DETERMINING THE DIGESTIBLE LYSINE AND LYSINE: THREONINE RATIOS FOR GROWING TURKEYS

M.S. Lilburn
Department of Animal Sciences
OARDC/ Ohio State University
Wooster, OH 44691

Phone: 330-263-3992
FAX: 330-263-3949
Email: lilburn.1@osu.edu

Part 1: Determination of the Optimal Lysine Response of 2- to 20-wk-old Turkeys

There have been relatively few lysine requirement studies that have covered the full productive life of commercial toms (0 to 20 wk). Lysine is the reference amino acid for Ideal Protein ratios and accurately defining the requirement reduces fractional errors in the corresponding ideal protein ratios. A series of studies were conduct to determine the lysine concentrations (total and digestible) in g per Megacalorie (Mcal) of ME needed to support optimum performance of turkeys during five age periods that cover the full production cycle of commercial turkeys. The lysine concentration is reported as gram per mcal ME in order to adjust for the effect of metabolizable energy on nutrient intake for comparison with previous reports in the literature. Four dietary lysine levels were used in each of five studies conducted between 2 and 20 wk of age: The NRC (1994) recommended total lysine concentration, two levels below and one level above. Performance parameters included BW gain, feed efficiency and carcass weight. The maximal lysine response in the 2- to 4-wk poults was at 5.86 g per Mcal ME (1.70% total lysine). Poults fed 4.99 g per Mcal ME (1.54% total lysine) had the best performance from 4 to 8 wk. There were no dietary lysine effects in the 8- to 12-wk and 12- to 16-wk turkey toms except for carcass protein efficiency in 12- to 16-wk. Turkeys fed diets containing 3.29 g (1.05% total lysine) or above, performed maximally during the 16- to 20-wk period.

Introduction

There have been relatively few studies that have addressed digestible amino acid requirements of turkeys and none that have covered the full productive life of commercial toms (Firman and Boiling; 1998, Baker et al., 2003). Formulating diets on a digestible amino acid basis has the potential to reduce feed cost through a reduction in total dietary protein thus enabling greater flexibility in the feed formulation ingredient matrix (Baker et al., 2003).

It is conventional to express amino acid requirements of animals as a percentage of the diet. D'Mello (1976) reported that growth increments resulting from a limiting supply of a nutrient is dependent upon the quantity of the nutrient consumed rather than on its concentration in the diet. It was subsequently suggested by Veldkamp et al. (2002) that in order to adjust for the potential influence of dietary differences in metabolizable energy (ME) on feed intake and report data more consistently across experiments, the dietary lysine requirements of male turkeys should be expressed as g of lysine per unit of metabolizable energy (ME).

Lysine is the reference amino acid for Ideal Protein ratios. The Ideal Protein concept expresses each essential amino acid as a percentage of lysine such that in response to varying genetic and/or production environments, once the lysine requirement is determined, the requirements for the other essential amino acids can be calculated as a ratio to lysine (Baker et al., 2003; Wijtten et al., 2004). It is therefore important to accurately define the lysine response under a variety of circumstances given that any variability in this determination will result in fractional errors in the corresponding ideal protein ratios (Baker and Han, 1994; Firman and Boling, 1998; Knowles and Southern, 1998; Baker et al., 2003).

Our objective was to conduct a series of studies to determine the lysine concentrations (total and digestible) in g per Megacalorie (Mcal) of ME (g / Mcal ME) needed to support optimum performance of turkeys during five age periods that cover the full production cycle of commercial toms

Materials and Methods

Five studies of similar experimental design were conducted over the entire production phase for commercial toms: 2- to 4-wk, 4- to 8-wk, 8- to 12-wk, 12- to 16-wk and 16- to 20-wk. A pool of five hundred day-old Hybrid Converter™ toms was obtained from a commercial hatchery (AgForte Inc., Danville OH) and wing-banded. At the start of each study, all the birds in the pool were weighed and sorted in ascending order of weight. Birds of similar BW were then selected and randomly assigned to experimental pens. One bird was randomly assigned to each experimental unit. Therefore, a total of 240 toms, 48 per study, were selected out of the initial pool of 500.

As explained in Chapter 3, the use of one bird per experimental unit was to avoid interactions between birds within a pen, which could affect their response to the treatments. It also enabled us to have a better idea of the range of response of the birds to the different digestible lysine concentrations. The use of birds of similar weights was to minimize the possible effects of differences in initial BW on the determined response to the experimental diets.

Four Petersime growing batteries were used for the 2- to 4-wk study and each battery consisted of twelve cages with a single cage serving as an experimental unit. For the other four studies, two rooms containing 24 floor pens each were used. Each pen ($3.92m^2$) was an experimental unit. Wood shavings were used for litter material and each pen was equipped with a hanging tube feeder and automatic drinker. The experimental design used for the studies was a randomized complete block design of four dietary treatments. The four batteries were the blocks while the floor pens in each of the two rooms were divided into two opposite rows of 12 separated by a common walkway and each row of pens was the block. Three battery cages or floor pens within a block of four were randomly assigned to each dietary treatment resulting in a total of 12 replicate pens per treatment.

Within each age study, a summit diet and a basal diet were formulated and mixed as shown in Tables 1 to 5. Formulation was based on the analyses of feed ingredients that were used. Two intermediate diets were subsequently formulated from proportional blends of the summit and basal diets. With the exception of lysine, the diets were formulated to meet the minimum NRC (1994) amino acid requirements for a particular age group. The lysine levels used were the NRC (1994) recommendations with two levels either above or below the recommended level. The diets were fed as crumbles from 2 to 8 wk and as short pellets from 8 to 20 wk.

Each diet contained 0.3 % chromic oxide that was used as an indigestible marker for the calculation of amino acid digestibility. In our results and discussion, we will use the g lysine per Mcal ME to make comparisons with the values that have been reported in the literature. Birds had ad libitum access to feed and water. Lighting was 24 h for studies 1 and 2, and 16 light: 8 dark for studies 3, 4 and 5. At the end of each study, total feed intake and final BW were determined. All toms were killed by cervical dislocation between the hours of 0900 and 1100.

Ileal digesta and carcass samples were collected and analyzed as described in Chapter 3. The percentage carcass N for each poult was analyzed on a % DM basis. We had three replicates per block per treatment and as such, ileal digesta samples were pooled per block per treatment such that we had four ileal digesta samples per treatment that were analyzed for amino acid content. Analyzed data were used to calculate the digestibility coefficient of the test diets using the formula below:

$$CIAD = \frac{(AA/Cr)_{d} - (AA/Cr)_{id}}{(AA/Cr)_{d}} \times 100$$

Where:

CIAD = calculated ileal apparent digestibility

$(AA/Cr)_d$ is the dietary ratio of amino acid to Cr

$(AA/Cr)_{id}$ is the ratio of amino acid to Cr in ileal digesta.

All studies were conducted in accordance with the principles and specific guidelines that are presented in Guidelines for the Care and Use of Agricultural Animals in Agricultural Research and Teaching, 1st revised edition, 1999.

Statistical Analyses

The experimental design for the five studies was a randomized complete block design with four dietary lysine levels and four blocks of batteries or rows of floor pens. The Mixed procedure of SAS (SAS V9.x.) was used for the statistical analyses. Blocks and the residuals were the random effects in the model while the levels of lysine were the fixed factors. When there were significant effects due to treatments ($P < 0.10$), means were separated by using the Fisher's protected least-significant difference (i.e., the PDIFF option of SAS). Thereafter, orthogonal polynomial tests were done to determine if differences were linear, quadratic or cubic.

Performance variables that were analyzed were final BW, BW gain, feed intake, feed efficiency ratio, carcass weight, P. major, P. minor, carcass nitrogen (% DM), carcass protein, and carcass protein retention efficiency. The statistical model used for all studies was:

$Y_{ijk} = U + b_i + L_j + e_{ijk}$

Where:

Y_{ijk} is the dependent variable; U is the population mean; b_i is the random block effect; L_j is Lysine fixed effect; e_{ijk} is the experimental error associated with the experiment.

Results

The average digestible lysine values for each study were 96% (2 to 4 wk), 93% (4 to 8 wk), 90% (8 to 12 wk), 85% (12 to 16 wk) and 82% (16 to 20 wk), respectively. Based on the very high lysine digestibility values reported in the studies, especially for the 2- to 4-wk and 4- to 8-wk groups, we determined the dry matter digestibility of our diets and the values were similar to expected standards (Table 6). The very high lysine values reported in our study at the early age could have been due to the high levels of crystalline lysine used in our diets which could have resulted in sampling errors. In the older turkeys, there were variable quantities of litter observed in the freeze-dried digesta. Consequently, the process of separating the litter from the digesta could have affected the quality of the digesta samples. Due to these circumstances, we opted to report lysine values on a total lysine basis.

In the 2- to 4-wk poults (Table 7) there was a cubic response in final BW ($P<0.02$), BW gain ($P<0.01$), feed efficiency ratio ($P<0.02$) and carcass weight ($P<0.04$) as lysine concentrations increased from 4.65g (1.35% total lysine) to 5.86g (1.70% total lysine) per Mcal ME. There was a quadratic response ($P<0.01$) response in P. major, P. minor, carcass protein and carcass protein efficiency, while there was a linear ($P<0.07$) response in feed intake. Poults fed 5.86 g (1.70% total lysine) per Mcal ME had the highest ($P < 0.001$) final BW, BW gain, feed efficiency ratio (FER), carcass weight, and P. minor weight.

From 4 to 8 wk, there was a cubic response in final BW ($P<0.01$), BW gain ($P<0.04$) and feed intake ($P<0.01$). The diets containing 4.99 g (1.54% total lysine) resulted in the highest final BW ($P<0.01$), and BW gain ($P<0.01$). There were no differences in the feed efficiency ratio. There were no dietary lysine effects from 8 to 12 wk (Table 9) and the only response from 12 to 16 wk (Table 10) was a cubic response in carcass protein efficiency in that the birds fed 3.62 g (1.15% total lysine) had the highest values.

For the 16- to 20-wk poults (Table 11), there was a linear ($P<0.001$) increase in final BW, BW gain, carcass weight, P. major and P. minor with increasing dietary lysine concentration. Response to feed efficiency ratio was cubic ($P<0.04$). Carcass protein and carcass protein efficiency responded in a quadratic ($P<0.01$) fashion.

Discussion

The maximal lysine response from 2 to 4 wk was in poults fed 5.86 g (1.70% total lysine) per Mcal ME. The lysine requirement for the age period (0 to 4 wk) was reported by numerous authors (Tuttle and Balloun, 1974; NRC, 1994; Waldroup et al., 1997; and Veldkamp et al., 2003) to range from 5.17 g (1.50% total lysine) to 6.13 g (1.86% total lysine) per Mcal ME.
Our maximal BW gain response was lower than that reported by Veldkamp et al. (2003). However, our study used 17- to 31-d poults while Veldkamp et al. (2003) used 0- to 28-d poults. Therefore, our BW gain was lower because our experimental period was shorter and the poults that we used were older. The feed efficiency ratio reported by Veldkamp et al. (2003) was 0.77, which was higher than the 0.63 that was observed in the current study. This could have been due to the slightly older age of the poults that we used in the current study.

