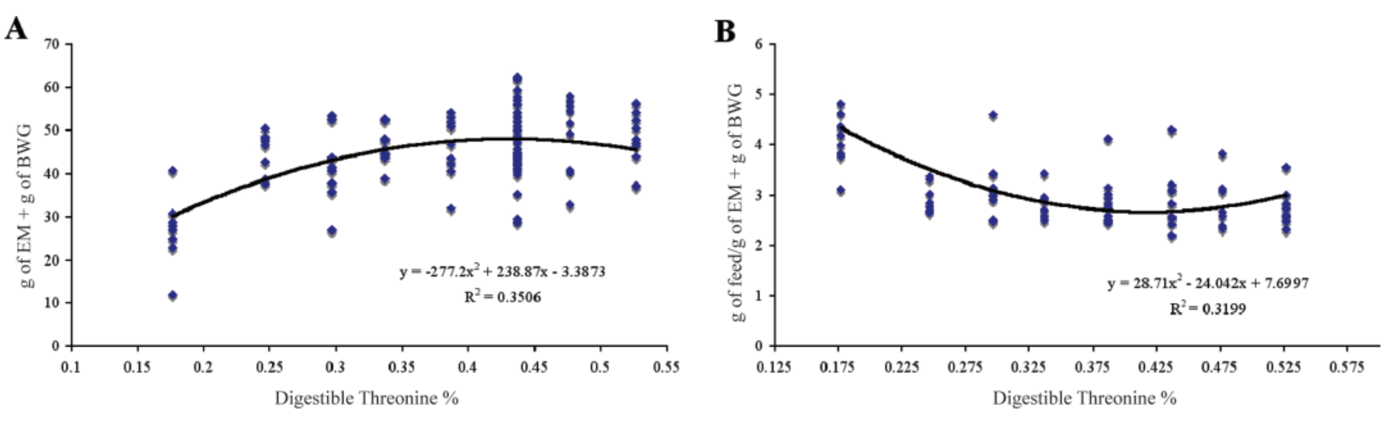

Figure 10. The polynomial response of digestible Thr for grams of egg mass (EM) + grams of BW gain (BWG; A) and daily grams of feed/gram of EM + grams of BWG (B) for broiler breeders for trial 2. Color version available in the online PDF.

Table 8. Urine pH of hens fed a low (300 mg/d) or standard (800 mg/d) Ile diet, collected twice a day over 3 d

Item	pH
Ile level	
Low	6.72
Standard	8.45
SEM	0.14
P > *F*	<0.0001
Sample day	
1	7.58
2	7.62
3	7.56
SEM	0.17
P > *F*	0.9654
Sample time	
AM	7.49
PM	7.68
SEM	0.14
P > *F*	0.3666

recommendations, there are very few data available in the scientific literature to aid in truly establishing the broiler breeder requirement for Ile. Peganova and Elder (2002) investigated the total Ile requirements of laying hens and suggested ranges of 412 to 770 mg/bird per d for optimal egg mass in 25- to 32-wk-old hens. They also concluded that dietary Ile levels over 0.8% reduced BW and dietary levels over 1.0% reduced daily egg mass. The digestible Val requirements are reported to be 693 mg/bird per d by Fisher (1998) and 653 mg/bird per d by the NRC (1994). The digestible Val value determined in the present study (overall average of 799 mg/bird per d) is consistent with that of the NRC (1994). Harms and Ivey (1992) placed the total requirement of Val at 837 mg/bird per d with levels as low as 778 mg/bird per d producing adequate performance. Bornstein et al. (1979) reported the total Val requirement to be 920 mg/bird per d. in 3.4 to 3.5 kg broiler breeders housed in floor pens (800 mg/bird per d of digestible Val). The data reported in the present study suggests that elevated levels of Ile decrease fertility. Overweight birds have been reported to have reproductive problems (Robinson and Wilson, 1996). Overfeeding certain amino acids may lead to overweight birds; however, this was not observed in the present study. Investigation of urine pH from hens fed a low Ile diet and a standard Ile diet reveals that the pH became more alkaline with the higher level of Ile (pH 8.45 vs. pH 6.72; Table 8). Bogdonoff and Shaffner (1954) reported that an alkaline condition was much more harmful to fertility than a slightly acidic condition in semen diluted from New Hampshire roosters. They reported a natural pH range of 6.72 to 6.94 and that the optimal range is close to pH 7. Further studies by Lake and Ravie (1979) and Holm and Wishart (1998) confirm the importance of pH on fertility and sperm motility, respectively. Mobilization of skeletal tissue during periods of Ile and Lys deficiency may lead to the formation of uric acid and other acids, creating a more favorable acidic condition. Mejia et al. (2012), feeding a semipurified diet, were also able to detect a decrease in fertility in broiler breeders consuming 1,020 mg of Lys each day, but not on a diet typical of that used in the industry. This finding may be partially explained by the additional sodium bicarbonate added to the industry diet. In light of the possible pH effect, such an addition may temper the negative effects of high Lys, Ile, or both. It can be speculated that these amino acids alter the microenvironment of the storage tubules, perhaps by the catabolism of these amino acids into ketone bodies. The possible negative impact of elevated Lys/Ile levels on fertility in broiler breeders creates a new dilemma for the breeder industry: feed for optimal product or feed for optimal fertility.

