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S. Hurwitz, D. Polin

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ABSTRACT

This project represents a research across a wide front of nutrition, as modified by environmental temperature, and of male reproduction in turkeys.

- Results were obtained of the energy needs at different ages as a function of constant and fluctuating environmental temperatures. These requirements and performance data were used as essential components of models to calculate the amino acid requirements and of predicting performance and feed intake in a general economic optimization, computer simulation program. The response to dietary caloric density was evaluated at different ages. The minimal level was found to increase from 2700 kcal/kg at 5 week to 2900 kcal/kg at 14 weeks of age.

A model to calculate the amino acid requirements has been constructed using results of body composition along the growing period, maintenance requirements, determined in balance trials and energy requirements (see above). The model can calculate requirements for both sexes, and for different environmental temperatures. The model has been tested experimentally and validated for methionine and lysine.

A system of analyses has been established in order to determine the etiology of rickets in turkeys. These analyses included the determination of plasma calcium and phosphorus, vitamin D metabolites and calcium-binding protein, bone mineral, intestinal calcium-binding protein and kidney vitamin D hydroxylases. Following the evaluation of the efficacy of calcium, phosphorus and vitamin D metabolites supplementation of diets for treating nutritional rickets, a diet enriched with calcium and phosphorus was found most suitable to treat nutritional rickets of any nutritional etiology.

Using radioactive isotopes, the dependence of water intake on sodium

intake and environmental temperature has been established. Water intake and water excretion increased linearly with sodium intake. Some increase also occurred in water intake at high environmental temperatures. in climatized turkeys. The dependence of water intake on salt intake disappeared at environmental temperatures above 30°C. The turkey was found to be strongly resistant to abnormal dietary cation-anion ratios, which had been found inductive to metabolic acidosis or alkalosis in chickens.

Turkeys absorbed alfa-tocopherol as efficiently as chickens, but excreted more vitamin E glucuronides. Thus, plasma and tissue concentrations of the vitamin were low in the turkey. These were also found to be dependent on the vitamin E intake and increased with dietary lipid concentration.

Meat stability as detected by a tasting panel or TBA determinations was improved by dietary vitamin E supplementation. Respiration of spermatozoa increased with pH of the medium; however, sperm preservation and fertilization capacity were optimal at pH 7.4 when HEPES buffer was used.

A computer program using nutritional-environmental information determined in the project was formulated in order to determine feeding schedules, and optimize marketing age, dietary nutrient density and environment. The program has been tested under field conditions both in Israel and in the U.S.A.

Following the evaluation of the efficacy of calcium, phosphorus and vitamin D metabolites supplementation of diets for treating nutritional rickets, a diet enriched with calcium and phosphorus was found most suitable to treat nutritional rickets of any nutritional

Using radioactive isotopes, the dependence of water intake on sodium

ENERGY REQUIREMENTS

PROTEIN AND AMINO ACID REQUIREMENTS

The Amino Acid Requirements of Growing Turkeys

1. Model Construction and Parameter Estimation¹

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1 ABSTRACT. A model to calculate the protein and amino acid requirements
2 for growing turkeys, has been formulated. A requirement was taken as the
3 sum of the needs for maintenance, for gain in carcass weight without
4 feathers and for the feathers. Parameters used in the model were obtained
5 from a study of carcass composition along the growth period, and from two
6 balance trials with adult turkeys. The maintenance requirement was
7 considered to be the sum of the needs for replacing skin and intestinal
8 protein losses and for the obligatory creatinine excretion in the urine.
9 Nitrogen retention was determined at 2.3 g/d in protein-fed adult (17 kg)
10 male turkeys, as an estimate for the replacement needs for skin protein
11 loss. Creatinine excretion in these birds was 123 mg/d. When fed an
12 N-free diet, 16.5 kg adult turkeys excreted a total of 3.5 g/d of amino
13 acids as a result of intestinal losses. The protein requirement for
14 maintenance was estimated at $32 \text{ mg/d/g}^{2/3}$ of body weight, by summing up
15 the different needs and dividing by 0.85, the coefficient of protein
16 absorption. Protein and amino acid analyses of nude carcass and feathers,
17 and the growth curve were used to calculate the requirements for growth.
18 These were then related to energy intake predicted by equations which
19 included previously determined coefficients for maintenance and growth
20 (Hurwitz et al., 1980), and the results of carcass lipid analysis. The
21 calculated amino acid requirements were similar to those of the NRC (1977).

Poultry Science, 1983.

INTRODUCTION

The usefulness of models for the calculation of the energy, protein and amino acid requirements has been discussed in relation to laying hens (Hurwitz and Bornstein, 1973) and chicks (Hurwitz et al., 1978, 1980a; Plavnik and Hurwitz, 1983). Predictive models were considered advantageous since they could provide requirement values for birds at different ages and environmental temperatures, and to some extent also for different breeds, thus eliminating the need for repetitious experimentation.

Two main approaches have been used to model amino acid requirements. One approach was based on numerical analysis of the response of birds to dietary amino acids, obtained empirically (Combs, 1964; Fisher and Morris, 1970). According to the other approach (Hurwitz et al., 1978), the requirements for protein and amino acids are considered to be the sums of the needs for maintenance and deposition in carcass and feather protein. The model does not use any term for biological utilization, but contains a term for the efficiency of intestinal absorption. The latter, in healthy birds, is a function of the digestibility of the protein and is not influenced by the nutritional-physiological state of the animal.

To the best of our knowledge, the only detailed evaluation of the protein and amino acid requirements for maintenance in birds is that of Leveille et al. (1958, 1960) obtained in the rooster. Thus, this type of information is not available for the turkey. Furthermore, carcass composition as a function of age has not been studied in turkeys in sufficient detail. Recent studies of Leeson and Summers (1980 a,b) demonstrated important differences between chickens and turkeys in the carcass concentration of protein and fat. Their study, however, did not

1 include the evaluation of fractional feather weight and composition and
2 is therefore incomplete for the model used here.

3 The amino acid composition of the turkey carcass was documented in
4 early studies (Scott, 1959). A more recent study by Fisher and Scougall
5 (1982) found some age-dependent differences in the amino acid composition.
6 of turkey carcass which could be related to the changing proportion
7 between feather and carcass protein. It therefore appeared necessary
8 to obtain the composition of the turkey body as a function of sex and age,
9 in terms of protein and amino acids, separate for carcass and feathers.
10 Evaluation of carcass lipid, as done in this study, was important for
11 the calculation of the energy required for growth.

12 The model

13 A model describing the energy and amino acid requirements in chicks
14 was proposed previously (Hurwitz et al., 1978). In subsequent studies
15 (Hurwitz et al., 1980b; Plavnik and Hurwitz, 1983.) the scope of the model
16 was expanded to include the effects of environmental temperature on the
17 energy needs for maintenance in both chickens and turkeys, and the effect
18 of carcass lipid on the energy requirements for weight gain.

19 The energy requirements can be summarized by

$$20 \quad EC = M \overline{BW}^{2/3} + D \cdot G \quad [1]$$

$$21 \quad M = f(T) \quad [2]$$

$$22 \quad D = 0.6 + 9.3 \cdot F \quad [3]$$

23 where, EC is the energy intake (kcal/d); $\overline{BW}$ is the average body weight
24 for the period, in g; G is the daily weight gain, in g/d; M is the energy
25 requirement for maintenance, in kcal/g^{2/3}/d; D is the requirement for
26 weight gain, in kcal/g; T is the environmental temperature, in °C; and
27 F is the lipid fraction in the body weight gained during the respective

1 period.

2 For the present calculations, values for the maintenance requirements
3 as a function of environmental temperature
4 were taken from the previous study (Hurwitz et al., 1980b).

5 The fraction of body lipid (F) used in equation [3] is one of the
6 parameters evaluated in the present study.

7 The protein requirement for growing birds has been defined as the
8 sum of the requirements for maintenance, carcass gain and of feather gain
9 (Hurwitz et al., 1978). This separation is due to the difference
10 in the amino acid composition among these three compartments.

11 The protein requirement for maintenance has been considered to be
12 proportional to metabolic body weight as theorized in classical
13 studies (Mitchell 1962). It is self evident that
14 the loss of skin integuments must be proportional to skin surface.

15 Also, intestinal losses are probably related to body surface
16 since, in the turkey, intestinal length varies with metabolic body weight
17 (S. Hurwitz, unpublished). Intestinal and skin losses are regarded as
18 major components in determining the protein needs for maintenance. The
19 net protein required for growth is the protein gained in carcass and
20 feathers. The net requirement is divided by 0.85, the coefficient of
21 protein absorption in the young turkey (Hurwitz et al., 1979). Thus,

$$22 \quad \text{for maintenance, } PRM = MA \cdot \overline{BW}^{2/3} / 0.85 \quad [4]$$

$$23 \quad \text{for carcass growth, } PRC = CP \cdot G / 0.85 \quad [5]$$

$$24 \quad \text{for feather growth, } PRF = FP \cdot G / 0.85 \quad [6]$$

$$25 \quad \text{and total requirement, } PR = PRM + PRC + PRF \quad [7]$$

26 where, MA is the coefficient of protein needed for maintenance; $\overline{BW}$ is the
27 body weight; CP is the protein concentration in carcass gain; G is the

1 rate of weight gain; and FP is feather protein as a fraction of weight
2 gain.

3 The amino acid requirement is the sum of the products of the protein
4 requirement and the proportion of the amino acid in each of the compartments:

$$5 \quad \text{AAR} = \text{PRM} \cdot \text{AA}_m + \text{PRC} \cdot \text{AA}_c + \text{PRF} \cdot \text{AA}_f \quad [8]$$

6 where, AA_m , AA_c and AA_f are the proportions of amino acids in the protein
7 of maintenance, carcass and feathers, respectively.

8 In the chick model (Hurwitz et al., 1978), the amino acid compositions
9 of carcass and feathers were taken from Scott et al. (1969) and Block and
10 Weiss (1956), respectively. The amino acid required for maintenance was
11 taken from Leveille et al. (1960). In the present study, amino acid analyses
12 were made of feathers and carcass, and the amino acid requirements for
13 maintenance were obtained experimentally.

14 For determination of the maintenance requirements it has been
15 assumed that tissue renewal does not involve any significant net losses
16 of essential amino acids except for specific amino acids which are catabolized
17 irreversibly such as proline which is hydroxylated into hydroxyproline,
18 and histidine which is methylated. A net loss of amino acid occurs via
19 (a) the intestine, the result of unabsorbed digestive secretions and of
20 epithelial breakdown; (b) continuous loss of skin integuments in the form
21 of macroscopic and microscopic scales; and (c) catabolism of equivalent
22 amounts of methionine, glycine and arginine involved in the obligatory
23 synthesis of creatinine (Narayanan and Appeltson, 1980), which is subsequently
24 lost in the urine.

25 The loss of amino acid from the intestine has been determined in the
26 study by analyzing the amino acid excretion of birds consuming a protein-
27 free diet.

1 For the measurement of the loss of protein and amino acid in the
2 sloughed off skin integuments, it has been assumed that in the non-growing
3 adult bird with an unchanged nitrogen concentration in its carcass, the
4 nitrogen balance must equal zero. When feeding an adequate protein diet,
5 and after the careful removal of any feathers or scales which have dropped
6 into the excreta, a positive nitrogen retention value is obtained which
7 must be equivalent to the loss of skin integuments to the environment.
8 The amino acid composition of this keratin loss is the same as that of
9 feathers. These assumptions are supported by the similarity in the amino
10 acid composition between the maintenance needs and of feather protein as
11 noted by Leveille et al. (1960). During the experiment, creatinine excretion
12 was also measured.