Orthogonal contrasts showed linear and cubic responses in final BW, BW gain, feed efficiency and carcass wt to increasing lysine concentrations, which could imply an increasing response beyond the maximum lysine level used in this study. Therefore, we could suggest that the lysine requirement for this age group may be higher than 5.86 g per Mcal ME of lysine.

From 4 to 8 wk, poults fed diets containing 4.99 g (1.54% total lysine) per Mcal ME had the best BW gain. Reports in the literature (Tuttle and Balloun, 1974); NRC, 1994; Waldroup et al., 1997; and Veldkamp et al., 2003) reported a lysine requirement range of 4.57g (1.40% total lysine) to 5.45g (1.58% total lysine). Although the lysine level used in our diet was 1.54% when compared to the NRC (1994) level of 1.50%, the g per Mcal ME was 4.99 vs. 5.17. Feed intake (5.23kg vs. 5.08kg) and feed efficiency ratio (0.58 vs. 0.59) were similar and this supports the observations of both D'Mello (1976) and Veldkamp et al. (2002) about the potential influence of metabolizable energy content of a diet on nutrient intake.

Orthogonal contrasts showed a linear and a cubic response in final BW and BW gain. The 5.35 g (1.65% total lysine) treatment decreased responses when compared with the 4.99 g (1.54% total lysine) treatment. The BW gains (3.12 kg and 3.33.kg) and feed efficiency ratios (0.63 and 0.65) reported by Waldroup et al. (1997) and Veldkamp et al. (2003) would suggest that the lysine requirement for optimal poult performance would lie between 4.99 g (1.54% total lysine) and 5.35 g (1.65% total lysine) per Mcal ME.

There was no lysine effect in the 8- to 12-wk turkey toms. Lysine requirements reported in the literature (Tuttle and Balloun, 1974; Potter et al., 1981; NRC, 1994; Waldroup et al., 1997; and Veldkamp et al., 2003) ranged from 3.66 g (1.12% total lysine) to 4.57 g (1.37% total lysine) per Mcal ME. These were for BW gains that ranged from 4.05 kg to 4.51 kg and feed intakes from 7.11 kg to 10 kg. Compared to the reported results in the literature, the turkey toms in our study consumed more feed and gained less weight, resulting in a lower feed efficiency. We cannot account for the lack of a growth response given the quantity of feed consumed.

With the exception of carcass protein efficiency, lysine also had no effect on the 12- to 16-wk toms. Reports in the literature (Potter et al., 1981; NRC, 1994; Waldroup et al., 1997; and Veldkamp et al., 2003) show the lysine requirement for this age of birds to be between 3.22 g (1.0% total lysine) and 3.40 g (1.08% total lysine) per Mcal ME. These were for BW gains of 3.8 kg to 4.5 kg at feed intakes of 12.49 kg to 14.37 kg. Compared to reports in the literature, our birds gained less weight and had a lower feed efficiency, but unlike in the 8- to 12-wk group, these birds consumed less feed. Therefore, the birds could have performed less because of the reduced feed intake, which could have been caused by environmental stress such as heat (the study was in August). Turkey toms fed the diet containing 3.29 g (1.05% total lysine) per Mcal ME performed the best from 16 to 20 wk. There were, however, no differences between the toms fed 2.82 g (0.90% total lysine) and 3.29 g (1.05% total lysine) per Mcal ME[l1]. Literature reports (Jensen et al., 1976; Potter et al., 1981; NRC, 1994; Waldroup et al., 1997; and Veldkamp et al., 2003) showed lysine requirements to range from 2.5 g (0.80% total lysine) to 3.0 g (0.90% total lysine). Our results showed a higher BW gain, lower feed intake and a superior feed efficiency ratio when compared to the cited reports in the literature. Orthogonal contrasts showed a mostly linear response and as such, we would conclude that the lysine requirement could be at or above the 3.29 g (1.05% total lysine) per Mcal ME.

Approximately 37% of the total feed intake for the experiment was consumed from 16 to 20 wk and the lysine response estimate was significantly greater than more recent reports in the literature. So, it would appear that the data generated for this age might be important with respect to commercial application.

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Table 1 Composition of experimental diets in study 1 for 2- to 4-wk male commercial turkeys[1].

	Basal Diets	
	1	2
Lysine level (%)	1.70	1.35
Ingredient (%)		
Corn	44.80	45.25
Soybean meal (48%)	33.40	33.40
Wheat midds	5.00	5.00
Corn gluten meal (60%)	7.80	7.80
Salt	0.40	0.40
L-Lysine	0.50	0.05
DL-Methionine	0.40	0.40
Limestone	1.50	1.50
Dicalcium phosphate	3.10	3.10
Chromic oxide	0.30	0.30
Blended fat	2.30	2.30
Premix[2]	0.50	0.50
Calculated composition		
ME (Kcal/kg)	2895	2911
CP (%)	25.7	25.3
Analyzed composition[3]		
Lysine	1.69	1.34
Methionine	0.82	0.83
TSAA	1.23	1.23

[1] Diet 3 is 65% diet 1 and 35% diet 2 (1.58% Lys); Diet 4 is 57.5% diet 1 and 42.5% diet 2 (1.55% Lys).

[2] The premix contains (in kg/100kg premix): ground corn, 54.0; amprolium (25%), 2.5; selenium premix (200 mg Se/kg), 5.0; BMD, 2.5; choline chloride (60%), 6.0; vitamin premix, 25.0; and trace mineral premix, 5.0. The vitamin premix contributes (per kg of diet): vitamin A, 8,745 IU; cholecalciferol, 3,745 ICU; vitamin E, 60 IU; vitamin K (menadione sodium bisulfite), 2.91mg; thiamin HCl, 2.2 mg; riboflavin, 6.6mg; niacin, 99 mg; pantothenic acid, 15.4 mg; folic acid, 1.2 mg; pyridoxine, 2.2 mg; biotin, 165 mg; vitamin B12, 15 mg; and ethoxyquin, 113.5 mg. The trace mineral premix contributes (per kg of diet); zinc oxide (72% Zn), 147 mg; manganous oxide (55% Mn), 152 mg; copper sulfate (25.2% cu), 35 mg; ferrous sulphate monohydrate (31% Fe), 72 mg; and potassium iodide, 1.5 mg

[3] The ingredients used were analyzed prior to formulation and these values were subsequently used for dietary formulation

Table 2 Composition of experimental diets in study 2 for 4- to 8-wk male commercial turkeys[1].

	Basal Diets	
	1	2
Lysine level (%)	1.65	1.30
Ingredient (%)		
Corn	41.80	47.30
Soybean meal (48%)	40.10	35.30
Corn gluten meal (60%)	5.00	4.80
Salt	0.38	0.40
L-Lysine	0.27	--
DL-Methionine	0.35	0.35
Choline chloride (60%)	0.10	0.10
Limestone	2.00	1.80
Dicalcium phosphate	3.10	3.55
Chromic oxide	0.30	0.30
Blended fat	6.10	5.60
Premix[2]	0.50	0.50
Calculated composition		
ME (Kcal/kg)	3080	3091
CP (%)	26.0	24.0
Analyzed composition[3]		
Lysine	1.66	1.31
Methionine	0.77	0.74
TSAA	1.17	1.11

[1] Diet 3 is 68% diet 1 and 32% diet 2 (1.54% Lys); Diet 4 is 32% diet 1 and 68% diet 2 (1.41% Lys).

[2] The premix contains (in kg/100kg premix): ground corn, 54.0; amprolium (25%), 2.5; selenium premix (200 mg Se/kg), 5.0; BMD, 2.5; choline chloride (60%), 6.0; vitamin premix, 25.0; and trace mineral premix, 5.0. The vitamin premix contributes (per kg of diet): vitamin A, 8,745 IU; cholecalciferol, 3,745 ICU; vitamin E, 60 IU; vitamin K (menadione sodium bisulfite), 2.91mg; thiamin HCl, 2.2 mg; riboflavin, 6.6mg; niacin, 99 mg; pantothenic acid, 15.4 mg; folic acid, 1.2 mg; pyridoxine, 2.2 mg; biotin, 165 mg; vitamin B12, 15 mg; and ethoxyquin, 113.5 mg. The trace mineral premix contributes (per kg of diet); zinc oxide (72% Zn), 147 mg; manganous oxide (55% Mn), 152 mg; copper sulfate (25.2% cu), 35 mg; ferrous sulphate monohydrate (31% Fe), 72 mg; and potassium iodide, 1.5 mg.

[3] The ingredients used were analyzed prior to formulation and these values were subsequently used for dietary formulation

Table 3 Composition of experimental diets in study 3 for 8- to 12-wk male commercial turkeys[1].

	Basal Diets	
	1	2
Lysine level (%)	1.20	1.50
Ingredient (%)		
Corn	54.20	55.00
Soybean meal (48%)	33.50	32.70
Salt	0.50	0.48
L-Lysine	--	0.40
DL-Methionine	0.20	0.22
Choline chloride (60%)	0.10	0.10
Limestone	1.40	1.60
Dicalcium phosphate	2.90	2.30
Chromic oxide	0.30	0.30
Blended fat	6.40	6.40
Premix[2]	0.50	0.50
Calculated composition		
ME (Kcal/kg)	3168	3168
CP (%)	20.4	20.4
Analyzed composition[3]		
Lysine	1.22	1.51
Methionine	0.52	0.53
TSAA	0.84	0.85

[1] Diet 3 is 70% diet 1 and 30% diet 2 (1.29% Lys); Diet 4 is 30% diet 1 and 70% diet 2 (1.41% Lys).

[2] The premix contains (in kg/100kg premix): ground corn, 54.0; amprolium (25%), 2.5; selenium premix (200 mg Se/kg), 5.0; BMD, 2.5; choline chloride (60%), 6.0; vitamin premix, 25.0; and trace mineral premix, 5.0. The vitamin premix contributes (per kg of diet): vitamin A, 8,745 IU; cholecalciferol, 3,745 ICU; vitamin E, 60 IU; vitamin K (menadione sodium bisulfite), 2.91mg; thiamin HCl, 2.2 mg; riboflavin, 6.6mg; niacin, 99 mg; pantothenic acid, 15.4 mg; folic acid, 1.2 mg; pyridoxine, 2.2 mg; biotin, 165 mg; vitamin B12, 15 mg; and ethoxyquin, 113.5 mg. The trace mineral premix contributes (per kg of diet); zinc oxide (72% Zn), 147 mg; manganous oxide (55% Mn), 152 mg; copper sulfate (25.2% cu), 35 mg; ferrous sulphate monohydrate (31% Fe), 72 mg; and potassium iodide, 1.5 mg.

[3] The ingredients used were analyzed prior to formulation and these values were subsequently used for dietary formulation.

Table 4 Composition of experimental diets in study 4 for 12- to 16-wk male commercial turkeys[1].

	Basal Diets	
	1	2
Lysine level (%)	1.30	0.85
Ingredient (%)		
Corn	54.30	64.80
Soybean meal (48)	32.70	19.30
Corn Gluten meal (60)	--	5.80
Salt	0.50	0.50
L-Lysine	0.15	--
DL-Methionine	0.20	0.20
L-Threonine	--	0.10
Limestone	1.40	1.40
Dicalcium Phosphate	3.25	3.30
Chromic oxide	0.30	0.30
Blended Fat	6.70	3.80
Premix[2]	0.50	0.50
Calculated composition		
ME (Kcal/kg)	3172	3181
CP (%)	20.2	18.0
Analyzed composition[3]		
Lysine	1.31	0.85
Methionine	0.51	0.52
TSAA	0.83	0.82

[1] Diet 3 is 70% diet 1 and 30% diet 2 (1.16% Lys); Diet 4 is 50% diet 1 and 50% diet 2 (1.07% Lys).