Much like Met and Cys, Phe and Tyr are usually considered in concert. In the present study, Tyr was added to provide the nonessential portion of the Phe + Tyr

Table 9. Broiler breeder digestible amino acid and CP requirements (mg/bird per d)

	Requirement (g of egg mass + g of BW gain/d)		Requirement (g of feed/g of egg mass + g of BW gain/d)		Digestible amino acid requirement		
Item	Trial 1	Trial 2	Trial 1	Trial 2	Average of trials 1 and 2[1]	Fisher (1998)[2]	NRC (1994)[3]
Amino acid							
Met	409	425	436	427	424	372	392
Cys		468		485	477		
TSAA		893		912	901	621	700
Phe	689		689		689		
Phe + Tyr[4]	997		997		997	1,032	967
Trp		243		261	252	186	165
Arg	1,101	1,060	922	1,022	1,026	803	966
Lys	909	919	926	911	916	893	666
Ile	826	829	846	820	830	598	740
Val		786		811	799	693	653
Thr		613		613	613	558	626
CP (g/d)	20.9		19.4		20		17

[1]Average of both trials and across both optimal product and feed conversion.

[2]Factorial requirements assuming available amino acids.

[3]Recalculated to an assumed 87% digestibility.

[4]The digestible Phe and Tyr requirement is based on adding digestible Phe requirement with Tyr included in Phe test diet.

Table 10. Ideal digestible amino acid profile (%) for broiler breeders relative to Lys

Amino acid	Trial 1	Trial 2	Average	Fisher	NRC
Lys	100	100	100	100	100
Met	46	46	46	43	59
Cys		52	52		
TSAA		99	99	73	
Phe	76		76		
Phe + Tyr	108		108	120	145
Trp		28	28	22	25
Arg	110	114	112	90	145
Ile	91	90	91	70	111
Val		88	88		98
Thr		69	69	64	94

requirement. From the data collected in the present study it is possible to conclude that the digestible Phe requirement to be 689 mg/bird per d for optimal product and feed conversion. The Phe + Tyr requirement determined in the present study is proposed to be 997 mg/bird per d (trial 1). Present research is only for Phe with 50% of total Phe + Tyr requirement consisting of dietary Tyr. The Phe requirement was determined in trial 1. The digestible Phe plus Tyr requirement presented in Table 9 is based on adding the correct Phe requirement to the basal Tyr level. Fisher (1998) did not report a Phe requirement by itself, but instead reported the available Phe + Tyr requirement to be 1,032 mg/bird per d. Similarly, NRC (1994) only recommends a digestible Phe + Tyr requirement of 967 mg/bird per d. Bornstein et al. (1979) placed the total Phe requirement of broiler breeders at 610 mg/bird per d. The digestible Arg requirements, when expressed as g of EM + g of BW gain/d and g of feed/g of EM + g of BW gain/d, presented in Table 9 for trial 1 and 2 of 1,101 mg/bird per d and 1,060 mg/bird per d, respectively, match closely the digestible Arg requirement given for broiler breeders in the NRC (1994) of 966 mg/bird per d. This is true for their average value of 1,026 mg/bird per d. However, these requirements values do not closely reflect the value proposed by Fisher (1998) of 803 mg/bird per d. The available tryptophan requirement proposed by Fisher (1998) of 186 mg/bird per d and the NRC (1994) of 165 mg/bird per d are below the digestible requirement found in the present study of 243 mg/bird per d in trial 1 and 261 mg/bird per d in trial 2 (average value of 252 mg/bird per d). In caged egg-type layers, the total Trp requirement was found to be 149 mg/bird per d for egg contents of 45.4 g/d (Harms and Russell, 2000).