13 For calculation of the requirements for maintenance, the losses in
14 intestine, skin and creatinine thus measured are summed and divided by
15 0.85, the coefficient of absorption in turkeys (Hurwitz et al., 1979).

17 MATERIALS AND METHODS

18 Trial 1: Carcass composition. Male and female Broad Breasted White
19 turkeys (British United Turkeys, BUT) were obtained at 1 day of age and
20 placed in oil-heated battery-brooders until the age of 5 weeks. They were
21 then transferred to open sheds where they were reared on litter, and
22 received diets based essentially on NRC (1977) recommendations.

23 At various times (Table 2), three birds of each sex were
24 weighed, and killed by an intracardiac injection of sodium pentobarbital.
25 Their feathers and viscera were removed and weighed. All samples were
26 then sealed in polyethylene bags, where they were kept at -18° until further
27 processed.

1 When all samples were collected, carcasses and viscera were autoclaved,
2 pooled and homogenized. Samples were then taken for nitrogen determination
3 by the Kjeldahl procedure. For lipid assays, samples were extracted
4 according to Folch et al. (1957), except that the extract was washed with
5 water. The amount of lipid was obtained gravimetrically after evaporation
6 of the solvent. Feathers were ground and samples were taken directly for
7 the Kjeldahl procedure.

8 Trials 2 and 3 : Balance studies. Male BUT turkeys were obtained at 1 day
9 of age from a commercial hatchery and raised to 5 weeks of age in electrically
10 heated battery-brooders placed at in a temperature-controlled room at 24°.
11 They were then transferred into individual cages situated in similar rooms,
12 where they were kept until used for the experiments at the age of 12 and
13 15 months, in the two trials, respectively. Until the
14 experimental period, the birds were fed diets designed essentially according
15 to NRC (1977) recommendations. About 2 weeks prior to the experiment,
16 the birds were fed a semipurified diet similar to that of trial 2 (Table 1),
17 for a period of adjustment. During this time body weight and feed intake
18 were recorded in order to ensure steady-state conditions.

19 The experimental diets (Table 1) were then fed for 8 days. Excreta
20 were collected during the last 6 days on stainless steel trays placed
21 under the cages. A saturated boric acid solution was sprayed twice daily
22 over the excreta in order to prevent any loss of nitrogen. Any scales or
23 feathers which had dropped into the collecting trays were removed. The
24 excreta were homogenized in a blender and the volume was standardized
25 with water. Samples were then taken, by volume, for analysis.
26 Chemical assays.

26 For nitrogen assays, aliquots were digested with sulfuric acid and
27 a selenium catalyst. Ammonia was then determined in an Autoanalyzer

TABLE 1.—Composition of the experimental diets fed in the
balance trials

Ingredient	Trial 2 ¹	Trial 3
	%	
Soybean oil meal	20.00	-
Soybean oil, refined	4.00	3.00
Cellulose (Alphacell)	-	10.00
Dicalcium phosphate	1.80	1.80
Calcium carbonate	1.00	1.00
Choline chloride (50%)	.20	.20
Vitamin mixture ²	.40	.40
Trace mineral mixture ³	.10	.10
Sodium chloride	.40	.50
Magnesium carbonate	-	.50
Potassium carbonate	-	.70
DL methionine	.10	-
Glucose	72.90	82.00

¹ The dietary protein content was 7.3%.

² Supplying in mg per kg of diet: thiamin, 25; riboflavin, 16; Ca-pantothenate, 20; pyridoxine, 6; biotin, .6; folic acid, 4; menadion, 2; niacin, 150; ascorbic acid, 250; vitamin B₁₂, .02. Also per kg: vitamin A, 10,000 IU ; α -tocopherol, 5 IU ; vitamin D₃, 2000 ICU.

³ In mg per kg of diet: Mn, 80; Zn, 50; Fe, 25; I, 1.2, Cu, 2; Co, .2.

1 (Technicon Instrument Corp., Tarrytown, N.Y.) using the recommended
2 procedure, except that the alkaline-phenol reagent was replaced by a
3 reagent containing 20% salicylic acid, 20% sodium hydroxide and 0.07%
4 sodium nitropruside, as suggested by Krown (1980).

5 For creatinine determination, the homogenate of the excreta was treated
6 with perchloric acid to a final concentration of 7.5%. The resulting
7 filtrate was neutralized by 2 N potassium bicarbonate and the resulting
8 potassium perchlorate precipitate was removed by centrifugation. Creatinine
9 was determined in the supernatant colorimetrically according to Folin (1904).

10 For amino acid determination, samples of 2-day collections were pooled
11 and an aliquot of the pooled samples was lyophilized. Tissue was lyophilized
12 and extracted with ether. Samples of 2-4 mg were then hydrolyzed in 6 N
13 acetic acid in vacuum at 110° for 24 h and an aliquot was taken for analysis
14 in a Dionex D-502 Amino Acid Analyzer with their commercial buffer system
15 and Ninhydrin detection at 570 nm.

16

17 RESULTS

18 Trial 1. The distribution of weights between carcass,
19 feathers and viscera is given in Table 2. The fraction of the viscera
20 decreased with age, and at 90-130 days it was about one-half of the value
21 at one week. The relative weight of the feathers increased with age, peaked
22 between 72 and 99 days, and then gradually decreased. As a result of the
23 changes in viscera and feathers the relative weight of the nude deviscerated
24 carcass increased with age.

25 The protein content of carcass components is given in Table 3. The
26 protein content of the carcass slightly increased during the first weeks
27 of life and subsequently underwent only minor changes. On the other hand,

TABLE 2.— Weight distribution of carcass, internal organs and feathers in male and female turkeys¹

Age, d	<u>Carcass</u>		<u>Viscera</u>		<u>Feathers</u>	
	Male	Female	Male	Female	Male	Female
<u>% of body weight</u>						
1	64.4		33.6		2.0	
8	76.5	76.1	21.0	21.2	2.5	2.7
15	75.4	79.3	21.6	17.1	3.0	3.6
23	76.3	80.0	21.6	16.3	3.1	3.7
37	79.6	75.8	16.1	20.0	4.3	4.2
51	80.8	78.0	14.3	17.6	4.9	4.4
72	82.3	80.2	12.6	15.2	6.1	4.6
99	84.4	82.2	10.5	12.5	5.1	5.3
133	87.6	84.6	7.9	10.5	4.5	4.9
154	85.8	-	10.2	-	4.0	-
168	87.6	-	8.7	-	3.7	-

¹ Average from a sample of 3 birds.

TABLE 3.— Protein concentration in carcass, internal organs and feathers of male and female BUT turkeys¹

Age, d	<u>Carcass</u>		<u>Viscera</u>		Feathers
	Male	Female	Male	Female	
			<u>%</u>		
8	19.2	18.5	20.8	19.9	87.0
15	18.7	18.6	18.6	18.3	87.1
23	18.7	20.4	17.8	18.0	87.5
37	20.7	22.6	16.6	17.0	87.9
51	20.0	20.2	17.9	16.8	88.4
72	22.2	21.5	17.0	17.0	89.0
99	22.8	18.6	17.9	17.0	89.5
133	20.2	20.0	17.4	16.0	89.5
154	21.0	-	15.7	-	89.2
168	20.6	-	14.4	-	88.8

¹ Average of duplicate determinations of pooled samples from 3 and 6 birds for carcass and viscera, and for feathers, respectively.

FIG. 1. Protein contained in feathers of turkeys in relationship to

age.

The relationship is $y = 1.91 + 0.056x - 0.00029x^2$;

$S_{gx} = 0.26$; $R = 0.956$. Open symbols, females; closed symbols, males-

1 the protein content of the viscera decreased with age and that of feathers
2 increased slightly with age. There were no consistent differences between
3 males and females in the protein content of the carcass and viscera.

4 The lipid content of the main carcass components is given in Table 4.
5 There were hardly any changes in the lipid content of either carcass or
6 viscera up to the age of 72 days. The first increase in carcass lipid is
7 apparent at the age of 99 days in both sexes. Carcass and viscera lipid
8 then continued to increase until the termination of the experiment at
9 133 days in females and 168 days in males. In most cases, lipid content
10 was higher in females than in males. However, since assays were made on
11 pooled samples, this difference could not be analyzed statistically.

12 Trial 2. Results of this balance trial in which the birds received the
13 protein-containing diet are given in Table 5. During the 6-day balance
14 period body weight changed very slightly. About 64% of the nitrogen
15 consumed was retained by the birds. The creatinine N excretion was less
16 than 1% of the nitrogen retained.

17 Trial 3. Results of feeding of the N-free diet are given in Table 6.
18 Feed intake during this period was somewhat lower than when the birds
19 were fed the complete diet; the initial body weight was, however, slightly
20 lower. The birds lost a small amount of weight during the period.
21 About 3.5 g of amino acid were excreted daily of which about 40% were
22 essential amino acids. The excretion of glutamic acid and glycine was
23 the highest among all the amino acids. It should be noted that tryptophane
24 excretion was not determined, since it is destroyed during acid hydrolysis.

25 Calculation of the protein requirements for maintenance. The requirement
26 for loss of skin integuments is equal to the N retention (Table 5) multiplied
27 by 6.25. The protein required to cover obligatory losses in the excreta

TABLE 4.- Lipid content of the carcass and internal organs of male and female turkeys¹

Age, d	<u>Carcass</u>		<u>Viscera</u>	
	Male	Female	Male	Female
	<u>%</u>			
8	2.51	2.52	3.40	3.56
15	1.91	2.08	2.73	2.65
23	1.31	2.16	2.62	2.43
72	1.80	2.47	2.31	2.44
99	2.76	5.12	3.46	3.75
133	7.73	9.96	5.10	8.52
154	8.50	-	6.74	-
168	9.94	-	9.03	-

¹ See footnote 1, table 3.

TABLE 5.—Results of a nitrogen balance trial of
adult turkeys consuming a protein-
containing diet

Parameter	Value
Body weight, initial (g)	17000 $\pm$ 1721 ¹
Body weight, final (g)	17114 $\pm$ 1790
Feed intake, g/d	301 $\pm$ 85
N intake, mg/d	3505 $\pm$ 1004
N excretion, mg/d	1202 $\pm$ 242
N retention, mg/d	2303 $\pm$ 890
Creatinine excretion, mg/d	123 $\pm$ 27

¹ Average of six birds $\pm$ Standard Deviation.

The experiment lasted 6 days.

TABLE 6.—Amino acid excretion of adult turkeys
consuming a nitrogen-free diet¹

Amino acid	mg/d	% of total amino acids
Aspartic acid	324 ± 88 ²	9.13
Threonine	215 ± 60	6.06
Serine	288 ± 81	8.12
Glutamic acid	425 ± 119	12.00
Proline	262 ± 67	7.39
Glycine	423 ± 117	11.93
Alanine	209 ± 65	5.89
Cystine	23 ± 14	.65
Methionine	54 ± 19	1.52
Valine	176 ± 46	4.96
Isoleucine	132 ± 31	3.72
Leucine	257 ± 64	7.24
Tyrosine	149 ± 43	4.20
Phenylalanine	150 ± 37	4.23
Histidine	87 ± 21	2.45
Lysine	190 ± 44	5.36
Arginine	182 ± 46	5.13

¹Body weight, initial, g 16528 ± 1981

 final, g 16325 ± 1916

Feed intake, g/d 249 ± 47

²Average of six birds ± standard deviation.