[2] The premix contains (in kg/100kg premix): ground corn, 54.0; amprolium (25%), 2.5; selenium premix (200 mg Se/kg), 5.0; BMD, 2.5; choline chloride (60%), 6.0; vitamin premix, 25.0; and trace mineral premix, 5.0. The vitamin premix contributes (per kg of diet): vitamin A, 8,745 IU; cholecalciferol, 3,745 ICU; vitamin E, 60 IU; vitamin K (menadione sodium bisulfite), 2.91mg; thiamin HCl, 2.2 mg; riboflavin, 6.6mg; niacin, 99 mg; pantothenic acid, 15.4 mg; folic acid, 1.2 mg; pyridoxine, 2.2 mg; biotin, 165 mg; vitamin B12, 15 mg; and ethoxyquin, 113.5 mg. The trace mineral premix contributes (per kg of diet); zinc oxide (72% Zn), 147 mg; manganous oxide (55% Mn), 152 mg; copper sulfate (25.2% cu), 35 mg; ferrous sulphate monohydrate (31% Fe), 72 mg; and potassium iodide, 1.5 mg

[3] The ingredients used were analyzed prior to formulation and these values were subsequently used for dietary formulation.

Table 5 Composition of experimental diets in study 5 for 16- to 20-wk male commercial turkeys[1].

	Basal Diets	
	1	2
Lysine level (%)	0.60	1.05
Ingredient (%)		
Corn	73.80	70.20
Soybean meal (48%)	10.20	20.20
Corn gluten meal (60%)	7.00	--
Salt	0.50	0.50
L-Lysine	--	0.30
DL-Methionine	--	0.05
Limestone	1.50	1.50
L-Threonine	0.10	0.05
Dicalcium phosphate	3.60	2.40
Chromic oxide	0.30	0.30
Blended fat	2.50	4.00
Premix[2]	0.50	0.50
Calculated composition		
ME (Kcal/kg)	3201	3179
CP (%)	15.0	15.5
Analyzed composition[3]		
Lysine	0.60	1.06
Methionine	0.29	0.30
TSAA	0.55	0.56

[1] Diet 3 is 62.5% diet 1 and 37.5% diet 2 (0.77% Lys); Diet 4 is 50% diet 2 and 50% diet 3 (0.90% Lys).

[2] The premix contains (in kg/100kg premix): ground corn, 54.0; amprolium (25%), 2.5; selenium premix (200 mg Se/kg), 5.0; BMD, 2.5; choline chloride (60%), 6.0; vitamin premix, 25.0; and trace mineral premix, 5.0. The vitamin premix contributes (per kg of diet): vitamin A, 8,745 IU; cholecalciferol, 3,745 ICU; vitamin E, 60 IU; vitamin K (menadione sodium bisulfite), 2.91mg; thiamin HCl, 2.2 mg; riboflavin, 6.6mg; niacin, 99 mg; pantothenic acid, 15.4 mg; folic acid, 1.2 mg; pyridoxine, 2.2 mg; biotin, 165 mg; vitamin B12, 15 mg; and ethoxyquin, 113.5 mg. The trace mineral premix contributes (per kg of diet); zinc oxide (72% Zn), 147 mg; manganous oxide (55% Mn), 152 mg; copper sulfate (25.2% cu), 35 mg; ferrous sulphate monohydrate (31% Fe), 72 mg; and potassium iodide, 1.5 mg.

[3] The ingredients used were analyzed prior to formulation and these values were subsequently used for dietary formulation.

Table 6 Apparent lysine and dry matter digestibility for the diets used in studies 1 to 5 of male commercial turkeys fed four concentrations of lysine from 2 to 20 wk post-hatch[1].

	Period of study (wk)					SEM	P-value (Digestibility)
	2 to 4	4 to 8	8 to 12	12 to 16	16 to 20		
Apparent lysine digestibility	95.6	93.1	90.5	85.4	87.6	1.24	0.01
Dry matter digestibility	72.0	68.5	75.1	70.2	69.6	1.19	0.01

[1] Means represent 48 pens of one bird per pen.

Table 7 Main effect means and contrasts for growth performance and carcass weights of male commercial poults fed four concentrations of lysine from 2 to 4 wk post-hatch[1].

Lysine level, %	1.35	1.50	1.60	1.70			P-value[2]		
Lysine, g / Mcal ME	4.65	5.17	5.51	5.86	SEM	P-Value	Linear	Quadratic	Cubic
Final BW, kg	1.05	1.13	1.13	1.20	0.014	0.01	0.01	NS[3]	0.02
BW gain, Kg	0.58	0.66	0.66	0.71	0.009	0.01	0.01	0.07	0.01
Feed intake, kg	1.09	1.11	1.11	1.12	0.013	NS	0.07	NS	NS
Feed efficiency ratio	0.54	0.60	0.60	0.63	0.008	0.01	0.01	0.08	0.02
Carcass weight, Kg	0.61	0.68	0.69	0.71	0.007	0.01	0.01	0.01	0.04
P. major, g	76.3	84.9	88.5	88.3	1.59	0.01	0.01	0.01	NS
P. minor, g	18.5	21.5	22.2	22.4	0.59	0.01	0.01	0.01	NS
Carcass nitrogen, % DM	11.5	11.6	11.7	11.6	0.12	NS	NS	NS	NS
Carcass protein, g DM	112	135	140	132	1.84	0.01	0.01	0.01	NS
Carcass protein efficiency	0.25	0.33	0.34	0.31	0.006	0.01	0.01	0.01	NS

[1] Means represent 12 pens of one poult per pen
[2] Contrasts of lysine main effects only when lysine (P<0.01)
[3] NS = not significant (P>0.10)

Table 8 Main effect means and contrasts for growth performance and carcass weights of male commercial poults fed four concentrations of lysine from 4 to 8 wk post-hatch[1].

Lysine level, %	1.30	1.42	1.54	1.65			P-value[2]		
Lysine, g / Mcal ME	4.21	4.60	4.99	5.35	SEM	P-Value	Linear	Quadratic	Cubic
Final BW, kg	3.87	3.82	4.20	3.99	0.084	0.01	0.02	NS[3]	0.01
BW gain, kg	2.69	2.70	3.02	2.82	0.086	0.01	0.02	NS	0.01
Feed intake, kg	4.80	4.58	5.23	4.78	0.15	0.01	NS	NS	0.01
Feed efficiency ratio	0.57	0.59	0.58	0.59	0.011	NS	--	--	--
Carcass weight, kg	2.39	2.45	2.53	2.46	0.075	NS	--	--	--
P. major, kg	0.28	0.29	0.29	0.29	0.007	NS	--	--	--
P. minor, g	75.3	78.9	80.5	77.5	2.85	NS	--	--	--
Nitrogen, %	11.3	11.2	11.2	11.3	0.07	NS	--	--	--
Carcass protein, g DM	407	496	500	481	32.5	NS	--	--	--
Carcass protein efficiency	0.25	0.27	0.26	0.27	0.006	NS	--	--	--

[1]Means represent 12 pens of one poult per pen
[2] Contrasts of lysine main effects only when lysine ($P<0.01$)
[3] NS = not significant ($P>0.10$)
[4]ADL: Apparent digestible lysine (93% digestibility)

Table 9 Main effect means and contrasts for growth performance and carcass weights of male commercial turkeys fed four concentrations of lysine from 8 to 12 wk post-hatch[1].

Lysine level, %	1.20	1.30	1.40	1.50		
Lysine, g / Mcal ME	3.79	4.10	4.42	4.73	SEM	P-Value
Final BW, kg	8.47	8.64	8.37	8.69	0.63	NS[2]
BW gain, kg	3.89	4.12	3.83	4.13	0.39	NS
Feed intake, kg	10.3	10.3	10.4	10.8	0.76	NS
Feed efficiency ratio	0.38	0.41	0.37	0.39	0.015	NS
Carcass weight, kg	5.51	5.56	5.42	5.56	0.32	NS
P. major, kg	0.61	0.62	0.62	0.64	0.036	NS
P. minor, kg	0.17	0.18	0.17	0.17	0.007	NS
Nitrogen, %	10.6	10.5	10.5	10.7	0.095	NS
Carcass protein, kg DM	1.11	1.17	0.97	1.16	0.092	NS
Carcass protein efficiency	0.26	0.28	0.27	0.28	0.006	NS

[1]Means represent 12 pens of one poult per pen
[2] NS = not significant ($P>0.10$) for any contrast
[3]ADL: Apparent digestible lysine (90% digestibility)

Table 10 Main effect means and contrasts for growth performance and carcass weights of male commercial turkeys fed four concentrations of lysine from 12 to 16 wk post-hatch[1].

Lysine level, %	0.85	1.00	1.15	1.30				P-value[2]	
Lysine, g / Mcal ME	2.68	3.15	3.62	4.09	SEM	P-Value	Linear	Quadratic	Cubic
Final BW, kg	13.5	13.2	13.6	13.4	0.45	NS[3]	--	--	--
BW gain, kg	3.31	3.30	3.65	3.27	0.22	NS	--	--	--
Feed intake, kg	10.6	11.1	10.9	11.6	0.39	NS	--	--	--
Feed efficiency ratio	0.31	0.30	0.34	0.29	0.019	NS	--	--	--
Carcass weight, kg	9.02	9.24	9.35	9.30	0.30	NS	--	--	--
P. major, kg	1.19	1.17	1.24	1.21	0.059	NS	--	--	--
P. minor, kg	0.30	0.28	0.31	0.30	0.012	NS	--	--	--
Nitrogen, %	10.7	10.7	10.9	10.4	0.21	NS	--	--	--
Carcass protein, kg DM	1.90	1.87	1.97	1.94	0.043	NS	--	--	--
Carcass protein efficiency	0.34	0.30	0.36	0.34	0.011	0.01	NS	NS	0.01

[1]Means represent 12 pens of one poult per pen
[2] Contrasts of lysine main effects only when lysine ($P<0.01$)
[3] NS = not significant ($P>0.10$)
[4]ADL: Apparent digestible lysine (85% digestibility)

Table 11 Main effect means and contrasts for growth performance and carcass weights of male commercial turkeys fed four concentrations of lysine from 16 to 20 wk post-hatch[1].

