Nutrient Requirements of Poultry

Ninth Revised Edition, 1994

Subcommittee on Poultry Nutrition
Committee on Animal Nutrition
Board on Agriculture
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SUBCOMMITTEE ON POULTRY NUTRITION

JERRY L. SELL, *Chair*, Iowa State University
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Preface

Formulation of balanced diets is fundamental to economical poultry production, and this process depends on a knowledge of nutrient requirements of poultry and the nutritional attributes of nutrient sources. Thus, a compilation of information on nutrient requirements and sources that can be used by feed formulators as a guideline is an important resource. This ninth revised edition of the *Nutrient Requirements of Poultry* contains a reassessment of data used in the previous edition and incorporates new information. The committee conducted an extensive review of the literature, and documentation of most of this literature is included in this ninth edition. Note, however, that the review of literature was completed and the nutrient requirements data compiled by the committee in September 1991.

The committee found that scientifically based knowledge about many nutrient requirements was incomplete. Consequently, calculations and interpolations were necessary to derive estimated requirements for some nutrients. These estimated requirements are identified in the requirements tables. In some instances, the committee decided that estimation of the requirements was inappropriate and a question mark was used in the tables to indicate the absence of data.

Nutrient requirements given herein were derived, in most instances, from empirical observations of responses of poultry to changes in dietary concentrations or intakes of specific nutrients. In some instances, nutritional models were used to estimate amino acid requirements. Criteria used in establishing nutrient requirements included growth, reproduction, and feed efficiency and, where possible, poultry health and quality of poultry products.

This report, as compared with previous editions, contains additional information on feedstuffs, including a description of procedures used to determine metabolizable energy values and methods to estimate amino acid contents of feed ingredients. A detailed discussion of dietary fat sources has been added, and the data presented on the nutrient composition of feedstuffs have been expanded to include true metabolizable energy values and coefficients of true amino acid digestibility.

This ninth edition was prepared by the Subcommittee on Poultry Nutrition, which was appointed in 1989 under the guidance of the Board on Agriculture's Committee on Animal Nutrition. The Committee on Animal Nutrition, the Board on Agriculture, and several other experts reviewed the report. The subcommittee is grateful to these individuals for their efforts. The subcommittee also thanks Roseanne Price for her editorial assistance and Mary Cochran and Ann Shuey of Iowa State University for their secretarial assistance in preparing many drafts of the report.

JERRY L. SELL, *Chair*

Subcommittee on Poultry Nutrition

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Overview

The ninth revised edition of *Nutrient Requirements of Poultry* contains substantially more information than previous editions. In addition to presenting updated nutrient requirements data, this edition includes more discussion on key facets of nutrients, nutrient requirements, and nutrient sources. Detailed documentation of the scientific literature used to establish or estimate the requirements is also included in Appendix A.

Scientifically based knowledge about many nutrient requirements is incomplete. Consequently, calculations and interpolations were necessary to derive estimated requirements. These nutrient requirements were derived mostly from empirical observations of responses of poultry to changes in dietary concentrations or intakes of specific nutrients. In some instances, nutritional models were used to estimate amino acid requirements.

Few nutritional models are available for poultry, primarily because data to support the development of these models are scarce. There are, however, modeling equations for estimating the energy and amino acid requirements of poultry. Hurwitz et al. (1978) integrated the energy and amino acid needs of broiler chicks to develop a mathematical model for predicting amino acid requirements. Models for estimating the amino acid requirements of growing turkeys were proposed by Fisher (1982a) and Hurwitz et al. (1983a). Modeling equations also have been developed for predicting the energy requirements (National Research Council, 1987a) and amino acid requirements (Hurwitz and Bornstein, 1973) of laying hens. Additional research is needed to determine maintenance requirements and partial efficiency of nutrient use for growth versus egg production.

Energy, specific nutrients, and certain nonnutritive feed ingredients are discussed in general terms in Chapter 1. Definitions of terms used to describe the energy value of poultry feeds are given, and an expanded section on procedures for determining and estimating dietary metabolizable energy is provided. General aspects of protein and amino acid nutrition and metabolism have been updated. The section on fats includes information on sources, factors affecting metabolizable energy (ME_n) values, effects on composition of poultry products, and metabolic functions. Overviews are given for minerals, vitamins, and water. Data on water consumption for chickens and turkeys have been revised according to recent field observations of contemporary breeds and strains. General characteristics and uses of xanthophylls, unidentified growth factors, and antimicrobials in poultry diets also are discussed.

Nutrient requirements for specific types of poultry are presented and discussed in Chapters 2 through 6, with each chapter devoted to a different type. Each of these chapters contains a table or tables detailing the nutrient requirements of the respective groups. Requirements data are presented on the basis of 90 percent dietary dry matter, which approximates most feeding conditions. These data are also presented on the basis of total concentrations in the diet or total consumed per day, not on an available or digestible basis.

In the tables, requirements that are well delineated in the literature, the "established requirement," are set in regular type. "Estimated requirements," made on the basis of meager data or by interpolation, are set in bold italicized type. In some instances, the committee decided to insert a question mark rather than make estimates with no bases.

The committee emphasizes that the requirements values reported herein have not been increased by a "margin of safety." The values represent the judgment of the subcommittee after its review of the published data. Criteria of adequacy included growth, reproduction, feed efficiency, health, and quality of poultry products.

Ambient temperature and other environmental factors usually were not specified in papers presenting requirements data. Most experiments, however, have been conducted under moderate conditions, with temperatures of 16° to 21°C and relative humidities of 40 to 60 percent. When temperature or humidity conditions deviate from these ranges, adjustments in nutrient concentrations may be needed to compensate for changes in feed intake.

Chapter 2, on the nutrient requirements of chickens, has been divided according to Leghorn-type and meat-type fowl. For the former, sections are included for starting and growing pullets and for hens in egg production. Similarly, for the latter, separate sections are presented for starting and growing market broilers, broiler breeder pullets and hens, and broiler breeder males. Requirements of starting and growing turkeys and turkey breeders are given in Chapter 3. Nutrient requirements of geese, ducks, and pheasants and quail are provided in Chapters 4, 5, and 6, respectively. These data, however, were based on a relatively meager amount of literature.

Chapter 7, on signs of nutritional deficiencies in chickens and turkeys, has been enlarged considerably to include more descriptive information and documentation. Tables present biochemical and physiological indicators of nutrient deficiencies, signs of nutrient deficiencies in embryos, and nutrient deficiencies that may be associated with specific deficiency signs. Chapter 8 includes an update presentation on toxic levels of elements as related to diets or drinking water.

Feedstuff composition data and related information are presented in Chapter 9. The tabular data of Tables 9-2 and 9-3 have been revised according to recent analytical results obtained with contemporary feedstuffs. This revision primarily involved changes in proximate and amino acid compositions of numerous feedstuffs. True metabolizable energy (TME_n) values of many feedstuffs also have been included in Table 9-2. Two new sections have been added to Chapter 9. One section briefly discusses and presents equations estimating amino acid composition on the basis of protein content or proximate analysis. The second covers amino acid availability and includes a listing of true digestibility coefficients for selected amino acids in many poultry feedstuffs. The tabular presentation in Chapter 9 on fatty acid composition and ME_n values of dietary fats for poultry is extensive and well documented. Information on the crude protein equivalents and nitrogen-corrected ME_n values of amino acids and on the element concentrations in common mineral sources also is provided.

The nutrient composition of feedstuffs is, of course, variable. In addition, the effective concentrations of nutrients in diets may be reduced by inadequate feed mixing, improper processing, and unfavorable storage conditions. Nutritionists may accordingly add a "margin of safety" to the stated requirements in arriving at nutrient allowances to be used in formulation to compensate for these aforementioned conditions.

Examples of practical, semipurified, and chemically defined reference diets for chicks are given in Chapter 10.

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Components of Poultry Diets

Poultry diets are composed primarily of a mixture of several feedstuffs such as cereal grains, soybean meal, animal by-product meals, fats, and vitamin and mineral premixes. These feedstuffs, together with water, provide the energy and nutrients that are essential for the bird's growth, reproduction, and health, namely proteins and amino acids, carbohydrates, fats, minerals, and vitamins. The energy necessary for maintaining the bird's general metabolism and for producing meat and eggs is provided by the energy-yielding dietary components, primarily carbohydrates and fats, but also protein.

Poultry diets also can include certain constituents not classified as nutrients, such as xanthophylls (that pigment and impart desired color to poultry products), the "unidentified growth factors" claimed to be in some natural ingredients, and antimicrobial agents (benefits of which may include improvement of growth and efficiency of feed utilization). Each of these components of poultry diets is considered in the following sections.

ENERGY

Energy is not a nutrient but a property of energy-yielding nutrients when they are oxidized during metabolism. The energy value of a feed ingredient or of a diet can be expressed in several ways. Thus, a description is presented below of terminology associated with dietary energy values, including units of measure (digestible energy, metabolizable energy, etc.). Because metabolizable energy values are most commonly used to define the dietary energy available to poultry, several procedures for determining metabolizable energy values, by using bioassays or estimates based on proximate analysis, are described. An example of the disposition of dietary energy ingested by a laying hen and some general considerations regarding setting dietary energy concentrations of diets follow. Finally, some caveats are given concerning the energy values listed in the nutrient requirement tables in this report.

Energy Terminology

Energy terms for feedstuffs are defined and discussed in detail in *Nutritional Energetics of Domestic Animals and Glossary of Energy Terms* (National Research Council, 1981b). For a more in-depth discussion of energy terms related specifically to poultry, the reader is referred to Pesti and Edwards (1983). A brief description of the terms most frequently used in connection with poultry feeds appears below.

A calorie (cal) is the heat required to raise the temperature of 1 g of water from 16.5° to 17.5° C. Because the specific heat of water changes with temperature, however, 1 cal is defined more precisely as 4.184 joules.

A kilocalorie (kcal) equals 1,000 cal and is a common unit of energy used by the poultry feed industry.

A megacalorie (Mcal) equals, 1,000,000 cal and is commonly used as a basis for expressing requirements of other nutrients in relation to dietary energy.

A joule (J) equals 10^7 ergs (1 erg is the amount of energy expended to accelerate a mass of 1 g by 1 cm/s). The joule has been selected by Le Systéme International d'Unites (SI; International System of Units) and the U.S. National Bureau of Standards (1986) as the preferred unit for expressing all forms of energy. Although the joule is defined in mechanical terms (that is, as the force needed to accelerate a mass), it can be converted to calories. The joule has replaced the calorie as the unit for energy in nutritional work in many countries and in most scientific journals. In this publication, however, calorie is used because it is the standard energy terminology used in the U.S. poultry industry and there is no difference in accuracy between the two terms.

A kilojoule (kJ) equals 1,000 J.

A megajoule (MJ) equals 1,000,000 J.

Gross energy (E) is the energy released as heat when a substance is completely oxidized to carbon dioxide and water. Gross energy is also referred to as the heat of combustion. It is generally measured using 25 to 30 atmospheres of oxygen in a bomb calorimeter.

Apparent digestible energy (DE) is the gross energy of the feed consumed minus the gross energy of the feces. (DE = [E of food per unit dry weight × dry weight of food] - [E of feces per unit dry weight × dry weight of feces]). Birds excrete feces and urine together via a cloaca, and it is difficult to separate the feces and measure digestibility. As a consequence, DE values are not generally employed in poultry feed formulation.

Apparent metabolizable energy (*ME*) is the gross energy of the feed consumed minus the gross energy contained in the feces, urine, and gaseous products of digestion. For poultry the gaseous products are usually negligible, so *ME* represents the gross energy of the feed minus the gross energy of the excreta. A correction for nitrogen retained in the body is usually applied to yield a nitrogen-corrected *ME* (ME_n) value. ME_n, as determined using the method described by Anderson et al. (1958), or slight modifications thereof, is the most common measure of available energy used in formulation of poultry feeds.

True metabolizable energy (*TME*) for poultry is the gross energy of the feed consumed minus the gross energy of the excreta of feed origin. A correction for nitrogen retention may be applied to give a TME_n value. Most ME_n values in the literature have been determined by assays in which the test material is substituted for part of the test diet or for some ingredient of known *ME* value. When birds in these assays are allowed to consume feed on an ad libitum basis, the ME_n values obtained approximate TME_n values for most feedstuffs.

Net energy (*NE*) is metabolizable energy minus the energy lost as the heat increment. *NE* may include the energy used for maintenance only (NE_m) or for maintenance and production (NE_{m+p}). Because *NE* is used at different levels of efficiency for maintenance or the various productive functions, there is no absolute *NE* value for each feedstuff. For this reason, productive energy, once a popular measure of the energy available to poultry from feedstuffs and an estimate of *NE*, is seldom used.

Disposition of Dietary Energy

Figure 1-1 illustrates the proportional relationships in the disposition of dietary energy ingested by a laying hen. Energy is voided or used at various stages following consumption of 1 kg feed by the hen.

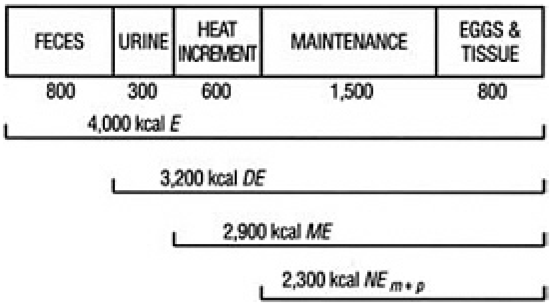

Figure 1-1 Disposition of dietary energy ingested by a laying hen.

Of 4,000 kcal provided in 1 kg of this particular diet, 2,900 kcal are capable of being metabolized by the hen and about 2,300 kcal are available for maintenance and transfer into body tissue and egg (net energy) (Fraps, 1946; Hill and Anderson, 1958; Titus, 1961). The relative amounts of both metabolizable and net energy will, of course, vary with the composition of the feedstuffs in the diet. Other factors, such as the species, genetic makeup, and age of poultry, as well as the environmental conditions, also influence the precise distribution of dietary energy into the various compartments (Scott et al., 1982).

Procedures for Determining Metabolizable Energy

Metabolizable energy is determined by various bioassay procedures whereby feed intake and excreta output are related over a 2- to 5-day test period. Apparent metabolizable energy is most commonly determined through actual measurement of feed intake and excreta output, or by determining the ratio of dry matter intake to output through use of an inert dietary marker, such as chromic oxide (Cr_2O_3). A number of potential problems arise with use of markers (Kane et al., 1950; Vohra and Kratzer, 1967; Duke et al., 1968; Vohra, 1972a), and thus the latter method often leads to more variation in final determined *ME* values (Potter, 1972).

When the *ME* value of an ingredient is to be determined, two or more diets must be used, since feeding an ingredient by itself can cause palatability problems and fails to accommodate potential synergism between nutrients. The two methods most frequently used in substituting the test ingredient into a control basal diet are those described by Anderson et al. (1958) and Sibbald and Slinger (1963). In the former method the test ingredient is substituted for glucose, but in the latter method the test ingredient is substituted for all the energy-yielding ingredients of the basal diet. Anderson et al. (1958) proposed that the value of 3.65 kcal/g be used as the standard for glucose. The basal diet used by Anderson et al. (1958), containing about 50 percent glucose and designated as E9, has been used extensively in determinations of nitrogen-corrected *ME* (ME_n).

In the method of Sibbald and Slinger (1963) the test ingredient is substituted essentially for part of the complete basal diet. However, to avoid mineral and vitamin deficiencies, components of the diet containing these nutrients are left intact, The use of two basal diets of differing protein contents was proposed to maintain the protein contents of substituted diets within an acceptable range. An advantage of the substitution method of Sibbald and Slinger (1963) is that the ME_n value of the reference basal diet is necessarily determined in each ME_n assay. Although samples of glucose are likely to be less variable than samples of regular feed ingredients, the ME_n of glucose may vary under different dietary conditions, and its ME_n value should be determined under the experimental conditions used (Mateos and Sell, 1980).

The test ingredient may be substituted at one or more levels. Regardless of the basal diet used, the accuracy of the ME_n value obtained depends to some extent on the proportions of the test ingredient substituted into test diets. In extrapolating to calculate the ME_n value of the test ingredient, the error of determination of the test ingredient is therefore multiplied by a factor of 100 divided by percentage of substitution. Therefore the highest proportion of the test ingredient possible in the test diet should be used. Usually, this amount is determined by nutrient balance and palatability.

Potter et al. (1960) proposed a linear regression procedure for the calculation of ME_n values for ingredients substituted at several levels. The ingredient ME_n value is derived by extrapolation to 100 percent inclusion from a regression equation relating test diet ME_n values and proportion of test ingredient in such diets. As for most other methods of ME_n determination, a criticism of the regression methods is that the extrapolation is beyond the range of experimental data. Sibbald and Slinger (1962) pointed out that this general criticism is of little significance as long as the range of inclusion levels used is within that normally encountered under practical conditions because it is the application of ingredient ME_n values in commercial dietary formulation that is of interest.

TME was described as an estimate of *ME* in which correction is made for metabolic fecal and endogenous urinary energy (National Research Council, 1981b). These energy components of excreta are not directly of dietary origin, and, as suggested by Sibbald (1980), correction for their excretion in bioassays leads to *TME*. It should be noted that *ME* as determined using the procedure of Anderson et al. (1958) inherently corrects for metabolic fecal and endogenous urinary energy excretion, whereas the method of Sibbald (1976) for determining *ME* does not. The *TME* method is quite rapid in that it takes only a 48-hour collection period and, because ingredients are force-fed, there is no need to use a series of basal and test diets.

The *TME* procedure, however, has been subjected to criticism. *TME* determinations assume that fecal metabolic and urinary endogenous energy excretions are constant, irrespective of feed intake. Data have been presented showing that, to the contrary, metabolic and endogenous energy excretions are influenced by amount and nature of materials passing through the gastrointestinal tract (Farrell, 1981; Farrell et al., 1991; Tenesaca and Sell, 1981; Hartel, 1986). Another criticism is that ingredients are often force-fed alone, thereby preventing synergistic or antagonistic effects between or among ingredients on energy utilization. Synergism is known to occur between fatty acids (Young, 1961; Artman, 1964; Leeson and Summers, 1976a) and there is evidence for synergism between protein concentrates (Woodham and Deans, 1977). A third criticism of the *TME* method relates to the imposition of 48 periods of feed deprivation, which would result in an abnormal physiological status of the bird.

Both *ME* and *TME* should be corrected for nitrogen retention that occurs during the assay period. If, during an *ME* determination, nitrogen is retained by the animal, the excreta will contain less urinary nitrogen and hence less energy would be excreted as compared with an animal that is not retaining N. Because the extent of nitrogen retention differs with age and species, a correction factor is essential if comparisons of *ME* values for the same ingredient with different animals are to be made.

Hill and Anderson (1958), assuming that if nitrogen is not retained it will appear as uric acid, proposed a correction value of 8.22 kcal/g nitrogen retained because this is the energy obtained when uric acid is completely oxidized. This assumption has been criticized because only 60 to 80 percent of the nitrogen of chicken urine is in the form of uric acid (Coulson and Hughes, 1930). However, the assumption that oxidation of varying amounts of protein would yield a consistent pattern of nitrogenous excretory products seems no more correct than the assumption that all nitrogen would be excreted as uric acid (Hill and Anderson, 1958). Thus, from a practical viewpoint, the uric acid value has been used most frequently and is generally quoted (Scott et al., 1982).

Sibbald and Slinger (1963) questioned the validity of correcting for nitrogen retention, suggesting that correction does little to improve the usefulness of classical *ME* values and that the extra work involved is not justified. Potter (1972), however, suggested that correction to zero nitrogen retention is essential for reproducible results when the ME_n of a single diet is to be measured with birds of various ages because of differences in rates of protein accretion or protein catabolism. Correction to a species-specific or age-specific nitrogen retention, although having the advantage of applicability for specific circumstances, cannot be used in comparative work because "typical" nitrogen retention varies with species and age. Leeson et al. (1977a) indicated the need for nitrogen correction in interpretation of bioassay data.

An alternative to classical bioassay is based on changes in rate of growth in response to dietary energy. Squibb (1971) suggested a method for the "standardization and simplification" of ME_n determination procedures. The method is a modification of that described by Yoshida and Morimoto (1970). It is based on the premise that rapidly growing immature animals restricted in terms of energy intake but given adequate protein will show an increase in growth in direct proportion to energy added to the diet. Considering the restricted feeding of the energy-deficient diet used by Squibb (1971), the adequacy of the protein in terms of quantity and quality can be questioned. However, the concept warrants further study as a means of evaluating the energy value of ingredients, such as fats, that are difficult to assay using conventional procedures.

Most ME_n values reported for feedstuffs have been determined with young chicks. Although adult male chickens have been used to determine TME_n content of many feedstuffs, few studies have been done to determine either ME_n or TME_n for poultry of different ages. More ME_n and TME_n data are needed for many feed ingredients for chickens, turkeys, and other poultry of different ages.

Estimation from Proximate Composition

Several researchers have developed prediction equations to estimate the energy content of feed ingredients from their proximate components. Prediction of the "usable" energy value of a feed from its chemical composition has been attempted for many years. The Weende, or proximate analysis, system was developed as an attempt to predict the nutritional value (including the energy value) of an ingredient or of mixed feed from its component parts. Fraps et al. (1940) predicted the *ME* content of feeds from the values for digestible crude protein, ether extract, and nitrogen-free extract (NFE). Titus (1955) used this concept to derive a series of "percentage multipliers" for the calculation of *ME* values for different types of feed ingredients. Later, these "percentage multipliers" were updated and extended to a wider range of ingredients (Titus and Fritz, 1971).

Janssen et al. (1979) conducted a series of studies to correlate the chemical composition of different types of feed ingredients to the *ME* value. By using multiple regression analysis, equations were derived to estimate ME_n (kcal/kg dry matter) from chemical composition. More recently, a subcommittee of the European Federation of the World's Poultry Science Association (1989) developed a set of equations to estimate the energy value of ingredients. Data sets from a number of European laboratories were combined to develop the equations. A list of prediction equations that have been published recently is provided in Appendix Table B-1. Dale et al. (1990) developed an equation to estimate the TME_n value of dried bakery products, a blend of various by-products produced by the baking industry.

The *ME* value of grain sorghums is known to be influenced by their tannin content. Sibbald (1977) reported *TME* values of 3,300 and 3,970 kcal/kg for high- and low-tannin grain sorghums, respectively, and Queiroz et al. (1978) found ME_n values of 2,886 and 3,091 kcal/kg for high- and low-tannin grain sorghums. Gous et al. (1982) found a highly significant negative correlation between the ME_n of grain sorghums and their tannic acid content, the relationship due to a decreased digestibility with increasing tannic acid concentration. These researchers developed a regression equation to estimate *ME* from tannic acid concentration. A similar equation was developed by the European Federation of the World's Poultry Science Association in 1989. Although these equations may result in slightly different estimates, they both point out the adverse effects of the tannin content on digestibility of grain sorghums.

Moir and Connor (1977) developed equations to predict ME_n of grain sorghums using three different types of crude fiber assays. The ME_n content of sorghum was predicted from the three fiber assay methods with precision of, respectively, ±117, ±148, and ±126 kcal/kg dry matter. These values correspond to coefficients of variation of 3.0, 3.8, and 3.3 percent, respectively. Thus, any of the three fiber methods could be used to predict the ME_n of grain sorghums for poultry.