Results of a 6-day balance trial.

1 is the sum of the amino acids excreted during consumption of an N-free
2 diet (Table 6) plus the equivalent of glycine, arginine and methionine
3 needed for creatinine excretion (Table 5). Ten percent of this sum is
4 then deducted to account for the water contained in the amino acids
5 relative to protein. The calculated net requirements are then divided
6 by 0.85, the absorption coefficient. For use in the model, the result
7 is then divided by body weight raised to the power of $2/3$. The coefficient
8 (MA) thus calculated for the protein required for maintenance in the
9 turkey is $31.9 \text{ mg/g}^{2/3}$ of body weight, per day. The requirement for
10 maintenance was then calculated using Equation 4 and this coefficient.

11 Calculation of the protein requirements for weight gain. The percentage
12 of protein in the featherless carcass was obtained by combining the
13 percentage of protein in carcass and viscera (Table 3), weighted according
14 to the distribution of both (Table 2). The result of this calculation
15 did not show any consistent changes in protein composition with age nor
16 any consistent differences between sexes. Apparently an increase in
17 carcass protein concentration with age, as noted in broilers (Plavnik and
18 Hurwitz, 1983), was balanced by the increase in carcass fat. Thus, for
19 calculation of the requirement for weight gain, a constant average coefficient
20 of 0.1977 (CP) of protein in weight gain was taken and used in equation 5.

21 Calculation of the protein requirements for feathering. The product
22 of the relative weight of the feathers (Table 2) and their protein contents
23 (Table 3) is given in Fig. 1. Feather protein, as a fraction of body
24 weight, increased with age and peaked between 80 and 100 days, followed
25 by a decline. No consistent sex effect could be observed, and
26 the same function was taken for both males and females. Also in this
27 case, the protein values taken from the function were divided by 0.85,

1 the absorption coefficient as given in Equation 6.

2 Calculation of the amino acid requirements. For calculation of the amino
3 acid requirements, the protein requirement for each of the three functions
4 was multiplied by the appropriate fraction of the amino acid according to
5 Equation 8. The fractions (Table 7) of each
6 amino acid for maintenance was obtained by combining the endogenous
7 intestinal amino acid excretion (Table 6) with the product of the protein
8 retention (Table 5) and the amino acid composition of feathers, and with
9 the amino acids required for creatinine production. This sum was then
10 divided by the total protein required for maintenance. The fractional
11 amino acid requirements for feather and maintenance were similar, as also
12 noted by Leveille et al., 1960) for the chicken. The requirements for
13 carcass gain were higher for histidine and lysine, and lower for sulfur
14 amino acids than those for feathers and maintenance (Table 7).

15 Calculation of energy requirement. The parameters used for calculation
16 of the maintenance requirements as a function of temperature (Equations
17 1 and 2) given previously (Hurwitz et al., 1980b). The energy
18 required for weight gain was calculated according to the model, using
19 the values for fat content as given in Table 4 and Equation 3.

20 Body weight curve. The body weight curve, as given in Table 8, is the
21 result of measurements made on 25 male BUT birds, under the 24°C temperature-
22 controlled conditions.

23 The calculated requirements. The requirements for turkeys kept at 20° is
24 given in Tables 8 and 9. The requirements for energy increased with age
25 as body weight increased and peaked at the age of 127-133 days. The
26 requirements for total protein also peaked at the same time. When expressed
27 per calorie, the requirements for protein and amino acids changed only

TABLE 7.—The fractional essential amino acid requirements for turkeys

Amino acid	Maintenance	Carcass ¹	Feather
		$\frac{\% \text{ of N} \times 6.25}{6.9}$	
Arginine	7.3	6.9	7.2
Histidine	1.0	3.0	0.7
Lysine	2.4	8.0	1.9
Tryptophane	?	?	0.7
Aromatic amino acids ²	7.4	7.6	7.8
Phenylalanine	4.6	4.6	5.1
Sulfur amino acids	8.1	3.0	9.1
Methionine	1.7	2.7	0.7
Threonine	4.6	4.6	4.6
Leucine	7.4	9.0	8.1
Isoleucine	5.0	4.4	5.0
Valine	6.7	5.4	7.7

¹Including viscera.

²Phenylalanine and tyrosine.

TABLE 8.— The protein and energy requirements of male
BUT turkeys

Age d	Body weight ¹ g	Energy ² kcal/d	Protein ³	
			mg/d	mg/kcal
8	151	105	8366	80.0
15	338	158	13057	82.6
22	628	221	17642	79.8
29	1006	293	23672	80.7
36	1499	416	28135	67.6
43	2082	504	33625	66.7
50	2755	591	36625	66.7
57	3488	690	43410	62.9
64	4355	771	44672	58.9
71	5195	835	40916	49.0
78	5952	894	39738	44.4
85	6657	994	40866	41.1
92	7369	1055	40509	38.4
99	8052	1188	44408	37.4
106	8812	1264	43506	34.4
113	9569	1379	50467	36.6
120	10529	1458	50063	34.3
127	11422	1547	46487	30.0
134	12262	1437	37822	26.0
141	12862	1458	31775	21.8
148	13315	1487	29703	20.0

¹ Average of 25 birds.

² Requirements calculated for birds kept at 20° from the age of 36 d. Up to this age birds are kept under heaters. For calculation of the requirements, body weights were used as recorded.

³ In terms of ideal amino acid mixtures- not recommended for use in practical diets.

TABLE 9.—The protein and amino acid requirements of BUT male turkeys at 20°C¹

AGE	ARG	HIS	LYS	TRY	ARO	PHE	SAA	MET	THR	LEU	ISO	VAL
Days							mg/kcal					
8	5.61	1.92	5.11	.75	6.07	3.73	3.62	1.84	4.03	6.95	3.65	4.70
15	5.78	1.97	5.25	.77	6.26	3.84	3.76	1.89	4.16	7.17	3.77	4.86
22	5.60	1.86	4.96	.74	6.06	3.72	3.75	1.79	4.01	6.91	3.65	4.75
29	5.67	1.84	4.92	.75	6.13	3.77	3.89	1.78	4.05	6.99	3.71	4.83
36	4.75	1.54	4.11	.62	5.13	3.16	3.26	1.50	3.39	5.84	3.10	4.04
43	4.69	1.48	3.96	.61	5.06	3.12	3.31	1.45	3.33	5.75	3.07	4.02
50	4.36	1.38	3.68	.57	4.70	2.90	3.07	1.35	3.10	5.33	2.85	3.73
57	4.42	1.40	3.73	.58	4.77	2.94	3.12	1.37	3.14	5.41	2.90	3.78
64	4.09	1.24	3.31	.53	4.40	2.71	2.99	1.23	2.88	4.96	2.68	3.52
71	3.45	1.04	2.78	.45	3.71	2.28	2.54	1.05	2.43	4.17	2.27	2.97
78	3.14	.93	2.46	.40	3.36	2.07	2.35	.95	2.20	3.76	2.06	2.70
85	2.90	.85	2.25	.37	3.11	1.91	2.20	.87	2.03	3.47	1.91	2.50
92	2.71	.78	2.07	.35	2.90	1.79	2.09	.81	1.89	3.23	1.79	2.34
99	2.64	.76	2.03	.34	2.82	1.74	2.02	.79	1.84	3.15	1.74	2.28
106	2.43	.71	1.89	.31	2.59	1.60	1.83	.74	1.70	2.89	1.60	2.08
113	2.58	.80	2.12	.34	2.76	1.69	1.84	.82	1.82	3.09	1.69	2.18
120	2.42	.72	1.91	.31	2.59	1.59	1.80	.75	1.70	2.89	1.59	2.07
127	2.12	.54	1.70	.28	2.26	1.38	1.54	.67	1.48	2.51	1.39	1.79
134	1.84	.53	1.38	.24	1.94	1.19	1.41	.57	1.27	2.13	1.21	1.56
141	1.55	.42	1.09	.20	1.62	0.99	1.24	.48	1.06	1.76	1.03	1.31
148	1.42	.37	.97	.18	1.48	0.91	1.16	.44	.96	1.59	.94	1.21

¹The temperature effect prevails from 36 d of age. See Fig. 2 for abbreviations. The growth function and the energy and protein requirements are given in Table 8.

1 slightly during the first 5 weeks of age. From this age on the requirements
2 gradually decreased to about a quarter of the initial values, at the age of
3 148 days.

DISCUSSION

6 The BUT birds studied here grew at a somewhat faster rate than the
7 turkeys studied by Leeson and Summers (1980b), but the weight distribution
8 of the viscera and the protein in carcass were similar in the two studies. The
9 lipid content reported here is somewhat lower than that reported by
10 Leeson and Summers (1980b). This difference could have resulted either
11 from differences in the extraction method used by the two laboratories,
12 or from a true strain difference. It is also of interest to note that the
13 body lipid in both studies hardly changed in early life. An increase in
14 body lipid occurred between 84 and 91 days in the study of Leeson and
15 Summers^(1980b), whereas in the present study the increase occurred only after
16 99 days. In both studies little difference was noted in body lipid between
17 males and females at the young ages. In comparison with chickens (Leeson and
18 Summers, 1980a; Plavnik and Hurwitz, 1983), the carcass lipid in turkeys
19 is lower and carcass protein is higher at any given age. Similar to
20 chickens (Plavnik and Hurwitz, 1983), feathering increased with age during
21 early life. In the chicken the feathers tended to reach a plateau, whereas the
22 present results show a peak for turkeys at about 100 days of age, followed
23 by a decrease. This decrease in the proportion of feathers may have been
24 related to the increase with age in the proportion of muscle, specially
25 in the breast (Leeson and Summers, 1980b), without corresponding increases
26 in the length of bones (Hurwitz, S., unpublished), and also to the
27 increase in the proportion of deviscerated carcass with age (Table 2).

1 The present results indicate that of the total net protein requirements
2 for maintenance, close to 1/5 was needed for intestinal secretions and
3 about 3/4 was needed for replenishment of the protein lost from the skin.
4 A small fraction of some amino acid^s was required to support the obligatory
5 creatinine loss. When expressed on a metabolic weight basis, the protein
6 requirement of turkeys for maintenance, as determined in this study, was
7 about 40% higher than that determined for the chicken by Leveille and
8 Fisher (1958).

9 Examination of the requirements as given in Table 8 shows that the
10 model-calculated protein requirements are considerably lower than the
11 values given by the NRC (1977). From the nature of the model, however,
12 it is apparent that the calculated protein requirements are in terms of
13 ideal amino acid mixtures, not accounting for any waste due to excess
14 of amino acids. In order to evaluate the implication of the model on
15 the actual dietary protein levels, the model requirements have been used
16 as a basis in linear-program computations of practical type diets. Results
17 of this examination; not detailed here; show that the diets based on
18 the model requirements are lower in protein by about 1 to 2 percentage
19 points than the recommended levels of NRC(1977).