Lysine level, %	0.60	0.75	0.90	1.05				P-Value[2]	
Lysine, g / Mcal ME	1.88	2.35	2.82	3.29	SEM	P-Value	Linear	Quadratic	Cubic
Final BW, kg	17.3	17.9	18.4	18.9	0.44	0.01	0.01	NS[3]	NS
BW gain, kg	3.12	3.33	4.20	4.20	0.24	0.01	0.01	NS	NS
Feed intake, kg	15.1	16.4	16.3	16.1	0.50	NS	NS	NS	NS
Feed efficiency ratio	0.21	0.20	0.26	0.26	0.013	0.01	0.01	NS	0.04
Carcass weight, kg	12.0	12.4	13.2	13.3	0.38	0.01	0.01	NS	NS
P. major, kg	1.82	1.77	1.94	2.07	0.079	0.01	0.01	NS	NS
P. minor, kg	0.39	0.42	0.42	0.45	0.013	0.01	0.01	NS	NS
Nitrogen, %	10.1	10.3	10.3	10.5	0.21	NS	NS	NS	NS
Carcass protein, kg DM	2.86	2.69	2.78	2.97	0.064	0.02	NS	0.01	NS
Carcass protein efficiency	0.39	0.30	0.34	0.42	0.023	0.01	NS	0.01	NS

[1]Means represent 12 pens of one poult per pen
[2] Contrasts of lysine main effects only when lysine ($P<0.02$)
[3] NS = not significant ($P>0.10$)
[4]ADL: Apparent digestible lysine (82% of Total lysine)

Part 2: Determination Of The Optimal Threonine Concentrations For The Maximal Performance Of 2- To 20-Wk-Old Turkeys

Threonine is the third limiting amino acid after methionine and lysine in a typical corn-soybean meal poultry diet. A review of the literature shows that only two studies have recommended threonine requirements that covered the full growth cycle for commercial turkeys (0 to 20 wk). The Ideal Protein concept expresses each essential amino acid as a percentage of lysine. It was our hypothesis that threonine concentrations that supports maximal responses in commercial turkeys may change if there are changes in lysine concentrations. Therefore, using the NRC (1994) requirements as a guide, a series of growth and ileal digestibility assays were conducted with a pool of 500 male turkeys over a period of 2 to 20 wk in order to determine the threonine concentrations at two lysine concentrations that would support maximal performance in turkeys. Results showed that there were increases in recommended lysine and threonine requirements when compared with published NRC (1994) values for both nutrients in 4- to 20-wk male turkeys. The average digestible lysine and threonine values for each study were 88% and 81% (4 wk), 91% and 83% (8 wk), 84% and 79% (12 wk), 85% and 79% (16 wk) and, 87% and 80% (20 wk), respectively.

Introduction

In poultry, there has been considerable research devoted to determining the dietary requirement needs for lysine and methionine while research on the other essential amino acids has been somewhat limited and often confined to younger birds (Kidd and Kerr, 1997; Lehmann et al., 1997; Waldroup et al., 1997; Waldroup et al., 1998a). The NRC (1994) amino acid recommendations for turkeys after 4 wk of age for ten of the thirteen essential amino acids have been based on values obtained from other species or from estimates derived from modeling experiments rather than from data generated from actual feeding trials.

Threonine has been reported to be the third limiting amino acid after methionine and lysine in a typical corn-soybean meal poultry diet (Lehmann et al., 1997). A review of the literature (Table 1) shows that the only threonine requirement estimates that have covered the full growth cycle for commercial turkeys (0 to 20 wk) are those of NRC (1994) and those of Waldroup et al. (1997). Of the two sources, the NRC recommendations after 0- to 4-wk period are estimates from data generated by models or extrapolated from other ages or species.

As is characteristic of most studies conducted through the 1990's, the requirement estimates reported by Waldroup et al. (1997) are based on the total amino acid content of the diet, not the digestible values. Waldroup et al. (2002) have cautioned about the use of total values in the formulation of feeds due to the variability in nutrient digestibility among different feed ingredients. Kamyab and Firman (2000) and Baker et al. (2003) are the only reports to date that have generated requirement estimates based on digestible threonine concentrations in the diet.

The Ideal Protein concept expresses each essential amino acid as a percentage of lysine such that, once the lysine requirement is determined, the requirements for the other indispensable amino acids can be calculated as a ratio of lysine in response to varying genetic and/or production environments (Baker et al., 2003; Wijtten et al., 2004). In Chapter 6, our data suggested that the maximal response of turkeys to lysine were at lysine concentrations that were higher than the NRC (1994) lysine requirements for 4- to 8-wk and 16- to 20-wk male poults. As lysine is a reference amino acid in the Ideal Protein concept, it is our hypothesis that threonine concentrations for maximal responses in commercial turkeys may change along with changes in lysine concentrations.

Our objective was to conduct a series of growth and ileal digestibility assays to determine the digestible threonine concentrations at two lysine concentrations that would support maximal performance of turkeys during the five age periods covering the full production cycle of commercial toms. As explained in Chapter 6, the nutrient concentrations will be reported as g threonine and lysine per megacalorie (Mcal) of ME.

Material and Methods

Five studies of similar experimental design were conducted to cover the five phases of commercial turkey production: 2- to 4-wk, 4- to 8-wk, 8- to 12-wk, 12- to 16-wk and 16- to 20-wk. A pool of 500 day-old male Hybrid Converter turkeys were obtained from a local hatchery (AgForte Inc., Danville, OH) and brooded in a thermostatically controlled building. Poults were wing-banded at day-old. All the birds in the pool were weighed and sorted in ascending order of weight at the start of each study (2, 4, 8, 12 and 16 wk).

Birds of similar BW were selected and randomly assigned to experimental pens such that there was one turkey tom per experimental unit. This gave a total of 240 turkey toms of 48 birds per study. As explained in Chapter 3, using one bird per experimental unit prevented interactions between birds within a pen that could affect their response to the treatment. It also enabled us to have a better idea of the range of response of the birds to the different lysine and threonine concentrations. Using birds of similar weights removed the possible effects of differences in initial BW on the determined response to the experimental diets.

The materials and methods used were similar to those of Chapter 6. We used a randomized incomplete block design in 2- to 4-wk and 4- to 8-wk studies, and randomized complete block design in the other studies. Four Petersime grower batteries were used for the 2- to 4-wk study and each battery consisted of twelve cages. Two rooms containing 24 floor pens each were used for the other studies. The 24 pens were divided into two opposite rows of 12 pens each. Each battery and each row of pens served as the blocks while each cage or floor pen was the experimental unit. Each experimental unit within a block was randomly assigned to each of the dietary treatments.

For each study, dietary treatments (Tables 2-6) contained two levels of lysine and four levels of threonine in a 2 x 4 factorial arrangement of eight treatments. Diets were isonitrogenous and isocaloric. The four levels of threonine consisted of the NRC (1994) recommended threonine level for that phase of production together with one or two levels above the NRC (1994) recommendation. The two levels of lysine were the NRC (1994) requirement for that phase of production and a level above that, similar to what is used by commercial turkey nutritionists (W. Williams, Akey Inc, personal communication).

A summit and a basal diet were formulated for the studies with the intermediate diets being proportional blends of these two diets. The dietary formulation was such that all essential amino acids except for lysine and threonine met or exceeded the NRC (1994) recommendations. The diet formulation was based on actual analyses of the feed ingredients that were used in each diet. Each diet contained 0.3 % chromic oxide, which was used as an indigestible marker for the computation of amino acid digestibility. During each study, turkey toms had ad libitum access to feed and water. Constant lighting was used for the 2- to 8-wk poults and a photoperiod of 16 h light and 8 h dark for used for the older birds.

At the end of each study, total feed intake and final body weight were measured. All poults were killed by cervical dislocation between the hours of 09:00 and 11:00. Ileal digesta and carcass samples were collected, freeze-dried and analyzed as already described in Chapter 3. Ileal digesta samples were pooled per block per treatment such that we had four ileal digesta samples per treatment. A sample of the ground carcass from each poult was analyzed for carcass nitrogen. Procedures used for the amino acid and carcass nitrogen analyses are as described in Chapter 3. The data obtained from the amino acid analyses were used to calculate digestibility coefficients as shown in the formula below:

$$\text{CIAD} = \frac{(\text{AA/Cr})_{d} - (\text{AA/Cr})_{id}}{(\text{AA/Cr})_{d}} \text{ X } 100$$

Where:
CIAD = calculated ileal apparent digestibility
$(\text{AA/Cr})_{d}$ is the dietary ratio of amino acid to Cr
$(\text{AA/Cr})_{id}$ is the ratio of amino acid to Cr in ileal digesta.

Studies were conducted in accordance with the principles and specific guidelines that are presented in Guidelines for the Care and Use of Agricultural Animals in Agricultural Research and Teaching, 1st revised edition, 1999.

Statistical Analyses

The experimental design for the five studies was a randomized incomplete block design with a 2 X 4 factorial arrangement of two levels of lysine and four levels of threonine. Each row of floor pens and each battery were the blocks. The Mixed procedure of SAS (SAS V9.x.) was used for the statistical analyses. The blocks and the residual error were random factors in the model, while lysine, threonine and their interaction were the fixed effect factors. When effects of a factor were significant at $P < 0.10$, means were separated using Fisher's protected least-significant difference (i.e., the PDIFF option of MIXED). Thereafter, orthogonal polynomial tests were done to determine if differences were linear, quadratic or cubic.

The performance variables that were analyzed were final BW, BW gain, feed intake, feed efficiency ratio, carcass weight, P. major weight, P. minor weight, carcass nitrogen (% DM), carcass protein and carcass protein efficiency. The statistical model used for all studies was:

$$Y_{ijk} = \mu + b_i + L_j + T_k + LTj_k + e_{ijk}$$

Where:
Y_{ijk} is the dependent variable; μ is the population mean; b_i is the random block effect (i=1 – 4); L_j is the lysine effect (j=1 and 2); T_k is the threonine effect (k=1 – 4); LT_{kl} is lysine by Threonine interaction; e_{ijk} is the residual error associated with the experiment.

Results

The average apparent digestible lysine (ADL) and threonine (AD-Thr) values for each study were 88% and 81% (2 to 4 wk), 91% and 83% (4 to 8 wk), 84% and 79% (8 to 12 wk), 85% and 79% (12 to 16 wk) and, 87% and 80% (16 to 20 wk), respectively. These values are more realistic when compared with the values that we obtained in the Lysine study of Chapter 6. When endogenous amino acids secretions are considered by standardizing the dietary treatments with endogenous values reported by (Adedokun et al., 2008), the apparent digestibility values reported herein would be close to the true digestibility values that are calculated from the True digestibility coefficients table in NRC (1994). In all the age groups, lysine had a higher digestible value. This is because threonine is a major amino acid constituent of endogenous secretions. Consequently, apparent digestible threonine values are lower because the threonine in the ileal digesta is the sum of the undigested dietary threonine and the threonine that is a constituent of endogenous secretions.

Study 1 (2 to 4 wk)

There was no lysine by threonine interaction for these poults. Increasing lysine concentration from 5.54 g (1.60% total lysine) to 6.06 g (1.75% total lysine) per Mcal ME increased ($P<0.01$) the feed efficiency ratio (Table 7). As shown in Table 8, increasing threonine concentration from 2.77 g (0.75% total threonine) to 3.81 g (1.10% total threonine) per Mcal ME resulted in a linear ($P<0.01$) response for BW gain ($P<0.04$). The response was both linear ($P<0.01$) and quadratic ($P<0.02$) for carcass nitrogen ($P<0.01$).

Study 2 (4 to 8 wk)

There was a lysine by threonine interaction effect on final BW ($P<0.06$), BW gain ($P<0.06$), feed efficiency ratio ($P<0.03$) and P. major ($P<0.05$). As shown in Table 9, orthogonal analyses showed that within the 5.18 g (1.50%) lysine per Mcal ME treatment, there was a quadratic response by the poults whereas within the 5.70 g per Mcal ME, there was no effect except for feed efficiency ratio where there was a quadratic response.