Considerable variation exists in the nutrient composition of poultry by-product meal from various production lots and among producers, depending on raw material used (e.g., proportions of feet, legs, blood, and offal may vary considerably). Pesti et al. (1986) determined the TME_n of a number of samples of poultry by-product and derived several equations to estimate TME_n from various measurements. The equations vary in complexity, some using only one parameter to estimate TME_n and others using two measurements. The coefficients of determination (R^2) for the two-measurement equations were similar; thus, persons using these equations may select measurements that are in concert with the capability of their own laboratory.

Perhaps the most difficult feed ingredients to analyze for ME_n are supplemental fats. Many factors influence the digestibility and subsequent ME_n of fats; these have been extensively reviewed by Renner and Hill (1961), Young and Garrett (1963), Lewis and Payne (1966), Hakansson (1974), Leeson and Summers (1976a), Fuller and Dale (1982), Ketels et al. (1987), Ketels and DeGroote (1988), and many others. Prominent among these factors are age of poultry, level of fat inclusion in the diet, and overall fatty acid composition of the diet. Several studies have been conducted to estimate the energy value of a fat from its composition. Janssen et al. (1979) estimated the energy value of fats produced by Dutch renderers (Appendix Table B-1). Huyghebaert et al. (1988) evaluated a wide variety of fats and developed prediction equations for ME_n using multiple linear regression analysis involving different characteristics of fats. Several equations were developed for (1) all fats and oils examined and (2) different categories of fats (e.g., animal or vegetable fats). The accuracy of the equations was improved by separating the fats into different categories.

It is well known that utilization of saturated fatty acids is improved by the presence of unsaturated fatty acids in the fat blend (Young and Garrett, 1963; Young, 1965; Lewis and Payne, 1966; Garrett and Young, 1975; Leeson and Summers, 1976a). The nature of the fat in the basal diet has a significant effect on the utilization of supplemental fats (Sell et al., 1976; Sibbald and Kramer, 1978; Fuller and Dale, 1982). These interactions between the supplemental fat and the basal dietary fat are especially noticeable at low inclusion levels of supplemental fat (Wiseman et al., 1986; Ketels et al., 1987).

Ketels and DeGroote (1989) evaluated the relationship between the ratio of unsaturated to saturated fatty acids (U:S) in the diet and ME_n of a number of fats and developed equations relating fat ME_n, fat utilization, and the utilization of specific fatty acids to the U:S for young broiler chickens. Best fit regression equations for supplemental fat utilization and fat ME_n were exponential. Fat utilization increased rapidly in the U:S range of 0 to 2.5, reaching a near-asymptotical maximum at a U:S of 4. Synergism between added fats, due either to blending vegetable oils with animal fats or to using basal diets with unsaturated lipid fractions, led to increased utilization of animal fats. Utilization of vegetable oils was not influenced by changing U:S ratios. The effect of factors influencing fat utilization, such as level of supplemental fat and basal diet composition, seemed to be primarily through variation in degree of saturation of the total dietary lipid fraction. For young broilers, about 75 percent of the variation in fat utilization and ME_n was due to differences in the chemical composition of the fat fraction.

Excellent summaries of the use of indirect methods for estimating the *ME* in feed ingredients have been presented by Harris et al. (1972), Sibbald (1975, 1982), Eackhout and Moermans (1981), Fisher (1982b), Fonnesbeck et al. (1984), and Just et al. (1984). These reports discuss many of the problems associated with the use of indirect procedures to replace conventional bioassays for *ME*.

At this time, the committee cannot recommend the best equation(s) to use to estimate *ME* from chemical composition. To date, no studies have compared the various equations with a determined value. In addition, some of the chemical determinations are subject to much variability or are relatively complex and may not be easy to adapt to some laboratory situations. Users may wish to calculate *ME* by using as many of the equations as seem feasible and then evaluating the results before selecting the procedure that is most appropriate for their situation.

Setting Dietary Levels

In formulating poultry diets, energy level is usually selected as the starting point. An appropriate energy level is one that most likely results in the lowest feed cost per unit of product (weight gain or eggs). The feed cost per unit of product, in turn, is determined by the cost per unit weight of diet and the amount of diet required to produce a unit of product. In areas of the world where high-energy grains and feed-grade fats are relatively inexpensive, high-energy diets are often most economical (i.e., the lowest feed cost per unit of product); however, if a leaner carcass is desired, it may be necessary to consider other levels of dietary energy. In areas where lower-energy grains and by-products are less expensive, low-energy diets are often most economical.

The dietary energy level selected is often used as a basis for setting most nutrient concentrations in a diet. This approach to formulation of poultry diets is based on the concept that poultry tend to eat to meet their energy needs, assuming that the diet is adequate in essential nutrients (Hill and Dansky, 1950; 1954; Hill et al., 1956; Scott et al., 1982). Such an assumption, however, must be used with caution and with an understanding of its potential limitations. For example, if a diet is deficient in any nutrient, daily feed consumption may decrease in relation to the severity of the deficiency. One exception may occur with an amino acid deficiency, whereby a marginal deficiency may result in a small increase in feed consumption. If a diet has a gross excess of any nutrient, daily feed consumption usually decreases in relation to the severity of the potential toxicity.

The physiological mechanisms by which poultry respond to different dietary energy concentrations are not known, although several possible mechanisms have been proposed (National Research Council, 1987a). Equations that can be used to predict feed and energy intakes of laying hens and coefficients to predict the energy requirements of broiler chickens have been given by the National Research Council (1987a).

Although poultry generally adjust feed consumption to achieve a minimum energy intake from diets containing different energy levels, these adjustments are not always precise. Morris (1968) summarized data from 34 experiments and found that laying hens overconsumed energy when fed high-energy diets, and the degree of overconsumption was greatest for strains with characteristically high-energy intakes. Data from a large number of broiler chicken experiments also showed that changes in feed intake were not inversely proportional to changes in dietary energy level, especially when broilers were fed moderateto high-energy diets (Fisher and Wilson, 1974). More recent studies also illustrated that growing broilers and turkeys consume more energy when fed high-energy diets than those fed low- to moderate-energy diets (Sell et al., 1981; Owings and Sell, 1982; Sell and Owings, 1984; Brue and Latshaw, 1985; Potter and McCarthy, 1985). For laying hens, some combinations of carbohydrates, fat, and protein resulted in more energy intake than others (Rising et al., 1989). Diets with 3 percent fat increased daily feed intake in comparison with diets containing no added fat, and hens fed diets that provided more protein also consumed greater amounts of energy. Generally, regulation of energy intake by laying hens and broilers is more precise when relatively low-energy diets are fed (Morris, 1968; Fisher and Wilson, 1974; Latshaw et al., 1990). In some instances, however, laying hens are fairly accurate in regulating energy consumption when fed high-energy diets (Horani and Sell, 1977).

Because the preponderance of data shows that changes in feed intake usually are not proportional to changes in dietary energy concentration, the use of specific protein/amino acid-to-dietary energy ratios (originally termed energy-to-protein ratios) in formulating poultry diets (Baldini and Rosenberg, 1955; Combs, 1961; Scott et al., 1982; Thomas et al., 1986) must be carefully evaluated. Relating nutrient concentrations to dietary energy level seems to have greatest practical application for Leghorn chickens that generally are fed diets of low to moderate energy content. In the instance of growing broiler chickens and turkeys, however, maintaining specific nutrient-to-energy ratios seems questionable. This is particularly true for protein-to-energy ratios intended to support economical growth and feed efficiency (Pesti and Fletcher, 1983; Sell et al., 1985; 1989). If the production of lean broiler or turkey carcasses is of economic importance, appropriate dietary protein-to-energy ratios may be of greater significance. It would be desirable to have mathematical models available that would facilitate the selection of most economical combinations of dietary concentrations of protein/amino acids (and other nutrients) and energy to achieve poultry production goals. Development of such models will be contingent on research designed to obtain more relevant information than is currently available.

Factors other than dietary energy and nutrient balance that affect feed intake include bulk density of the diet (Cherry et al., 1983) and ambient temperature (National Research Council, 1981a). The latter can have considerable impact on feed consumption of poultry, especially adult birds, because feed intake decreases as ambient temperature increases. Leghorn-type hens consume approximately 1.5 g less feed per hen daily for each 1°C increase in ambient temperature over the range of 10° to 35°C (Davis et al., 1973; Sykes, 1979). At temperatures above 30°C, the decrease in feed consumption may be 2.5 to 4 g for each 1°C increase (Sykes, 1979; Sell et al., 1983). Similar responses of decreasing feed intake with increasing temperatures have been reported for turkeys (Parker et al., 1972; Hurwitz et al., 1980).

Energy Values in the Nutrient Requirement Tables

The ME_n values heading the lists of nutrient requirements given in Chapters 3 through 6 should not be regarded as energy requirements. The committee chose these as bases of reference. They represent the dietary energy concentrations frequently used under practical conditions of feed formulation and poultry management. For those persons preferring to use TME_n values, the TME_n values of numerous feed ingredients are included in Table 9-1. Generally, ME_n values as determined by the method of Anderson et al. (1958) and TME_n values as determined by Sibbald (1983) are similar for many ingredients. However, ME_n and TME_n values differ substantially for some ingredients, such as feather meal, rice bran, wheat middlings, and corn distillers' grains with solubles, and so in these instances ME_n values should not be indiscriminately interchanged with TME_n values for purposes of diet formulation.

CARBOHYDRATES

Dietary carbohydrates are important sources of energy for poultry. Cereal grains such as corn, grain sorghum, wheat, and barley contribute most of the carbohydrates to poultry diets. The majority of the carbohydrates of cereal grains occurs as starch, which is readily digested by poultry (Moran, 1985a). Other carbohydrates occur in varying concentrations in cereal grains and protein supplements. These carbohydrates include polysaccharides, such as cellulose, hemicellulose, pentosans, and oligosaccharides, such as stachyose and raffinose, all of which are poorly digested by poultry. Thus, these dietary carbohydrates often contribute little to meeting the energy requirement of poultry, and some adversely affect the digestive processes of poultry when present in sufficient dietary concentrations. For example, the pentosans of rye and beta glucans of barley increase the viscosity of digesta and thereby interfere with nutrient utilization by poultry (Wagner and Thomas, 1978; Antoniou and Marquardt, 1981; Classen et al., 1985; Bedford et al., 1991). Supplementation of rye or barley-containing diets with appropriate supplemental enzyme preparations improves nutrient utilization and growth of young poultry (Leong et al., 1962; Edney et al., 1989; Friesen et al., 1992).

PROTEINS AND AMINO ACIDS

Dietary requirements for protein are actually requirements for the amino acids contained in the dietary protein. Amino acids obtained from dietary protein are used by poultry to fulfill a diversity of functions. For example, amino acids, as proteins, are primary constituents of structural and protective tissues, such as skin, feathers, bone matrix, and ligaments, as well as of the soft tissues, including organs and muscles. Also, amino acids and small peptides resulting from digestion-absorption may serve a variety of metabolic functions and as precursors of many important nonprotein body constituents. Because body proteins are in a dynamic state, with synthesis and degradation occurring continuously, an adequate intake of dietary amino acids is required. If dietary protein (amino acids) is inadequate, there is a reduction or cessation of growth or productivity and a withdrawal of protein from less vital body tissues to maintain the functions of more vital tissues.

There are 22 amino acids in body proteins, and all are physiologically essential. Nutritionally, these amino acids can be divided into two categories: those that poultry cannot synthesize at all or rapidly enough to meet metabolic requirements (essential) and those than can be synthesized from other amino acids (nonessential). The essential amino acids must be supplied by the diet. If the nonessential amino acids are not supplied by the diet, they must be synthesized by poultry. The presence of adequate amounts of nonessential amino acids in the diet reduces the necessity of synthesizing them from essential amino acids. Thus, stating dietary requirements for both protein and essential amino acids is an appropriate way to ensure that all amino acids needed physiologically are provided.

Variations in Requirements

Protein and amino acid requirements vary considerably according to the productive state of the bird, that is, the rate of growth or egg production. For example, turkey poults and broiler chickens have high amino acid requirements to meet the needs for rapid growth. The mature rooster has lower amino acid requirements than does the laying hen, even though its body size is greater and its feed consumption is similar.

Body size, growth rate, and egg production of poultry are determined by their genetics. Amino acid requirements, therefore, also differ among types, breeds, and strains of poultry, as can be seen by comparing the values shown in the requirement tables provided in this report for the different types of poultry. Genetic differences in amino acid requirements may occur because of differences in efficiency of digestion, nutrient absorption, and metabolism of absorbed nutrients (National Research Council, 1975).

Although dietary requirements for amino acids and protein usually are stated as percentages of the diet, the quantitative needs of poultry must be met by a balanced source to obtain maximum productivity. Thus factors that affect feed consumption also will affect quantitative intakes of amino acids and protein, and, consequently, will influence the dietary concentration of these nutrients needed to provide adequate nutrition. Factors affecting feed consumption are discussed in the section on "Setting Dietary Levels" and have been reviewed in the National Research Council (1987a) publication, *Predicting Feed Intake of Food-Producing Animals*.

As discussed in the section "Setting Dietary Levels," adjustments in the protein and amino acids concentration of diets may be necessary to compensate for difference in energy concentration of diets. This is especially true for White Leghorn chickens (Morris, 1968; Byerly et al., 1980) and turkey hens (Kratzer et al., 1976).

Ambient temperature also affects feed intake of poultry (Hurwitz et al., 1980). Protein and amino acid requirements listed herein generally pertain to poultry kept in moderate temperatures (18° to 24°C). Ambient temperatures outside of this range cause an inverse response in feed consumption; that is, the lower the temperature, the greater the feed intake and vice versa (National Research Council, 1981c). Consequently, percentage requirements of protein and amino acids should be increased in warmer environments and decreased in cooler environments, in accordance with expected differences in feed intake. These adjustments may aid in ensuring required daily intakes of amino acids. Some precautions, however, should be used in increasing the dietary protein concentration for poultry subjected to high ambient temperature. Waldroup et al. (1976d) reported that performance of broiler chicks was improved by minimizing excess dietary amino acids.

Information available from research documenting the influence of dietary energy concentration and ambient temperature on feed intake has been integrated with data describing amino acid needs for maintenance, body growth (such as for muscle and feathers), or egg production to derive mathematical models to predict the dietary amino acid requirements of poultry (Fisher et al., 1973; Hurwitz and Bornstein, 1973; Hurwitz et al., 1978; Emmans, 1981; Slagter and Waldroup, 1984). Prediction models may be useful in feed formulation, and they also provide valuable insight into areas of amino acid and protein nutrition where more definitive information is needed on requirements.

Dietary protein concentrations can affect the requirements for individual essential amino acids. Generally, as dietary protein level increases, essential amino acid requirements (expressed as a percentage of the diet) increase, although when expressed as a percentage of the protein, essential amino acid requirements are little affected (Almquist, 1952; Boomgaardt and Baker, 1971, 1973a; Morris et al., 1987; Robbins, 1987; Mendonca and Jensen, 1989a). These observations demonstrate the importance of maintaining a balance among the concentrations of essential and nonessential amino acids in poultry diets. Optimal balance is important for efficient utilization of dietary protein.

The protein and amino acid concentrations presented as requirements herein are intended to support maximum growth and production. Achieving maximum growth and production, however, may not always ensure maximum economic returns, particularly when prices of protein sources are high. If decreased performance can be tolerated, dietary concentrations of amino acids may, accordingly, be reduced somewhat to maximize economic returns.

Specific Amino Acid Relationships

Although each amino acid can be metabolized independently of others, relationships between certain amino acids exist. In some instances, the relationship may be beneficial. For example, one amino acid may be converted to another to fulfill a metabolic need. In other instances, a metabolic antagonism may exist with undesirable consequences. A brief description of amino acid relationships that may be of importance in poultry nutrition is given in the following section.

Methionine Plus Cystine

Methionine can donate its methyl group to biological processes, and the resulting sulfur-containing compound, homocysteine, together with serine, can be used to synthesize cysteine via cystathionine. The sulfhydryl groups of two molecules of cysteine are oxidized to form cystine. This conversion cannot be reversed, and two methionine molecules are needed to ultimately supply the two sulfur atoms of cystine (du Vigneaud, 1952; Creek, 1968; Baker, 1976). The requirement for methionine can be satisfied only by methionine, whereas that for cystine can also be met with methionine.

The catabolism of methionine and cystine largely leads to conversion of the associated sulfur into sulfate. This sulfate may be used in metabolism, particularly as a part of certain connective tissues. Similarly, methyl groups of methionine may be used in transmethylation and the de novo synthesis of sarcosine, betaine, and choline. Choline is a constituent of phospholipids, and its incorporation into membranes is extensive. During rapid growth, when accrual of connective tissue and expansion of membrane surfaces are great, an increased sensitivity to methionine at levels marginal to the requirement may occur if dietary choline and sulfate are not sufficient (Baker et al., 1983; Miles et al., 1983; Blair et al., 1986).

Phenylalanine Plus Tyrosine

Tyrosine is the initial product formed during the biological degradation of phenylalanine. In turn, phenylalanine can be used to meet the bird's need for tyrosine on a mole-for-mole basis (Creek, 1968; Sasse and Baker, 1972). Although this conversion may be reversed to a small extent and tyrosine used to form phenylalanine, its contribution is too small to be of practical significance (Ishibashi, 1972).

Glycine Plus Serine

Although glycine can be synthesized by fowl, the rate is not adequate to support maximal growth (Featherston, 1976). Serine can be converted to glycine on an equimolar basis. This reaction is reversible, and glycine can be used to form serine (Sugahara and Kandatsu, 1976).

Imbalance, Antagonism, And Toxicity

The essential amino acids are related to one another by virtue of need to support production plus maintenance. The combined need for production and maintenance represents the bird's requirement. Requirement for any one essential amino acid represents the combined need for maintenance plus production. Each essential amino acid is unique in its catabolism, and an inadequacy of any one of them (the first limiting) usually necessitates some catabolism of the others. The bird's response can vary with the essential amino acid, the extent of its inadequacy, and existing relationships among the remainder. As an example, Sugahara et al. (1969) fed chicks a purified amino acid diet corresponding to 100 percent of the requirement for all essential amino acids as the positive control and compared the performance response to when all amino acids were reduced to 60 percent of the requirement as opposed to 60 percent reduction with each one alone. Weight gain was better with individual decreases of methionine-cystine, leucine, lysine, and arginine than when a total reduction was imposed, whereas additional weight loss occurred with individual decreases of phenylalanine, tyrosine, tryptophan, isoleucine, valine and threonine. A reduction in dietary histidine gave a similar response to that observed when all amino acids were reduced.

Deficiencies of any one of the essential amino acids can be exaggerated by adding purified amino acids and/or combining complete proteins such that the extent of difference between the first and second limiting amino acid increases. The response is generally an additional impairment of body weight gain. Accentuation of the deficiency in this manner usually involves diets of low protein content, and a decrease in feed intake is the fundamental reason for poor weight gain rather than alteration in effectiveness of the first limiting amino acid (Fisher et al., 1960; Fisher and Shapiro, 1961; Netke et al., 1969).

Amino acid antagonisms may also accentuate a deficiency of the first limiting amino acid, but these differ from imbalances because utilization of the limiting amino acid is reduced. Antagonisms can occur between amino acids having side chains exhibiting similar structural and/or chemical characteristics, and increasing the dietary concentration of one that is in excess of productive use adversely affects metabolism of the other. In a situation in which one essential amino acid is first limiting, increasing the other's concentration to enlarge the difference antagonizes the use of the first limiting amino acid and induces or exacerbates a deficiency.

Antagonisms have been shown to exist for leucine-isoleucine-valine, arginine-lysine, and threonine-tryptophan (D'Mello and Lewis, 1970). The most important of these antagonisms occurs with leucine and isoleucine. Certain feedstuff combinations (for example, corn plus corn gluten meal) can lead to practical diets in which leucine is at particularly high levels while isoleucine is marginal in adequacy. Amino acid levels that would be likely to provoke the other antagonisms probably would not occur in practice unless high levels of supplemental amino acids were used in low-protein diets.

An amino acid toxicity requires a particularly high level of one amino acid relative to all others. Such an occurrence is unlikely under practical circumstances because differences of sufficient magnitude do not exist in most protein feedstuffs. Supplemental methionine and lysine are routinely used by the feed industry but usually in quantities low enough to pose no threat of toxicity.

Errors in amino acid use may lead to toxicities, however. Methionine is toxic when excessive. Ueda et al. (1981) observed severe depression in feed consumption and growth of chicks given ad libitum access to a diet containing 10 percent protein and 1.5 percent L-methionine. Force-feeding this high-methionine, low-protein diet in amounts equal to the feed intake of controls resulted in death of the chicks. Edmonds and Baker (1987) added excesses of several amino acids to a 23 percent protein corn-soybean meal diet for chicks. Methionine at 4 percent of the diet led to a 92 percent reduction in weight gain, whereas similar excesses of tryptophan, lysine, and threonine were far less toxic.

Amino Acid Conversion to Vitamins

Niacin is the only vitamin that can be synthesized from an amino acid. Tryptophan can be used to alleviate a dietary niacin deficiency, but the rate of conversion is poor (Baker et al., 1973). When methionine is provided at levels exceeding use for protein synthesis, the additional methyl groups may decrease the dietary choline requirement (Pesti et al., 1980). Using amino acids to spare other nutrients is not currently economical under practical conditions.

Amino Acid Availability

It is well known that the availability of amino acids varies greatly among feedstuffs. The importance of considering amino acid availability in formulation of poultry diets is discussed in Chapter 9.

FATS

Fat is usually added to the feed for meat-type poultry to increase overall energy concentration and, in turn, improve productivity and feed efficiency. Oxidation of fat is an efficient means to obtain energy for the cell in large quantity, whereas anabolic use involves direct incorporation into the body as a part of growth. Lipid accrual is most obvious in adipose tissue; however, cell multiplication also requires an array of lipids to form associated membranes. These two uses can occur simultaneously; however, the extent of each may vary considerably.

Sources

Feed-grade fat may come from many different sources. Grease from restaurants, the rendering of animal carcasses, and the refuse from vegetable oil refining are major sources. These sources represent several types and categories, and each is defined by the Association of American Feed Control Officials (1984). These definitions indicate fat components and limits of nonfat material (Sell, 1988). Moisture (M) and those compounds that are either insoluble in ether (I) or unsaponifiable (U) are usually of no value, and their composite (MIU) essentially acts as a diluent.

Total fatty acids contributed by all lipid categories, the proportion that are in free form, and the types of fatty acids present provide information related to expected digestibility as well as how the fat may be used subsequently. Fatty acid chain length, extent of unsaturation, and nature of esterification all influence intestinal absorption (Moran, 1989a). The percentage MIU and percentage digestibility combine to influence the ME_n value. All feed fats should be stabilized by an antioxidant to preserve unsaturated fatty acids and routinely monitored for the possible presence of undesirable residues such as insolubles, chlorinated hydrocarbons, and unsaponifiables and for peroxides (Rouse, 1986).

Metabolizable Energy Value

Factors influencing the ME_n value of fat that are not directly associated with fat quality are age of poultry and method of measurement. Improved utilization of dietary fats has been shown to occur after 2 to 6 weeks of life for chickens (Renner and Hill, 1960, 1961; Sibbald, 1978a; Lessire et al., 1982) and turkeys (Whitehead and Fisher, 1975; Sell et al., 1986b). This improvement is particularly evident with long-chain saturated fatty acids and fats containing substantial proportions of these fatty acids (Young and Garrett, 1963; Sell et al., 1986b).