20 Reliability tests for the model predictions included some empirical
21 evaluation which will be detailed in a succeeding paper (Hurwitz et al.
22 1983). A comparison of the model-calculated requirements for amino acids
23 with those given by the NRC (1977) was made by plotting the two sets of
24 requirements against each other (Fig. 2). For most amino acids, the values
25 are distributed on the two sides of the $Y = X$ line. However, the model-
26 requirements for sulfur amino acids appeared to be always slightly higher
27 than those of the NRC (1977) and the lysine requirements were slightly

FIG. 2. The relationship between the model-calculated amino acid requirements and those of NRC (1977). The line describes $y = x$. Abbreviations: ARG = arginine; HIS = histidine; ISO = isoleucine; LEU = leucine; LYS = lysine; MET = methionine; ARO = phenylalanine + tyrosine; PHE = phenylalanine; THR = threonine; TRY = tryptophan; VAL = valine.

1 lower. The average percentage difference between the model and the NRC
2 (1977) requirements was $-1.7 \pm 15.1\%$ which suggests a very good agreement
3 between the two sets of values.

4 When the model protein requirements, in terms of ideal amino acid mixtures
5 are used in computation of diets, the concentration of protein
6 in the diets is the result of the most limiting amino acid.

7 Thus, limiting amino acids in diets can be detected during diet computations.

8 After sulfur amino acids, threonine and valine are suggested as
9 most limiting in soybean-corn or soybean-milo diets for turkeys up to

10 120 days of age. These amino acids have been indicated by Stas and Potter

11 (1982) as limiting. The emergence of threonine and valine as the first

12 limiting amino acids after sulfur amino acids in the diets of young turkeys,

13 may offer an explanation for the lack of response to lysine noted by

14 Hurwitz et al. (1983). Lysine, however, was found to become limiting in

15 diets designed for turkeys over 16 weeks of age.

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The Amino Acid Requirements of Growing Turkeys
2. Experimental Validation of Model-Calculated
Requirements for Sulfur Amino Acids and Lysine¹

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ABSTRACT. The response to protein and the requirements for sulfur amino acids and lysine have been evaluated in male turkeys throughout the growth period as an experimental validation of model-calculated requirements (Hurwitz et al., 1983). The sulfur amino acid requirements were 3.4 and 3.1 mg/kcal for 1-week-old and 5-week-old turkeys, respectively. The requirements for lysine were 4.8, 2.7 and 2.2 mg/kcal for 1-, 12- and 16-week-old turkeys, respectively. These levels were in close agreement with the model predictions. Dietary protein in diets calculated on the basis of the model was sufficient to maintain maximal growth and feed efficiency. The results were the basis for accepting the general validity of the model-calculated requirements (Hurwitz et al., 1983).

POULTRY SCIENCE

INTRODUCTION

Requirements for amino acids in turkeys, as estimated empirically, tend to vary within a wide range. In many cases this variation may be traced to corresponding differences in growth rate and feed intake as determined by genetic and environmental factors. In a previous study, a model was suggested for the calculation of the amino acid requirements (Hurwitz et al., 1983) in which the growth curve, body composition and environmental temperature served as input variables. Requirements calculated by the model, appeared to be in fair agreement with those of NRC (1977) but some deviations from these requirements suggested the need for experimental validation of the model-estimates, under the conditions in which the model had been calibrated. As was expected on the basis of experimental work, the model suggested that sulfur amino acids, methionine and cystine, were first limiting in young turkey diets. Therefore, this amino acid pair was tested first in the validation experiments. Since lysine was marginal in the young turkey diet and became limiting in diets of turkeys over 16 weeks old (Hurwitz et al., 1983), its requirements were also examined.

The amino acid requirements in absolute terms and relative to each other vary with age. Therefore, the amino acids in the present study were tested at two or three ages. The classical approach was taken according to which the lowest level of the amino acid that supports maximal gain and feed efficiency was considered as the minimum requirement.

METHODS

Birds: One-day-old male Broad Breasted White turkeys

(British United Turkeys, BUT) were obtained from a commercial

TABLE 1.— Composition of the experimental diets, Trials 1 and 2

Ingredients	Trial 1		Trial 2	
	Diet 1	Diets 2-6 ¹	Diet 1	
			kg/ton	
Soybean oil meal (45% protein)	521	385	468	343
Fish meal, Norwegian	20	20	20	20
Soybean oil, refined	36.4	17.8	44.4	30.4
Limestone	12.6	13.7	13.7	13.7
Dicalcium phosphate	21.1	23.7	20	20
Sodium chloride	3	3	3	3
Vitamin and trace minerals ²	5.5	5.5	5.5	5.5
Lysine·HCl (80%)	-	3.0	.1	3.0
DL-methionine	2.3	Variable	1.3	Variable
Sorghum grain	380	Variable	524	Variable
<u>Calculated composition</u> ³				
Metabolizable energy, kcal/kg	2800	2800	2900	2900
Protein, %	28.0	23.5	26.0	21.9
Lysine, %	1.74	1.50	1.60	1.33
Sulfur amino acids, %	1.05	.69 ⁴	.90	.64 ⁴

¹Added DL-methionine, kg/ton: Diet 2, 0; Diet 3, 1; Diet 4, 2; Diet 5, 3; Diet 6, 4, at the expense of sorghum grain.

²Hurwitz et al. (1978a).

³The composition of feed ingredients was taken from Hubble (1971); the fractions of amino acids in protein were taken from Anderson and Warnick (1969).

⁴Basal concentration.

1 hatchery. Up to the age of 4½ weeks, they were housed in 3-deck battery
2 brooders situated in a temperature-controlled room at 24±1 C with constant
3 illumination. They were then transferred to individual growing cages
4 (Hurwitz et al., 1980) and kept under the same environmental conditions.
5 Until the beginning of each experiment, the birds were fed commercial
6 diets appropriate for their age, and were given feed and water ad libitum
7 at all times.

8 Before the start of an experiment, all birds were weighed. One-
9 third of the birds with extreme weights were eliminated and the rest
10 were distributed among the various groups ensuring a similar mean and
11 distribution in each group. Each dietary treatment was applied to four
12 or five replicate groups.

13 Diets. All diets were computer-formulated with
14 practical-type ingredients. Each experiment included a control diet
15 based on NRC (1977) recommendations.

16 Statistical analysis. Analyses of variance and regression analyses
17 were computed according to Snedecor and Cochrag (1967). Segmented
18 regressions were computed as suggested by Robbins et al. (1977), using
19 the SAS procedure (Helwig, 1979).

20 Design. The study included the evaluation of requirements at different ages
21 of sulfur amino acids (Trials 1 and 2), and of lysine (Trials 3-5).

22 RESULTS

23 Trials 1 and 2: Requirements for sulfur amino acids. Trial 1 was conducted
24 with 1-week-old males. The trial lasted 3 weeks and included six dietary
25 treatments (Table 1) given to five replicate groups of ten each.

1 Trial 2 was started with 5-week-old males, kept in individual
2 cages, and included six dietary treatments, each applied to four replicate
3 groups of six. The trial was continued for 2 weeks. The results are
4 given in Figs. 1 and 2. In both trials, weight gain and feed efficiency
5 were somewhat higher in the NRC (1977) controls than at the plateau value
6 representing the maximal response to the sulfur amino acid in the test
7 diets. The sulfur amino acid requirement for the 1-week-old turkey was
8 estimated at 0.92 ± 0.04 % according to weight gain and at $0.93 \pm .07$ %
9 according to feed efficiency. These represent 3.4 mg/kcal, compared with
10 the model prediction of 3.6 mg/kcal. The requirement for the 5-week-old
11 turkey was estimated at 0.91 ± 0.08 % and 0.94 ± 0.09 % according to weight gain
12 and feed efficiency, respectively, corresponding to 3.1-3.2 mg/kcal,
13 compared with a level of 3.3 mg/kcal as calculated by the model.

14
15 Trial 3: The lysine requirement of the 1-week old turkey. The experiment included:

16 Diet 1, designed according to NRC (1977) recommendations and
17 containing 29% protein; Diet 2, designed according to amino acid restrictions
18 slightly lower than the model-calculated requirements (Hurwitz et al.,
19 1983), containing 25.8% protein; and test diets containing 23.3% protein,
20 in order to reach lysine restriction.

21 The results presented in Table 3 indicate that a protein level
22 slightly lower than that contained in diets designed on the basis of the
23 model (Hurwitz et al., 1983) insured maximal weight gain and feed efficiency,
24 whereas a lower protein level as used in the test diets was deficient.
25 A response to lysine supplementation was obtained only with the lowest
26 level of supplementation, so that the lysine requirement with a somewhat
27 deficient protein level was between 1.36 and 1.44% or 4.7 and 4.8 mg/kcal,

FIG. 1. The response of 1-week-old male turkeys to dietary sulfur amino acids. Initial body weight was 149-151 g. The standard errors for the plotted values taken from the analysis of variance were 14, 21 and 0.012 for weight gain, feed intake and feed efficiency, respectively.

The regression equations are:

$$\text{Gain} = 855 + 590 (x - .92)$$

(12) (.491) (.04)

$$\text{for } x \geq .92, \text{ Gain} = 855$$

(12)

$$\text{Feed intake} = 1265 + 717 (x - .82)$$

(13) (316) (.05)

$$\text{for } x \geq .82, \text{ Feed intake} = 1265$$

(13)

$$\text{Efficiency} = .669 + .25 (x - .932)$$

(.009) (.01) (.068)

$$\text{for } x \geq .93, \text{ Feed efficiency} = .669$$

(.009)

The standard deviation for each parameter is given in parentheses, under the value. Each treatment included 4 replicate groups of ten birds. Results of trial 1.

FIG. 2. The response of 5-week-old male turkeys to dietary sulfur amino acids. The initial body weight was 1416-1475 g. The standard errors of the plotted values taken from the analysis of variance, were: 28,29 and .012 for weight gain, feed intake and feed efficiency, respectively. The regression equations are:

$$\text{Gain} = \underset{(18)}{832} + \underset{(176)}{550} (x - \underset{(.08)}{.91})$$

$$\text{for } x \geq .91, \text{ Gain} = \underset{(18)}{832}$$

$$\text{Feed intake} = \underset{(20)}{1878} + \underset{(205)}{495} (x - \underset{(.07)}{.84})$$

$$\text{for } x \geq .84, \text{ Feed intake} = \underset{(20)}{1878}$$

$$\text{Efficiency} = \underset{(.007)}{.442} + \underset{(.07)}{.18} (x - \underset{(.09)}{.94})$$

$$\text{for } x \geq .94, \text{ Efficiency} = \underset{(.007)}{.442}$$

The standard deviation for each parameter is given in parentheses, under the value. Results of trial 2. Each treatment included four replicate groups of six birds.

TABLE 2.— Composition of the experimental diets, Trial 3

Ingredient	Diet 1	Diet 2	Diets 3-8 ¹
		<u>Kg/ton</u>	
Soybean oil meal (45% protein)	581	483	411
Wheat bran	-	26	62
Soybean oil, refined	64	61	59
Limestone	15	15	15
Dicalcium phosphate	30	30	30
Sodium chloride	4	4	4
Vitamin and trace minerals ²	3.5	3.5	3.5
DL-methionine	2.5	3.5	4.1
Lysine·HCl (80%)	-	3.4	Variable
Sorghum grain	300	371	Variable
<u>Calculated composition</u> ³			
Metabolizable energy, kcal/kg	2900	2900	2900
Protein, %	29.0	25.8	23.3
Sulfur amino acid, %	1.09	1.09	1.09
Lysine, %	1.82	1.82	1.36 ⁴

¹Added lysine·HCl (80%), kg/ton: Diet 3, 0; Diet 4, 1; Diet 5, 2; Diet 6, 3; Diet 7, 4; Diet 8, 6, at the expense of sorghum grain.