Study 3 (8 to 12 wk)

There was a lysine by threonine interaction effect on carcass nitrogen ($P<0.07$). As shown in Table 10, orthogonal analyses showed that the birds that were fed the 4.82 g per Mcal ME diet had a linear ($P<0.03$) and a cubic ($P<0.01$) response to increasing threonine level while there was no response from those that were on the 4.33 g lysine. Carcass wt increased ($P<0.06$) when lysine was increased from 4.33 g to 4.82 g. When the threonine concentration was increased from 2.33 g (0.70% total threonine) to 2.99 g (0.90% total threonine), there was an increase in final BW ($P<0.04$), BW gain ($P<0.03$), carcass wt ($P<0.03$), P. major ($P<0.06$) and carcass protein ($P<0.08$; Table 11). The responses of the turkeys were both linear and cubic, except for P. major and carcass protein, where the responses were linear.

Study 4 (12 to 16 wk)

There was a lysine by threonine interaction on BW gain ($P<0.01$), feed efficiency ratio ($P<0.07$), carcass nitrogen ($P<0.01$), carcass protein ($P<0.05$) and carcass protein efficiency ($P<0.03$) as shown in Table 12. The turkeys fed 3.44 g (1.10% total lysine) had overall better performance when compared to those that were fed the 2.81 g (0.90% total lysine) diet. The effect of threonine on feed intake is shown in Figure 7.1. There was a quadratic response ($P<0.01$) of the turkeys to increasing dietary threonine concentration from 1.72 g (0.55% total threonine) to 2.65 g (0.85% total threonine) per Mcal ME.

Study 5 (16 to 20 wk of age)

There was a lysine x threonine interaction effect ($P<0.03$) on carcass nitrogen. As shown in Figure 7.2, there was a linear ($P<0.03$) response by birds fed 2.26 g (0.72% total lysine) while there was a quadratic ($P<0.02$) response in those toms fed 2.76 g (0.88% total lysine). Increasing dietary lysine from 2.26 g (0.72% total lysine) to 2.76 g

(0.88% total lysine) increased the P. major of the turkeys ($P<0.03$; Table 13). Carcass protein and carcass protein efficiency increased ($P<0.01$) when threonine was increased from 1.57 g (0.50% total threonine) to 1.88 g (0.60%). The responses were both linear ($P<0.01$) and quadratic ($P<0.01$).

Discussion

Within the literature there are numerous papers that have considered the lysine and threonine requirements for growing turkeys but with the exception of NRC (1994) and Waldroup et al. (1997), they have only considered a portion of the growing cycle and most published data have used diets with varying levels of ME. Likewise, the concept of digestible amino acids is well accepted by poultry nutritionists but there is a paucity of published data in turkeys to support the digestibility requirement values used by industry nutritionists.

Study 1 (2 to 4 wk)

There was no interaction between lysine and threonine for this age of poults. Increasing lysine concentration from 5.54 g (1.60% total lysine) to 6.06 g (1.75% total lysine) per Mcal ME increased the feed efficiency ratio but had no effect on BW gain. This is in agreement with previous authors (Kidd et al., 1997a; Kerr et al., 1999b; Boling and Firman, 1998; and Baker et al., 2003) who have reported that feed efficiency ratio is often observed in response to increased lysine concentrations.

In Chapter 6, we reported the optimal lysine requirement to be above 5.86g (1.70% total lysine) per Mcal ME whereas in the present study, BW gain was maximized at a lysine concentration of 5.54g (1.60% total lysine) per Mcal ME. This would suggest that the lysine requirement for 2- to 4-wk poults is between 5.54 g and 5.86 g lysine per Mcal ME, depending upon the level of feed intake during this early stage of growth.

The optimal response of poults was at the threonine concentration of 3.81 g (1.10% total threonine) per Mcal ME and orthogonal analyses showed a linear response to BW gain. This suggests that the threonine requirement is above 3.81 g per Mcal ME. We are not able to directly compare these results with reports in the literature (NRC, 1994; Lehmann et al., 1997; and Waldroup et al., 1997) because the period of study was for 2- to 4-wk as compared to 0- to 4-wk by those authors.

It was observed that 1.00% threonine in our study amounted to 3.46 g per Mcal ME whereas 1.00% threonine in the NRC (1994) published report was 3.57 g per Mcal ME. The different g per Mcal ME for the same percentage threonine level emphasizes the importance of compare nutrients on g per Mcal ME in order to have more consistent values for easy comparisons between studies.

Study 2 (4 to 8 wk)

There was a lysine by threonine effect on final BW, BW gain, feed efficiency ratio and P. major. Orthogonal analyses showed that within the 5.18 g (1.50%) lysine per Mcal ME treatment, there was a quadratic response by the poults whereas within the 5.70 g per Mcal ME, there was no effect except for the feed efficiency ratio where there was a quadratic response. However, there were no main effects due to lysine or threonine with the exception for P. minor. The maximal BW gain in Chapter 6 was at 4.99g (1.54% total lysine) per Mcal ME. Waldroup et al. (1997) and Veldkamp et al. (2003) have reported their best responses at lysine concentrations of 5.45 g (1.58% total lysine) and 5.40 g (1.67% total lysine) per Mcal ME, respectively.

At the 5.18 g (1.50% total lysine) concentration, optimal poults' performance was at 3.28g (0.95% total threonine). These are the NRC (1994) requirements for lysine and threonine, respectively. However, it is possible that a higher poult performance can be attained at the higher lysine concentration of 5.70 g (1.65% total lysine) if threonine concentration is also increased to 3.62 g (1.05%). With Waldroup et al. (1997) reporting a threonine requirement of 3.45g (1.00% total threonine), it is probable that the maximal performance of poults could be between 5.40 g to 5.70 g lysine and between 3.28 g to 3.62 g threonine per Mcal ME.

Study 3 (8 to 12 wk)

The only lysine by threonine interaction effect was on carcass nitrogen. The performance of turkeys on 4.33 g (1.30% total lysine) confirmed the report of NRC (1994). At this similar lysine concentration, the BW gain of 4.21 kg was similar to 4.20 kg as published by NRC (1994). However, the turkeys that were on the 4.82 g (1.45% total lysine) performed better than those on 4.33 g (1.30% total lysine) per Mcal ME.

The performance of the turkey toms that were fed threonine diets containing 2.66g (0.80%) per Mcal ME was unusually low. Maximal performance was observed in turkeys on the 2.99 g (0.90% total threonine) per Mcal ME. A further increase in the threonine concentration from 2.99 g to 3.33 g (1.00% total threonine) resulted in a cubic response by the birds. The 2.99 g threonine concentration is considerably higher than the estimates by Lehmann et al. (1997) who reported an optimal threonine requirement of 2.20 g per Mcal ME. However, the value is only slightly higher than the 2.82 g (0.85% total threonine) that was reported by Barbour et al. (2008) for 8- to 13-wk poults.

Therefore, we would conclude that optimal performance of turkeys would be at a lysine level between 4.33 g to 4.82 g per Mcal ME with a threonine level between 2.99 g to 3.33 g per Mcal ME.

Study 4 (12 to 16 wk)

Optimal performance was by turkeys that were fed 2.34 g (0.75% total threonine) at a lysine concentration of 3.44 g (1.10% total lysine) per Mcal ME. Maximal BW gain that has been reported in the literature (NRC, 1994; Waldroup et al., 1997; and Veldkamp et al., 2003) is at a lysine concentration of 3.40 g per Mcal ME, which is similar to our value of 3.44 g.

Of the two published reports on threonine requirement (NRC, 1994; and Waldroup et al., 1997), the maximal BW gain response was at a threonine concentration of 2.42 g per Mcal ME. This is slightly higher than our estimate of 2.34 g threonine in turkeys fed the higher level of lysine. Therefore, optimal performance should be at a lysine concentration of 3.40 g to 3.44 g and threonine concentration of 2.34 g to 2.65g per Mcal ME.

Study 5 (16 to 20 wk of age)

The only lysine by threonine effect was only on carcass nitrogen. There was a main effect of lysine on the P. major where the greatest response was in turkeys fed 2.76 g (0.88% total lysine) per Mcal ME. The influence of dietary lysine on the P. major is supported by the findings of Tesseraud et al. (1999; 2001). Literature reports (Jensen et al., 1976; Potter et al., 1981; NRC, 1994; Waldroup et al., 1997; and Veldkamp et al., 2003) have shown a lysine requirement that ranges from 2.5 g (0.80% total lysine) to 3.0 g (0.90% total lysine) per Mcal ME. Maximum BW gain has been reported to be at a lysine concentration of 2.90 g (0.94% total lysine) per Mcal ME, which is close to our estimates.

Increasing dietary threonine resulted in a linear and a quadratic response in carcass protein and carcass protein efficiency, respectively. Based on these two parameters, our data suggests that optimal performance is achieved at a threonine concentration of 1.88 g (0.60% total threonine) per Mcal ME. Literature reports (NRC, 1994; Lehmann et al., 1997; and Waldroup et al., 1997) indicate a threonine requirement range of 1.80 g to 1.97 g per Mcal ME that is similar to our estimate of 1.88 g. We could conclude that the optimal performance of birds could be at a lysine concentration between 2.26 g and 2.90 g, and a threonine concentration of between 1.80 g and 2.04 g per Mcal ME.

Our hypothesis was that threonine concentrations for maximal responses in commercial turkeys may change with changes in lysine concentrations and data from our studies validate this hypothesis. Our studies showed that there were increases in recommended lysine and threonine requirements when compared with published NRC (1994) values for both nutrients in 4- to 20-wk male turkeys.

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Table 1. Published threonine requirement for optimal BW gain in turkeys.

Age	Threonine level(%)	g threonine per Mcal ME	Authors
0 – 3	0.94	3.15	D'Mello (1976)
	0.93	3.21	Kidd et al. (1998)
1 - 3	0.67[1]	2.10[1]	Kamyab and Firman (2000)
0 – 4	0.95	3.30	Lehmann et al. (1997)
	1.0	3.57	NRC (1994)
	1.05	3.75	Waldroup et al. (1997)
3 – 6	0.88	2.81	Kidd et al. (1998)
	0.92	3.17	Waldroup et al. (1998a)
4 – 8	0.95	3.27	NRC (1994)
	1.00	3.45	Waldroup et al. (1997)
6 – 9	0.77	2.30	Kidd et al. (1998)
	0.86	2.86	Waldroup et al. (1998a)
8 – 12	0.69	2.20	Lehmann et al (1997)
	0.76	2.41	Waldroup et al. (2002)
	0.80	2.67	NRC (1994)
	0.83	2.77	Waldroup et al. (1997)
8 – 13	0.85	2.82	Barbour et al. (2008)
12 - 14	0.53[1]	1.47[1]	Baker et al. (2003)
12 – 16	0.75	2.42	NRC (1994)
	0.79	2.55	Waldroup et al. (1997)
16 – 20	0.58	1.80	Lehmann et al. (1997)
	0.60	1.87	NRC (1994)
	0.63	1.97	Waldroup et al. (1997)

[1] Digestible values were reported by the authors.