The methodology used in obtaining feedstuff energy values has an effect on the values obtained. (See the sections above on procedures for determination of ME_n and on estimating the ME_n content of ingredients from proximate composition.) Actual digestibility of fat may also be used to estimate energy content, and Sell et al. (1986b) found that values determined by this method agree with concurrent ME_n measurements.

When the effects of method of determination and age of the bird are superimposed on factors associated with the fat, it becomes evident that assigning a specific ME_n value to a fat may be inappropriate. The information in Table 9-9 provides a description of fats that may be used in feeds and their ME_n values observed under a variety of circumstances. Data indicate that considerable variation exists and several factors must be considered in determining feeding value. Some of these factors are included in the equations listed in Appendix Table B-1, which can be used to predict the ME_n value of fats.

Blending Fats

When animal tallow is added to feed at a low level, it may be beneficial to blend it with a small amount of vegetable oil. The resulting ME_n value of blends is greater than can be explained from the arithmetic combination. A synergism in the absorption of the saturated fatty acids related to the added amounts of unsaturated fatty acids is suspected (Ketels et al., 1986; Ketels and DeGroote, 1987).

The properties of animal tallows also may be enhanced by the presence of feed ingredients that contain unsaturated fatty acids. Corn is particularly advantageous in this respect because its fatty acids are mostly unsaturated and it usually constitutes a large portion of a feed. Sibbald and Kramer (1980) noted that the *TME* for beef tallow was greater when a corn-based carrier was used during measurement than when wheat was used.

Extra Caloric Effect

Employing high levels of added fat often leads to more ME_n than can be accounted for from the summation of ingredients. High level fat feeding evidently increases the intestinal retention time of feed and so allows for more complete digestion and absorption of the nonlipid constituents (Mateos and Sell, 1981; Mateos et al., 1982; Sell et al., 1983).

Improved Net Energy of Production

All body tissues have an energy value that corresponds to their heat of combustion. The net energy of production corresponds to this energy gained from either body growth or egg formation. Adding fat to feed as an isoenergetic substitution for carbohydrate usually results in an improved productive energy when the same level of ME_n has been derived. Such improvement is particularly obvious through that period preceding adolescent development. Sell and Owings (1984) noted that added fat increased the body weight gain of large turkeys, with the greatest advantage occurring between 12 and 20 weeks of age. After 20 weeks, the favorable effect of fat on body weight progressively dissipates, but the effect on feed efficiency remains (Moran, 1982).

Fatty acid synthesis within fowl occurs primarily in the liver. Immediately preceding sexual maturity the rate of synthesis increases dramatically, and the rate at which the body's depots accrue fat is great (Moran, 1985b). The provision of fat in feed obviates the cost of synthesis and is more energy-efficient than is synthesis of fat from carbohydrate.

Laying hens also may respond to added dietary fat. Most lipid in egg yolk is formed in the liver by using fatty acids obtained from the diet or from de novo synthesis. Providing dietary fat decreases the need for hepatic fatty acid synthesis and generally increases yolk formation and the weight of the egg (Whitehead, 1981;

March and MacMillan, 1990). Such advantages are particularly valuable during high environmental temperatures. As feed intake is reduced, the added fat permits the hen to maintain egg formation while minimizing heat generated (Valencia et al., 1980).

Fatty Acid Composition

Directly employing dietary fat in the assembly of either body or egg lipids results in a fatty acid composition similar to that of the diet. Fat absorbed from the fowl's intestine is transported to the liver, where some modifications may occur. For the most part, the unsaturated fatty acids are unchanged, but the saturated ones may undergo desaturation, especially stearic acid which can be converted to oleic acid. Also, elongation and further desaturation of 18:2(n-6) and 18:3(n-3) may occur in the liver.

Depot fat is the tissue most affected by the source of dietary fat. Depot fat of both broiler chickens (Schuler and Essary, 1971; Edwards et al., 1973) and turkeys (Moran et al., 1973; Salmon and O'Neil, 1973) are more influenced by the vegetable oils having high proportions of polyunsaturated fatty acids than by more saturated animal fats.

Fatty acid composition in depots can be altered by changing from one dietary fat to another (Watkins, 1988). The extent of influence that each fat has on body composition increases with the level of intake, duration of feeding, and stage of maturity (Bartov et al., 1974; Salmon, 1976). The hen's adipose depots respond to dietary fat in the same way as do those of growing birds, and the yolk lipid exhibits a fatty acid pattern resembling that of the dietary fat (Guenter et al., 1971; Sim et al., 1973).

Essential Fatty Acids

Linoleic acid (18:2, n-6) and a-linolenic acid (18:3, n-3) are recognized as metabolically essential fatty acids. The position of the double bonds in these n-6 and n-3 polyunsaturated fatty acids (PUFA) is unique because they are not formed in the fowl. The essential fatty acids are converted to long-chain PUFA in poultry through a series of desaturation (addition of a double bond) and elongation steps (chain-lengthening with 2 carbons) to form 20 and 22 carbon PUFA (Watkins, 1991). Membrane phospholipids contain a greater proportion of PUFA than do triacyglyerols although depot fat can contain a reserve of linoleic acid for the fowl. In poultry, specific PUFA are biosynthesized into compounds called eicosanoids which act as potent biological regulators.

Linoleic acid is the only essential fatty acid for which a dietary requirement has been demonstrated. Inadequacies of linoleic acid are not readily encountered, but symptoms that result are due to a loss of membrane integrity. An increased need for water and decreased resistance to disease are characteristic deficiency symptoms observed in poultry (Balnave, 1970). A deficiency of linoleic acid in the male can impair spermatogenesis and affect fertility. Insufficient deposition of linoleic acid in the egg will adversely affect embryonic development. The essential fatty acid requirements of growing and adult birds can usually be satisfied by feeding a diet with 1 percent of linoleic acid. Higher levels of linoleic acid may be needed by the laying hen to achieve and maintain satisfactory egg weight.

A dietary need for α-linolenic acid (18:3, n-3) has yet to be demonstrated for the fowl. α-Linolenic acid appears to be important, however, in the development of specialized membranes found in the retina and nervous system. These membranes contain relatively high concentrations of n-3 PUFA that can originate from 18:3(n-3) (Neuringer and Connor, 1986).

Certain PUFA derived from linolenic and α-linolenic acids are biosynthesized into a multitude of eicosanoids. The primary substrates for eicosanoid production are 20:4(n-6), 20:3(n-6) which are formed from linoleic acid, and 20:5(n-3) a product of α-linolenic acid. Preceding eicosanoid biosynthesis in poultry, the PUFA is released from membrane phospholipids by action of phospholipases. Liberation of PUFA is induced by a number of stimuli. Following a series of different enzymatic steps, several eicosanoids can be formed depending on the tissue and cell type (Watkins, 1991). The eicosanoids are categorized into prostaglandins, prostacyclins, thromboxanes, and leukotrienes. Formation of eicosanoids is widespread in the body and nearly every physiological system is affected by these hormone-like compounds. The eicosanoids are important in embryonic development, reproduction, immunological responses, and bone development in poultry (Watkins, 1991).

Eicosanoid production can be modulated depending upon the concentration of substrate PUFA found in tissues. Changing the dietary concentrations of n-3 and n-6 PUFA found in tissues will influence the types and amounts of eicosanoids formed (Watkins, 1991). Elevating the n-3 PUFA content of the diet relative to that for n-6 PUFA alters eicosanoid production in immunocompetent cells (Kinsella et al., 1990). These types of responses also seem to affect inflammatory reactions and blood clotting in animals and humans. To maintain the full spectrum of eicosanoid effects in the body a balanced intake of n-3 and n-6 PUFA is recommended.

MINERAL

Minerals are the inorganic part of feeds or tissues. They are often divided into two categories, based on the amount that is required in the diet. Requirements for major, or macro, minerals usually are stated as a percentage of the diet, whereas requirements for minor, or trace, minerals are stated as milligrams per kilogram of diet or as parts per million.

Minerals are required for the formation of the skeleton, as components of various compounds with particular functions within the body, as cofactors of enzymes, and for the maintenance of osmotic balance within the body of the bird. Calcium and phosphorus are essential for the formation and maintenance of the skeleton. Sodium, potassium, magnesium, and chloride function with phosphates and bicarbonate to maintain homeostasis of osmotic relationships and pH throughout the body. Most of the calcium in the diet of the growing bird is used for bone formation, whereas in the mature laying fowl most dietary calcium is used for eggshell formation. Other functions of calcium include roles in blood clotting and as a second messenger in intracellular communications.

An excess of dietary calcium interferes with the availability of other minerals, such as phosphorus, magnesium, manganese, and zinc. A ratio of approximately 2 calcium to 1 nonphytate phosphorus (weight/weight) is appropriate for most poultry diets, with the exception of diets for birds that are laying eggs. When poultry are laying eggs, a much higher level of calcium is needed for eggshell formation, and a ratio as high as 12 calcium to 1 nonphytate phosphorus (weight/weight) may be correct. But high levels of calcium carbonate (limestone) and calcium phosphates may tend to make the diet unpalatable and dilute the other dietary components. If a calcium source contains a high level of magnesium (as does dolomitic limestone), it probably should not be used in poultry diets (Stillmak and Sunde, 1971).

Phosphorus, in addition to its function in bone formation, is also required in the utilization of energy and in structured components of cells. Examples of phosphorus-containing compounds are adenosine 5'-triphosphate (ATP) and phospholipids. These forms of phosphorus, if present in plants, can be digested by poultry; however, such digestible forms usually account for only 30 to 40 percent of the total phosphorus. The remaining phosphorus is present as phytate phosphorus and is poorly digested. Only about 10 percent of the phytate phosphorus in corn and wheat is digested by poultry (Nelson, 1976). The phosphorus from animal products and phosphorus supplements is generally considered to be well utilized. Phosphorus supplements for poultry diets are listed in Table 9-10.

Sodium and chloride are essential for all animals. Dietary concentrations of salt generally used are those that will just support maximum growth rate or egg production. Higher concentrations lead to excessive consumption of water and attendant problems with ventilation control and wet droppings.

Dietary proportions of sodium, potassium, and chloride are important determinants of acid-base balance (Mongin, 1968; Hurwitz et al., 1973; Cohen and Hurwitz, 1974; Sauveur and Mongin, 1978). Other cations and anions such as calcium, sulfate, and phosphate also may be involved. The appropriate dietary balance of these electrolytes is often assessed by the levels of sodium and potassium versus chloride, where each element is expressed in milliequivalents per kilogram of diet. Experiments show that sodium and potassium are alkalogenic (have an alkaline-producing effect), whereas chloride is acidogenic (has an acid-producing effect). Chloride tends to decrease blood pH and bicarbonate concentration, whereas sodium and potassium tend to increase blood pH and bicarbonate concentration. The proper dietary balance of sodium, potassium, and chloride is necessary for growth, bone development, eggshell quality, and amino acid utilization (Mongin, 1981). However, an ideal balance among these electrolytes appropriate for a wide range of environmental situations has not been defined.

Trace elements, including copper, iodine, iron, manganese, selenium, and zinc are required in small amounts in the diet. Cobalt is also required, but it does not need to be supplied as a trace mineral because it is a part of vitamin B_{12}. In practical diets, copper and iron are often present at sufficient levels without supplementation.

Trace elements function as part of larger organic molecules. Iron is a part of hemoglobin and cytochromes, and iodine is a part of thyroxine. Copper, manganese, selenium, and zinc function as essential accessory factors to enzymes and, in the case of zinc, DNA structural motifs (zinc fingers). If one of these minerals is deficient, the functional activity of the organic moiety requiring the presence of the mineral will be decreased, as has been described in detail for each mineral by Mertz (1986).

The requirements for trace minerals are often fulfilled by concentrations present in conventional feed ingredients. Soils vary, however, in their content of trace minerals, and plants vary in their uptake of minerals. Consequently, feedstuffs grown in certain geographic areas may be marginal or deficient in specific elements. Thus, poultry diets may require supplementation to ensure adequate intake of trace minerals. Because of the interactions that occur between various minerals such as copper and molybdenum, selenium and mercury, calcium and zinc, calcium and manganese (Mertz, 1986), excessive concentrations of one element may result in a deficiency in the amount available to the bird of some other element. Formulators of poultry diets should be aware of these possible mineral interactions and of the potential effects that the chemical form (cation-anion combination) of mineral sources may have on their utilization by poultry (Allaway, 1986). Mineral salts used as feed supplements are not usually pure compounds but contain variable amounts of other minerals. The concentrations of minerals that may be present in feed-grade mineral supplements are shown in Table 9-10.

Experimental diets may sometimes be formulated from purified or chemically defined ingredients. Under these conditions, silicon and boron may be inadequate and biological responses may occur with the addition of these elements to the diet (Carlisle, 1970, 1980; Nielsen, 1986).

VITAMINS

Vitamins are generally classified under two headings: fat soluble vitamins, A, D, E, and K, and water-soluble vitamins, that include the so-called B-complex and vitamin C (ascorbic acid). Vitamin C is synthesized by poultry and is, accordingly, not considered a required dietary nutrient. There is some evidence, nevertheless, of a favorable response to vitamin C by birds under stress (Pardue et al., 1985).

The requirements for most vitamins are given in terms of milligrams per kilogram of diet. Exceptions are vitamins A, D, and E, for which requirements are commonly stated in units. Units are used to express the requirements for these vitamins because different forms of the vitamins have different biological activities (Anonymous, 1990).

Requirements for vitamin A are expressed in either International Units (IU) or U.S. Pharmacopeia units (USP) per kilogram of diet. The international standards for vitamin A activity are as follows: 1 IU of vitamin A = 1 USP unit = vitamin A activity of 0.3 µg crystalline vitamin A alcohol (retinol), 0.344 µg vitamin A acetate, or 0.55 µg vitamin A palmitate. One IU of vitamin A activity is equivalent to the activity of 0.6 µg of β-carotene; alternatively, 1 mg β-carotene = 1,667 IU vitamin A (for poultry).

Vitamin D for poultry must be in the form of vitamin D_3, which is found naturally in fish liver oil or may be synthesized by the irradiation of animal sterol. Vitamin D_2, which is from plant sources, is active for rats and most mammals but has very low activity for poultry. One unit of vitamin D_3 (USP or IU) is defined as the activity of 0.025 µg of vitamin D_3 (cholecalciferol). The requirements listed herein for vitamin D are based on diets containing the stated requirements for calcium and available phosphorus.

One IU of vitamin E is the activity of 1 mg of synthetic DL-α-tocopheryl acetate, 0.735 mg D-α-tocopheryl acetate, 0.671 mg D-α-tocopherol, or 0.909 mg DL-α-tocopherol. The dietary requirement for vitamin E is highly variable and depends on the concentration and type of fat in the diet, the concentration of selenium, and the presence of prooxidants and antioxidants.

Vitamin K activity is exhibited by a number of naturally occurring and synthetic compounds with varying solubilities in fat and water. Menadione (2-methyl-1,4-naphthoquinone) is a fat soluble synthetic compound that can be considered the reference standard for vitamin K activity. Two naturally occurring forms are K1 or phylloquinone (2-methyl-3-phytyl-1,4-naphthoquinone) and K2 or menaquinone (K1 substituted with 2 to 7 isoprene units). Water-soluble forms include menadione sodium bisulfite (MSB), menadione sodium bisulfite complex (MSBC), and menadione dimethylpyrimidol (MPB). The theoretical activity of these compounds is 33, 50, and 45 percent, respectively, as calculated on the basis of the proportion of menadione present in the molecule.

Dietary supplements frequently contain, as a factor of safety, levels of vitamins in considerable excess of the minimum requirements. Vitamin tolerances have been reviewed by the National Research Council (1987b). Maximum tolerances for vitamins are of the order of 10 to 30 times the minimum requirement for vitamin A, 4 to 10 times for vitamin D_3, and 2 to 4 times for choline chloride (possibly because of the chloride). Niacin, riboflavin, and pantothenic acid are generally tolerated at levels as great as 10- to 20-fold their nutritional requirement. Vitamin E is generally tolerated at intakes as great as 100-fold the required level. Vitamins K and C, thiamin, and folic acid are generally tolerated at oral intake levels of at least 1,000-fold the requirement. Pyridoxine may be tolerated at 50 times or more of the requirement (Aboaysha and Kratzer, 1979). High levels of biotin and vitamin B_{12} have not been tested.

WATER

Water must be regarded as an essential nutrient, although it is not possible to state precise requirements. The amount needed depends on environmental temperature and relative humidity, the composition of the diet, rate of growth or egg production, and efficiency of kidney resorption of water in individual birds (Medway and Kare, 1959). It has been generally assumed that birds drink approximately twice as much water as the amount of feed consumed on a weight basis, but water intake actually varies greatly.

Several dietary factors influence water intake and water:feed ratios. Increasing crude protein increases water intake and water:feed ratios (Marks and Pesti, 1984). Crumbling or pelleting of diets increases both water and feed intake relative to mash diets, but water:feed ratios stay relatively the same (Marks and Pesti, 1984). Increasing dietary salt increases the water intake (Marks, 1987).

The data given for water consumption in Table 1-1 are for environmental temperatures of about 21°C except for brooding chicks and poults. With broilers, water consumption increases about 7 percent for each 1°C above 21° C. Laying hens may consume from 150 to 300 liters (40 to 80 gal) per 1,000 birds daily, depending on temperature and other factors. Survival under extremely hot conditions is influenced by the ability to consume large quantities of water or, more precisely, the ability to use water to remove heat from the respiratory surfaces of the body. This ability varies from strain to strain.

Water intake data for broilers listed herein are based on studies using modern commercial broilers (Marks, 1981; Ross and Hurnik, 1983; Gardiner and Hunt, 1984; Pesti et al., 1985; Miller et al., 1988). Most of the studies were carried out under moderate temperature conditions, with corrections for evaporative losses. In most of the studies, data also were collected on feed intake, allowing for calculation of water:feed ratios.

Documented water intake data for laying hens are limited, especially data related to cage systems. Dun and Emmans (1971) compared the water consumption of caged hens on trough and nipple watering systems in a 3-year study. Feed and water consumption were 126 g and 254 ml with the trough system and 124.9 g and 166 ml with the nipple system (four hens per nipple). Hearn and Hill (1978) compared feed and water consumption of hens on trough and nipple watering systems, with varying numbers of birds per nipple. During the study, that was conducted from 20 to 72 weeks of age, hens on trough waterers consumed an average of 115 g of feed and 213 ml of water. Hens with 2.5, 5, and 10 birds per nipple consumed 109, 109, and 108 g of feed and 182, 169, and 165 ml of water, respectively. Gardiner (1982) examined the water intake of individually caged hens for a 336-day period beginning when they were 32 weeks of age. Over this period of time, mean feed consumption of laying hens was 109 g and daily water intake was 183 ml, for a feed:water ratio of 1.68. There was no indication of type of drinker used. It is evident that the type of watering system used will influence water consumption (or, more correctly, water disappearance) of laying hens. Although many tables of estimated water consumption can be found in the literature, the sources of the data used to compile these tables cannot be documented.

Water consumption data for turkeys obtained from experimental studies are meager (Enos et al., 1967). Thus, the data on water consumption of turkeys shown in Table 1-1 are based mainly on information obtained recently from commercial turkey production companies.

TABLE 1-1 Water Consumption by Chickens and Turkeys of Different Ages

Age (weeks)	Broiler Chickens (ml per bird per week)[a]	White Leghorn Hens (ml per bird per week)[a]	Brown-Egg-Laying Hens (ml per bird per week)[a]	Large White Turkeys (ml per bird per week)[a,b]	
				Males	Females
1	225	200	200	385	385
2	480	300	400	750	690
3	725	–	–	1,135	930
4	1,000	500	700	1,650	1,274
5	1,250	–	–	2,240	1,750
6	1,500	700	800	2,870	2,150
7	1,750	–	–	3,460	2,640
8	2,000	800	900	4,020	3,180
9	–	–	–	4,670	3,900
10	–	900	1,000	5,345	4,400
11	–	–	–	5,850	4,620
12	–	1,000	1,100	6,220	4,660
13	–	–	–	6,480	4,680
14	–	1,100	1,100	6,680	4,700
15	–	–	–	6,800	4,720
16	–	1,200	1,200	6,920	4,740
17	–	–	–	6,960	4,760
18	–	1,300	1,300	7,000	–
19	–	–	–	7,020	–
20		1,600	1,500	7,040	–

NOTE: Dash indicates that information is not available.

[a] Varies considerably depending on ambient temperature, diet composition, rates of growth or egg production, and type of equipment used. The data presented apply under moderate (20° to 25°C) ambient temperatures.

[b] Based on data obtained from commercial turkey production units.

Water deprivation for 12 hours or more has adverse effects on the growth of young poultry and egg production of laying hens, and water deprivation of 36 hours or more results in a marked increase in mortality of young and old poultry (Bierer et al., 1965a,b; Haller and Sunde, 1966; Adams, 1973). Water restoration, after extended periods of water deprivation (36 to 40 hours), may cause a "drunken syndrome" or "water intoxication," leading to death (Marsden et al., 1965). Young turkeys are especially susceptible to this condition.

The salt content and pH of water may influence the use of the drinking water to administer vitamins and drugs. Turkeys are known to detect minor differences in the flavor of medicated water and may accept drugs in one water supply but not in another. Intermittent provision of water is sometimes used to reduce the water content of the droppings and to control feed intake in laying hens without reducing egg production (Maxwell and Lyle, 1957). Because birds differ in their ability to conserve body water by increasing kidney resorption, there is a danger of causing dehydration of some birds by practicing water restriction of a flock.

Some water supplies contain considerable concentrations of sulfur or sulfates, nitrates, and various trace minerals. These are usually readily absorbed from the intestine and may be either useful or harmful to the bird, depending on concentration. Table 1-2 gives the guidelines suggested by the National Research Council (1974) for the suitability for poultry of water with different concentrations of total dissolved solids (TDS); that is, the total concentration of all dissolved elements in water.

TABLE 1-2 Guidelines for Poultry for the Suitability of Water with Different Concentrations of Total Dissolved Solids (TDS)

TDS (ppm)	Comments
Less than 1,000	These waters should present no serious burden to any class of poultry.
1,000–2,999	These waters should be satisfactory for all classes of poultry. They may cause watery droppings (especially at the higher levels) but should not affect health or performance.
3,000–4,999	These are poor waters for poultry, often causing watery droppings, increased mortality, and decreased growth (especially in turkeys).
5,000–6,999	These are not acceptable waters for poultry and almost always cause some type of problem, especially at the upper limits, where decreased growth and production or increased mortality probably will occur.
7,000–10,000	These waters are unfit for poultry but may be suitable for other livestock.
More than 10,000	These waters should not be used for any livestock or poultry.

SOURCE: National Research Council. 1974. Nutrients and Toxic Substances in Water for Livestock and Poultry. Washington, D.C.: National Academy of Sciences.

XANTHOPHYLLS

A number of carotenoid pigments are responsible for the yellow-orange coloration of egg yolks and poultry fat and also may contribute to coloration of the skin, shanks, feet, and beak. The xanthophylls, which are characterized by the presence of hydroxyl groups, are the carotenoids of most interest in poultry nutrition. The most commonly considered xanthophylls are lutein in forages such as alfalfa and zeaxanthin in corn. Relative xanthophyll contribution by various xanthophyll-rich ingredients is shown in Table 1-3.