²Hurwitz et al. (1978a)

³See footnote 3, Table 1.

⁴Basal concentration.

TABLE 3.— The response of 1-week-old poult to diets with different concentrations of protein and lysine, Trial 3¹

Diet No.	Description	Weight gain ² g/2wk	Feed intake g/2wk	Efficiency
1	NRC (1977)	659	1035	0.628
2	Model ³	663	1030	0.625
3	Test, 0 lysine	566	936	0.600
4	Test, 0.8 lysine ⁴	600	1001	0.610
5	Test, 1.6 lysine	601	990	0.611
6	Test, 2.4 lysine	599	985	0.600
7	Test, 3.2 lysine	604	1020	0.582
8	Test, 4.8 lysine	607	984	0.614
	SE ⁵	11	20	0.013

¹Dietary protein level is given in Table 2. Each treatment included five replicate groups of ten birds.

²Initial body weight was 133 g.

³Hurwitz et al. (1983).

⁴Kg/ton.

⁵Standard error, taken from the tables of analysis of variance.

TABLE 3.— The response of 1-week-old poult to diets with different concentrations of protein and lysine, Trial 3¹

Diet No.	Description	Weight gain ² g/2wk	Feed intake g/2wk	Efficiency
1	NRC (1977)	659	1035	0.638
2	Model ³	663	1030	0.646
3	Test, 0 lysine	566	936	0.605
4	Test, 0.8 lysine ⁴	600	1001	0.600
5	Test, 1.6 lysine	601	990	0.610
6	Test, 2.4 lysine	599	985	0.608
7	Test, 3.2 lysine	604	1020	0.592
8	Test, 4.8 lysine	607	984	0.617
	SE ⁵	11	20	0.013

¹Dietary protein level is given in Table 2. Each treatment included five replicate groups of ten birds.

²Initial body weight was 133 g.

³Hurwitz et al. (1983).

⁴Kg/ton.

⁵Standard error, taken from the tables of analysis of variance.

1 compared with the 5.1 and 5.2 mg/kcal, predicted by the model.

2 Trial 4 : The lysine requirement of 12-week-old turkeys.

3 The trial included an NRC (1977) control diet; a
4 diet based on the model requirements (Hurwitz et al., 1983), fortified
5 with lysine; and four low-protein test diets with graded levels of lysine
6 (Table 4). The results (Table 5) show that poult fed the diet based on
7 the model performed as well as, or slightly better than, the NRC controls.
8 The lower protein test diets supported a poorer feed efficiency than the
9 higher protein diets. A response to lysine with regard to both gain and
10 feed efficiency was obtained only with the first level of lysine
11 supplementation. At this level, the lysine concentration was 2.7 mg/kcal,
12 in good agreement with the model requirement of 2.6 mg/kcal.

13 Trial 5: The lysine requirement of 16-week old male turkeys.

14 The 3-week experiment consisted of
15 six dietary treatments (Table 6), including an NRC (1977) control (Diet 1)
16 and diets based on the model (Diets 2-6) supplemented with graded amounts
17 of lysine. The results of this trial are given in Fig. 3. For some
18 reason the plateau weight gain and feed efficiency obtained with
19 the model diets exceeded those obtained with the NRC (1977) diet which
20 was higher in protein.

21 The lysine requirement level as estimated in this trial was $.73 \pm .02$ %
22 and $.73 \pm .02$ % from weight gain and feed efficiency data, respectively,
23 corresponding to 2.2 mg/kcal, in comparison with the model requirement
24 of 2.0 mg/kcal.

26 DISCUSSION

27 The protein requirements, calculated by the model (Hurwitz et al.,

TABLE 4.— Composition of the experimental diets, Trial 4

Ingredients	Diet 1	Diet 2	Diets 3-6 ¹
		kg/ton	
Soybean oil meal (45% protein)	252	172	137
Fish meal, Norwegian	20	20	20
Soybean oil, refined	36	25.6	19.4
Limestone	5	5	5
Dicalcium phosphate	24	24	24
Sodium chloride	3	3	3
Vitamins and trace minerals ²	5.5	5.5	5.5
DL-methionine	.1	2.0	2.0
Lysine·HCl (80%)	.3	4.0	Variable
Sorghum grain	655	740	Variable
<u>Calculated composition</u> ³			
Metabolizable energy, kcal/kg	3100	3100	3100
Protein, %	18.6	16.2	14.7
Sulfur amino acids, %	.66	.67	.64
Lysine, %	1.02	1.02	.68 ⁴

¹Added lysine·HCl (80%), kg/ton: Diet 3, 0; Diet 4, 2; Diet 5, 3; Diet 6, 4, at the expense of sorghum grain.

²Hurwitz *et al.* (1978a).

³See footnote 3, Table 1.

⁴Basal concentration.

TABLE 5.- The response of 12-week-old turkeys to dietary lysine, results of Trial 4

Diet No.	Description	Weight gain ¹ g/3 wk	Feed intake g/3 wk	Efficiency
1	NRC (1977)	1880	6609	0.284
2	Model ²	1923	6540	0.292
3	Test, 0 lysine ³	1370	6113	0.226
4	Test, 1.6 lysine	2009	6568	0.304
5	Test, 2.4 lysine	1716	6070	0.282
6	Test, 3.2 lysine	1838	6308	0.291
	SE ⁴	186	270	0.020

¹Initial body weight was 6037-6238 g.

²Hurwitz et al. (1983).

³Kg/ton.

⁴Standard error, taken from the tables of analysis of variance. Each treatment included four replicate groups of five birds.

TABLE 6.— Composition of the experimental diets, trial 5

Ingredient	Diet 1	Diets 2-6 ¹
		<u>kg/ton</u>
Soybean oil meal	168	110
Fish meal, Norwegian	10	10
Soybean oil, refined	55.3	51.4
Limestone	5.7	4.4
Dicalcium phosphate	21.6	31.6
Sodium chloride	3	3
Vitamin and trace minerals ²	5.5	5.5
DL-methionine	1.2	1.2
Lysine·HCl (80%)	-	variable
Sorghum grain	731	variable
<u>Calculated composition</u> ³		
Metabolizable energy, kcal/kg	3300	3300
Protein, %	14.9	12.9
Sulfur amino acids, %	.46	.50
Lysine, %	.71	.56 ⁴

¹With added lysine·HCl (80%), kg/ton: Diet 3, 0; Diet 4, 1; Diet 5, 2; Diet 5, 3; Diet 7, 4; at the expense of sorghum grain.

²For composition, see Hurwitz et al. (1978a).

³See footnote 1, Table 1.

⁴Basal concentration.

FIG. 3. The response of 16-week-old turkeys to dietary protein and lysine. Initial body weight was 8620-9170 g. The standard errors of the plotted values, taken from the analysis of variance, were 114, 368 and 0.012 for weight gain, feed intake and feed efficiency, respectively. The regression equations are:

$$\text{Gain} = 2189 + 6003 (x - .73) \\ (776) \quad (1180) \quad (.02)$$

$$\text{for } x \geq 0.73, \text{ Gain} = 2189 \\ (776)$$

$$\text{Feed intake} = 8335 + 8190 (x - .73) \\ (200) \quad (3077) \quad (.04)$$

$$\text{for } x \geq .73, \text{ Feed intake} = 8335 \\ (200)$$

$$\text{Efficiency} = .263 + .65 (x - .73) \\ (.006) \quad (.10) \quad (.02)$$

$$\text{for } x \geq .73, \text{ Efficiency} = .263 \\ (.006)$$

The standard deviation for each parameter is given in parentheses under the value. Results of trial 5. Each treatment included two replicate groups of ten birds.

1 1983), are given in terms of ideal protein mixtures. Since an excess of
2 amino acids cannot be avoided in practical diets, these requirements do
3 not become effective restrictions in computer diet-formulation. The
4 dietary protein level is then the result of the limiting amino acid(s).
5 Thus, the dietary protein in turkey-diets designed according to the model
6 was determined by the supply of valine and threonine up to 16 weeks of
7 age, and also by lysine at more advanced ages. The protein levels as
8 calculated by the model were lower by 2 to 3 percentage points than the
9 NRC (1977) recommendations but, according to the results of trials 3 to
10 5, they were sufficient to support maximal growth and feed efficiency
11 during the period for which they were designed. Similar protein levels
12 have been found by Behrends and Waibel (1980) to be adequate. The results
13 of this testing for protein requirements at ages distributed throughout
14 the growing period, confirm the usefulness of the model for prediction
15 of the dietary protein level.

16 The model-calculated requirements for sulfur amino acids were similar
17 to those of the NRC (1977). The results of trials 1 and 2 provide
18 requirement levels in slightly protein-deficient diets, which are somewhat
19 below the model-calculated requirements, but not significantly different
20 when the variance of the determined requirement is considered. This
21 agreement between the calculated (Hurwitz et al., 1983) and the determined
22 requirements (Figs. 1 and 2), on the one hand, and with the results of
23 Potter and Shelton (1976, 1979, 1980), Murillo and Jensen (1976) and
24 Kummero et al. (1970) on the other, validates the model for calculation
25 of the sulfur amino acid requirements. It should be pointed out, however,
26 that these calculated requirements are 10-20% higher than those of D'Mello
27 (1976) and Behrends and Waibel (1980).

1 The model-calculated lysine requirements are about 10% lower than
2 those of NRC (1977) and of those of Kummer et al., (1970). They are,
3 however, in good agreement with those of D'Mello and Emmans (1975), and
4 with Warnick and Anderson (1973). The demonstration by the model that
5 in soybean-corn or soybean-milo diets, lysine is not the first limiting
6 amino acid for the young (1-4-week-old) turkey after sulfur amino acids,
7 is in agreement with the results of Potter and Shelton (1976) and those
8 of Waldroup et al. (1979) who were not able to obtain a response to added
9 lysine in practical diets of young turkeys. At early ages, a low-protein
10 diet was needed to obtain a lysine response (Tables 2-5). A significant
11 lysine response could be shown in protein-adequate diets fed to 16-week-
12 old birds (Fig. 3). As was the case with sulfur amino acids, the empirically
13 determined lysine requirements are in agreement with the model-calculated
14 ones.

15 The model requirements, presented in the preceding paper (Hurwitz
16 et al., 1983), represent the sum of the needs for maintenance and growth.
17 The parameters needed for the model were collected at the level of detail
18 which separated the requirements into these entities - amino acids excretion
19 and retention, and carcass composition. The examination of the model in
20 the present study included the evaluation of the overall requirements for
21 various age points at a higher level of organization. The validity of
22 the model is then affirmed by the agreement of the model requirements for
23 protein, sulfur amino acid and lysine with the independently determined
24 requirements of the present study.

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MINERAL METABOLISM

SPERM METABOLISM AND PRESERVATION

Metabolism and fertility of turkey spermatozoa: The effect of pH*

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Summary. The oxygen uptake during a 4-h incubation period at 37°C, and the motility of turkey spermatozoa before and after incubation, increased significantly with increasing pH from 6.3 to 8.8. The glucose consumption by the spermatozoa and its oxidation were also higher at pH 7.8 than 6.8.