Table 2 Composition of experimental diets in study 1 for 2- to 4-wk male commercial turkey[1].

Ingredient (%)	Diets 1 1.60% Lys 0.80% Thr	2 1.60% Lys 1.10% Thr	3 1.75% Lys 0.80% Thr	4 1.75% Lys 1.10% Thr
Corn	58.40	57.70	58.00	57.35
Soybean meal (48%)	33.00	33.00	33.00	33.00
Salt	0.50	0.50	0.50	0.50
L-Lysine HCl	0.52	0.55	0.70	0.70
DL-Methionine	0.58	0.60	0.60	0.60
L-Threonine	--	0.35	--	0.35
Limestone	2.30	2.30	2.30	2.30
Dicalcium Phosphate	2.50	2.50	2.50	2.50
Chromic Oxide	0.30	0.30	0.30	0.30
Blended Fat	1.40	1.70	1.60	1.90
Premix[2]	0.50	0.50	0.50	0.50
Calculated composition				
ME (kcal/kg)	2882	2882	2897	2882
CP (%)	22.0	21.5	22.0	21.7
Analyzed composition[3]				
Lysine	1.62	1.64	1.75	1.76
Threonine	0.75	1.10	0.76	1.09
TSAA	1.23	1.24	1.25	1.24

[1] Diet 5 is 62% diet 1 and 38% diet 2 (1.60% Lys, 0.91% Thr); Diet 6 is 30% diet 1 and 70% diet 2 (1.60% Lys, 1.01% Thr); Diet 7 is 62% diet 3 and 38% diet 4 (1.75% Lys, 0.91% Thr) and; Diet 8 is 30% diet 3 and 70% diet 4 (1.75% Lys, 1.01% Thr).

[2] The premix contains (in kg/100kg premix): ground corn, 54.0; amprolium (25%), 2.5; selenium premix (200 mg Se/kg), 5.0; BMD, 2.5; choline chloride (60%), 6.0; vitamin premix, 25.0; and trace mineral premix, 5.0. The vitamin premix contributes (per kg of diet): vitamin A, 8,745 IU; cholecalciferol, 3,745 ICU; vitamin E, 60 IU; vitamin K (menadione sodium bisulfite), 2.91mg; thiamin HCl, 2.2 mg; riboflavin, 6.6mg; niacin, 99 mg; pantothenic acid, 15.4 mg; folic acid, 1.2 mg; pyridoxine, 2.2 mg; biotin, 165 mg; vitamin B12, 15 mg; and ethoxyquin, 113.5 mg. The trace mineral premix contributes (per kg of diet); zinc oxide (72% Zn), 147 mg; manganese oxide (55% Mn), 152 mg; copper sulfate (25.2% Cu), 35 mg; ferrous sulfate monohydrate (31% Fe), 72 mg; and potassium iodide, 1.5 mg.

[3] The ingredients used were analyzed prior to formulation and these values were subsequently used for dietary formulation.

Table 3 Composition of experimental diets in study 2 for 4- to 8-wk male commercial turkey[1].

Ingredient (%)	Diets 1 1.50% Lys 0.75% Thr	2 1.50% Lys 1.05% Thr	3 1.65% Lys 0.75% Thr	4 1.65% Lys 1.05% Thr
Corn	58.00	57.9	57.95	57.85
Soybean meal (48%)	32.60	32.5	32.50	32.40
Salt	0.50	0.50	0.50	0.50
L-Lysine HCl	0.45	0.45	0.60	0.60
DL-Methionine	0.35	0.35	0.35	0.35
L-Threonine	-	0.30	-	0.30
Choline Chloride (60%)	0.10	0.10	0.10	0.10
Limestone	1.80	1.80	1.70	1.80
Dicalcium phosphate	3.40	3.30	3.50	3.30
Chromic Oxide	0.30	0.30	0.30	0.30
Blended Fat	2.00	2.00	2.00	2.00
Premix[2]	0.50	0.50	0.50	0.50
Calculated composition				
ME (kcal/kg)	2899	2897	2897	2895
CP (%)	21.0	21.0	20.8	21.0
Analyzed composition				
Lysine	1.55	1.55	1.66	1.66
Threonine	0.74	1.04	0.74	1.04
TSAA	1.00	1.00	1.00	1.00

[1] Diet 5 is 66.7% diet 1 and 33.3% diet 2 (1.53% Lys, 0.85% Thr); Diet 6 is 33.3% diet 1 and 66.7% diet 2 (1.53% Lys, 0.95% Thr); Diet 7 is 66.7% diet 3 and 33.3% diet 4 (1.65% Lys, 0.85% Thr) and; Diet 8 is 33.3% diet 3 and 66.7% diet 4 (1.65% Lys, 0.95% Thr).

[2] The premix contains (in kg/100kg premix): ground corn, 54.0; amprolium (25%), 2.5; selenium premix (200 mg Se/kg), 5.0; BMD, 2.5; choline chloride (60%), 6.0; vitamin premix, 25.0; and trace mineral premix, 5.0. The vitamin premix contributes (per kg of diet): vitamin A, 8,745 IU; cholecalciferol, 3,745 ICU; vitamin E, 60 IU; vitamin K (menadione sodium bisulfite), 2.91mg; thiamin HCl, 2.2 mg; riboflavin, 6.6mg; niacin, 99 mg; pantothenic acid, 15.4 mg; folic acid, 1.2 mg; pyridoxine, 2.2 mg; biotin, 165 mg; vitamin B12, 15 mg; and ethoxyquin, 113.5 mg. The trace mineral premix contributes (per kg of diet); zinc oxide (72% Zn), 147 mg; manganese oxide (55% Mn), 152 mg; copper sulfate (25.2% Cu), 35 mg; ferrous sulfate monohydrate (31% Fe), 72 mg; and potassium iodide, 1.5 mg.

[3] The ingredients used were analyzed prior to formulation and these values were subsequently used for dietary formulation.

Table 4 Composition of experimental diets in study 3 for 8- to 12-wk male commercial turkey[1].

	Diets			
	1	2	3	4
Ingredient (%)	1.30% Lys 0.70% Thr	1.30% Lys 1.00% Thr	1.45% Lys 0.70% Thr	1.45% Lys 1.00% Thr
Corn	60.80	59.00	58.00	54.30
Soybean meal (48%)	20.60	21.60	23.80	25.80
Wheat midds	5.00	5.00	5.00	5.00
Meat and bone meal	4.00	3.00	3.00	3.00
Corn gluten meal (60%)	3.00	3.00	1.50	3.00
Salt	0.35	0.40	0.40	0.37
L-Lysine HCl	0.40	0.40	0.45	0.45
DL-Methionine	0.25	0.25	0.30	0.25
L-Threonine	--	0.30	--	0.23
Limestone	1.50	1.50	1.50	1.50
Dicalcium phosphate	1.65	2.15	2.15	2.10
Chromic Oxide	0.30	0.30	0.30	0.30
Blended Fat	1.65	2.60	3.10	3.20
Premix[2]	0.50	0.50	0.50	0.50
Calculated composition				
ME (kcal/kg)	2992	3014	3014	3003
CP (%)	20.0	20.0	20.0	21.5
Analyzed composition				
Lysine	1.32	1.31	1.50	1.48
Threonine	0.68	0.95	0.68	0.97
TSAA	0.89	0.88	0.92	0.93

[1] Diet 5 is 67% diet 1 and 33% diet 2 (1.3% Lys, 0.80% Thr); Diet 6 is 33% diet 1 and 67% diet 2 (1.3% Lys, 0.90% Thr); Diet 7 is 67% diet 3 and 33% diet 4 (1.45% Lys, 0.80% Thr) and; Diet 8 is 33% diet 3 and 67% diet 4 (1.45% Lys, 0.90% Thr).

[2] The premix contains (in kg/100kg premix): ground corn, 54.0; amprolium (25%), 2.5; selenium premix (200 mg Se/kg), 5.0; BMD, 2.5; choline chloride (60%), 6.0; vitamin premix, 25.0; and trace mineral premix, 5.0. The vitamin premix contributes (per kg of diet): vitamin A, 8,745 IU; cholecalciferol, 3,745 ICU; vitamin E, 60 IU; vitamin K (menadione sodium bisulfite), 2.91mg; thiamin HCl, 2.2 mg; riboflavin, 6.6mg; niacin, 99 mg; pantothenic acid, 15.4 mg; folic acid, 1.2 mg; pyridoxine, 2.2 mg; biotin, 165 mg; vitamin B12, 15 mg; and ethoxyquin, 113.5 mg. The trace mineral premix contributes (per kg of diet); zinc oxide (72% Zn), 147 mg; manganese oxide (55% Mn), 152 mg; copper sulfate (25.2% Cu), 35 mg; ferrous sulfate monohydrate (31% Fe), 72 mg; and potassium iodide, 1.5 mg.

[3] The ingredients used were analyzed prior to formulation and these values were subsequently used for dietary formulation.

Table 5 Composition of experimental diets in study 4 for 12- to 16-wk male commercial turkey[1].

Ingredient (%)	Diets 1: 0.90% Lys 0.55% Thr	2: 0.90% Lys 0.85% Thr	3: 1.10% Lys 0.55% Thr	4: 1.10% Lys 0.85% Thr
Corn	69.0	69.3	69.1	69.4
Soybean meal (48%)	18.7	19.0	18.7	18.4
Salt	0.5	0.5	0.5	0.5
L-Lysine	0.15	0.15	0.4	0.4
DL-Methionine	0.25	0.25	0.25	0.25
L-Threonine	--	0.30	--	0.3
Limestone	1.6	1.9	1.55	1.25
Dicalcium phosphate	3.8	3.0	3.7	3.7
Chromic Oxide	0.3	0.3	0.3	0.3
Blended Fat	5.2	4.8	5.0	5.0
Premix[2]	0.5	0.5	0.5	0.5
Calculated composition				
ME (kcal/kg)	3190	3187	3212	3214
CP (%)	15.0	15.0	14.9	15.1
Analyzed composition				
Lysine	0.95	0.95	1.05	1.08
Threonine	0.56	0.77	0.56	0.79
TSAA	0.76	0.74	0.65	0.71

[1] Diet 5 is 60% diet 1 and 40% diet 2 (0.90% Lys, 0.67% Thr); Diet 6 is 30% diet 1 and 70% diet 2 (0.90% Lys, 0.76% Thr); Diet 7 is 60% diet 3 and 40% diet 4 (1.10% Lys, 0.67% Thr) and; Diet 8 is 30% diet 3 and 70% diet 4 (1.10% Lys, 0.76% Thr).
[2] The premix contains (in kg/100kg premix): ground corn, 54.0; amprolium (25%), 2.5; selenium premix (200 mg Se/kg), 5.0; BMD, 2.5; choline chloride (60%), 6.0; vitamin premix, 25.0; and trace mineral premix, 5.0. The vitamin premix contributes (per kg of diet): vitamin A, 8,745 IU; cholecalciferol, 3,745 ICU; vitamin E, 60 IU; vitamin K (menadione sodium bisulfite), 2.91mg; thiamin HCl, 2.2 mg; riboflavin, 6.6mg; niacin, 99 mg; pantothenic acid, 15.4 mg; folic acid, 1.2 mg; pyridoxine, 2.2 mg; biotin, 165 mg; vitamin B12, 15 mg; and ethoxyquin, 113.5 mg. The trace mineral premix contributes (per kg of diet); zinc oxide (72% Zn), 147 mg; manganese oxide (55% Mn), 152 mg; copper sulfate (25.2% Cu), 35 mg; ferrous sulfate monohydrate (31% Fe), 72 mg; and potassium iodide, 1.5 mg.
[3] The ingredients used were analyzed prior to formulation and these values were subsequently used for dietary formulation.