Individual xanthophylls differ in their ability to impart color. Although β-carotene has little pigmenting value, other xanthophylls and synthetic products are effective in influencing yolk and skin color. Less than 1 percent of dietary β-carotene is deposited in the yolk, but for zeaxanthin, as found in corn, the value is closer to 7 percent, and for some synthetic products, such as β-apo-8-carotenoic acid ethyl ester, the incorporation rate may be as high as 34 percent (Roche Vitamins and Fine Chemicals, 1988). Fletcher et al. (1985) and Saylor (1986) reported that natural sources of xanthophyll differed in their ability to pigment egg yolk and the skin of broilers. Alfalfa meal contains several types of xanthophylls, but the one of greatest abundance and importance is lutein, which tends to impart a yellow color, whereas corn and corn gluten meal contain primarily zeaxanthin, which tends to impart an orange-red color.

TABLE 1-3 Xanthophyll and Lutein Content of Selected Ingredients

Ingredient	Xanthophyll (mg/kg)	Lutein (mg/kg)
Alfalfa meal, 17% crude protein	220	143
Alfalfa meal, 22% crude protein	330	—
Alfalfa protein concentrate, 40% crude protein	800	—
Algae meal	2,000	—
Corn	17	0.12
Corn gluten meal, 60% crude protein	290	120
Marigold petal meal	7,000	—

NOTE: Dash indicates that information is not available.

Avian tissue normally accumulates xanthophylls, although the retina may accumulate other carotenoids (Goodwin, 1986). In the laying hen, 50 percent of total body zeaxanthin (as derived from corn) is found in the ovary (Scheidt et al., 1985). Goodwin (1986) indicated that body stores of xanthophylls in the muscle and skin are transferred to the ovary at onset of sexual maturity. Presumably, this transfer occurs throughout the egg production cycle and contributes to the gradual loss of pigment from the shank and beak as egg production continues.

Synthetic carotenoids that have been approved for use by regulatory agencies are used in poultry diets, because levels of desired pigments in natural feedstuffs are not always constant and many of the carotenoid-containing natural feedstuffs are relatively low in energy content. Approval of use of these synthetics varies among countries. Synthetic pigments, such as canthaxanthin and β-apo-8-carotenoic acid (usually as an ethyl ester), can be used to control pigmentation more precisely to yield varying degrees of yellow-orange-red coloration. In natural products, xanthophylls are unstable, and effective levels may decline as a result of oxidation during prolonged storage. This decline can be reduced by the inclusion of antioxidants in the feed.

A number of factors can adversely affect absorption of xanthophylls and thus lead to reduced pigmentation. Broilers infected with *Eimeria* sp. exhibit reduced pigmentation and blood xanthophylls (Bletner et al., 1966), and the viral infection that may be responsible for malabsorption syndrome also results in altered xanthophyll status of the bird (Winstead et al., 1985). Exposing feed to light may have variable effects on subsequent pigmentation (Fletcher, 1981). The presence of certain mycotoxins in feeds seems to be detrimental to pigmentation (Tyczkowski and Hamilton, 1987).

UNIDENTIFIED GROWTH FACTORS

So-called unidentified growth factors have been reported throughout the history of poultry nutrition studies. Natural ingredients claimed to contain such factors are most often animal proteins or fermentation by-products (Summers et al., 1959; Al-Ubaidi and Bird, 1964; Dixon and Couch, 1970; Waldroup et al., 1970). Ingredients containing unidentified growth factors are claimed to improve chick growth and reproductive performance (Morrison et al., 1956; Touchburn et al., 1972). Bhargava and Sunde (1969) described a chick assay for quantitation of such unidentified factors.

The mode of action of these unidentified factors is far from clear, however. With the identification of vitamins and consideration of the significance of trace minerals, many nutritionists now disregard the importance of growth factors. That responses may still occur could relate to truly unidentified nutrients or, more likely, to changes in feed palatability and/or quality (Alenier and Combs, 1981; Cantor and Johnson, 1983), mineral chelation, or simple improvement in the balance of available nutrients.

ANTIMICROBIALS

Antimicrobial feed additives, although not nutrients in the sense that they are required by poultry, are included in diets to improve growth, efficiency of feed utilization and livability (Stokstad et al., 1949; Coates et al., 1951; Libby and Schaible, 1955; Milligan et al., 1955; Bird, 1968; Begin, 1971; Morrison et al., 1974). Antimicrobial agents are included in diets at relatively low concentrations (1 to 50 mg/kg), depending on the agent and stage of development of poultry. They are, accordingly, classified as additives and as growth promoters. Egg production is also frequently improved by dietary supplementation with antimicrobial agents (Carlson et al., 1953; Balloun, 1954; Andrews et al., 1966). The mechanisms by which antimicrobials improve performance are not clearly understood. Because antimicrobials do not stimulate growth of chicks kept in a germfree environment (Coates and Harrison, 1969), it is likely that stimulation of growth results from either suppression of microorganisms that may cause adverse effects or encouragement of other microorganisms that may have favorable effects on poultry performance.

There is some concern that feeding of low concentrations of antibiotics may favor the proliferation of antibiotic-resistant microorganisms, which could have serious consequences for disease control in humans or domestic animals. A study by the National Research Council (1980a) examined this concern and concluded that "the postulations concerning the hazards to human health that might result from the addition of subtherapeutic antimicrobials to feeds have been neither proven nor disproven." Continued monitoring of bacterial resistance in humans and animals has not provided clear-cut answers to this concern.

Constraints and regulations on use of particular antimicrobials in poultry feeds vary among countries and are subject to change. Detailed information on specific antimicrobial agents, levels of usage, and legal requirements for use in the United States and Canada may be found in the *Feed Additive Compendium* (published each year by the Miller Publishing Company, 2501 Wayzata Boulevard, Minneapolis, MN 55440) and in the compendium of "Medicating Ingredient Brochures" (Plant Products Division, Canada Department of Agriculture, Ottawa, Ontario, Canada).

For official information concerning Food and Drug Administration approval of antibiotics and other animal drugs, the *Code of Federal Regulations* (CFR), Title 21, should be consulted. Title 21 is revised at least once each year as of April 1. The CFR is kept up to date by the individual issues of the *Federal Register*. These two publications must be used together to determine the latest version of any given rule. Title 21 is published in six parts: Part 500-599 covers animal drugs, feeds, and related products and is available from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402. The *Federal Register* is available from the Superintendent of Documents and includes monthly issues of the "List of CFR Sections Affected" and "The Federal Register Index."

2

Nutrient Requirements of Chickens

Chickens vary greatly according to the purpose for which they have been developed. Those intended for the production of eggs for human consumption (Leghorn-type) have a small body size and are prolific layers, whereas those used as broilers or broiler breeders (meat-type) have rapid growth rates and a large body size. They are less efficient egg layers. Methods of feeding differ for these two kinds of chickens.

LEGHORN-TYPE CHICKENS

Methods of feeding Leghorn-type chickens depend on the age and activity (laying or breeding) of the bird. Feed requirements change as birds pass through the starting and growing, pre-egg-laying, egg production, and molt phases.

Starting and Growing Pullets

Relatively little research has been conducted in the last 10 years to obtain definitive nutrient requirements for immature Leghorn-type birds. In large part, this situation is due to the use of meat-strain birds in requirement studies involving avian species. Thus, although growth and maturity characteristics of egg-strain pullets have changed considerably over the last 10 years, particularly for brown-egg-laying birds, the only data available on requirements for many nutrients are dated. Most current research activity deals with nutrients of major economic significance. The available information is reviewed in Appendix Table A-1.

Nutrient requirements of immature Leghorn-type chickens (pullets) are listed in Table 2-1. Although requirements are assessed ultimately in terms of subsequent reproductive performance, the criteria used by the committee were adequate growth rate (in terms of final body weight at different ages) and normal metabolism. It is well documented that mature body weight can greatly influence the subsequent reproductive performance (Leeson and Summers, 1987a), and, as such, this criterion becomes critical in the assessment of nutritional status.

The dearth of research information for immature pullets is even more acute for brown-egg-laying strains. Because brown-egg-laying birds predominate in many parts of the world, the committee has attempted to define their nutrient requirements as well. In large part, however, these requirement values have been extrapolated from studies conducted with Leghorns with consideration for the larger body weight and/or appetite and increased maintenance requirement of brown-egg layers.

The nutrient requirement values shown in Table 2-1 and the performance characteristics shown in Table 2-2 are based on the assumption that the birds will be allowed to consume feed in an ad libitum manner. Ad libitum feed consumption is important for Leghorn birds, especially when reared in hot climates, because of their inherently low appetites. Managers should routinely consider restricted feeding only for brown-egg-laying strains, and even then only in temperate climates and with high-energy diets.

Protein And Energy

In discussing the protein needs of growing pullets, it is assumed that the amino acid profile is balanced according to the requirement values shown in Table 2-1. Pullets allowed to self-select diets based on protein or energy content seem to voluntarily consume much less protein in early life and more protein as they approach maturity (Summers and Leeson, 1978) than do pullets on more conventional programs. However, low-protein or low-lysine starter diets invariably depress the growth

TABLE 2-1 Nutrient Requirements of Immature Leghorn-Type Chickens as Percentages or Units per Kilogram of Diet

		White-Egg-Laying Strains				Brown-Egg-Laying Strains			
Nutrient	Unit	0 to 6 Weeks; 450 g[a] 2,850[b]	6 to 12 Weeks; 980 g[a] 2,850[b]	12 to 18 Weeks; 1,375 g[a] 2,900[b]	18 Weeks to First Egg; 1,475 g[a] 2,900[b]	0 to 6 Weeks; 500 g[a] 2,800[b]	6 to 12 Weeks; 1,100 g[a] 2,800[b]	12 to 18 Weeks; 1,500 g[a] 2,850[b]	18 Weeks to First Egg; 1,600 g[a] 2,850[b]
Protein and amino acids									
Crude protein[c]	%	18.00	16.00	15.00	17.00	***17.00***	15.00	14.00	***16.00***
Arginine	%	1.00	0.83	0.67	0.75	***0.94***	***0.78***	***0.62***	***0.72***
Glycine + serine	%	0.70	0.58	***0.47***	***0.53***	***0.66***	***0.54***	***0.44***	***0.50***
Histidine	%	0.26	0.22	0.17	0.20	***0.25***	***0.21***	***0.16***	***0.18***
Isoleucine	%	0.60	0.50	0.40	0.45	***0.57***	***0.47***	***0.37***	***0.42***
Leucine	%	1.10	0.85	0.70	0.80	***1.00***	***0.80***	***0.65***	***0.75***
Lysine	%	0.85	0.60	0.45	0.52	***0.80***	***0.56***	***0.42***	***0.49***
Methionine	%	0.30	0.25	0.20	0.22	***0.28***	***0.23***	***0.19***	***0.21***
Methionine + cystine	%	0.62	0.52	0.42	0.47	***0.59***	***0.49***	***0.39***	***0.44***
Phenylalanine	%	0.54	0.45	0.36	0.40	***0.51***	***0.42***	***0.34***	***0.38***
Phenylalanine + tyrosine	%	1.00	0.83	0.67	0.75	***0.94***	***0.78***	***0.63***	***0.70***
Threonine	%	0.68	0.57	0.37	0.47	***0.64***	***0.53***	***0.35***	***0.44***
Tryptophan	%	0.17	0.14	0.11	0.12	***0.16***	***0.13***	***0.10***	***0.11***
Valine	%	0.62	0.52	0.41	0.46	***0.59***	***0.49***	***0.38***	***0.43***
Fat									
Linoleic acid	%	1.00	***1.00***	***1.00***	***1.00***	***1.00***	***1.00***	***1.00***	***1.00***
Macrominerals									
Calcium[d]	%	0.90	0.80	0.80	2.00	***0.90***	***0.80***	***0.80***	***1.80***
Nonphytate phosphorus	%	0.40	0.35	0.30	0.32	0.40	0.35	0.30	0.35
Potassium	%	***0.25***	***0.25***	***0.25***	***0.25***	***0.25***	***0.25***	***0.25***	***0.25***
Sodium	%	0.15	0.15	0.15	0.15	***0.15***	***0.15***	***0.15***	***0.15***
Chlorine	%	0.15	***0.12***	***0.12***	***0.15***	***0.12***	***0.11***	***0.11***	***0.11***
Magnesium	mg	600.0	***500.0***	***400.0***	***400.0***	***570.0***	***470.0***	***370.0***	***370.0***
Trace minerals									
Manganese	mg	60.0	***30.0***	***30.0***	***30.0***	***56.0***	***28.0***	***28.0***	***28.0***
Zinc	mg	40.0	***35.0***	***35.0***	***35.0***	***38.0***	***33.0***	***33.0***	***33.0***
Iron	mg	80.0	***60.0***	***60.0***	***60.0***	***75.0***	***56.0***	***56.0***	***56.0***
Copper	mg	***5.0***	***4.0***	***4.0***	***4.0***	***5.0***	***4.0***	***4.0***	***4.0***
Iodine	mg	0.35	***0.35***	***0.35***	***0.35***	***0.33***	***0.33***	***0.33***	***0.33***
Selenium	mg	0.15	***0.10***	***0.10***	***0.10***	***0.14***	***0.10***	***0.10***	***0.10***
Fat soluble vitamins									
A	IU	1,500.0	1,500.0	1,500.0	1,500.0	***1,420.0***	***1,420.0***	***1,420.0***	***1,420.0***
D_3	ICU	200.0	200.0	200.0	300.0	***190.0***	***190.0***	***190.0***	***280.0***
E	IU	***10.0***	***5.0***	***5.0***	***5.0***	***9.5***	***4.7***	***4.7***	***4.7***
K	mg	0.5	***0.5***	***0.5***	***0.5***	***0.47***	***0.47***	***0.47***	***0.47***
Water soluble vitamins									
Riboflavin	mg	3.6	1.8	1.8	2.2	***3.4***	***1.7***	***1.7***	***1.7***
Pantothenic acid	mg	***10.0***	***10.0***	***10.0***	***10.0***	***9.4***	***9.4***	***9.4***	***9.4***
Niacin	mg	27.0	11.0	11.0	11.0	***26.0***	***10.3***	***10.3***	***10.3***
B_{12}	mg	0.009	0.003	0.003	0.004	***0.009***	***0.003***	***0.003***	***0.003***
Choline	mg	1,300.0	900.0	500.0	500.0	***1,225.0***	***850.0***	***470.0***	***470.0***
Biotin	mg	***0.15***	***0.10***	***0.10***	***0.10***	***0.14***	***0.09***	***0.09***	***0.09***
Folic acid	mg	***0.55***	***0.25***	***0.25***	***0.25***	***0.52***	***0.23***	***0.23***	***0.23***
Thiamin	mg	***1.0***	***1.0***	***0.8***	***0.8***	***1.0***	***1.0***	***0.8***	***0.8***
Pyridoxine	mg	3.0	***3.0***	***3.0***	***3.0***	***2.8***	***2.8***	***2.8***	***2.8***

NOTE: Where experimental data are lacking, values typeset in bold italics represent an estimate based on values obtained for other ages or related species.

[a] Final body weight.

[b] These are typical dietary energy concentrations for diets based mainly on corn and soybean meal, expressed in kcal ME_n/kg diet.

[c] Chickens do not have a requirement for crude protein per se. There, however, should be sufficient crude protein to ensure an adequate nitrogen supply for synthesis of nonessential amino acids. Suggested requirements for crude protein are typical of those derived with corn-soybean meal diets, and levels can be reduced somewhat when synthetic amino acids are used.

[d] The calcium requirement may be increased when diets contain high levels of phytate phosphorus (Nelson, 1984).

rate of both white-egg- (Douglas and Harms, 1982; Kwakkel et al., 1991) and brown-egg-laying pullets (Maurice et al., 1982), and early growth depression often depresses mature body weight and thereby adversely affects adult performance (Milby and Sherwood, 1953; Leeson and Summers, 1979, 1987a). Low-protein diets have a transitory effect on muscle fiber size rather than any long-term effect on numbers of such fibers (Timson et al., 1983). Although low-protein diets seem to adversely affect growth rate, there is little indication that excessively high levels of protein have any benefit on growth and development. Data of Keshavarz (1984) and Leeson and Summers (1989) suggest that in Leghorn pullets reduction in growth is often seen when total protein intake to 140 days of age is less than 1 kg. An intake of 1 kg of balanced protein during the same period seems to result in maximum growth.

TABLE 2-2 Body Weight and Feed Consumption of Immature Leghorn-Type Chickens

	White-Egg-Laying Strains		Brown-Egg-Laying Strains	
Age (weeks)	Body Weight[a] (g)	Feed Consumption (g/week)	Body Weight[a] (g)	Feed Consumption (g/week)
0	35	50	37	70
2	100	140	120	160
4	260	260	325	280
6	450	340	500	350
8	660	360	750	380
10	750	380	900	400
12	980	400	1,100	420
14	1,100	420	1,240	450
16	1,220	430	1,380	470
18	1,375	450	1,500	500
20	1,475	500	1,600	550

[a] Average genetic potential when feed is consumed on an ad libitum basis.

Different commercial strains may show different growth rates and different final mature body weights.

Energy intake may be the limiting factor for growth of egg-strain birds reared under most environmental conditions. Assuming no amino acid deficiency, and an intake of 1 kg of protein from 1 day to 20 weeks, growth and development seem most responsive to energy intake (Leeson and Summers, 1989). A total intake of 21 Mcal *ME* to 20 weeks seems ideal for white-egg-laying pullets. However, manipulation of energy intake is not always easy, since the pullet appears to have a fairly precise innate ability to regulate its energy intake regardless of dietary energy level (Cunningham and Morrison, 1976; McNaughton et al., 1977b; Doran et al., 1983). Manipulation of energy intake is, therefore, best considered in relation to feeding management and, in particular, methods of stimulating feed intake. For example, feed intake may be increased through use of pelleted feed, increased frequency of feeding, feeding at cooler times of the day, and, where possible, use of longer periods of light. Leeson and Summers (1989) concluded that pullet growth is initially most sensitive to dietary protein and amino acids, whereas energy intake becomes more critical as the bird approaches maturity.

Skeletal size has also been considered as a criterion for assessment of pullet development. Lerner (1946) suggested that skeletal size is a limiting factor for growth, and Jaap (1938) indicated that shank length can be used as a reliable estimate of skeletal size per se. Skeletal development is related to adequate supplies of calcium, phosphorus, and vitamin D_3, although deficiencies of most nutrients can adversely affect normal vascularization of cartilage at the growth plate, a prerequisite to normal calcification (Leeson and Summers, 1988). Skeletal growth is intimately associated with general growth and development, and it is difficult to influence either independently. Leeson and Summers (1984) indicated that increased skeletal size of pullets in response to dietary protein was associated with reduced ash content of bones.

Minerals And Vitamins

As indicated above, little work has been done recently to evaluate the mineral and vitamin requirements of young egg-strain birds. There has been some interest in reevaluating nonphytate phosphorus needs, although, in general, the new data indicate no major change in previously reported requirement values. Both the young white-egg- (Douglas and Harms, 1986) and the young brown-egg-laying pullets (Carew and Foss, 1980) exhibit an inferior growth rate when fed starter diets containing less than 0.4 percent nonphytate phosphorus. The sodium requirement of the Leghorn pullet is approximately 0.15 percent of the diet regardless of age, although somewhat lower levels can be used after 10 weeks of age if excessive water intake is problematic (Manning and McGinnis, 1980).

Prelay Period

Daily nutrient requirements of pullets 10 to 17 days before first egg are generally considered to be greater than during the preceding 4 to 6 week period, although there is little evidence to show that pullets cannot meet these requirements through increased voluntary feed intake.

Hoyle and Garlich (1987) found no change in growth or development of Leghorn pullets in response to elevated levels of dietary energy or protein. As suggested above, energy intake is probably the most critical component for this age of bird, and energy intake can perhaps be manipulated best through stimulation of feed intake rather than by simply increasing the energy level of the feed.

The committee's review of research on the changes in metabolism of medullary bone immediately prior to maturity has led to reevaluation of the pullets' requirement for calcium at this time. Since modern egg-strain pullets exhibit a rapid increase in egg production and prolonged first multiegg clutch, it is obvious that a change in the requirements related to calcification must be accommodated before or at time of first egg. Keshavarz (1987) indicated that feeding a diet containing 3.5 percent calcium from as early as 14 weeks of age had no adverse effect on skeletal integrity, apparent renal function, or subsequent reproductive performance. Leeson et al. (1986, 1987a) also observed normal pullet development, skeletal integrity, and kidney histology when immature 19-week-old pullets were fed diets containing 3.5 percent calcium. These same workers indicated that calcium levels of 0.9 to 1.5 percent at this age were detrimental to early shell quality. In studies in which pullets were allowed to self-select nutrients, Classen and Scott (1982) showed that the birds consumed calcium in relation to needs for deposition of medullary bone and (or) onset of shell calcification.

There has been little research on the phosphorus and vitamin D_3 requirements of the prelay pullet.

Hens in Egg Production

Progress continues in the quest to use less feed in producing eggs. Most of this progress has resulted from decreasing the amount of feed that is required for body maintenance of laying hens.

Body Maintenance Needs

Management practices, as well as nutritional regimes, can affect the maintenance requirement. In warmer houses, layers need less energy from their feed because they expend less energy in maintaining body temperature. Hens eat less feed with increasing temperatures and decrease feed consumption drastically at temperatures above 30°C (Davis et al., 1973; National Research Council, 1981c).

Genetic selection can also affect the amount of feed required for maintenance. With chickens bred for higher rates of egg production, there is a decrease in the maintenance requirement relative to eggs produced. At a rate of 100 percent egg production (that is, one egg per hen per day), maintenance requirements must be fulfilled for the 12 days needed to produce a dozen eggs; at a rate of 75 percent egg production, 16 days of maintenance requirements must be met to obtain a dozen eggs.

Body size also affects maintenance requirements. A compilation of information from nonpasserine birds showed that basal metabolism was equal to 78.3 kcal per day × (kg body weight)723 (Lasiewski and Dawson, 1967). Conditions for collection of these data were that the birds were in a postabsorptive state, in a thermoneutral environment, and as nearly at rest as possible. Maintenance requirement, or the energy needed to sustain normal body processes and activities other than growth and egg production, is greater than that of basal metabolism. In the thermoneutral range of temperatures, maintenance for hens is approximately 100 kcal per day per kg body weight (MacLeod and Jewitt, 1988; Pesti et al., 1990). Strains of hens may differ in their maintenance needs because of metabolic or behavioral characteristics (Pesti et al., 1990).

Production Needs

Nutritional factors can affect the amount of feed required to produce eggs. For example, some research indicates that hens are able to make a good adjustment of feed intake to provide nearly identical daily energy intakes with up to 6 percent added dietary fat (Sell et al., 1987). But other research suggests that the hen is not very accurate in adjusting feed intake to provide equal daily energy intake when offered a range of dietary energy conditions (Morris, 1968; Rising et al., 1989). Regardless of the accuracy of energy adjustment, hens eat less of a high-energy, nutritionally balanced feed than of a low-energy feed to produce a dozen eggs.