The fertility of turkey semen, on the other hand, was better preserved both in vivo and in vitro when suspended in a low-than in a high pH medium.

Introduction

Few studies have been carried out of the metabolism of turkey spermatozoa and of its relationship to the preservation of their fertilizing capacity in vitro. McIndoe & Lake (1973) and Sexton (1974) investigated the metabolism of fowl and turkey spermatozoa and found that sperm respiration rate of both was stimulated by glucose and fructose and that endogenous respiration takes place also in the presence of exogenous substrates.

Hydrogen ion concentration is one of the factors which influence motility, viability and metabolism of spermatozoa (Mann & Mann, 1981). Sexton & Giesen (1982) reported that turkey spermatozoa showed higher

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motility and lower fertility at pH 7.5 than at pH 6.5; the effect of pH was, however, conditioned by the osmolarity of the medium. Lake & Ravie (1982) obtained better fertility of turkey spermatozoa at pH 7.1 than at pH 5.8 or 7.4. Brown, Graham & Crabo (1972) reported that the integrity of turkey spermatozoa during storage was maintained better in some hydrogen ion buffers described by Good, Winget, Winter & Connolly (1966) than in the "traditional" ones, and that at a pH of ~ 7.5 motility was better with Na or K than with Tris as the titration base.

One has to consider the possibility that various functions of spermatozoa may respond differently to different buffers or hydrogen ion concentrations and that there may be also interactions between them. The present study deals with the effect of a wide range of buffers and hydrogen ion concentrations and their interactions on the motility, metabolic activity and fertility of turkey spermatozoa.

Materials and Methods

Semen collection.

Pooled ejaculates, uncontaminated with transparent fluid, were obtained by abdominal massage (Lake & Stewart, 1978) from British United turkeys. The toms were housed in individual cages at 25°C and under continuous light. The males were kept on a regular routine of semen collection spaced not more than 5 days apart, in order to minimize the number of degenerated spermatozoa in the ejaculates (El-Jack & Lake, 1966). Only semen with vigorously swirling motion was used. The semen was collected and kept at 20°C until the start of the laboratory work 30-40 min later. Sperm density was measured with an EEL colorimeter calibrated against haemocytometer counts.

Metabolic tests

The composition of the medium used for the sperm suspensions was:
NaCl - 111 mM; KCl - 3 mM; CaCl_2 - 0.8 mM, MgCl_2 - 0.5 mM; NaH_2PO_4 - 2.0 mM;

glucose - 15 mM; vitamins* - 7.0 µg/100 ml; amino acids** - 1.0 mg/100 ml; penicillin - 200 U/ml; streptomycin - 200 µg/ml; neomycin and kanamycin - 10 µg/ml of each. The medium's osmolarity was 330 mOsm.

In order to cover a pH range of 6.3-9.3, six different buffers were used at a concentration of 15 mM, having pK values at 20°C around the pH it was desired to maintain. The buffers used were: Aces (N-[2-acetamido]-2-aminoethane sulfonic acid) - pK 6.9; Hepes (N-2-hydroxyethyl piperazine-N'-2-ethane sulfonic acid) - pK 7.55; Tricine (N-Tris[hydroxymethyl]methyl glycine) - pK 8.15; glycylglycine - pK 8.4; Tris ([hydroxy-methyl]amino methane) - pK 8.3; glycine - pK 9.2.

In each experiment the effect of two or three pH values, provided by a particular buffer, was examined. The pH ranges of two, and sometimes three, buffers overlapped so that it was possible to examine also the effects of the different buffers at the same pH (except for the extreme cases). In order to remove the seminal plasma, the semen was diluted at a ratio of 1:1 with the above medium buffered with Hepes at pH 7.3 and centrifuged at 1200 x g for 15 min. The supernatant was discarded and the sperm was resuspended to the original volume of semen with the same medium but buffered at one (the lowest) of the pH values to be tested. The resuspended sperm was then split and further diluted to a concentration of 1×10^9 cells/ml with the medium buffered at two or three pH values.

The oxygen uptake of the spermatozoa was measured at 30-min intervals during 4 h of incubation by the direct Warburg technique (Umbreit, Burris

** The composition of vitamins and amino acids was as in Eagle's Basal Medium, excluding L-glutamine (Bio-Lab Cat., Bio-Lab Ltd. Lab., Jerusalem, Israel.

& Stauffer, 1957) with 13-ml flasks containing 1.0 ml sperm suspensions (1×10^9 spermatozoa). The glycolytic activity of the spermatozoa was assessed by measuring glucose disappearance (Hugget & Nixon, 1957), lactic acid accumulation (Barker & Britton, 1957), as well as the formation of fructose in the medium (Mann, 1948). Glucose consumption was calculated by reduction of accumulated fructose from the glucose which had disappeared. The CO_2 production from glucose was determined by using ^{14}C -U-glucose (Radiochemical Centre, Amersham, England), which was added to the medium, and the $^{14}\text{CO}_2$ trapped in the KOH of the center well was assayed. The glucose oxidized was calculated on the basis of specific activity of the ^{14}C -U-glucose (Murdoch, White & Seamark, 1970).

The pH of the sperm suspensions was measured before and after incubation.

Sperm viability before and during incubation was assessed in the 1×10^9 /ml sperm suspensions by estimating the percentage of motile sperms - PMC (0-100) at x 400 magnification with an interference microscope at room temperature.

Fertility tests

Semen was pooled from several toms. Only semen with vigorously swirling motion and a concentration of at least 7.5×10^9 sperm/ml was used for inseminations. The semen was divided into 2-3 portions, diluted at a ratio of one part of semen with 2 parts (1:2) of medium buffered with Hepes at pH 6.8, 7.3 or 7.8 and used either fresh or after storage for 4 h. Storage was carried out in vials containing 1 ml of the sperm suspensions and kept at 15°C . The semen vials (10 mm diameter) were plugged lightly with tissue paper (Lake & Ravie, 1979) and were slightly agitated at 30-min intervals to provide aeration (Lake, personal communication). Viability was scored before and after storage.

The insemination dose was 0.06 ml of diluted semen and contained at least 150×10^6 spermatozoa.

Several series of single inseminations of females held in individual cages were carried out. Eggs were collected during days 2-22 after insemination. Fertility was determined by candling the eggs after 8 days of incubation.

Since time of insemination relative to the time of oviposition has been shown to have a major effect on fertilization (Christensen & Johnston, 1975), insemination with both fresh and stored semen were carried out at the same hour of the day. Therefore, semen designed to be used after storage was collected from one group of randomly chosen males 4 h before the scheduled time of inseminations, whereas semen to be used in the fresh state was collected from another group of males, immediately before the inseminations. It was assumed that the differences in the fertility between fresh and stored semen were due to the effect of storage rather than to the differences in the fertility between the different sperm samples, because only semen samples of very high quality were used.

Statistical analysis

The "net effect" of the pH after its dissociation from the effect of the different buffers on the oxygen uptake of the spermatozoa was analyzed by the General Linear Models procedure (SAS Users Guide, 1979), and the means of each pH value were compared by the t-test.

The results of the aerobic metabolism which included respiration and glycolysis were subjected to analysis of variance and to Duncan's Multiple Range Test.

Chi-square test was used to compare the fertilization rates of semen under various treatments.

Results

Oxygen uptake

The oxygen uptake and viability of the spermatozoa during a 4-h incubation period in different buffers and in different pH values are presented

in Table 1. The effect of the buffer at each given pH was found to be not significant. The "net effect" of the pH, dissociated from that of the buffer, was calculated. The results show that the oxygen uptake and the motility of the spermatozoa increased significantly with rising pH up to 8.8. At these pHs the motility was also depressed even before incubation and the spermatozoa were immotile before the end of the incubation period (Table 1).

Glucose metabolism was measured at three pH levels (6.8, 7.3, 7.8), which could be covered by one single buffer (Hepes) during a 2-h incubation period, i.e., before the viability of the spermatozoa was severely affected by the low pH.

The glucose consumption and its oxidation to CO_2 were measured and the rate of oxidation other than that due to glucose was calculated. The results are summarized in Table 2. The oxygen uptake by the spermatozoa at the higher pH values was significantly higher. No particular trend was found in the glucose disappearance at the different pH values, but a decrease in the accumulation of fructose with increasing pH was apparent.

The glucose consumption, therefore, increased with increasing pH. A similar increase was found in the CO_2 production from glucose, and more in the second than in the first hour of incubation (Table 2). The amount of glucose converted to lactic acid did not differ significantly among the different pHs. The calculated values of oxygen needed for the glucose oxidation revealed that a large proportion of the oxygen consumption was used for the oxidation of substances other than glucose, more during the first than the second hour of incubation.

Fertility tests

The results (Table 3) show that the fertilizing capacity of turkey spermatozoa is better preserved, both in vivo and in vitro, in media with

Table 1: Oxygen uptake ($\mu\text{M O}_2/10^9$ sperm/4 h) by turkey spermatozoa in different buffers and hydrogen ion concentrations

Buffer	pH						
	6.3	6.8	7.3	7.8	8.3	8.8	9.3
Aces	(3)2.7±.3*	(3)4.7±.6	(3)6.8±.6				
Hepes		(5)5.5±.9	(5)8.1±.4	(9)11.8±.5			
Tricine				(9) 9.2±.7	(9)10.6±.8		
Glycylglycine					(9) 9.6±.6	(9)12.6±.5	
Tris					(6)10.8±1.3	(6)12.6±.7	
Glycine						(6)12.0±.5	(6)11.1±.4
Calculated oxygen uptake**	1.5±1.8 ^a	3.3±1.0 ^a	5.8±.84 ^b	9.5±.6 ^c	10.9±.5 ^c	13.5±.7 ^d	12.7±1.3 ^{cd}
Final pH	6.25	6.76	7.11	7.54	7.88	8.18	8.76
PMC (initial-final)	38 - 0	45 - 0	48 - 27	55 - 40	84 - 46	77 - 51	73 - 58

* Results are shown as mean $\pm$ SE. In parentheses, number of experiments.

** The results are least square estimates of the adjusted means $\pm$ SE and show the "net effects" of the pH. Different superscript letters represent significantly different results ($P < .01$) - t-test.

Table 2: Aerobic metabolism of turkey spermatozoa at different pH levels

($\mu\text{M}/10^9$ spermatozoa; Means $\pm$ SEM of five replicates)*

Length of incubation (min)	pH	Glucose disappearance	Fructose accumulation	Glucose consumption	Lactic acid accumulation	CO ₂ production from glucose	O ₂ uptake	O ₂ used for other than glucose oxidations
0-60	6.8	1.77 $\pm$.28	1.17 $\pm$.08	0.60 $\pm$.28	0.26 $\pm$.07	0.78 $\pm$.16 ^A	2.67 $\pm$.22 ^A	1.89 $\pm$.16 ^A
	7.3	1.69 $\pm$.22	1.03 $\pm$.13	0.66 $\pm$.28	0.18 $\pm$.03	1.44 $\pm$.14 ^B	3.61 $\pm$.05 ^B	2.17 $\pm$.15 ^A
	7.8	1.74 $\pm$.23	0.99 $\pm$.16	0.75 $\pm$.24	0.32 $\pm$.06	1.36 $\pm$.17 ^B	4.17 $\pm$.30 ^B	2.81 $\pm$.24 ^B
60-120	6.8	1.46 $\pm$.21	1.09 $\pm$.16	0.37 $\pm$.15	0.12 $\pm$.04	1.12 $\pm$.16 ^a	2.31 $\pm$.24 ^a	1.19 $\pm$.15
	7.3	1.85 $\pm$.35	0.97 $\pm$.16	0.89 $\pm$.25	0.15 $\pm$.03	1.78 $\pm$.36 ^{ab}	3.16 $\pm$.17 ^b	1.38 $\pm$.39
	7.8	1.63 $\pm$.22	0.90 $\pm$.10	0.73 $\pm$.19	0.29 $\pm$.12	2.53 $\pm$.25 ^b	3.75 $\pm$.29 ^b	1.22 $\pm$.22

* Comparisons as to the significance of the results were made vertically and separately for 0-60 and 60-120 min of incubation. Different superscript letters indicate statistically significant differences ($P < 0.05$) - Duncan's Multiple Range Test.