Table 6 Composition of experimental diets in study 5 for 16- to 20-wk male commercial turkey[1].

	Diets			
	1	2	5	6
Ingredient (%)	0.72% Lys 0.65% Thr	0.72% Lys 0.50% Thr	0.88% Lys 0.65% Thr	0.88% Lys 0.50% Thr
Corn	75.6	77.5	77.95	77.65
Soybean meal (48%)	16.6	14.35	14.1	14.0
Salt	0.5	0.5	0.5	0.5
L-Lysine	--	0.1	0.3	0.3
DL-Methionine	0.1	0.15	0.1	0.15
L-Threonine	0.12	--	0.15	--
Limestone	1.3	1.3	1.3	1.3
Dicalcium phosphate	2.0	2.3	2.0	2.3
Chromic Oxide	0.3	0.3	0.3	0.3
Blended Fat	3.0	3.0	2.8	3.0
Premix[2]	0.48	0.5	0.5	0.50
Calculated composition				
ME (Kcal/kg)	3190	3196	3190	3193
CP (%)	14.0	13.1	13.3	13.1
Analyzed composition				
Lysine	0.73	0.75	0.89	0.89
Threonine	0.62	0.47	0.61	0.46
TSAA	0.57	0.59	0.55	0.59

[1] Diet 5 is 66% diet 1 and 34% diet 2 (0.72% Lys, 0.60% Thr); Diet 6 is 35% diet 1 and 65% diet 2 (0.72% Lys, 0.55% Thr); Diet 7 is 75% diet 3 and 25% diet 4 (0.88% Lys, 0.61% Thr) and; Diet 8 is 25% diet 3 and 75% diet 4 (0.88% Lys, 0.54% Thr).

[2] The premix contains (in kg/100kg premix): ground corn, 54.0; amprolium (25%), 2.5; selenium premix (200 mg Se/kg), 5.0; BMD, 2.5; choline chloride (60%), 6.0; vitamin premix, 25.0; and trace mineral premix, 5.0. The vitamin premix contributes (per kg of diet): vitamin A, 8,745 IU; cholecalciferol, 3,745 ICU; vitamin E, 60 IU; vitamin K (menadione sodium bisulfite), 2.91mg; thiamin HCl, 2.2 mg; riboflavin, 6.6mg; niacin, 99 mg; pantothenic acid, 15.4 mg; folic acid, 1.2 mg; pyridoxine, 2.2 mg; biotin, 165 mg; vitamin B12, 15 mg; and ethoxyquin, 113.5 mg. The trace mineral premix contributes (per kg of diet); zinc oxide (72% Zn), 147 mg; manganese oxide (55% Mn), 152 mg; copper sulfate (25.2% Cu), 35 mg; ferrous sulfate monohydrate (31% Fe), 72 mg; and potassium iodide, 1.5 mg.

[3] The ingredients used were analyzed prior to formulation and these values were subsequently used for dietary formulation.

Table 7 Main effect means of lysine averaged over threonine for growth performance and carcass weights of male commercial turkeys fed two concentrations of lysine and four concentrations of threonine from 2 to 4 wk post-hatch[1].

Lysine[4] level, %	1.60	1.75		P-Value[2]
Lysine, g / Mcal ME	5.54	6.06	SEM	Lysine
Final BW, kg	1.19	1.17	0.036	NS[3]
BW gain, kg	0.825	0.818	0.025	NS
Feed intake, kg	1.29	1.25	0.032	NS
Feed efficiency ratio	0.635	0.657	0.006	0.01
Carcass wt, kg	0.641	0.648	0.018	NS
P. major, g	73.9	76.5	2.12	NS
P. minor, g	18.1	18.6	0.69	NS
Carcass nitrogen, % DM	11.6	11.5	0.076	NS
Carcass protein, g DM	137	138	4.26	NS

[1] Means represent 24 pens of one poult per pen;
[2] No lysine x threonine interaction (P>0.10). Main effects of threonine are shown in Table 8;
[3] NS = not significant (P>0.10);
[4] ADL: Apparent digestible lysine (88% digestibility).

Table 8 Main effect means and contrasts of threonine averaged over lysine for growth performance and carcass weights of male commercial turkeys fed two concentrations of lysine and four concentrations of threonine from 2 to 4 wk post-hatch[1].

Threonine[4] level, %	0.80	0.90	1.00	1.10		P-Value[2]			
Threonine, g / Mcal ME	2.77	3.12	3.46	3.81	SEM	Threonine	L	Q	C
Final BW, kg	1.13	1.18	1.20	1.21	0.036	NS[3]	--	--	--
BW gain, kg	0.769	0.821	0.842	0.855	0.029	0.04	0.01	NS[3]	NS
Feed intake, kg	1.21	1.27	1.29	1.32	0.039	NS	--	--	--
Feed efficiency ratio	0.638	0.645	0.654	0.646	0.006	NS	--	--	--
Carcass wt, kg	0.615	0.654	0.644	0.666	0.022	NS	--	--	--
P. major, g	71.3	76.2	74.2	79.1	2.59	NS	--	--	--
P. minor, g	17.2	18.2	19.2	18.9	0.80	NS	--	--	--
Carcass nitrogen, % DM	11.9	11.6	11.3	11.5	0.11	0.01	0.01	0.02	NS
Carcass protein, g DM	142	138	131	139	5.23	NS	--	--	--

[1] Means represent 12 pens of one poult per pen;
[2] Contrasts of main effects of threonine (L = linear; Q = quadratic; C = cubic) when no lysine x threonine (P>0.10). Main effects of lysine are shown in Table 7;
[3] NS = not significant (P>0.10);
[4] AD-Thr: Apparent digestible threonine (81% digestibility).

Table 9 Effect means and contrasts for growth performance and carcass weights of male commercial turkeys fed two concentrations of lysine and four concentrations of threonine from 4 to 8 wk post-hatch[1].

Lysine[4] level, %	1.50				1.65					P-Value[2]						
Lysine, g / Mcal ME	5.18				5.70											
Threonine[5] level, %	0.75	0.85	0.95	1.05	0.75	0.85	0.95	1.05			5.18 g lysine			5.70 g lysine		
Threonine, g / Mcal ME	2.59	2.93	3.28	3.62	2.59	2.93	3.28	3.62	SEM	Lys x Thr	L	Q	C	L	Q	C
Final BW, kg	3.47	3.64	3.74	3.44	3.77	3.58	3.64	3.79	0.099	0.06	NS[3]	0.02	NS	NS	NS	NS
BW gain, kg	2.41	2.58	2.69	2.41	2.68	2.53	2.56	2.74	0.11	0.06	NS	0.02	NS	NS	NS	NS
Feed intake, kg	4.89	4.84	4.94	4.63	4.74	5.07	4.81	4.96	0.18	NS	--	--	--	--	--	--
Feed efficiency ratio	0.500	0.536	0.547	0.523	0.567	0.502	0.536	0.554	0.017	0.03	NS	0.08	NS	NS	0.02	NS
Carcass wt, kg	2.14	2.26	2.31	2.10	2.30	2.20	2.25	2.28	0.068	NS	--	--	--	--	--	--
P. major, g	245	255	269	232	255	253	258	251	10.7	0.05	NS	0.03	NS	NS	NS	NS
P. minor, g	63.4	65.0	71.9	58.9	71.1	68.9	70.8	67.1	2.79	NS	--	--	--	--	--	--
Carcass nitrogen, % DM	10.8	10.9	10.9	10.9	10.7	10.8	11.1	10.8	0.11	NS	--	--	--	--	--	--
Carcass protein, g DM	428	457	465	445	463	447	454	447	15.4	NS	--	--	--	--	--	--
Carcass protein efficiency	0.291	0.315	0.322	0.319	0.332	0.296	0.322	0.305	0.013	NS	--	--	--	--	--	--

[1] Means represent 6 pens of one poult per pen (Lys = lysine; Thr = threonine);
[2] Contrasts of threonine effects in lysine (L = linear; Q = quadratic; C = cubic) when lysine x threonine (P<0.06); Main effects of threonine on P. minor (P<0.04; L = NS, Q and C = 0.06); Main effects of lysine on P. minor (P<0.02). Other main effects of threonine and lysine (P>0.10);
[3] NS = not significant (P>0.10);
[4] ADL: Apparent digestible lysine (91% digestibility);
[5] AD-Thr: Apparent digestible Threonine (83% digestibility).

Table 10 Effect means and contrasts for growth performance and carcass weights of male commercial turkeys fed two concentrations of lysine and four concentrations of threonine from 8 to 12 wk post-hatch[1].

Lysine[4] level, %	1.30				1.45					P-Value[2]						
Lysine, g / Mcal ME	4.33				4.82											
Threonine[4] level, %	0.70	0.80	0.90	1.00	0.70	0.80	0.90	1.00			4.33 g lysine			4.82 g lysine		
Threonine, g / Mcal ME	2.33	2.66	2.99	3.33	2.33	2.66	2.99	3.33	SEM	Lys x Thr	L	Q	C	L	Q	C
Final BW, kg	9.05	8.77	10.1	9.53	9.64	9.45	9.78	10.0	0.31	NS[3]	--	--	--	--	--	--
BW gain, kg	3.87	3.63	4.88	4.46	4.48	4.23	4.59	4.91	0.30	NS	--	--	--	--	--	--
Feed intake, kg	9.33	9.49	10.4	10.2	10.1	9.91	10.3	11.9	0.61	NS	--	--	--	--	--	--
Feed efficiency ratio	0.414	0.386	0.477	0.432	0.444	0.425	0.448	0.414	0.022	NS	--	--	--	--	--	--
Carcass wt, kg	5.80	5.62	6.57	6.15	6.28	6.14	6.39	6.50	0.21	NS	--	--	--	--	--	--
P. major, kg	0.661	0.655	0.779	0.711	0.708	0.682	0.745	0.780	0.043	NS	--	--	--	--	--	--
P. minor, kg	0.161	0.149	0.158	0.158	0.149	0.169	0.177	0.160	0.038	NS	--	--	--	--	--	--
Carcass nitrogen, % DM	11.3	11.9	11.5	11.4	10.7	12.0	11.0	11.8	0.23	0.07	NS	NS	NS	0.03	NS	0.01
Carcass protein, kg DM	1.24	1.29	1.45	1.31	1.28	1.39	1.33	1.47	0.057	NS	--	--	--	--	--	--
Carcass protein efficiency	0.316	0.329	0.35	0.321	0.312	0.374	0.326	0.341	0.019	NS	--	--	--	--	--	--

[1] Means represent 6 pens of one poult per pen (Lys = lysine; Thr = threonine);
[2] Contrasts of threonine effects in lysine (L = Linear; Q = Quadratic; C = Cubic) when lysine x threonine ($P<0.07$); Main effects of lysine on carcass wt ($P<0.06$); Other lysine main effects ($P>0.10$); Main effects of threonine are shown in Table 11;
[3] NS = not significant ($P>0.10$);
[4] ADL: Apparent digestible lysine (84% digestibility); AD-Thr: Apparent digestible (79% digestibility).