Now that eggs can be produced with less feed, nutritionists have been permitted, or sometimes forced, to formulate diets differently than they did several years ago. Generally, it is assumed that a hen's daily requirements for nutrients, other than energy, are not changed by the level of feed consumption. If this is correct, then the difference in composition between the diet of a layer eating 80 g of feed per day and the diet of one eating 120 g of feed per day should be about 40 g of energy-supplying ingredients. But differences in daily feed consumption can cause the need for dramatic differences in dietary nutrient concentration, if diets are formulated to supply a specified amount of nutrient, other than energy, each day. Nutrient requirements of egg-type laying hens (Table 2-3) are expressed in terms of dietary concentrations for three levels of daily feed consumption. (The research reports on which the committee based its nutrient requirement decisions are listed in Appendix Table A-2.) Just how different rates of feed consumption can influence the formulation of a diet can be seen by using one nutrient—say, lysine, as an example. The lysine required each day by a white-egg-laying hen is 690 mg, or 0.69 g. Thus the diet of a white-egg-laying layer eating 100 g of feed per day should have a lysine concentration of 0.69 percent.

TABLE 2-3 Nutrient Requirements of Leghorn-Type Laying Hens as Percentages or Units per Kilogram of Diet (90 percent dry matter)

		Dietary Concentrations Required by White-Egg Layers at Different Feed Intakes	Amounts Required per Hen Daily (mg or IU)				
			White-Egg Breeders at 100 g of Feed per Hen Daily[b]	White-Egg Layers at 100 g of Feed per Hen Daily	Brown-Egg Layers at 110 g of Feed per Hen Daily[c]		
Nutrient	Unit	80[a,b]				100[a,b]	120[a,b]
Protein and amino acids							
Crude protein[d]	%	18.8	15.0	12.5	15,000	15,000	16,500
Arginine[e]	%	***0.88***	***0.70***	***0.58***	***700***	***700***	***770***
Histidine	%	***0.21***	***0.17***	***0.14***	***170***	***170***	***190***
Isoleucine	%	0.81	0.65	0.54	650	650	***715***
Leucine	%	***1.03***	***0.82***	***0.68***	***820***	***820***	***900***
Lysine	%	0.86	0.69	0.58	690	690	***760***
Methionine	%	0.38	0.30	0.25	300	300	***330***
Methionine + cystine	%	0.73	0.58	0.48	580	580	***645***
Phenylalanine	%	***0.59***	***0.47***	***0.39***	***470***	***470***	***520***
Phenylalanine + tyrosine	%	***1.04***	***0.83***	***0.69***	***830***	***830***	***910***
Threonine	%	***0.59***	***0.47***	***0.39***	***470***	***470***	***520***
Tryptophan	%	0.20	0.16	0.13	160	160	***175***
Valine	%	***0.88***	***0.70***	***0.58***	***700***	***700***	***770***
Fat							
Linoleic acid	%	1.25	1.0	0.83	1,000	1,000	***1,100***
Macrominerals							
Calcium[f]	%	4.06	3.25	2.71	3,250	3,250	3,600
Chloride	%	0.16	0.13	0.11	130	130	***145***
Magnesium	mg	625	500	420	50	50	***55***
Nonphytate phosphorus[g]	%	0.31	0.25	0.21	250	250	***275***
Potassium	%	0.19	0.15	0.13	150	150	***165***
Sodium	%	0.19	0.15	0.13	150	150	***165***
Trace minerals							
Copper	mg	?	?	?	?	?	?
Iodine	mg	0.044	0.035	0.029	0.010	0.004	***0.004***
Iron	mg	56	45	38	6.0	4.5	***5.0***
Manganese	mg	25	20	17	2.0	2.0	***2.2***
Selenium	mg	0.08	0.06	0.05	0.006	0.006	***0.006***
Zinc	mg	44	35	29	4.5	3.5	***3.9***
Fat soluble vitamins							
A	IU	3,750	3,000	2,500	300	300	***330***
D_3	IU	375	300	250	30	30	***33***
E	IU	***6***	***5***	***4***	***1.0***	0.5	***0.55***
K	mg	0.6	0.5	0.4	0.1	***0.05***	***0.055***
Water soluble vitamins							
B_{12}	mg	0.004	***0.004***	***0.004***	0.008	***0.0004***	***0.0004***
Biotin	mg	***0.13***	***0.10***	***0.08***	***0.01***	***0.01***	***0.011***
Choline	mg	1,310	1,050	875	105	105	***115***
Folacin	mg	0.31	0.25	0.21	0.035	0.025	***0.028***
Niacin	mg	12.5	10.0	8.3	1.0	1.0	***1.1***
Pantothenic acid	mg	2.5	2.0	1.7	0.7	0.20	***0.22***
Pyridoxine	mg	3.1	2.5	2.1	0.45	0.25	***0.28***
Riboflavin	mg	3.1	2.5	2.1	0.36	0.25	0.28
Thiamin	mg	0.88	0.70	0.60	0.07	***0.07***	***0.08***

NOTE: Where experimental data are lacking, values typeset in bold italics represent an estimate based on values obtained for other ages or related species.

[a] Grams feed intake per hen daily.

[b] Based on dietary ME_n concentrations of approximately 2,900 kcal/kg and an assumed rate of egg production of 90 percent (90 eggs per 100 hens daily).

[c] Italicized values are based on those from white-egg layers but were increased 10 percent because of larger body weight and possibly more egg mass per day.

[d] Laying hens do not have a requirement for crude protein per se. However, there should be sufficient crude protein to ensure an adequate supply of nonessential amino acids. Suggested requirements for crude protein are typical of those derived with corn-soybean meal diets, and levels can be reduced somewhat when synthetic amino acids are used.

[e] Italicized amino acid values for white-egg-laying chickens were estimated by using Model B (Hurwitz and Bornstein, 1973), assuming a body weight of 1,800 g and 47 g of egg mass per day.

[f] The requirement may be higher for maximum eggshell thickness.

[g] The requirement may be higher in very hot temperatures.

Hens eating 80 g of feed per day need a dietary lysine concentration of 0.86 percent to obtain 0.69 g per day; hens eating 120 g per day need a dietary lysine concentration of only 0.58 percent lysine to provide 0.69 g per hen per day. The basic concept is that high daily feed consumption permits low nutrient concentrations and low daily feed consumption demands high nutrient concentrations.

Equations have been developed to predict the energy required by chickens during egg production (McDonald, 1978; National Research Council, 1981c). These equations use the expected energy requirements of hens as related to body weight, daily egg mass, change in body weight, and ambient temperature to predict a total daily energy requirement. The data of Table 2-4 show the predicted daily energy requirements of hens as related to different body weights and rates of egg production, assuming no change in body weight and an ambient temperature of 22°C. The energy requirements derived from such calculations can be used to estimate daily feed intake by relating the hen's energy needs to the dietary energy concentration. Diets for laying hens, however, can be most accurately formulated on the basis of feed intake data obtained frequently (every 1 to 2 weeks) for individual flocks.

Most egg-type hens are given ad libitum access to feed; however, feeding programs may be modified after the maximum rate of egg mass output has been attained (Cerniglia et al., 1984; Cunningham, 1984). Laying hens eat more feed than is needed to support egg production. As a result, it may be more profitable to limit their feed intake. Doing so would also reduce the likelihood of health problems that can also result when hens are overly fat. Data on feed consumption in individual flocks, together with information on body weight, ambient temperature, and rate of egg production, may be used to determine the degree of feed restriction deemed appropriate.

Phase Feeding

Nutrient requirements presented in Table 2-3 assume that the amount of nutrient needed each day remains the same throughout a hen's time of production. Some feeding programs, however, are based on the assumption that the amount of nutrient needed each day is different at different stages of the production cycle. These programs are called phase feeding.

In phase feeding for flocks of laying hens, Phase 1 is designated as the time from the onset of egg production until past the time of the maximum egg mass output, usually at about 36 weeks of age, which is the time of maximum egg mass output. Phase 2 is the period between 36 and approximately 52 weeks, a period of high but declining egg production and increasing egg weight. Phase 3 is from about 52 weeks to the end of the production cycle, in some instances to 80 weeks. During Phase 3 the rate of egg production continues to decline while egg weight increases only slightly.

TABLE 2-4 Estimates of Metabolizable Energy Required per Hen per Day by Chickens in Relation to Body Weight and Egg Production (kcal)

Body	Rate of Egg Production (%)					
Weight (kg)	0	50	60	70	80	90
1.0	130	192	205	217	229	242
1.5	177	239	251	264	276	289
2.0	218	280	292	305	317	330
2.5	259	321	333	346	358	371
3.0	296	358	370	383	395	408

NOTE: A number of formulas have been suggested for prediction of the daily energy requirements of chickens. The formula used here was derived from that in *Effect of Environment on Nutrient Requirements of Domestic Animals* (National Research Council, 1981c):

ME per hen daily = $W^{0.75}$ (173 - 1.95T) + 5.5 δW + 2.07 EE

where W = body weight (kg), T = ambient temperature (°C), δW = change in body weight (g/day), and EE = daily egg mass (g). Temperature of 22°C, egg weight of 60 g, and no change in body weight were used in calculations.

A phase feeding program adjusts daily nutrient intakes according to expected requirements for maintenance and egg production. Generally, daily intakes of protein, amino acids, and phosphorus are reduced with each succeeding phase. Daily calcium intake usually is increased with each phase. Thus the dietary concentrations of these nutrients are changed accordingly.

The scientific validity of the phase feeding concept has not been established. Experimental results have failed to prove that a hen requires more nutrient per day at one stage of production than at another stage (Latshaw, 1981; Ousterhout, 1981; Sell et al., 1987). Relatively low levels of feed intake during early egg production, however, necessitate the use of high nutrient concentrations in diets during this phase of production.

Egg Weight

Egg weight is correlated with body weight of laying hens (Jull, 1924). The relative egg weight during a laying cycle parallels the relative body weight. Within a flock, heavier birds lay heavier eggs (Leeson and Summers, 1987a). A body weight decline in summer may account for the production of smaller eggs during that season (Cunningham et al., 1960).

Nutritional means may be used to alter egg weight slightly. Early in the egg production cycle, the objective would be to increase egg weight. In one study (Summers and Leeson, 1983), the weight of eggs from pullets was not affected by increases in dietary levels of methionine, linoleic acid, or protein above the established requirement. Another study showed that increasing the level of dietary linoleic acid from 0.6 percent to 4.3 percent increased by egg weight during the first 14 weeks of production; however, average daily egg yield was not affected (March and MacMillan, 1990). In a different study, adding 3 or 6 percent fat to diets fed during early egg production increased egg weight by increasing yolk weight whether the diets were isocaloric or nonisocaloric (Sell et al., 1987).

When egg weight is increased by fat supplementation of diets, it is not known if the response is due to fat in general or is a specific response to linoleic acid (Whitehead, 1981; Balnave, 1982; Scragg et al., 1987). Increasing the percentage of fat or oil in isoenergetic diets caused hens to lay heavier eggs (Whitehead, 1981; Sell et al., 1987). Decreasing the dietary energy level, as may occur when sorghum or barley is substituted for corn, may decrease egg weight (Coon et al., 1988). Diet costs may increase when supplemental fats are used to obtain higher dietary fat and energy concentrations. Thus managers should determine the economic effectiveness of increasing egg weight in this way.

Older laying hens produce a high proportion of extralarge eggs for which monetary returns often do not offset costs of production. Thus, a goal of feed formulators may be to reduce the weight of eggs produced by older hens. Decreasing dietary levels of the most limiting amino acid can affect egg weight (Morris and Gous, 1988). For example, weight of eggs produced by hens more than 38 weeks of age was reduced by limiting methionine intake to 270 mg per hen daily, compared with feeding 300 mg methionine per hen daily (Peterson et al., 1983). A review of 12 scientific papers indicated that as the most limiting amino acid level decreased below the required level, egg weight and rate of egg production were proportionally reduced. This reduction occurred until egg weight decreased to about 90 percent of maximum. Further decreases in the amino acid level decreased only the rate of egg production. An exception to the general effects of amino acid adequacy and egg weight occurs with tryptophan, whereby a deficiency of this amino acid failed to decrease egg weight (Jensen et al., 1990).

Minerals And Vitamins

Mineral requirements of egg-type chickens in production are similar to mineral requirements of other poultry, with the exception of calcium. The onset of egg production creates a need for more calcium to make the eggshell.

A question arises about the best time to switch pullets from a low-calcium growing diet to a high-calcium laying diet. Feeding a diet with 3.25 percent calcium starting at 50 days of age increased the incidence of urolithiasis in later life (Wideman et al., 1985). Changing from a low- to a high-calcium diet at 14 weeks of age or later, however, caused no detrimental effects on performance through 60 weeks (Keshavarz, 1987). Although high-calcium levels are detrimental when fed early in a pullet's life, feeding high-calcium levels several weeks before the onset of egg production seems to do no harm.

The calcium requirement listed in Table 2-3 is similar to values listed in earlier editions. Definitive research is still lacking regarding several questions, however. Tests that cover a whole production cycle and that provide increments of calcium ranging from 3 to 4.5 g per hen daily would be helpful. Such tests would answer questions related to amounts of calcium needed, especially for the maintenance of eggshell strength in older layers. Conditions under which larger-particle-size calcium sources consistently improve eggshell strength should also be identified.

Levels of nutrients other than calcium may also affect eggshell strength. A wide sodium-to-chloride ratio can increase blood pH and bicarbonate concentrations (Cohen et al., 1972). These increases may be the mechanism by which eggshell strength is improved at thermoneutral zone temperatures with some diets when sodium chloride is replaced by sodium bicarbonate in the water (Frank and Burger, 1965) or feed (Miles and Harms, 1982; Makled and Charles, 1987).

Phosphorus levels may also affect eggshell strength. Excess dietary phosphorus may decrease eggshell strength (Arscott et al., 1962; Miles and Harms, 1982). The amount of phosphorus needed each day (Table 2-3) has been decreased from amounts recommended in earlier editions. A daily intake of 250 mg of nonphytate phosphorus should be adequate for normal production and health. Although feeding diets containing excess phosphorus is generally undesirable, poultry encountering heat stress may require additional phosphorus. Garlich et al. (1978) and McCormick et al. (1980) reported that chickens fed diets containing relatively high phosphorus levels were more tolerant of high ambient temperatures than were those fed normal phosphorus levels. The use of dietary phosphorus at requirement levels should result in less phosphorus in excreta. This fact may assume more importance in the future if manure application rates to land are determined on the basis of phosphorus content.

Research information published about vitamin requirements does not indicate the need for any major change in recommendations from the previous edition. However, results from several reports showed that, for maximum egg yield, the choline requirement was about 1,050 mg per hen daily (Parsons and Leeper, 1984; Keshavarz and Austic, 1985; Miles et al., 1986). Therefore the choline requirement for laying hens has been increased.

Brown-Egg-Laying Layers

Estimated nutrient requirements of brown-egg layers are listed in Table 2-3. Because little research has been done with brown-egg-laying layers, the committee had little quantitative information to review for establishing nutrient requirements. Estimates of daily requirements given in Table 2-3 are listed as 10 percent greater than those of the white-egg-laying layers. The 10 percent increase is justified on the basis that brown-egg-laying layers have heavier body weights and generally produce more egg mass per hen daily.

Egg-Type Breeders

Nutrient requirements for egg-type breeders are listed in Table 2-3. Major nutrient requirements are the same for producing an egg for human consumption as for producing an egg for hatching; however, dietary levels of trace minerals and vitamins that result in maximum egg yield per day may be too low for the developing embryo (Naber, 1979). Vitamin and trace mineral levels in the egg can be increased by increasing the dietary levels. Higher riboflavin, pantothenic acid, and vitamin B_{12} levels are especially critical for maximum hatchability, although several other nutrients may also become limiting. As a result, several of the micronutrient requirements are higher in breeding diets than in laying diets.

Molting Hens

After 8 to 12 months of egg production, some flocks are molted as a means of extending the period of production (Zimmerman and Andrews, 1987). A combination of feed, water, and light restriction is usually used to stop egg production and cause a rest, which may last from 3 to 6 weeks. A rest can also be induced by free-choice feeding of a diet containing a deficiency or excess of a specific nutrient. Examples of nutrients used to induce molt include excess iodine (Arrington et al., 1967), excess zinc (Supplee et al., 1961), and sodium chloride deficiency (Whitehead and Shannon, 1974; Naber et al., 1984). After the rest, egg production can be initiated by stimulatory lighting. Little research information is available on the nutrient requirements of molted hens; therefore the committee has assumed that requirements are similar to those of hens during the first cycle of production.

TABLE 2-5 Typical Body Weights, Feed Requirements, and Energy Consumption of Broilers

Age (weeks)	Body Weight (g)		Weekly Feed Consumption (g)		Cumulative Feed Consumption (g)		Weekly Energy Consumption (kcal *ME*/bird)		Cumulative Energy Consumption (kcal *ME*/bird)	
	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female
1	152	144	135	131	135	131	432	419	432	419
2	376	344	290	273	425	404	928	874	1,360	1,293
3	686	617	487	444	912	848	1,558	1,422	2,918	2,715
4	1,085	965	704	642	1,616	1,490	2,256	2,056	5,174	4,771
5	1,576	1,344	960	738	2,576	2,228	3,075	2,519	8,249	7,290
6	2,088	1,741	1,141	1,001	3,717	3,229	3,651	3,045	11,900	10,335
7	2,590	2,134	1,281	1,081	4,998	4,310	4,102	3,459	16,002	13,794
8	3,077	2,506	1,432	1,165	6,430	5,475	4,585	3,728	20,587	17,522
9	3,551	2,842	1,577	1,246	8,007	6,721	5,049	3,986	25,636	21,508

NOTE: Values are typical for broilers fed well-balanced diets providing 3,200 kcal *ME*/kg.

MEAT-TYPE CHICKENS

Dietary requirements for meat-type chickens vary according to whether the birds are broilers being started and grown for market, broiler breeder pullets and hens, or broiler breeder males.

Starting and Growing Market Broilers

Chickens of broiler strains have been selected for rapid weight gain and efficient utilization of feed. Broilers are usually allowed to feed on an ad libitum basis to ensure rapid development to market size, although some interest has been expressed in controlling feed intake in an attempt to minimize the development of excessive carcass fat. Broilers are marketed at a wide range of ages and body weights (Table 2-5). Females may be grown to 900- to 1,000-g body weight to supply Cornish hens, mixed sexes may be reared to 1.8 to 2 kg for use as whole birds and specialty parts, and males may be grown to 2.8 to 3 kg for deboned meat. Thus it is difficult to establish a single set of requirements that is appropriate to all types of broiler production. Furthermore, nutrient requirements may vary according to the criterion of adequacy. In the instance of essential amino acids, greater dietary concentrations may be required to optimize efficiency of feed utilization than would be needed to maximize weight gain. There also is evidence that the dietary requirement for lysine to maximize yields of breast meat of broilers is greater than that needed to maximize weight gain (Acar et al., 1991) and that differences exist among strains of broilers with respect to this need for more lysine (Bilgili et al., 1992).

Expression of a requirement for any nutrient is relative, and many factors must be considered. Many nutrients are interdependent, and it is difficult to express requirements for one without consideration of the quantity of the other. Examples include the relationships that exist between lysine and arginine and among calcium, phosphorus, and vitamin D_3 levels in the diet.

Other factors that may affect requirements include age and gender of the animal. Some studies suggest that males require greater quantities of nutrients than do females at a similar age; however, when expressed as a percentage of the diet, there seems to be little difference in nutrient requirements of the sexes. The requirements for many nutrients seem to diminish with age, but for most nutrients there have been few research studies designed to precisely estimate requirements for all age periods, especially for those beyond 3 weeks of age.

Any expression of nutrient requirements can be only a guideline representing a consensus of research reports. These guidelines must be adjusted as necessary to fit the wide variety of ages, sexes, and strains of broiler chickens.

The values given in Table 2-6 are generally minimum levels that satisfy general productive activities and(or) prevent deficiency syndromes. Requirements are presented for specific age periods. *These age periods are based on the chronology for which research data were available.* These nutrient requirements are often implemented for younger age intervals or on a weight-of-feed consumed basis. Where information is lacking, bold italicized values represent an estimate based on values attained for other ages or related species. The data from the peer-reviewed scientific literature that serve as a basis for the committee's estimation of nutrient requirements are presented in Appendix Table A-3a.

Amino Acids

Relatively high concentrations of dietary amino acids are needed to support the rapid growth of meat-type chickens. Body weights of commercial meat-type chickens will increase 50- to 55-fold by 6 weeks after hatching. A large part of this increase in weight is tissue of substantial protein content. Thus, adequate amino acid nutrition is vital to the successful feeding program for this type of chicken.

Methionine plus Cystine

The greatest disagreement concerning amino acid requirements for broilers centers on the sulfur amino acids, methionine and cystine. In

TABLE 2-6 Nutrient Requirements of Broilers as Percentages or Units per Kilogram of Diet (90 percent dry matter)

Nutrient	Unit	0 to 3 Weeks[a]; 3,200[b]	3 to 6 Weeks[a]; 3,200[b]	6 to 8 Weeks[a]; 3,200[b]
Protein and amino acids				
Crude protein[c]	%	23.00	20.00	18.00
Arginine	%	1.25	1.10	1.00
Glycine + serine	%	1.25	***1.14***	***0.97***
Histidine	%	0.35	***0.32***	***0.27***
Isoleucine	%	0.80	***0.73***	***0.62***
Leucine	%	1.20	***1.09***	***0.93***
Lysine	%	1.10	1.00	0.85
Methionine	%	0.50	0.38	0.32
Methionine + cystine	%	0.90	0.72	0.60
Phenylalanine	%	0.72	***0.65***	***0.56***
Phenylalanine + tyrosine	%	1.34	***1.22***	***1.04***
Proline	%	0.60	***0.55***	***0.46***
Threonine	%	0.80	0.74	0.68
Tryptophan	%	0.20	0.18	0.16
Valine	%	0.90	***0.82***	0.70
Fat				
Linoleic acid	%	1.00	1.00	1.00
Macrominerals				
Calcium[d]	%	1.00	0.90	0.80
Chlorine	%	0.20	0.15	0.12
Magnesium	mg	600	***600***	***600***
Nonphytate phosphorus	%	0.45	0.35	0.30
Potassium	%	0.30	0.30	0.30
Sodium	%	0.20	0.15	0.12
Trace minerals				
Copper	mg	8	***8***	***8***
Iodine	mg	***0.35***	0.35	0.35
Iron	mg	80	***80***	***80***
Manganese	mg	***60***	***60***	***60***
Selenium	mg	0.15	0.15	0.15
Zinc	mg	40	***40***	***40***
Fat soluble vitamins				
A	IU	***1,500***	***1,500***	***1,500***
D_3	ICU	200	200	200
E	IU	***10***	***10***	***10***
K	mg	0.50	0.50	0.50
Water soluble vitamins				
B_{12}	mg	0.01	***0.01***	***0.007***
Biotin	mg	0.15	0.15	***0.12***
Choline	mg	1,300	***1,000***	***750***
Folacin	mg	0.55	0.55	***0.50***
Niacin	mg	35	30	25
Pantothenic acid	mg	***10***	***10***	***10***
Pyridoxine	mg	3.5	3.5	***3.0***
Riboflavin	mg	3.6	3.6	3
Thiamin	mg	***1.80***	***1.80***	***1.80***

NOTE: Where experimental data are lacking, values typeset in bold italics represent an estimate based on values obtained for other ages or related species.