Table 3: Percentages of fertile eggs after single inseminations with fresh or stored (for 4 h) semen suspended in a medium at different pHs.

Semen type	pH	Days after inseminations		
		2 - 8	9 - 15	16 - 22
Fresh	6.8 (27)*	89.0 (100) ^{a**}	84.0 (100) ^a	80.0 (60) ^{ab}
	7.3 (31)	85.5 (110) ^a	77.6 (94) ^{ab}	71.9 (57) ^{bc}
	7.8 (23)	82.7 (52) ^a	75.9 (54) ^a	55.0 (40) ^c
Stored	6.8 (31)	79.5 (88) ^d	72.6 (95) ^{de}	60.0 (85) ^e
	7.3 (22)	86.1 (72) ^{ad}	77.9 (68) ^{ade}	62.8 (43) ^{ce}
	7.8 (35)	51.1 (90) ^f	44.2 (95) ^{fg}	37.2 (86) ^g

* In parentheses, number of hens.

** In parentheses, number of eggs.

Different superscript letters indicate significant differences at $P < 0.05$ - Chi-square test. Comparisons to be made within vertical columns of the semen type, between fresh and stored semen for each pH and between the different periods after insemination for each pH value.

low than with high pH values. With fresh semen, high and similar fertilization rates were obtained at all pH levels during the first and second weeks of egg collection. During the third week of collection the decrease in the fertilization rate was statistically significant with the semen diluted at the highest pH (7.8). Similarly, when stored semen was used, the decline in the fertility was more pronounced at pH 7.8 than at the lower pH values and during the third period than the first two periods of egg collection.

Discussion

The formation of fructose from glucose has so far been reported for fowl spermatozoa only (Lorenz, 1958; Scott, White & Annison, 1962). The present study revealed that the same process occurs also during incubation of turkey spermatozoa. The mechanism and the physiological purpose of this formation are not known.

The viability and metabolic rate of the sperm were depressed at the lower pHs. The O_2 consumption increased significantly with increasing pH. Sexton & Giesen (1982) found that at an osmolarity of 280 mOsm, but not at 350 mOsm, respiration rate was significantly higher at pH 7.5 than at pH 6.5. Opposite results were obtained with cock spermatozoa, *i.e.*, an adverse effect of increasing pH on the oxygen consumption (Lardy & Phillips, 1943; Schindler & Lehrer, 1969), indicating, perhaps, species differences.

Whereas O_2 consumption increased significantly with increasing pH, glucose disappearance remained the same but the amount of fructose formed during incubation decreased at the higher pH. It is reasonable to assume that turkey sperm cells either can utilize glucose only after its conversion to fructose and the latter's consumption increases with increasing pH; or that the rate of glucose use increases at the higher pHs while the process

of glucose conversion to fructose is depressed at the high pHs. Whatever the case, hexose consumption increased with increasing pH, as did total O_2 uptake.

The amounts of glucose which were converted to lactic acid and those oxidized to CO_2 increased significantly with increasing pH but were less than could be accounted for by the amount of hexose consumption. The difference is explained by the formation from glucose of metabolites other than lactic acid (Mann & Mann, 1981). On the other hand, only part of the total O_2 uptake could be accounted for by sugar oxidation, $\sim 35\%$ in the first hour and $\sim 60\%$ in the second hour of incubation. The other part must have been used for the oxidation of other-than-glucose extracellular as well as intracellular substances. This metabolic pathway is more pronounced during the first than during the second hour of incubation. It seems that turkey spermatozoa resort more to oxidation of lactic acid after a partial depletion of other sources of energy during the first hour of incubation, in contrast to mammalian sperm cells which use the glycolytic mechanism as a predominant source of energy (Mann & Mann, 1981).

All in all, the results of the present study confirm previous reports reviewed by Mann & Mann (1981) that avian spermatozoa energy requirements are much smaller than those of mammalian spermatozoa. The results also show that in a wide range of hydrogen ion concentrations of the medium, the metabolic and physical activity of turkey spermatozoa and the ability to preserve their fertilizing capacity both in vivo and in vitro were affected in opposite directions. It seems that higher metabolic rates in vitro in a certain medium do not necessarily indicate a greater capacity of the spermatozoa to preserve their fertilizing ability. Increased metabolic rates may even advance the senescence of the spermatozoa and the loss of their fertility.

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MANAGEMENT AND ECONOMICS

OPTIMIZATION OF THE ECONOMICS AND OF THE MANAGEMENT OF TURKEY PRODUCTION:
DIETARY NUTRIENT DENSITY, MARKETING AGE AND ENVIRONMENTAL TEMPERATURE¹

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INTRODUCTION

Profit maximization in broiler or turkey operations involves the optimization of dietary nutrient (energy) density, house temperature, marketing age and bird density, in addition to least-cost diet formulation. Since interactions exist between these factors, a simultaneous evaluation is needed.

The complexity and non-linearity of the system exclude the possibility of analytical solutions. The system can be solved by simulation which includes predictive equations for bird performance on the one hand, and husbandry and economic inputs on the other. The main purpose of the predictive equations is to calculate weight gains and feed intakes under different environmental temperature conditions and with diets of different nutrient densities.

Wathes et al. (1981) formulated a set of equations for broilers using parameters estimated by multiple regression techniques, which analyzed weight gain and feed intake of broilers consuming different diets at various environmental temperatures. They then proceed to use these equations for determination of optimal marketing age in a system that assumes feed intake of an average price as the only economic variable. Martini (1978) simplified body weight and feed intake into linear equations with age, but included in his model various important economic factors. Allison and Eli (1977) used equations in which a matrix of feed efficiency coefficients described changes with age and dietary energy.

The present simulation model represents a more general approach based on parameters related to the energy balance at any age. It is aimed at the optimization of marketing age, dietary energy density and environmental temperature.

GENERAL DESCRIPTION

Input. Input includes expenditures and their time of occurrence. These can be divided into two classes:

- a) Expenditures per capita - cost of day-old bird, inoculations, slaughter-house expenses, mortality and feed.
- b) Expenses per unit area of the house - cleaning and disinfection, electricity, fuel, labor, management, depreciation, etc.

The expenses are either of single occurrences or time-dependent.

Sales price is included as a series of body weight-dependent variables. The age-dependent feeding schedule input is described by a list of feeds with their metabolizable energy content, unit price and standard period of feeding. The temperature schedule during the entire growing period is included as a stepwise function of 10-day intervals.

Calculations. The program includes a basic growth and body composition curve. An actual body weight curve is constructed by the program as a result of dietary and environmental modifications. A modified feed schedule is then computed to suit the environmental temperature followed by feed consumption calculation. Expenses are then summed up, discounted through the use of the interest rate, and adjusted for mortality. Income and profit are then calculated.

All calculations are made by daily iterations. The program is written in FORTRAN.

Output. A printout can be obtained of input variables, the projected feeding schedule, daily performance and economics.

THE BODY WEIGHT CURVE

The growth curve is a complex non-linear function which has been described mathematically in several forms. Most prominent among these is

the Gompertz equation which has also been used for turkeys (Buffington et al., 1973). For the present model it has been felt that the use of the Gompertz equation to describe body weight of birds, specially of the turkey with its relatively long growing period is restrictive since (a) changes in the environmental temperature during the growing season cannot be readily handled by such equations, (b) dietary changes which are applied in a stepwise fashion influence body weight but cannot be handled. In the present model, therefore, the body weight (BW) function of age (t) is a set of values at weekly intervals typical for the well managed farms:

$$BW = h_1(t) \quad [1]$$

The program input includes an option of changing the weight gain at a constant proportion or feeding into the program a new growth curve in order to handle some breed variations and different husbandry conditions. Together with the growth curve, carcass fat values (F), taken from Hurwitz et al. (1983b) are included in the program as,

$$F = h_2(t) \quad [2]$$

Effect of temperature. The effect of temperature on weight gain is given by,

$$G = Ga \left[1 - FG(T - T_{st}) \right] \quad [3]$$

$T > T_{st}$

where, G is the temperature-corrected weight gain, Ga is the weight gain calculated from the basic growth curve, T is the environmental temperature, T_{st} is the "optimal" standard stemperature between 35° and 20°C from 1 day to 30 days of age and then remaining at 20°. FG equals 0.02 for birds up to 10-weeks of age based on the results of a previous study (Hurwitz et al., 1980). For the 20-24-week-old turkeys, FG is 0.05 (Hurwitz et al., 1983b). Values for intermediate ages are taken by linear interpolations.

Effect of dietary energy density. A previous study (Hurwitz *et al.*, 1983c) indicated a linear growth response to energy of 1.6% per increment of 100 kcal/kg of diet, above a certain minimal energy concentration. This minimum was 2700 kcal/kg for the 1-4-week pld birds and 2900 kcal/kg for the 14-17-week old birds. Values for minimal energy in and outside of this range are obtained by interpolation and extrapolation, respectively. The effect on growth is calculated similarly to that of temperature.

$$G_b = G [1 + 0.00016(E - E_m)] \quad [4]$$

$$E > E_m$$

where,

G_b is the adjusted weight gain, E and E_m are the actual and minimal energy concentrations, respectively.

Effect of husbandry. It is recognized that growth on any farm may depend on management conditions such as sanitation, bird density, etc. A gain modifier - greater than, equal to, or lower than zero - is introduced as input to account for this deviation from standard conditions.

Using all these modifying factors, actual gains are calculated for the respective period, thus constructing an adjusted growth curve, corrected for the different dietary environmental and husbandry conditions.

FEED INTAKE

Feed intake is calculated using the adjusted body weight function, the environmental temperature function and dietary energy levels and using the equations which calculate energy intake from the requirements for growth and maintenance (Hurwitz *et al.*, 1980):

$$EC = M \cdot BW^{2/3} + D \cdot G \quad [5]$$

$$M = h_3(T) \quad [6]$$

$$D = 0.6 + 9.3 \cdot F \quad [7]$$

$$FC = EC/E \quad [8]$$

where, EC and FC are the energy intake and feed intake, respectively;

$M = h_3(T)$ is the requirement for maintenance as a function of environmental temperature (T); D is the requirement for weight gain (Hurwitz et al., 1980), as a function of body fat (F) in the weight gained. $[E]$ is the energy concentration in feed.

In previous studies, the function of maintenance requirement (M) as a function of temperature (T) was evaluated in 5-10-week old (Hurwitz et al., 1980) and in 20-24-week old (Hurwitz et al., 1983c) turkeys. In general, the values for the older bird were somewhat lower than those for the younger ones, with a slightly different temperature dependence. In the model, the determined values are used for up to 10 weeks of age, and for the birds over 20 weeks of age. For intermediate ages, values are obtained by linear interpolation.