Table 11 Main effect means and contrasts of threonine for growth performance and carcass weights of male commercial turkeys fed two concentrations of lysine and four concentrations of threonine from 8 to 12 wk post-hatch[1].

Threonine[4] level, %	0.70	0.80	0.90	1.00		P-Value[2]			
Threonine, g / Mcal ME	2.33	2.66	2.99	3.33	SEM	Threonine	Linear	Quadratic	Cubic
Final BW, kg	9.35	9.11	9.94	9.78	0.22	0.04	0.04	NS[3]	0.04
BW gain, kg	4.17	3.93	4.74	4.68	0.21	0.03	0.02	NS	0.05
Feed intake, kg	9.71	9.70	10.3	11.0	0.43	NS	--	--	--
Feed efficiency ratio	0.429	0.405	0.462	0.423	0.016	NS	--	--	--
Carcass wt, kg	6.04	5.88	6.48	6.33	0.15	0.03	0.04	NS	0.03
P. major, kg	0.684	0.669	0.762	0.746	0.033	0.06	0.03	NS	NS
P. minor, kg	0.155	0.159	0.168	0.159	0.037	NA	--	--	--
Carcass protein, kg DM	1.26	1.34	1.39	1.39	0.042	0.08	0.02	NS	NS
Carcass protein efficiency	0.314	0.351	0.338	0.331	0.013	NS	--	--	--

[1] Means represent 12 pens of one poult per pen;
[2] Contrast effects of threonine when main effects (P<0.08). Main effects of lysine and mean effects of Lysine x threonine are shown in Table 10;
[3] NS = not significant (P>0.10);
[4]AD-Thr: Apparent digestible threonine (79% digestibility).

Table 12 Effect means and contrasts for growth performance and carcass weights of male commercial turkeys fed two concentrations of lysine and four concentrations of threonine from 12 to 16 wk post-hatch[1].

Lysine[4] level, %	0.90				1.10					P-Value[2]								
Lysine, g / Mcal ME	2.81				3.44													
Threonine[4] level, %	0.55	0.65	0.75	0.85	0.55	0.65	0.75	0.85					2.81 g lysine			3.44 g lysine		
Threonine, g / Mcal ME	1.72	2.03	2.34	2.65	1.72	2.03	2.34	2.65	SEM	Lys	Thr	Lys x Thr	L	Q	C	L	Q	C
Final BW, kg	14.7	14.7	14.1	14.4	14.6	14.5	15.1	14.6	0.37	NS	NS	NS	--	--	--	--	--	--
BW gain, kg	3.81	3.81	3.07	3.59	3.73	3.67	4.26	3.85	0.24	0.04	NS	0.01	NS	NS	0.04	NS	NS	0.09
Feed intake, kg	12.4	13.0	12.6	11.9	12.0	12.6	13.3	12.1	0.38	NS	0.01	NS	--	--	--	--	--	--
Fee efficiency ratio	0.307	0.293	0.243	0.303	0.311	0.293	0.322	0.318	0.015	0.03	NS	0.07	NS	0.03	0.04	NS	NS	NS
Carcass wt, kg	9.90	9.92	9.44	9.68	9.80	9.66	9.91	9.61	0.24	NS	NS	NS	--	--	--	--	--	--
P. major, kg	1.32	1.35	1.21	1.32	1.29	1.32	1.28	1.28	0.046	NS	NS	NS	--	--	--	--	--	--
P. minor, kg	0.305	0.316	0.291	0.318	0.307	0.312	0.304	0.315	0.009	MS	NS	NS	--	--	--	--	--	--
Carcass nitrogen, % DM	9.93	8.89	9.39	10.5	10.1	10.2	9.67	10.0	0.22	0.01	0.01	0.01	0.05	0.01	NS	NS	NS	NS
Carcass protein, kg DM	2.10	1.97	2.00	2.18	2.16	2.06	2.20	2.18	0.031	0.01	0.01	0.05	0.08	0.01	NS	NS	NS	0.02
Carcass protein efficiency	0.325	0.234	0.255	0.379	0.356	0.310	0.354	0.356	0.019	0.01	0.01	0.03	0.06	0.01	NS	NS	NS	NS

[1] Means represent 6 pens of one poult per pen (Lys = lysine; Thr = threonine);
[2] Contrasts of threonine effects in lysine (L = linear; Q = quadratic; C = cubic) when lysine x threonine (P<0.07); Main effects of threonine on feed intake are shown in Figure 7.1. All other lysine and threonine main effects are explained by lysine x threonine interactions;
[3] NS = not significant (P>0.10);
[4]ADL: Apparent digestible lysine (85% digestibility), AD-Thr: Apparent digestible Threonine (79% digestibility).

Table 13 Main effect means of lysine averaged over threonine on growth performance and carcass weights of male commercial turkeys fed two concentrations of lysine and four concentrations of threonine from 16 to 20 wk post-hatch[1].

Lysine[4] level, %	0.72	0.88		P-value[2]
Lysine, g / Mcal ME	2.26	2.76	SEM	Lysine
Final BW, kg	19.4	19.4	0.43	NS[3]
BW gain, kg	3.97	3.78	0.14	NS
Feed intake, kg	14.5	14.4	0.61	NS
Feed efficiency ratio	0.261	0.263	0.009	NS
Carcass wt, kg	13.2	13.3	0.26	NS
P. major, kg	1.99	2.10	0.056	0.03
P. minor, kg	0.414	0.425	0.006	NS
Carcass protein, kg DM	2.86	2.84	0.021	NS
Carcass protein efficiency	0.344	0.324	0.009	NS

[1] Means represent 24 pens of one poult per pen;
[2] Main effect means of threonine are shown in Table 14. Lysine x threonine interaction for carcass nitrogen is shown in Figure 7.2. All other effects (P>0.10);
[3] NS = not significant (P>0.10);
[4]ADL: Apparent digestible lysine (87% digestibility).

Table 14 Main Effects of threonine averaged over lysine for growth performance and carcass weights of male commercial turkeys fed two concentrations of lysine and four concentrations of threonine from 16 to 20 wk post-hatch[1].

Threonine level, %	0.50	0.55	0.60	0.65		P-Value[2]			
Threonine, g / Mcal ME	1.57	1.72	1.88	2.04	SEM	Threonine	L	Q	C
Final BW, kg	19.3	19.4	19.3	19.6	0.45	NS[3]	--	--	--
BW gain, kg	3.66	3.82	3.74	3.89	0.18	NS	--	--	--
Feed intake, kg	14.5	14.4	14.4	1.44	0.64	NS	--	--	--
Feed efficiency ratio	0.252	0.265	0.258	0.271	0.011	NS	--	--	--
Carcass wt, kg	13.2	13.1	13.2	13.4	0.28	NS	--	--	--
P. major, kg	2.03	1.98	2.10	2.06	0.066	NS	--	--	--
P. minor, kg	0.416	0.415	0.429	0.421	0.009	NS	--	--	--
Carcass protein, kg DM	2.71	2.89	2.95	2.84	0.031	0.01	0.01	0.01	NS
Carcass protein efficiency	0.251	0.356	0.386	0.344	0.012	0.01	0.01	0.01	NS

[1] Means represent 12 pens of one poult per pen;
[2] Main effects of lysine shown in Table 13. Lysine x threonine interaction for carcass nitrogen is shown in Figure 7.2. All other effects (P>0.10). Contrasts (L = Linear; Q = Quadratic; C = Cubic) of threonine main effect means when averaged over lysine concentrations;
[3] NS = not significant (P>0.10);
[4] AD-Thr: Apparent digestible Threonine (80% digestibility).

Figure 1 Main effect means of threonine concentration averaged over lysine on cumulative feed intake ($P<0.01$; SEM = 0.32) of male commercial turkeys fed two concentrations of lysine and four concentrations of threonine from 12 – 16 wk post-hatch. Means represent 12 pens of 1 turkey tom per pen. There was not a linear ($P>0.10$) but a quadratic ($P<0.01$; solid line) response for turkeys to total threonine concentrations ranging from 0.55% to 0.85%. Table 6 shows the mean effects of lysine x threonine interactions on growth performance and carcass weights.

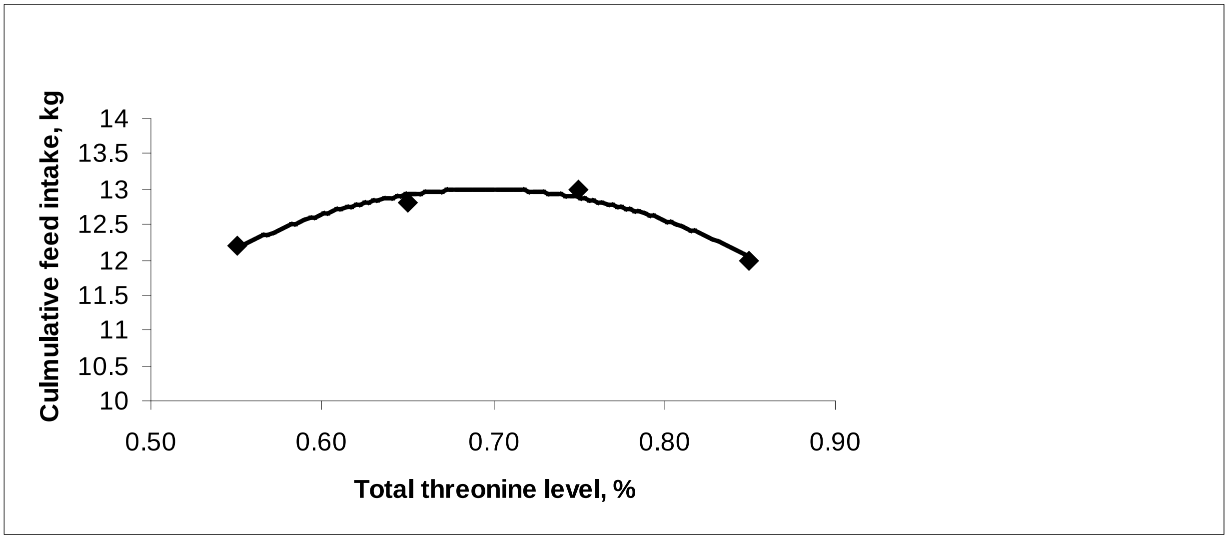

Figure 2 Effect means of threonine concentrations in lysine ($P<0.03$; SEM = 0.14) on carcass nitrogen of male commercial turkeys fed two concentrations of lysine and four concentrations of threonine from 16 – 20 post-hatch. Means represent 6 pens of 1 turkey tom per pen. There was a linear ($P<0.03$; dashed line) but not a quadratic ($P>0.10$) response to total threonine ranging from 0.50 to 0.65% for turkeys on 0.72% total lysine (♦); and not linear ($P>0.10$) but a quadratic ($P<0.01$; solid line) response to threonine for turkeys on 0.88% total lysine (■). Tables 8 and 9 show the main effects of lysine and threonine on growth performance and carcass weights, respectively.