[a] The 0- to 3-, 3- to 6-, and 6- to 8-week intervals for nutrient requirements are based on chronology for which research data were available; however, these nutrient requirements are often implemented at younger age intervals or on a weight-of-feed consumed basis.

[b] These are typical dietary energy concentrations, expressed in kcal ME_n/kg diet. Different energy values may be appropriate depending on local ingredient prices and availability.

[c] Broiler chickens do not have a requirement for crude protein per se. There, however, should be sufficient crude protein to ensure an adequate nitrogen supply for synthesis of nonessential amino acids. Suggested requirements for crude protein are typical of those derived with corn-soybean meal diets, and levels can be reduced when synthetic amino acids are used.

[d] The calcium requirement may be increased when diets contain high levels of phytate phosphorus (Nelson, 1984).

part, this is because most studies are not designed to determine both the requirements of methionine per se and the requirement for the combined quantity of methionine and cystine. Many attempts have been made, especially with purified diets, to ascertain the relative proportions needed of these two amino acids, with variable results. Many have attributed a share of the disagreement in estimated requirements to factors such as the sparing effects of choline (Quillen et al., 1961; Pesti et al., 1979) or sulfate (Gordon and Sizer, 1955; Ross and Harms, 1970) or the negative effects of copper sulfate (Baker and Robbins, 1979).

It is unfortunate that although a number of studies have been carried out to examine the effects of different dietary variables on the requirement for methionine, few of these actually made attempts to estimate an overall requirement value. Although calculations can be made in some instances, these do not have the statistical basis that values derived from the original data would have had.

Another factor that may contribute to the disagreement in results is the comparison of results using crystalline amino acid diets with results using diets based on practical ingredients, primarily corn and soybean meal. Although this difference may relate in part to the incomplete digestion of the protein in the intact ingredients, most recent digestibility studies suggest that amino acids in corn and soybean meal are well digested, on the order of 85 percent or more. Differences in digestibility of practical and semipurified diets are, therefore, not of sufficient magnitude to account for the major differences that seem to occur between these types of diets.

The cystine status of the basal diet is a major factor that contributes to the apparent disagreement in results, especially when diets with intact ingredients are used. Generally, a basal diet, considered deficient in sulfur amino acids, is supplemented with graded levels of methionine and the response determined. The point of maximum response is then noted, and the sum of dietary plus supplemental methionine is added to the dietary cystine content to arrive at the need for total sulfur amino acids (TSAA). However, this procedure assumes that the basal diet does not contain a surfeit of cystine. Therefore one must determine whether or not the basal diet is adequate or excessive in cystine before combining these values for a total TSAA estimate. Total dietary cystine levels can be influenced by dietary protein levels, choice of protein-contributing ingredients, and use of supplemental amino acids. Unfortunately, the majority of the reports estimate TSAA requirements and do not attempt to differentiate between needs for methionine and needs for TSAA.

For methionine per se, there is minimal research on which to base changes in the recommendation of 0.5 percent made in the previous edition. Of the reports in the literature for methionine requirements for the period from 0 to 21 days, two (Waldroup et al., 1979; Tillman and Pesti, 1985) are above the NRC (1984) recommendation, four (Dean and Scott, 1965; Robbins and Baker, 1980a; Moran, 1981; Thomas et al., 1985) are at or near that recommendation, and two (Klain et al., 1960; Hewitt and Lewis, 1972) are considerably below. For the period of 3 to 6 or 6 to 8 weeks, there is even less work on the requirements for methionine per se. The report of Moran (1981) plus estimates from a computer model (Hurwitz et al., 1978) would support retaining the previously recommended value until sufficient research has been conducted to support its modification.

Even greater diversity exists among estimates for TSAA requirements, as would be expected from the factors indicated above. Evaluation of results obtained from feeding crystalline amino acid diets certainly suggests a markedly lower TSAA value (Klain et al., 1960; Dean and Scott, 1965; Graber et al., 1971; Robbins and Baker, 1980a; Willis and Baker, 1980, 1981a; Baker et al., 1983). Although basing TSAA requirements on data using crystalline amino acids is perhaps not justifiable for practical diets, it does point out that the TSAA requirement could be less if a proper balance between available methionine and cystine existed.

In evaluating results from birds fed diets with intact ingredients, one can find values that support the change in recommended TSAA requirements for 0 to 3 weeks of age from 0.93 to 0.87 percent of the diet (Nelson et al., 1960; Hewitt and Lewis, 1972; Boomgaardt and Baker, 1973b,c; Woodham and Deans, 1975; Attia and Latshaw, 1979; Robbins and Baker, 1980a,b; Wheeler and Latshaw, 1981; Baker et al., 1983; Mitchell and Robbins, 1983; Thomas et al., 1985). In many of these studies, diets were supplemented with lysine, which permitted a lower protein level and reduced cystine content; therefore a surfeit of cystine was less likely to exist in these studies. Research is needed using practical ingredients to evaluate the separate needs for methionine and cystine in such diets.

For the 3- to 6-week period, most reports are in agreement with the previous recommendation (Graber et al., 1971; Holsheimer, 1981; Wheeler and Latshaw, 1981; Mitchell and Robbins, 1983). Two reports (Jensen et al., 1989; Mendonca and Jensen, 1989a) suggested a higher value, based in part on reduction in carcass fat content. There is minimal research on the TSAA needs from 6 to 8 weeks of age and little justification for change in the previous recommendation. More research is needed to delineate the separate needs for methionine and cystine in diets consisting of practical ingredients. This research may eliminate much of the current disagreement regarding TSAA needs of the broiler.

Arginine

The committee has made significant changes in its recommendation for the arginine requirements of broilers. It has eliminated from consideration all studies in which potential lysine:arginine antagonisms existed because such antagonisms are unlikely to occur with practical ingredients. Recommended requirements have been reduced to 1.25 and 1.1 percent for the 0-to 3- and 3- to 6- week growth periods, respectively.

Lysine

The requirement of broilers from 0 to 3 weeks of age has been reduced from 1.2 to 1.1 percent of the diet. There has been little recent research on the requirements for this amino acid, but evaluation of previous research supports this reduction (Edwards et al., 1956; Boomgaardt and Baker, 1973a,b; Woodham and Deans, 1975; McNaughton et al., 1978; Burton and Waldroup, 1979). There is a dearth of published recommendations for the period from 3 to 6 weeks of age. Limited research, however, supports the previous recommendation (Holsheimer, 1981). Research results for the period from 6 to 8 weeks are inconclusive. Some work suggests that the previous requirement is low (Bornstein, 1970; Boomgaardt and Baker, 1973b), whereas other studies suggest that it is high (Chung et al., 1973; Twining et al., 1973; Thomas et al., 1977). Therefore, the previous requirement of 0.85 percent was not changed.

Tryptophan

The committee has reduced the requirement for this amino acid from 0.23 to 0.2 percent for the broiler 0 to 3 weeks of age on the basis of its evaluation of published reports from many sources (Wilkening et al., 1947; Griminger et al., 1956; Klain et al., 1960; Boomgaardt and Baker, 1971; Hewitt and Lewis, 1972; Woodham and Deans, 1975; Steinhart and Kirchgessner, 1984; Smith and Waldroup, 1988a). Minimal research has been conducted on tryptophan requirements of the broiler at more than 3 weeks. Estimates from computer modeling (Hurwitz et al., 1978) suggest that lower levels of tryptophan may be required during this period, but these estimates have not been rigorously examined.

Threonine

Considerable work has been conducted on the threonine requirement for broiler chickens in recent years. The majority of the studies support the present recommended value of 0.8 percent for broilers at 0 to 3 weeks of age (Uzu, 1986; Robbins, 1987; Thomas et al., 1987; Bertram et al., 1988; Smith and Waldroup, 1988b; Austic and Rangel-Lugo, 1989). Little research has been done on threonine requirements for broilers older than 3 weeks of age.

Isoleucine, Leucine, Valine, Phenylalanine, Phenylalanine plus Tyrosine, Glycine plus Serine, Histidine, and Proline

Sufficient studies with intact protein diets have been conducted to allow estimation of the requirements for leucine, isoleucine, and valine during the 0-to 3-week period (Almquist, 1947; D'Mello, 1974; Woodham and Deans, 1975; Thomas et al., 1988). Only a few studies with intact protein diets have been conducted for phenylalanine or phenylalanine plus tyrosine (Almquist, 1947; Woodham and Deans, 1975) and for glycine plus serine (Ngo and Coon, 1976) during the period from 0 to 3 weeks. Therefore the committee considered studies with purified diets (Fisher et al., 1957; Klain et al., 1960; Dean and Scott, 1965; Sasse and Baker, 1972; Coon et al., 1974; Baker et al., 1979) in estimating these requirements. The reported values for phenylalanine plus tyrosine and glycine plus serine vary greatly among studies, particularly in the latter instance. The histidine requirement for the period from 0 to 3 weeks is based primarily on purified diet studies (Klain et al., 1960; Dean and Scott, 1965; Baker et al., 1979). Although proline is not usually considered to be an essential amino acid for poultry, research has shown that young chicks may not synthesize sufficient proline to meet their requirements (Greene et al., 1962; Graber et al., 1970); thus, a dietary source of proline must be provided.

The committee found no published research data for this group of amino acids for the periods from 3 to 6 and 6 to 8 weeks, although the study by Mendonca and Jensen (1989b) suggested that the valine requirement for 3 to 6 weeks exceeds 0.70 percent. Since the lysine requirements for these growth periods are documented, the requirements for this group of amino acids for the periods from 3 to 6 and 6 to 8 weeks have been estimated from the lysine values by using the amino acid:lysine ratio for the period from 0 to 3 weeks. Thus the committee assumed that the ratios or patterns between these amino acids and lysine are relatively consistent throughout the growth stages.

Minerals

The extent of research conducted on different minerals and vitamins is often in direct proportion to their economic value or to the likelihood of encountering a dietary deficiency in practical diets. Thus there is a great deal of literature concerning the calcium and phosphorus requirements of the broiler and minimal research concerning requirements for trace elements. The precise requirements for minerals such as potassium, magnesium, and iron in practical diets are not well defined because practical diets are usually adequate or only slightly deficient in these minerals. The requirements for minerals such as iron, manganese, and zinc are much lower for chicks fed semipurified diets containing little or no phytate and fiber than for those fed practical diets, mainly because of relatively poor bioavailability of some minerals in practical ingredients (Kratzer and Vohra, 1986). For example, the bioavailability of manganese is very low in most practical feedstuffs, and there is evidence that practical ingredients reduce the bioavailability of inorganic dietary manganese (Halpin and Baker, 1986). The bioavailability of minerals in inorganic mineral supplements also varies greatly. For example, the bioavailability of zinc in zinc sulfate is much higher than in zinc oxide (Wedekind and Baker, 1990). Consequently, the reported requirement for a mineral may vary among studies owing to differences in the bioavailability of the supplemental mineral source and the use of ingredients that interfere with utilization of the mineral under study.

Although substantial research has been conducted for most vitamins, the requirements for practical diets are not well defined. Practical diets are not markedly deficient in some vitamins. Consequently, several of the vitamin requirements are extrapolated from studies with purified or semipurified diets. The dietary levels needed to maximize some parameters may be higher than those needed to maximize growth. Examples of the latter include vitamin D_3 levels for maximum tibia ash (Waldroup et al., 1963a; Lofton and Soares, 1986), vitamin E levels for maximum immune response (Tengerdy and Nockels, 1973; Colnago et al., 1984), and riboflavin levels for prevention of leg paralysis (Ruiz and Harms, 1988a). It is generally assumed that vitamin requirements decrease with increasing age, although this relationship is not well documented with the exception of choline in purified diets.

Calcium and Phosphorus

No changes have been made in the previously recommended calcium requirement of the broiler chick. Requirements for phosphorus are expressed in terms of nonphytate phosphorus. The nonphytate phosphorus requirement for the chick at 0 to 3 weeks of age remains unchanged; however, recommended values for 3 to 6 and 6 to 8 weeks have been reduced on the basis of studies by O'Rourke et al. (1952), Waldroup et al. (1963b, 1974a), Twining et al. (1965), Sauveur (1978), Yoshida and Hoshii (1982a), and Tortuero and Diez Tardon (1983).

Potassium, Sodium, and Chlorine

A reduction has been made in the potassium requirement of the broiler. The potassium requirement of broilers fed a semipurified diet seems to be between 0.25 and 0.30 percent (Leach et al., 1959). The requirement for broilers fed a practical diet is not documented. The requirements for sodium and chlorine have been increased for the period from 0 to 3 weeks on the basis of recent studies. The requirements for these minerals seem to decrease with increasing age (Hurwitz et al., 1973; Edwards, 1984). The research of Edwards (1984) has justified a reduction in the levels of sodium and chlorine recommended for broilers at 6 to 8 weeks of age.

Magnesium

The reported requirement varies among studies. Part of this variation may be due to the calcium and phosphorus content of the diet. Although type of diet varies among studies, there does not seem to be a consistent relationship between diet type and the reported magnesium requirement. After 3 weeks of age, the values suggested by the committee are only estimates.

Iron and Copper

Although only a few studies have been conducted on iron requirements of broilers, the results are consistent and indicate that the requirement is approximately 80 mg/kg (Davis et al., 1968; McNaughton and Day, 1979). Southern and Baker (1982) report that the requirement was only 40 mg/kg for chicks fed a dextrose-casein diet. The copper requirement of 8 mg/kg is based on the study of McNaughton and Day (1979). The committee suggests only estimated values after 3 weeks of age.

Manganese

Values given for chicks of all ages show wide differences in requirements depending on the type of diet used. The requirement reported for chicks fed a semipurified dextrose-casein diet (14 mg/kg; Southern and Baker, 1983a) is much lower than that of chicks fed a diet containing practical ingredients (50 mg/kg/ Gallup and Norris, 1939a,b).

Zinc

The zinc requirement of the young broiler is approximately 35 to 40 mg/kg in semipurified diets containing isolated soy protein or casein (Morrison and Sarett, 1958; O'Dell et al., 1958; Roberson and Shaible, 1958). Studies on corn-soybean meal and sesame meal diets suggest that the requirement is in excess of 40 mg/kg (Edwards et al., 1959; Lease et al., 1960; Zeigler et al., 1961). This conclusion was based primarily on small growth responses to zinc supplementation of the basal diets. The estimated zinc requirement is somewhat tenuous, because the estimate was based on calculated values for zinc content of the feed ingredients. Recent work by Wedekind et al. (1990) showed that the tibia zinc concentration of chicks fed a corn-soybean meal diet was increased markedly by dietary zinc supplementation but did not provide an estimate of requirements. The source of supplemental zinc used in most of the cited studies was zinc sulfate or zinc chloride. Availability of zinc varies among sources (Wedekind and Baker, 1990). In a diet containing egg white as the primary protein source, the requirement for zinc is only 14 to 18 mg/kg (Southern and Baker, 1983b; Dewar and Downie, 1984). Only tentative values are given for chicks after 3 weeks of age.

Iodine

Little research has been conducted to establish the iodine requirement of the broiler chick. The present requirement is based on the study by Creek et al. (1957).

Selenium

No changes have been made in the recommended dietary selenium concentrations for broiler chickens. A concentration of 0.15 mg selenium per kilogram of diet is recommended (Jensen et al., 1986).

Vitamins

Vitamin A

Tentative requirement values have been listed for all ages. The requirement estimates vary from 900 to 2,200 IU/kg among studies. Requirement values from more recent studies are lower than those from earlier ones.

Vitamin D

The requirement estimates for maximum growth are consistent among most studies. The requirement for maximum tibia ash, however, may be higher than that for growth (Waldroup et al., 1965; Lofton and Soares, 1986).

Vitamin E

Tentative values have been expressed for all ages. The results of the few studies conducted are variable. The requirement for prevention of encephalomalacia may be higher than that for growth only (Singsen et al., 1955). In addition, the requirement for maximum immune response may be much higher than that for growth (Tengerdy and Nockels, 1973; Colnago et al., 1984).

Vitamin K

The vitamin K requirements of the broiler are unchanged. The requirement is estimated at approximately 0.5 mg/kg for chicks fed glucose-isolated soy protein diets (Nelson and Norris, 1960, 1961b).

Riboflavin

The riboflavin requirements for broilers at 0 to 3 and 3 to 6 weeks of age (3.6 mg/kg of diet) are unchanged. Most studies indicate that the riboflavin requirement is 2.5 to 3.5 mg/kg. Several studies have indicated that the requirement for prevention of leg paralysis is higher than that for growth (Ruiz and Harms, 1988c).

Pantothenic Acid

Tentative requirements have been expressed for broilers of all ages. Little work has been done, and there is no good basis for the requirement in practical diets. The requirement is 5 mg/kg in a purified diet, and thus twice this level should be adequate for practical diets to compensate for potentially limited availability of pantothenic acid from the ingredients. Bauernfeind et al. (1942) reported that 7.5 to 10 mg of pantothenic acid per kilogram of diet was adequate for Leghorn chicks and that practical diets normally contain sufficient levels of this vitamin. Jukes and McElroy (1943) also reported a pantothenic acid requirement of 10 mg/kg of diet.

Niacin

The niacin requirement has been increased for broilers of all ages (see Table 2-5). Requirement estimates vary from 22 to greater than 55 mg/kg among studies using intact protein diets, with most estimates being in the range of approximately 25 to 35 mg/kg. The requirement is somewhat lower for purified diets (Ruiz and Harms, 1988a; 1990).

Vitamin B12

Few requirement studies have been conducted. The requirement seems to be approximately 0.01 mg/kg (Looi and Renner, 1974; Rys and Koreleski, 1974).

Choline

No changes have been made in the choline requirement of the broiler at 0 to 3 weeks of age, and tentative requirements are given for broilers at 3 to 6 and 6 to 8 weeks. Many studies have been conducted on choline requirements, and the requirement estimates are highly variable. Choline requirements are influenced by protein and sulfur amino acid content of the diet and by age of broilers. The requirements listed in Table 2-5 should be sufficient for practical diets containing adequate levels of methionine and cystine. The choline requirement is much lower and decreases markedly with increasing age for chicks fed purified diets (Molitoris and Baker, 1976; Lowry et al., 1987). A decrease in choline requirement with age has not been documented when practical diets are fed. Requirement values for broilers from 3 to 6 and 6 to 8 weeks, however, have been extrapolated from studies that used purified diets (Gardiner and Dewar, 1976; Molitoris and Baker, 1976; Lowry et al., 1987).

Biotin

No changes have been made in the biotin requirement of the broiler to 6 weeks of age, with a tentative requirement expressed for 6 to 8 weeks. Estimates from most studies indicate that the requirement is between 0.15 and 0.20 mg/kg.

Folic Acid

No changes have been made in the folic acid requirement of the broiler at 0 to 3 and 3 to 6 weeks of age, with tentative requirements expressed for 6 to 8 weeks. Requirement values vary among studies. Recent studies, however, indicate that the requirement is between 0.35 and 0.50 mg/kg when determined with semipurified diets. Thus the requirement is probably higher when birds are fed practical diets.

Thiamin

Tentative requirements are expressed for broilers of all ages. There is little research with broilers on which to base a requirement. The requirement seems to be relatively low, and practical diets normally contain levels well in excess of the estimated requirements.

Pyridoxine

The pyridoxine requirement has been increased for broilers of all ages, with a tentative requirement given for broilers at 6 to 8 weeks of age. Many studies have been conducted, with requirement estimates ranging from 2.3 to 3.5 mg/kg for intact protein diets. The requirement seems to be only approximately 1.0 mg/kg for a purified diet (Lee et al., 1976; Yen et al., 1976). The pyridoxine requirement, however, increases with an increase in dietary protein level (Gries and Scott, 1972a; Daghir and Shah, 1973).

Essential Fatty Acid

Linoleic Acid

The linoleic acid requirement has been estimated as 1.0 percent of the diet (Balnave, 1970).

Broiler Breeder Pullets and Hens

Meat-type breeder hens will become obese if allowed ad libitum consumption of feed; therefore some form of nutrient limitation must be practiced. Most research has focused on feeding systems, with some form of quantitative restriction of intake generally practiced to maintain body weights within guidelines suggested by the breeder. Early research suggested that feeding bulky, high-fiber diets would successfully limit ME_n intake (Milby and Sherwood, 1953; Singsen et al., 1959; Isaacks et al., 1960; Summers et al., 1967; Fuller et al., 1973), but more recent studies indicate that modern broiler strains can consume large volumes of feed, a capability that makes this method impractical as a means of controlling weight (Waldroup et al., 1976a). Other studies have suggested that low-protein diets (Waldroup et al., 1966), diets low in specific amino acids (Singsen et al., 1964), or diets imbalanced in amino acids (Couch and Abbott, 1974) might control body weight when offered for ad libitum consumption, but such diets have not been readily accepted in commercial practice because of large variability in bird response.

Little research has been conducted to determine the specific nutrient requirements of meat-type females from hatch to maturity. Powell and Gehle (1975) estimated the tryptophan requirement of growing broiler breeder pullets; this seems to be the lone estimate of protein or amino acid needs during this age period. Harms (1980) and Harms and Wilson (1987) have suggested requirements for the growing pullet, but these have not been subjected to rigid evaluation. Therefore there is not sufficient research data on which to base suggested requirements for the growing and developing broiler breeder meat-type pullet at this time.

Nutrient requirement data presented in Table 2-7 for the broiler breeder meat-type hen are limited to those for which some documentation is available.

Protein And Amino Acids

Chickens do not require a specific level of crude protein per se; rather, they have a requirement for specific amino acids plus sufficient protein to supply either the nonessential amino acids themselves or amino nitrogen for their synthesis. In the instance of meat-type breeder hens, there is a paucity of research directed toward determining specific requirements for essential amino acids. Therefore a minimum crude protein intake is generally designated to provide adequate amounts of essential amino acids whose requirements are not adequately known.

Daily crude protein intakes of 18 to 20 g per hen seem adequate, assuming that essential amino acid needs are met (Waldroup et al., 1976b; Pearson and Herron, 1981; Spratt and Leeson, 1987), although more abundant levels (up to 23 g/day) may be needed during periods of highest productivity to achieve maximum egg mass yield (Jeroch et al., 1982; Schloffel et al., 1988). Because the size of the

TABLE 2-7 Nutrient Requirements of Meat-Type Hens for Breeding Purposes as Units per Hen per Day (90 percent dry matter)

Nutrient	Unit	Requirements
Protein and amino acids		
Protein[a]	g	***19.5***
Arginine	mg	***1,110***
Histidine	mg	205
Isoleucine	mg	850
Leucine	mg	1,250
Lysine	mg	765
Methionine	mg	***450***
Methionine + cystine	mg	***700***
Phenylalanine	mg	610
Phenylalanine + tyrosine	mg	***1,112***
Threonine	mg	720
Tryptophan	mg	190
Valine	mg	750
Minerals		
Calcium	g	***4.0***
Chloride	mg	***185***
Nonphytate phosphorus	mg	***350***
Sodium	mg	150
Vitamin		
Biotin	μg	16

NOTE: These are requirements for hens at peak production. Broiler breeder hens are usually fed on a controlled basis to maintain body weight within breeder guidelines. Daily energy consumption varies with age, stage of production, and environmental temperature but usually ranges between 400 and 450 *ME* kcal per hen at peak production. For nutrients not listed, see requirements for egg-type breeders (Table 2-3) as a guide. Where experimental data are lacking, values typeset in bold italics represent an estimate based on values obtained for other ages or related species.