DESIGN OF DIETS

The energy concentrations in the diet is changed parametrically above the minimum energy level as defined above, keeping constant the ratio of some of the nutrients such as protein and amino acids. These diets are then tested within the framework of the general optimization program.

Alternately, any well designed commercial diet with known nutritional specifications could be tested within the framework of the program, in order to arrive at the economically optimal energy density.

Least cost diets are formulated by linear programs, using LP 1, with 52 restrictions including all essential amino acids.

FEEDING SCHEDULE

The requirements for essential nutrients such as protein and amino acids, relative to energy, decreases hyperbolically with age. Therefore, in practice feeds are changed at various time intervals along the growing period, to accommodate these changes. This stepwise change is a compromise

between the continuously changing requirements and the number of diets which can be handled. Usually, the diet contains the minimal requirements at the time of change.

In a study with turkeys (Hurwitz *et al.*, 1980), we showed that the requirements for amino acids increased with environmental temperature approximately linearly up to 24°, due to the decrease in feed intake with temperature and the need to maintain the same amino acid intake for equivalent performance. Thus, it appeared possible that the same set of diets calculated for different ages could be used to accommodate the different temperature conditions. This can be obtained by changing from the diet with a high nutrient content to the next with the lower protein content at an age dependent on the environment. A higher environmental temperature would result in a later change of diets, whereas a temperature lower than the standard one would call for an earlier change.

In order to calculate the relationship between the amino acid requirements and the delay in diet change with temperature, the requirements for lysine as functions of age and temperature, were calculated using the previous model (Hurwitz *et al.*, 1983b).

A hyperbolic function was calculated for age, as a function of the requirement, using a SAS procedure (Helwig, 1979). A highly significant function ($P < 0.0001$, $R^2 = 0.965$ df = 44) was obtained. The effect of temperature was estimated at 1.28 ± 0.22 days per degree between 10 and 24°C. One day per degree was used for higher temperatures.

MORTALITY

First order mortality rate constants were included on a weekly basis. The values were based on data collected by the Israeli Poultry Extension Service.

BIRD DENSITY

According to experience, a proper husbandry practice is to produce a given body weight per unit of area (density) rather than operate at a given number of birds. The maximal density varies according to husbandry conditions. In Israel, $30 \text{ kg} \cdot \text{m}^{-2}$ and $25 \text{ kg} \cdot \text{m}^{-2}$ are considered as proper densities for turkeys and broiler-chickens, respectively. The present model calculates the actual density at any time, and the initial stocking rate, which accounts for the cumulative mortality.

ENVIRONMENTAL TEMPERATURE

In practice, records are seldom kept for actual temperature inside the poultry house. On the other hand, records are available for standard temperatures measured at the meteorological booths throughout country, and it appeared likely that reliable regressions could be obtained between the temperature in the poultry house and the standard recorded temperatures. In order to obtain these regressions, simultaneous measurements were made by temperature recorders placed in various regions inside chicken houses and the nearby meteorological booth. A full account of this study is beyond the scope of this communication but from measurements conducted during close to an entire year, the following regression was obtained:

$$T_{in} = 2.6 + 0.86 T_{out} \quad (S_{yx} = 1.7, R = 0.946) \quad [9]$$

where, T_{in} is the average temperature inside the house and T_{out} is the average temperature in the meteorological booth. The quenching effect of the building is expressed by the intercept which is greater than 0 and the slope which is lower than unity.

We showed previously that the response of weight gain and energy intake to diurnal cycling temperatures is similar to that obtained from an equivalent constant average temperature, provided that the upper temperature does not

exceed 30° (Hurwitz et al., 1982). On this basis, the average daily temperature values are used for simulation. These are calculated from 10-day averages compiled by the Meteorological Service for each geographical location.

When artificial means are used to modify the poultry house temperature, actual temperatures are used.

ECONOMIC CONSIDERATIONS

The profit parameter is defined as the daily profit per unit area of the house. All expenditures as well as revenues are discounted to the beginning of the growing period, using the equation:

$$PV = C(1 + R)^{-t} \quad [10]$$

where, PV is the present value, C the actual expenditure, and R the daily interest rate calculated from the yearly interest rate (RY) by

$$R = (1 + RY)^{1/365} - 1. \quad [11]$$

For summation of the expenses, the discounted expenses per bird are multiplied by the bird density and added to the expenses per area. The income is calculated by multiplying the yield per unit area by the discounted price appropriate to the particular body weight grade, and the profit (P) is the difference between the discounted expenses and income. The average daily profit is then calculated according to the daily capital recovery (Solomon, 1963) as,

$$PR = P[R(1+R)^{(t+t_0)}] / [(1+R)^{(t+t_0)} - 1] \quad [12]$$

where, PR is the daily profit, t_0 is the length of pause between batches,

SENSITIVITY EVALUATIONS

Effect of temperature. Using current market prices for Israel, and the feeding schedule and feed prices according to one of the central feedmills, the response to different temperatures was simulated. The simulated body weight and feed efficiency curves are given in Fig. 1. The same body weight curves are obtained for 10° and 20°, but body weight is considerably depressed at 30°. Cumulative feed efficiency, defined as the total weight gain over total feed intake, is higher at 20° than at 10°, due to the reduced feed intake resulting from reduced energy needs for maintenance. However, feed efficiency is reduced as the temperature is further increased to 30°, mainly due to the reduction in weight gain.

Feeding schedule of the different diets and the intake of feed of each of the diets, are given in Table 1. As the temperature increases the change of diet is effected later. The quantities consumed of each of the feeds are calculated by the model, as an aid to farm management.

Profit functions for the three temperatures is given in Fig. 2. Typically, the profit curves do not represent smooth functions due to the stepwise practice of husbandry. For example, profitability decreases at day 80, due to an inoculation given on that day. Furthermore, excluding day 80, profitability increases up to about 90 days, at both 10 and 20°. It then decreases slightly until 110 days and then increases again. This apparent phasic response is due to the change in diet which is made during this period. For all environmental temperatures, profit changes only slightly between 90 and 120 days. A steep decline starts at about 120 days.

In this comparison, profit was maximal at 20°, but the possible cost of fuel to obtain this temperature artificially has not been included in the analysis. ^{more} A detailed use of the algorithm can result in a more accurate optimization of the environmental temperature. Also, the comparison

TABLE 1.— The effect of environmental temperature on
the feeding schedule of turkeys

Temperature ¹	Diet No. ¹					
	2	3	4	5	6	
	<u>Last day on diet</u>					
10°	25	43	71	99	127	175
20°	25	56	84	112	140	175
30°	25	66	94	122	150	175
	<u>Intake of diet, g/bird</u>					
10°	1217	2327	7019	9008	11556	18816
20°	1217	4800	7378	8800	10594	14468
30°	1218	6782	5766	5562	5801	5839

¹The schedule of a commercial feedmill.

Fig. 1. Simulated body weights (lower graph) and feed efficiency (upper graph) of turkeys kept at 10° , 20° , and 30° .

Fig. 2. Computed daily profit resulting from turkey production at 10°, 20°, and 30°, as a function of marketing age.

was made with a constant temperature prevailing from 31 days of age, whereas any naturally-occurring temperature pattern or that resulting from artificially controlled environment, can be included for evaluation of performance.

Effect of dietary energy density. As mentioned, an increase in dietary energy above a certain minimum would lead to some stimulation of weight gain and a decrease in feed intake, resulting in an improved feed efficiency. However, such an increase is usually accompanied by an increase in the unit cost of the feed. Therefore, the simulation program has been used to evaluate the impact of dietary nutrient density on production economics.

As standard guidelines for diet formulations, the recommended schedule of the National Research Council (1977) was used. Least-cost diets were computer-formulated using practical ingredients at current prices. Three energy density schedules were compared with a stepwise increase of 150 kcal/kg from one to another. The energy increased while keeping a constant ratio of protein, amino acid and certain minerals to energy, in order to maintain a proper intake of these nutrients with an expected decrease in feed intake. The energy concentrations and prices of the diets are given in Table 2. The energy concentration increases with age due to the decrease in protein needs requiring the use of less soybean meal with its low energy content. This is also the reason for the reduction in the cost of the diets for older birds. The change in energy density resulted in an increase in the cost of diets. The increment in price with energy is greater for the early than for the later diets, and is not linearly related to energy. The price per calorie increased as the energy increased.

A summary of the simulated results of feeding the three diet regimes to birds kept at 20° is given in Table 3. The increase in body weight, decrease in feed intake and the substantial improvement in feed efficiency with increasing energy are illustrated. However, optimal marketing age and profitability did not change with this large change in dietary energy.

TABLE 2.— Properties of least cost diets
comprising three different energy regimes
for turkeys¹

Age, wk	Regime		
	Low	Medium	High
<u>Metabolizable energy, kcal/kg</u>			
0 -	2700	2850	3000
5 - 8	2750	2900	3050
9 - 12	2850	3000	3150
13 - 16	2950	3100	3250
17 - 20	3000	3150	3300
21 - 24	3050	3200	3350
<u>Price, IS/kg</u>			
0 - 4	10.51	11.82	12.28
5 - 8	9.66	10.51	11.33
9 - 12	9.11	9.71	10.42
13 - 16	8.45	8.96	9.65
17 - 20	7.98	8.50	9.16
20 - 24	7.54	7.94	8.55

¹Designed according to National Research Council
(1977) recommendations.

TABLE 3.— Simulated results of feeding growing turkeys regimes of different nutrient density

Regime ¹	Low	Medium	High
Marketing age, d	117	117	117
Body weight, g	10289	10553	10778
Feed intake, g	24997	24118	23320
Feed efficiency	0.409	0.434	0.460
Profit, IS/d	2.341	2.345	2.327

¹ Grades according to nutrient density, see table.

Cost of the day-old poult. The cost of the bird is 20-25% of the total expense; its effect on the optimal marketing age, were evaluated. Commercial feeding schedule and diets and 20° were included. It should be recalled that a constant yield of weight per unit area is maintained so that, as the marketing age and body weight increase the bird density in the house decreases.

The results, given in Fig. 4, show that marketing age increased non-linearly with an increase in the cost of the day-old poult to reach a plateau, while the bird density underwent changes reciprocal to the marketing age. It is of interest to note that the current price for the day-old turkey fell within the steeply ascending part of the curve..

Broilers. Although not detailed here, the program has also been adopted for use with broilers. Results with broilers at 20° and consuming commercial feeds are given in Fig. 4. It is evident that the males grew at a more rapid rate than the females. Not shown here is the greater fat deposition in the females, which is also a contributing factor to the reduced feed efficiency of this sex. This poorer performance of the females results in the poorer profitability. Peak profitability occurred in the males at about 6 weeks of age while in the females it was at 7 weeks of age.

Fig. 3. Optimal marketing age (lower graph) and bird density (upper graph) as a function of the cost of the day-old poult.

Fig. 4. Simulated body weight (upper graph) and profit (lower graph) in producing male () and female () broiler-chickens.

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Submitted for Publication

1. Hurwitz, S., Talpaz, H. and P.E. Waibel. Optimization of the management and economics of turkey production: dietary nutrient density, marketing age and environmental temperature.
2. Pinto, O. , D. Amir, H. Schindler and S. Hurwitz. Metabolism and fertility of turkey spermatozoa: the effect of pH.