The digestible Thr requirement determined in the present study was 613 mg/bird per d, and this requirement value fell between the available requirement values proposed by Fisher (1998) of 558 mg/bird per d and the NRC (1994) value of 626 mg/bird per d. In caged egg-type layers, the total Thr requirement was found to be 447 to 462 mg/bird per d for optimal egg mass (Faria et al., 2002). The CP recommendations of several broiler breeder management guides tend to place total requirements above 25 g of CP/bird per d (Leeson and Summers, 2000). The Ross (2008) management guide suggest upwards of 29 g of CP/bird per d. The present study suggests that the digestible CP requirement of broiler breeders is 20.9 g of CP/bird per d (trial 1) for optimal product and lower (19.4 g of CP/bird per d) for optimal feed conversion (Table 9). Most published reports suggest that CP levels over 22 g do not improve egg production of broiler breeders, although higher CP levels may improve egg weight. Joseph et al. (2000) reported that increasing total CP intake of breeders from 21.3 to either 23.4 or 26.6 g per day (144 g of feed intake at peak) during prelay and early lay in Cobb 500 broiler breeders increased egg weight and albumen weight, but did not increase BW. Spratt and Leeson (1987) suggested broiler breeders need 25 g of CP/d for maximal egg weight, whereas Waldroup et al. (1976) suggested 22 g of CP/d for maximal egg production. However, most advantages gained in egg weight did not translate to improved reproductive performance. Pearson and Herron (1982) reported an increase in dead and deformed embryos, thus resulting in decreased hatchability of fertile eggs with 27 versus 23.1 g of CP intake per bird per day. Furthermore, Lopez and Leeson (1995) reported a decrease in fertility in broiler breeder hens fed 16% CP rather than 10 to 14% CP. The highest fertility in the present study was found in broiler breeder hens fed 20.2 g of digestible CP/bird per d: near the optimum for product. Finally, Wilson and Harms (1984) found that protein intake from 19.9 to 23 g/bird per d had no effect on 49-d BW of offspring.

The daily requirements for several amino acids were able to be determined in the present study, many of which are similar to the recommendations presented in several previous reports. The digestible Met, Phe, Arg, Ile, Lys, and CP requirements for optimal product (egg mass plus BW gain) and feed conversion in trial 1 were determined to be 409 and 436 mg/bird per d, 689 and 689 mg/bird per d, 1,101 and 922 mg/bird per d, 826 and 846 mg/bird per d, 909 and 926 mg/bird per d, and 20.9 and 19.4 g/bird per d, respectively. The digestible Met, Cys, Trp, Arg, Ile, Lys, Val, and Thr requirements for optimal product (egg mass plus BW gain) and feed conversion in trial 2 were determined to be 425 and 427 mg/bird per d, 468 and 485 mg/bird per d, 243 and 261 mg/bird per d, 1,060 and 1,022 mg/bird per d, 829 and 820 mg/bird per d, 919 and 911 mg/bird per d, 786 and 811 mg/bird per d, and 613 and 613 mg/bird per d, respectively.

The overall average requirement (and ideal profile) for digestible amino acids for both optimal product and feed conversion for Met, Cys, TSAA, Phe, Phe + Tyr, Trp, Arg, Ile, Lys, Val, Thr, and CP requirements for both product and feed/product ratio from trials 1 and 2 were determined to be 424 mg/d (46), 477 mg/d (52), 901 mg/d (98), 689 mg/d (76), 997 mg/d (108), 252 mg/d (28), 1,026 mg/d (112), 830 mg/d (91), 916 mg/d (100), 799 mg/d (87), 613 mg/d (67), and 20.0 g/d, respectively. Taking into consideration the negative impact that daily Lys and Ile intake were shown to have on fertility, nutritionists and production managers should be concerned about the fundamental role of these 2 amino acids beyond their essential requirement for egg mass and BW.

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