[a] Broilers do not have a requirement for crude protein per se. There, however, should be sufficient crude protein to ensure an adequate nitrogen supply for synthesis of nonessential amino acids. Suggested requirements for crude protein are typical of those derived with corn-soybean meal diets, and levels can be reduced somewhat when synthetic amino acids are used.

egg has a significant effect on the initial weight of the chick and its subsequent performance (Gardiner, 1973; Guill and Washburn, 1973; Proudfoot and Hulan, 1981), maximum egg weight during early production is an important economic factor. The protein requirement for dwarf breeder hens does not exceed 13.6 percent of the diet (Larbier et al., 1979).

Excessive crude protein intakes are to be avoided. Daily intakes of 27 g per hen had adverse effects on hatchability (Pearson and Herron, 1981, 1982). Lower crude protein intakes may be satisfactory if additional amino acid supplementation is practiced. Bornstein et al. (1979) calculated that a daily crude protein intake of 15.6 to 16.5 g per hen would be sufficient in terms of an ideal amino acid mixture. Performance of hens fed corn-soybean meal diets providing 16 g protein per day was not improved by supplemental lysine and methionine (Waldroup et al., 1976b).

Few trials have been conducted to determine specific amino acid requirements. Harms and Wilson (1980) reported a daily requirement for methionine of between 400 and 478 mg; 400 mg per day gave performance statistically equivalent to that at higher levels of intake. Halle et al. (1984), using nitrogen balance studies, indicated a TSAA need of 694 mg per day. For dwarf (dw) hens, Guillaume (1977) estimated daily methionine and lysine needs of 360 to 380 and 750 mg per hen, respectively.

Wilson and Harms (1984) obtained satisfactory performance with average daily intakes per hen of 682 mg of TSAA, 808 mg of lysine, 1,226 mg of arginine, and 223 mg of tryptophan, with 18.6 g of crude protein per day. Using various prediction models or equations, several workers have estimated amino acid requirements (Waldroup and Hazen, 1976; Waldroup et al., 1976c; Scott, 1977; Bornstein et al., 1979). In the study by Bornstein et al. (1979), hens fed diets formulated to meet these requirements on the basis of prediction models performed as well as those fed diets formulated in the conventional way.

Energy

Broiler breeder hens are usually fed on a controlled basis to maintain body weight within breeder guidelines. Daily energy consumption will vary with age, stage of production, and environmental temperature, but will usually range from 400 to 450 kcal *ME* per hen daily (Waldroup and Hazen, 1976; Waldroup et al., 1976a; Bornstein et al., 1979; Bornstein and Lev, 1982; Pearson and Herron, 1982; Spratt and Leeson, 1987; Spratt et al., 1990a,b).

Minerals And Vitamins

Calcium

Shell strength of eggs from meat-type hens increases as calcium level is increased (Mehring, 1965). Egg production and hatchability of meat-type hens on litter were not improved by feeding more than 3.91 g of calcium per hen daily (Wilson et al., 1980). One of the best determinants of calcium adequacy for breeder hens is egg specific gravity; eggs should have a specific gravity of 1.080 or greater for optimal hatchability (McDaniel et al., 1979). Since meat-type hens are usually given a daily allotment of feed early in the morning before significant eggshell calcification occurs, supplying a portion of the calcium in an afternoon feeding may improve eggshell quality (Farmer et al., 1983; Van Wambeke and DeGroote, 1986). Feeding the entire dietary allocation in the afternoon, however, may significantly reduce hatchability because of production of eggs with thicker eggshells (Brake, 1988).

Phosphorus

No significant differences in egg production, hatchability of fertile eggs, or specific gravity of eggs were noted in feeding from 532 to 1,244 mg total phosphorus per hen daily (163 to 863 mg nonphytate phosphorus per hen daily), although egg production was improved numerically by feeding 718 mg total phosphorus (338 mg nonphytate phosphorus) per day (Wilson et al., 1980). For both calcium and phosphorus, requirements for hens maintained in cages may be significantly greater than for hens on litter floors (Harms et al., 1961; Singsen et al., 1962; Harms et al., 1984).

Sodium

Egg production, feed efficiency, egg weight, fertility, and hatchability of meat-type breeder hens were not improved by feeding more than 154 mg of sodium per hen daily (Damron et al., 1983); sodium intakes in excess of 320 mg per day were shown to reduce fertility.

Chlorine

Harms and Wilson (1984) reported that 254 mg of chlorine per hen daily resulted in the best overall performance of meat-type broiler hens, as measured by egg production and hatchability. However, performance on this intake did not differ significantly from performance on intakes of 185 mg per day.

Biotin

The requirement for biotin by the meat-type hen has been estimated to be 16 µg per hen daily. The hen may be considered to be receiving adequate biotin if the yolk biotin concentration is at least 550 ng/g (Whitehead et al., 1985).

Broiler Breeder Males

Historically, meat-type breeder cockerels have been grown with the females. Because of recent changes in genetics and management practices, an increasing number of males are being grown or fed separately. Males maintained in floor pens with natural mating may be fed from a separate feeding system; males maintained in cages for artificial insemination may be individually fed. The major advantage of separate feeding is control of body weight and its subsequent impact on fertility and mating ability. Thus a set of nutrient requirements for male meat-type breeders, although limited in scope, is listed in Table 2-8. It should be noted that diets intended for use by the breeder hen, when fed to control male body weight, appear to have no detrimental effects on male performance.

Protein

Protein requirements of breeder cockerels have been evaluated during the growing and adult periods by using both White Leghorn and Meat-type cockerels. In studies with Single Comb White Leghorn (SCWL) cockerels, low crude protein levels fed during the grower period reduced body weights and delayed testicular development, but, on subsequent feeding of adequate protein, reproductive performance was not impaired (Wilson et al., 1965; Jones et al., 1967). Diets containing 12.4 percent crude protein offered for ad libitum consumption to broiler breeder males during the period of 7 to 21 weeks of age were adequate for development of the reproductive system and subsequent reproductive performance (Wilson et al., 1971). Broiler breeder males can be fed 12 to 14 percent crude protein on a restricted basis after 4 weeks of age with no adverse effects on final body weight, sexual maturity, or semen quality; a greater number of males produced semen through 53 weeks when fed 12 percent crude protein than when fed higher levels (Wilson et al., 1987a). In a subsequent study (Wilson et al., 1987b), a 9 percent crude protein diet fed beginning at 43 days and continuing through 50 weeks was adequate to support maximum reproductive performance. In both these studies, amino acid content was maintained at a constant percentage of the protein level. There were no differences in semen characteristics of broiler breeder males fed 12 to 18 percent crude protein during the period from 4 to 20 weeks; males fed 15 percent crude protein during the period from 1 to 4 weeks had significantly higher fertility from 24 to 27 weeks than did males fed 20 percent crude protein (Vaughters et al., 1987). Semen production of broiler breeder males kept in cages can be maintained from 20 to 60 weeks on a daily protein intake of 10.9 to 14.8 g per day (Buckner and Savage, 1986).

TABLE 2-8 Nutrient Requirements of Meat-Type Males for Breeding Purposes as Percentages or Units per Rooster per Day (90 percent dry matter)

		Age (weeks)		
	Unit	0 to 4	4 to 20	20 to 60
Metabolizable energy[a]	kcal	—	—	350 to 400
Protein and amino acids				
Protein[b]	%	15.00	12.00	—
Lysine[c]	%	***0.79***	***0.64***	—
Methionine[c]	%	***0.36***	***0.31***	—
Methionine + cystine[c]	%	***0.61***	***0.49***	—
Minerals				
Calcium	%	***0.90***	***0.90***	—
Nonphytate phosphorus	%	***0.45***	***0.45***	—
Protein and amino acids				
Protein	g	—	—	12
Arginine[c]	mg	—	—	***680***
Lysine[c]	mg	—	—	***475***
Methionine[c]	mg	—	—	***340***
Methionine + cystine[c]	mg	—	—	***490***
Minerals				
Calcium	mg	—	—	***200***
Nonphytate phosphorus	mg	—	—	110

NOTE: For nutrients not listed, see requirements for egg-type pullets (Table 2-3) as a guide. Where experimental data are lacking, values typeset in bold italics represent an estimate based on values obtained for other ages or related species.

[a] Energy needs are influenced by the environment and the housing system. These factors must be adjusted as required to maintain the body weight recommended by the breeder.

[b] Broilers do not have a requirement for crude protein per se. There, however, should be sufficient crude protein to ensure an adequate nitrogen supply for synthesis of nonessential amino acids. Suggested requirements for crude protein are typical of those derived with corn-soybean meal diets, and levels can be reduced somewhat when synthetic amino acids are used.

[c] Amino acid requirements estimated by using the model of Smith (1978).

Energy

Daily energy intakes of 400 (McCartney and Brown, 1980) and 458 kcal *ME* per bird (Brown and McCartney, 1983) have been reported as adequate for broiler breeder males maintained on litter. For broiler breeder males maintained in cages, 346 (Brown and McCartney, 1986) or 358 kcal *ME* per bird daily (Buckner et al., 1986) were sufficient.

Minerals

The calcium requirement of the breeder cockerel is much lower than that of the hen, but levels fed to the hen apparently are not detrimental to the reproductive performance of the male. Wilson et al. (1969) indicated that the calcium requirement of SCWL cockerels did not exceed 0.2 percent, but that levels as high as 3 percent were not detrimental. In calcium balance studies with SCWL cockerels, Norris et al. (1972) found that the daily requirement was 7.98 mg per kg of body weight. Kappleman et al. (1982) concluded that there were no differences in the reproductive performance of broiler breeder cockerels fed 0.5 to 7 g of calcium daily per bird.

Phosphorus

Norris et al. (1972) found that diets containing 0.1 percent nonphytate phosphorus were satisfactory for SCWL cockerels. Bootwalla and Harms (1989) found that no more than 110 mg of nonphytate phosphorus per bird daily were needed for maintaining reproductive capacity and bone integrity in broiler breeder cockerels.

3

Nutrient Requirements of Turkeys

The nutrient requirements of turkeys are divided into needs of birds used as a source of growth and needs of those for reproduction. These two categories differ largely in the proportion of nutrients devoted to productive use as opposed to those used for maintenance activities.

Requirement values given in Table 3-1 are usually minimum levels that satisfy general productive activities and(or) prevent deficiency symptoms. The values given often represent an approximation of values from more than one study. Where information is lacking, italicized values represent an estimate based on values obtained for other ages or related species. Values selected by the committee as best representing the requirement were those for which the research was recent and performed under practical terms in which all nutrient needs in addition to the nutrient in question were satisfied. The experimental data from the peer-reviewed scientific literature that are the basis for the committee's nutrient requirement recommendations are given in Appendix Table A-4.

STARTING AND GROWING TURKEYS

The growth rate of turkeys has increased greatly during the past decade. Approximate live body weights per age and feed consumption data of contemporary turkeys are shown in Table 3-2. Increased growth rates have occurred through the efforts of the major commercial breeders, and parent stock has increased in size as well, particularly the hen. Further processing of the carcass into convenience products also has expanded and now occupies the greatest part of total production.

Substantial improvements in the rates of gain and feed efficiencies of commercially available strains have occurred during the last decade. The nutrient requirements given in Table 3-1 are based on earlier research and the chronological age of the experimental turkeys used at that time. For the most part, these nutrient levels are still being employed by the industry at large; however, because of improvements in growth rates these levels are now being used at earlier ages. Such changes have not been experimentally verified as being appropriate, but commercial results indicate satisfactory performance. Examples of these age adjustments for male and female turkeys are shown in Table 3-1, footnotes *a* and *b*, respectively.

Commercially available strains of turkey may differ in the chronology of their development. The nutrient requirements given on Table 3-1 represent the approximate needs for development of large-type turkeys. Medium- and small-type turkeys finish progressively earlier than the large. For the given nutrient levels to be employed effectively, those levels representing each age interval should be provided according to the corresponding stages of development.

The requirements are expressed as concentrations in the feed. These concentrations are such that adequate total intake is ensured and the nutrient balance is favorable. Both factors are necessary. A balanced feed having lower nutrient concentrations than shown may not permit sufficient intake to meet the bird's absolute need. Conversely, an increased concentration of nutrients ensures adequacy but may not be cost effective.

Pelleting is widely practiced in feed manufacturing, and feeding a pelleted diet usually leads to an improvement in performance. Pelleting may increase nutrient digestibility in some constituent feedstuffs; however, the primary result is improved use of the nutrients already available apparently because of reduced physical activity by the bird. Generally, pelleting facilitates feed intake, increases net energy of production from metabolizable energy (*ME*), and reduces overall feed wastage (Moran, 1989b). These benefits are accentuated as feed nutrient level decreases and as birds become progressively older, provided the feed remains in pelleted form.

TABLE 3-1 Nutrient Requirements of Turkeys as Percentages or Units per Kilogram of Diet (90 percent dry matter)

		Growing Turkeys, Males and Females						Breeders	
Nutrient	Unit	0 to 4 Weeks[a]; 0 to 4 Weeks[b]; 2,800[c]	4 to 8 Weeks[a]; 4 to 8 Weeks[b]; 2,900[c]	8 to 12 Weeks[a]; 8 to 11 Weeks[b]; 3,000[c]	12 to 16 Weeks[a]; 11 to 14 Weeks[b]; 3,100[c]	16 to 20 Weeks[a]; 14 to 17 Weeks[b]; 3,200[c]	20 to 24 Weeks[a]; 17 to 20 Weeks[b]; 3,300[c]	Holding; 2,900[c]	Laying Hens; 2,900[c]
Protein and amino acids									
Protein[d]	%	28.0	26	22	19	16.5	14	12	14
Arginine	%	1.6	***1.4***	***1.1***	***0.9***	***0.75***	***0.6***	***0.5***	***0.6***
Glycine + serine	%	1.0	***0.9***	***0.8***	***0.7***	***0.6***	***0.5***	***0.4***	***0.5***
Histidine	%	0.58	***0.5***	***0.4***	***0.3***	***0.25***	***0.2***	***0.2***	***0.3***
Isoleucine	%	1.1	***1.0***	***0.8***	***0.6***	***0.5***	***0.45***	***0.4***	***0.5***
Leucine	%	1.9	***1.75***	***1.5***	***1.25***	***1.0***	***0.8***	***0.5***	***0.5***
Lysine	%	1.6	1.5	1.3	1.0	0.8	0.65	***0.5***	***0.6***
Methionine	%	0.55	0.45	0.4	0.35	0.25	***0.25***	***0.2***	***0.2***
Methionine + cystine	%	1.05	0.95	0.8	0.65	0.55	***0.45***	***0.4***	***0.4***
Phenylalanine	%	1.0	***0.9***	***0.8***	***0.7***	***0.6***	***0.5***	***0.4***	***0.55***
Phenylalanine + tyrosine	%	1.8	***1.6***	***1.2***	***1.0***	***0.9***	***0.9***	***0.8***	***1.0***
Threonine	%	1.0	***0.95***	***0.8***	***0.75***	***0.6***	***0.5***	***0.4***	***0.45***
Tryptophan	%	0.26	***0.24***	***0.2***	***0.18***	***0.15***	***0.13***	***0.1***	***0.13***
Valine	%	1.2	***1.1***	***0.9***	***0.8***	***0.7***	***0.6***	***0.5***	***0.58***
Fat									
Linoleic acid	%	1.0	***1.0***	***0.8***	***0.8***	***0.8***	***0.8***	***0.8***	1.1
Macrominerals									
Calcium[e]	%	1.2	1.0	0.85	0.75	0.65	0.55	0.5	2.25
Nonphytate phosphorus[f]	%	0.6	0.5	0.42	0.38	0.32	0.28	0.25	0.35
Potassium	%	0.7	***0.6***	***0.5***	***0.5***	***0.4***	***0.4***	***0.4***	***0.6***
Sodium	%	0.17	***0.15***	***0.12***	***0.12***	***0.12***	***0.12***	***0.12***	***0.12***
Chlorine	%	0.15	***0.14***	***0.14***	***0.12***	***0.12***	***0.12***	***0.12***	***0.12***
Magnesium	mg	500	***500***	***500***	***500***	***500***	***500***	***500***	***500***
Trace minerals									
Manganese	mg	60	***60***	***60***	***60***	***60***	***60***	***60***	***60***
Zinc	mg	70	***65***	***50***	***40***	***40***	***40***	***40***	***65***
Iron	mg	***80***	***60***	***60***	***60***	***50***	***50***	***50***	***60***
Copper	mg	***8***	***8***	***6***	***6***	***6***	***6***	***6***	***8***
Iodine	mg	***0.4***	***0.4***	***0.4***	***0.4***	***0.4***	***0.4***	***0.4***	***0.4***
Selenium	mg	0.2	***0.2***	***0.2***	***0.2***	***0.2***	***0.2***	***0.2***	***0.2***
Fat soluble vitamins									
A	IU	5,000	5,000	***5,000***	***5,000***	***5,000***	***5,000***	***5,000***	***5,000***
D_3[g]	ICU	1,100	***1,100***	***1,100***	***1,100***	***1,100***	***1,100***	***1,100***	1,100
E	IU	12	***12***	***10***	***10***	***10***	***10***	***10***	25
K	mg	1.75	***1.5***	***1.0***	***0.75***	***0.75***	***0.50***	***0.5***	***1.0***
Water soluble vitamins									
B_{12}	mg	0.003	0.003	***0.003***	***0.003***	***0.003***	***0.003***	***0.003***	***0.003***
Biotin[h]	mg	0.25	0.2	***0.125***	***0.125***	***0.100***	***0.100***	***0.100***	0.20
Choline	mg	1,600	1,400	***1,100***	***1,100***	***950***	***800***	***800***	***1,000***
Folacin	mg	1.0	1.0	***0.8***	***0.8***	***0.7***	***0.7***	***0.7***	1.0
Niacin	mg	60.0	60.0	***50.0***	***50.0***	***40.0***	***40.0***	***40.0***	***40.0***
Pantothenic acid	mg	10.0	9.0	***9.0***	***9.0***	***9.0***	***9.0***	***9.0***	16.0
Pyridoxine	mg	***4.5***	***4.5***	***3.5***	***3.5***	***3.0***	***3.0***	***3.0***	***4.0***
Riboflavin	mg	4.0	3.6	***3.0***	***3.0***	***2.5***	***2.5***	***2.5***	***4.0***
Thiamin	mg	2.0	2.0	***2.0***	***2.0***	***2.0***	***2.0***	***2.0***	***2.0***

NOTE: Where experimental data are lacking, values typeset in bold italics represent estimates based on values obtained from other ages or relate species or from modeling experiments.

[a] The age intervals for nutrient requirements of males are based on actual chronology from previous research. Genetic improvements in body weight gain have led to an earlier implementation of these levels, at 0 to 3, 3 to 6, 6 to 9, 9 to 12, 12 to 15, and 15 to 18 weeks, respectively, by the industry at large.

[b] The age intervals for nutrient requirements of females are based on actual chronology from previous research. Genetic improvements in body weight gain have led to an earlier implementation of these levels, at 0 to 3, 3 to 6, 6 to 9, 9 to 12, 12 to 14, and 14 to 16 weeks, respectively, by the industry at large.

[c] These are approximate metabolizable energy (*ME*) values provided with typical corn-soybean-meal-based feeds, expressed in kcal ME_n/kg diet. Such energy, when accompanied by the nutrient levels suggested, is expected to provide near-maximum growth, particularly with pelleted feed.

[d] Turkeys do not have a requirement for crude protein per se. There, however, should be sufficient crude protein to ensure an adequate nitrogen supply for synthesis of nonessential amino acids. Suggested requirements for crude protein are typical of those derived with corn-soybean meal diets, and levels can be reduced when synthetic amino acids are used.

[e] The calcium requirement may be increased when diets contain high levels of phytate phosphorus (Nelson, 1984).

[f] Organic phosphorus is generally considered to be associated with phytin and of limited availability.

[g] These concentrations of vitamin D are considered satisfactory when the associated calcium and phosphorus levels are used.

[h] Requirement may increase with wheat-based diets.

TABLE 3-2 Growth Rate and Feed and Energy Consumption of Large-Type Turkeys

Age (weeks)	Body Weight (kg)		Feed Consumption per Week (kg)		Cumulative Feed Consumption (kg)		*ME* Consumption per Week (Mcal)	
	Male	Female	Male	Female	Male	Female	Male	Female
1	0.12	0.12	0.10	0.10	0.10	0.10	0.28	0.28
2	0.25	0.24	0.19	0.18	0.29	0.28	0.53	0.5
3	0.50	0.46	0.37	0.34	0.66	0.62	1.0	1.0
4	1.0	0.9	0.70	0.59	1.36	1.21	2.0	1.7
5	1.6	1.4	0.85	0.64	2.21	1.85	2.5	1.9
6	2.2	1.8	1.10	0.80	3.31	2.65	3.2	2.3
7	3.1	2.3	1.40	0.98	4.71	3.63	4.1	2.8
8	4.0	3.0	1.73	1.21	6.44	4.84	5.0	3.5
9	5.0	3.7	2.00	1.42	8.44	6.26	6.0	4.3
10	6.0	4.4	2.34	1.70	10.78	7.96	7.0	5.1
11	7.1	5.2	2.67	1.98	13.45	9.94	8.0	5.9
12	8.2	6.0	2.99	2.18	16.44	12.12	9.0	6.8
13	9.3	6.8	3.20	2.44	19.64	14.56	9.9	7.6
14	10.5	7.5	3.47	2.69	23.11	17.25	10.8	8.4
15	11.5	8.3	3.73	2.81	26.84	20.06	11.6	9.0
16	12.6	8.9	3.97	3.00	30.81	23.06	12.3	9.6
17	13.5	9.6	4.08	3.14	34.89	26.20	13.1	10.1
18	14.4	10.2	4.30	3.18	39.19	29.38	13.8	10.5
19	15.2	10.9	4.52	3.31	43.71	32.69	14.5	10.9
20	16.1	11.5	4.74	3.40	48.45	36.09	15.2	11.2
21	17.0	[a]	4.81	[a]	53.26	[a]	15.9	[a]
22	17.9	[a]	5.00	[a]	58.26	[a]	16.5	[a]
23	18.6	[a]	5.15	[a]	63.41	[a]	17.1	[a]
24	19.4	[a]	5.28	[a]	68.69	[a]	17.4	[a]

[a] No data given because females are usually not marketed after 20 weeks of age.

Energy

In calculating the total metabolizable energy for the complete feed, the metabolizable energies provided by each feedstuff are assumed to be additive. The ME_n content of the complete feed influences feed intake, which, in turn, may influence the concentrations of most other nutrients that are needed to satisfy requirements. An inverse relationship exists between the ME_n concentration of the diet and feed consumption of turkeys. However, as discussed in Chapter 1 (Setting Dietary Levels), changes in dietary ME_n concentration and thus, the use of specific nutrient-to-dietary ME_n ratios in formulating turkey diets is questionable, especially when economical growth and feed efficiency are primary objectives (Pesti and Fletcher, 1983; Sell et al., 1985; 1989).

The ME_n levels given in Table 3-2 at each age period are not intended to be absolute but to establish a feed intake reference for other nutrients. The energy and amino acid levels given would be satisfied largely when corn and soybean meal are combined with a small amount of added fat, in turn permitting near-maximum growth. Nutrient levels may be increased without adversely affecting performance; however, a moderate reduction in nutrient levels would likely require pelleting of the associated feed to prevent adverse effects on growth rate.

Net energy of production is difficult to estimate because maintenance expenditures vary extensively. Environmental temperature is one of the most influential factors affecting maintenance, which, in turn, may lead to changes in feed intake.

Changes in the maintenance energy requirement in response to environmental temperature may not be linear. Hurwitz et al. (1980) observed that the maintenance energy requirement for both sexes of turkeys, during the period from 32 to 60 days of age, was between 2.45 and 2.70 kcal/g^{67} of body weight at 12°C. This requirement progressively decreased from 12° to 24° C, then remained constant between 24° and 28°C and increased thereafter through 35°C. The maintenance energy need in response to temperature also differs with age. In a study on the 20-week-old male turkey, Hurwitz et al. (1983b) found the requirement at 10°C to approximate 2.15 kcal/g^{67}, but unlike the requirement for the younger bird (32 to 60 days) there was an uninterrupted decrease through to 35°C. In both of these studies the advantage to net energy of production increased as temperature increased; however, feed intake and growth were not altered accordingly.

Protein And Amino Acids

A protein requirement of 28 percent for starting poults is supported by the work of Lloyd et al. (1949), Atkinson et al. (1957), Herz et al. (1975a), and Richter et al. (1980). Reduced levels of protein can decrease early growth, but if the protein reduction is moderate, compensatory gain of large-type turkeys prior to marketing may overcome the deficit. The progressive reduction in the protein requirement as the turkey grows is well established. A level of 12 percent protein with 2,900 kcal *ME*/kg for holding turkeys prior to reproduction is consistent in terms of the protein:energy ratio with the 14 percent protein at 3,526 kcal ME_n reported by Meyer et al. (1980a). The protein need for egg production has been observed to vary from 10 to 18 percent of the diet, with the value of 14 percent chosen as being the most representative.

Research on the amino acid requirements of turkeys has largely been conducted on the starting poult. With the exception of lysine and the sulfur amino acids, little experimentation has been done to determine the amino acid requirements of growing turkeys. Fisher (1982a) and Hurwitz et al. (1983a) employed body analyses and feed intake together with calculated maintenance needs to estimate requirements. The protein requirements shown in Table 3-1 are based on either actual experimentation, modeling, or are calculated as a ratio with lysine when the requirement for lysine at the ages in question has been measured experimentally.

The starting poult's arginine requirement of 1.6 percent of the diet is supported by the research of Almquist (1952) and Warnick and Anderson (1973) and the modeling of Hurwitz et al. (1983a). Dunkelgod et al. (1970) and D'Mello and Emmans (1975) reported higher arginine requirement values when they fed amino acid mixtures or diets based on wheat-corn gluten meal, respectively.

The isoleucine requirement listed for starting turkeys (1 percent of the diet) is based largely on the research of Warnick and Anderson (1973) and agrees well with the value of 1.03 percent obtained from modeling by Hurwitz et al. (1983a). Similarly, the leucine requirement (1.9 percent of the diet) is based on the determined value of 1.86 percent reported by Warnick and Anderson (1973) and 1.96 percent from modeling by Hurwitz et al. (1983a).

The lysine and sulfur amino acid needs have been well investigated because of their frequent limitation under practical conditions. Starting poults require 1.6 percent lysine in the diet. This value represents an average of the determined values 1.55 percent (Balloun and Phillips, 1957b), 1.6 percent (Kummero et al., 1971), 1.68 percent (Warnick and Anderson, 1973), 1.5 percent (Tuttle and Balloun, 1974), and 1.55 percent (D'Mello and Emmans, 1975). The value of 1.42 percent obtained by modeling (Hurwitz et al., 1973) is noticeably lower than those measured by bioassay. Lysine needs after the first 4 weeks of life have been derived mainly from the research of Tuttle and Balloun (1974), Jensen et al. (1976), and Potter et al. (1981).

The poult's requirement of 0.55 percent methionine in the diet is greater than the 0.53 percent given in the previous edition of this report and is the value that best represents the reports of Almquist (1952), Baldini et al. (1957), and Murillo and Jensen (1976a). Requirement values beyond starting were provided from the experimentation of Murillo and Jensen (1976a) and Behrends and Waibel (1980). The total sulfur amino acid requirement value of 1.1 percent for starting poults was derived from the observations of 1.04 percent by Warnick and Anderson (1973), 1.05 percent by Murillo and Jensen (1976b), 1.10 percent by Potter and Shelton (1979), and 1.1 percent by Behrends and Waibel (1980), as well as the 1.05 percent from modeling by Hurwitz et al. (1983a). Requirement values specifically for methionine subsequent to starting largely represent the observed needs to optimize performance as reported by Potter and Shelton (1979, 1980), Murillo and Jensen (1976a), and Behrends and Waibel (1980), together with the modeling estimate by Hurwitz et al. (1983a).

Minerals

The calcium requirement determined with starting poults has been reported to be as high as 1.7 percent (Motzok and Slinger, 1948) and 1.5 percent (Wilcox et al., 1953) and as low as 1.0 percent (Slinger et al., 1961) and 0.81 percent (Formica et al., 1962). Neagle et al. (1968) reported a requirement of 1.2 percent dietary calcium when total phosphorus and vitamin D levels were 0.8 percent and 1,100 ICU/kg of diet, respectively. The latter calcium requirement for growing turkeys has been substantiated by Nelson et al. (1961), Sullivan (1961), and Formica et al. (1962). Hens in egg production need approximately 2.25 percent calcium in the feed, as shown by Balloun and Miller (1964a), Arends et al. (1967), Potter et al. (1974), and Waldroup et al. (1974b).

The nonphytate phosphorus requirement of 0.6 percent for starting poults agrees with the research reported by Almquist (1954), Bailey et al. (1986), and Stevens et al. (1986). This value has been shown to decrease with age (Day and Dilworth, 1962; Sullivan, 1962). Reported nonphytate phosphorus requirements for breeder hens in egg production range from 0.3 percent (Waldroup et al., 1974b; Slaugh et al., 1989) to 0.55 percent (Atkinson et al., 1976). The latter relatively high value probably occurred because of a low phosphorus availability in the feedstuffs employed; thus 0.35 percent was selected to represent the requirement.

The magnesium requirement, given as 500 mg/kg of diet, has been reduced from the 600 mg listed in the previous edition to better reflect the value of 475 mg/kg reported by Sullivan (1964). The manganese requirement may vary with the type of diet and supplement used. The recommended value of 60 mg/kg is the same as the requirement observed by Kealy and Sullivan (1966). The same level was reported by Atkinson et al. (1967b) as the requirement for breeder hens. Zinc needs are known to depend on the levels of other dietary constituents. The recommended level of 70 mg/kg was determined with practical diets having phytic acid present, whereas 41 mg/kg were adequate in a purified diet where phytic acid was absent (Dewar and Downie, 1984).

Vitamins

The previous requirement for vitamin A was listed as 4,000 IU/kg of diet. Vitamin A at 5,000 IU/kg of feed provides for maximum growth performance and liver storage (Prinz et al., 1986) and has been chosen to represent the requirement, although 2,000 IU/kg will also support optimal performance (Prinz et al., 1983). Vitamin A at 5,000 IU/kg is also recommended for breeder hens, but lower levels (about 2,500 IU/kg) have been shown to maintain egg production, hatchability, and survival (Stoewsand and Scott, 1961; Jensen et al., 1965).

Vitamin D_3 at 900 IU/kg of feed has been shown to be more than adequate for the starting poult in most studies (Baird and Greene, 1935; Hammond, 1941; Stadelman et al., 1950); however, Neagle et al. (1968) found that 1,100 IU/kg was necessary to maximize both growth and toe ash concentration when the diet contained 1.2 percent calcium and 0.8 percent total phosphorus. Discrepancies in vitamin D_3 needs of poults may relate to the level of this vitamin in the breeder hen's feed. Stevens et al. (1984) observed that 900 IU/kg in the breeder hen's diet supported maximum egg yield, hatchability, and subsequent survival of the poult, but liver storage was considered marginal.

The value given as the vitamin E requirement of starting turkeys is the same as that reported by Scott et al. (1965) when the dietary selenium concentration was 0.1 mg/kg. The vitamin E requirement of breeder hens was observed to be twice this level (24 IU/kg; Jensen and McGinnis, 1957). Extensive increases in vitamin E well above requirements for optimal growth are necessary in order to provide the carcass meaningful protection against oxidative rancidity when carcasses are held in frozen storage (Sheldon, 1984).

All other vitamin requirements have been determined only for the first 4 or 8 weeks of age. In some instances, there is good agreement among the researchers on the requirement value but, in other instances, considerable disparity exists. The committee has revised the requirement values given for several vitamins either to better represent old information or to reflect new reports. Vitamin K at 1 mg/kg of diet was increased to 1.75 mg/kg to be the same as the value observed by Griminger (1957) to optimize blood prothrombin time. The new value is considered adequate under practical conditions because poults used by Griminger (1957) were reared in wire-floored pens and coprophagy, as an additional source of vitamin K, was prevented.

Ruiz and Harms (1989a) reported that the poult's requirement for riboflavin was greater than 3.5 mg/kg of diet. The value given in the previous edition was 3.6 mg/kg, and this has been increased to 4.0 mg/kg. Conversely, Ruiz and Harms (1989b) reported the pantothenic acid requirement to be less than 8.6 mg/kg of diet; thus the previously listed requirement of 11 mg/kg was reduced to 10 mg/kg.

The dietary need for choline is known to be influenced by the levels of other nutrients involved in methyl group metabolism. The previously listed choline requirement was 1,900 mg/kg of diet, which was largely based on the report of Evans (1943), wherein the levels of ancillary nutrients influential to methyl group metabolism were not ensured. Harms and Miles (1984) reported that the choline requirement for poults between 0 and 4 weeks of age was less than 1,490 mg/kg of diet. Blair et al. (1986), using turkeys between 4 and 8 weeks of age, reported that the requirement was less than 1,250 mg/kg. To reflect these observations, the present requirement has been reduced to 1,600 and 1,400 mg/kg of diet for the period from 0 to 4 and 4 to 8 weeks, respectively.

The requirements for many vitamins after 8 weeks of age have not been determined for turkeys. Only measurements of the vitamin D_3, pantothenic acid, biotin, and folacin requirements have been conducted on breeder hens.

TABLE 3-3 Body Weights and Feed Consumption of Large-Type Turkeys during the Holding and Breeding Periods

	Females			Males	
Age (weeks)	Weight (kg)	Egg Production (%)	Feed per Turkey Daily (g)	Weight (kg)	Feed per Turkey Daily (g)
20	8.4	0	260	14.3	500
25	9.8	0	320	16.4	570
30	11.1	0[a]	310	19.1	630
35	11.1	68	280	20.7	620
40	10.8	64	280	21.8	570
45	10.5	58	280	22.5	550
50	10.5	52	290	23.2	560
55	10.5	45	290	23.9	570
60	10.6	38	290	24.5	580

NOTE: These values are based on experimental data involving "in-season" egg production (that is, November through July) of commercial stock. It is estimated that summer breeders would produce 70 to 90 percent as many eggs and consume 60 to 80 percent as much feed as in-season breeders.

[a] Light stimulation is begun at this point.

Requirement values for other vitamins were estimated from experimentally determined values for younger ages and changes in requirements observed with chickens.

TURKEY BREEDERS

Through the first 12 to 16 weeks of age, male and female turkeys being grown for reproductive purposes generally have been fed the same diet as birds intended for meat production. Thereafter, various efforts have been implemented to avoid obesity. Limiting body weight gain of males by either restricting feed access (Krueger et al., 1978) or providing a low-protein feed for ad libitum consumption (Meyer et al., 1980b) is effective as long as the practices are not so severe that they delay semen production. Typical nutrient levels employed from this time through the active breeder period correspond to those of the holding feed, as given in Table 3-1.

Excess body weight of hens is less of a problem than with males because an extensive loss of body weight occurs with hens as time in lay progresses. Table 3-3 includes a sample of hen performance through the breeder period. Inadequate body weight gain prior to stimulatory lighting delays the onset of lay and reduces egg production (Krueger et al., 1978; Meyer et al., 1980a). Starting both sexes on feed having the lowest concentration of nutrients for which a balance can be formulated and continuing this regimen to and through the breeder period on an ad libitum consumption basis minimizes the likelihood of obesity without adversely affecting performance (Ferket and Moran, 1985, 1986).

4

Nutrient Requirements of Geese

Geese are reared under a variety of feeding programs. In the production of "farm geese," the goslings are given starter feed for about 2 weeks and then allowed to forage for a variety of pasture and grain feedstuffs. Under these conditions, they are marketable at about 18 weeks. In another program, the goslings are fed limited amounts of prepared feed throughout the growing period but are still allowed considerable foraging. These geese are marketed at about 14 weeks of age, following liberal feeding of a high-energy finishing diet. Geese may also be provided feed for ad libitum consumption in confinement and marketed as "junior" or "green geese" at about 10 weeks. A program practiced in European countries involves the production of goose livers for *paté de foie gras*. The geese are grown to about 12 weeks and are then force-fed a high-energy diet for the production of livers of high-fat content. Geese for breeding purposes are fed holding and breeding diets for the intensive production of fertile eggs.

The nutrient requirements data presented in Table 4-1 are primarily applicable to geese reared in confinement. The nitrogen-corrected metabolizable energy (ME_n) concentrations heading each column are not requirements; instead they represent what are considered typical dietary ME_n values used for rearing geese commercially. Feed consumption by growing geese decreases as dietary ME_n level increases, but not in direct proportion (Stevenson, 1985). Consequently, geese fed high-energy diets consume greater amounts of energy, and deposit more body fat, than do geese fed lower-energy diets (Roberson and Francis, 1963a; Stevenson, 1985).

Data obtained from research done since 1980 by using fast-growing geese were used to establish the protein requirements given in Table 4-1. These data show that starting geese (0 to 4 weeks of age) require no more than 20 percent protein (Allen, 1981; Nitsan et al., 1983; Summers et al., 1987) for satisfactory growth, carcass composition, and feathering. Earlier research (Roberson and Francis, 1963a,b) with White Chinese geese had indicated that the protein requirement during the period from 0 to 6 weeks was 24 percent. In view of recent data, it is questionable whether this higher requirement applies to modern, commercial geese. No research data on the protein requirement of geese used for breeding or egg production were found in the literature.

Little information has been published describing the amino acid, mineral, or vitamin requirements of geese (Appendix Table A-5). Roberson and Francis (1966) reported that 0.90 percent lysine was needed for maximum growth and efficiency of feed utilization by 0- to 3-week-old White Chinese geese fed a diet containing

TABLE 4-1 Nutrient Requirements of Geese as Percentages or Units per Kilogram of Diet (90 percent dry matter)

Nutrients	Unit	0 to 4 Weeks; 2,900[a]	After 4 Weeks; 3,000[a]	Breeding; 2,900[a]
Protein and amino acids				
Protein	%	***20***	***15***	***15***
Lysine	%	1.0	0.85	***0.6***
Methionine + cystine	%	0.60	0.50	***0.50***
Macrominerals				
Calcium	%	***0.65***	***0.60***	***2.25***
Nonphytate phosphorus	%	***0.30***	***0.3***	***0.3***
Fat soluble vitamins				
A	IU	***1,500***	***1,500***	***4,000***
D_3	IU	***200***	***200***	***200***
Water soluble vitamins				
Choline	mg	***1,500***	***1,000***	*?*
Niacin	mg	***65.0***	***35.0***	***20.0***
Pantothenic acid	mg	***15.0***	***10.0***	***10.0***
Riboflavin	mg	3.8	***2.5***	***4.0***

NOTE: For nutrients not listed or those for which no values are given, see requirements of chickens (Table 2-5) as a guide. Where experimental data are lacking, values typeset in bold italic represent an estimate based on values obtained for other ages or species.

[a] These are typical dietary energy concentrations expressed in kcal ME_n/kg diet.

20 percent protein and 2,950 kcal ME_n/kg. More recently, Mateova et al. (1980) found that 1.10 percent lysine was satisfactory for starting geese. Mateova et al. (1980) also reported that from 4 to 8 weeks of age geese needed 0.85 percent lysine in a diet containing 2,945 kcal ME_n/kg. Nitsan et al. (1983) used body composition, maintenance needs, and absorption rate of amino acids to estimate the lysine requirements of geese. Subsequent testing of the results in feeding trials indicated that goslings required 1.07 and 0.60 percent lysine during the period from 0 to 2 and 2 to 7 weeks, respectively. Requirements of geese for other essential amino acids were estimated by Nitsan et al. (1983), and the results indicated that 0.58 percent total sulfur amino acids (TSAA) and 0.29 percent methionine were needed from 0 to 2 weeks of age and 0.47 percent TSAA and 0.15 percent methionine were required from 2 to 7 weeks.

Calcium and total phosphorus requirements of geese were estimated at 0.4 percent and 0.46 percent of the diet, respectively, for geese from 0 to 4 weeks of age (Aitken et al., 1958). These estimates have not been corroborated by recent research. Briggs et al. (1953) documented the need for dietary folic acid, choline, and niacin by goslings but did not estimate requirements. Battig et al. (1953) reported that 66 mg of dietary niacin per kilogram of diet (40 mg supplemented plus 26 mg in the ingredients) were required to prevent perosis and maximize growth of geese to 3 weeks of age.

Serafin (1981) fed purified diets to Embden goslings from hatch to 2 or 3 weeks and found that, for growth and liveability, requirements for riboflavin, niacin, pantothenic acid, and choline were no more than 3.8, 31.2, 12.6, and 1,530 mg/kg, respectively. Laboratory analysis of the basal purified diet showed that concentrations of the vitamins studied were very low; hence the requirement data reported herein represent levels of supplemental vitamins that were supplied in highly available forms. Thus, supplemental vitamins, which probably were readily utilized by the geese, were used to establish the requirements for riboflavin, niacin, pantothenic acid, and choline. Requirements established in this way may not be totally applicable to feeding commercial geese because vitamins supplied by commonly used ingredients of geese diets are less available than those of supplemental origin.

TABLE 4-2 Approximate Body Weights and Feed Consumption of Commercially Reared Male and Female Geese to 10 Weeks of Age

Age (weeks)	Average Body Weight (kg)	Feed Consumption by 2-Week Period (kg)	Cumulative Feed Consumption (kg)
0	0.11	0.00	0.00
2	0.82	0.96	0.96
4	2.05	2.93	3.89
6	3.05	3.20	7.09
8	4.05	4.34	11.43
10	4.85	4.68	16.11

The paucity of research on the nutrient requirements of geese illustrates the need for additional efforts focused on this area of nutrition.

Body weight and feed consumption data presented in Table 4-2 are approximations obtained from a combination of research results and input from persons involved in the production of geese.

5

Nutrient Requirements of Ducks

Ducks can be grown successfully in either of two environments—an open rearing system, in which the growing house opens to an exercise yard with water for wading or swimming, or a confinement growing system, in which ducks are raised in environmentally controlled houses with litter or combination litter and wire floors.

Pelleted diets are utilized more efficiently by ducks than are diets in mash form primarily because of reduced wastage and ease of consumption (Wilson, 1973; Dean, 1986). Starter diets (0 to 2 weeks) usually are fed as pellets of 3.18 mm (1/8 inch) diameter, and grower diets (after 2 weeks) are given in 4.76-mm (3/16 inch) form (Elkin, 1987).

Ducks typically are given 2 or 3 feeds during the growing period. Information presented in Table 5-1 is on the basis of a two-feed program; a diet containing 22 percent protein for the period of 0 to 2 weeks and a 16 percent protein diet for the period from 2 to 7 weeks (Dean, 1972a, 1986). The need for 22 percent protein during the starting period, however, is questionable because Wilson (1975) and Siregar et al. (1982) reported that protein levels of 18 and 19 percent, respectively, in diets providing 3,000 to 3,025 kcal ME_n/kg, were adequate from 0 to 2 weeks. A typical three-feed program may consist of diets containing 20, 18, and 16 percent protein for the periods from 0 to 2, 2 to 4, and 4 to 7 weeks, respectively. The growth rate of ducklings is not affected greatly by the ME_n concentration of the diet; however, feed efficiency is usually improved and carcass fat increased when dietary ME_n is increased (Wilson, 1975; Leclercq, 1986). Few data are available documenting the ME_n values of feed ingredients for ducks. Mohamed et al. (1984) found that the ME_n values of several feedstuffs were very similar for ducks and broiler chickens.

Although most ducks grown commercially in the United States are White Pekins, considerable research

TABLE 5-1 Nutrient Requirements of White Pekin Ducks as Percentages or Units per Kilogram of Diet (90 percent dry matter)

Nutrient	Unit	0 to 2 Weeks; 2,900[a]	2 to 7 Weeks; 3,000[a]	Breeding; 2,900[a]
Protein and amino acids				
Protein	%	***22***	16	***15***
Arginine	%	***1.1***	***1.0***	
Isoleucine	%	***0.63***	***0.46***	***0.38***
Leucine	%	***1.26***	***0.91***	***0.76***
Lysine	%	***0.90***	***0.65***	***0.60***
Methionine	%	0.40	***0.30***	***0.27***
Methionine + cystine	%	0.70	0.55	***0.50***
Tryptophan	%	***0.23***	***0.17***	***0.14***
Valine	%	***0.78***	***0.56***	***0.47***
Macrominerals				
Calcium	%	***0.65***	***0.60***	***2.75***
Chloride	%	0.12	***0.12***	***0.12***
Magnesium	mg	***500***	***500***	***500***
Nonphytate phosphorus	%	***0.40***	***0.30***	
Sodium	%	0.15	***0.15***	***0.15***
Trace minerals				
Manganese	mg	***50***	?[b]	?
Selenium	mg	0.20	?	?
Zinc	mg	***60***	?	?
Fat soluble vitamins				
A	IU	***2,500***	***2,500***	***4,000***
D_3	IU	***400***	***400***	***900***
E	IU	***10***	***10***	***10***
K	mg	***0.5***	***0.5***	***0.5***
Water soluble vitamins				
Niacin	mg	***55***	***55***	***55***
Pantothenic acid	mg	***11.0***	***11.0***	***11.0***
Pyridoxine	mg	***2.5***	***2.5***	***3.0***
Riboflavin	mg	***4.0***	***4.0***	***4.0***

NOTE: For nutrients not listed or those for which no values are given, see requirements of broiler chickens (Table 2-5) as a guide. Where experimental data are lacking, values typeset in bold italics represent an estimate based on values obtained for other ages or species.

[a] These are typical dietary energy concentrations as expressed in kcal ME_n/kg diet.

[b] Question marks indicate that no estimates are available.

data obtained by using other breeds of ducks (that is, Muscovy and "mule" ducks) have been used to fill several voids in the requirement data of Table 5-1, especially with respect to amino acids and minerals. Published research reviewed in Appendix Table A-6 on lysine and total sulfur amino acid (TSAA) requirements indicates that values listed in the previous edition of this report were too high (Jeroch and Hennig, 1965; Dean, 1967; Gazo et al., 1970; Leclercq and de Carville, 1977a,b; Adams et al., 1983; Elkin et al. 1986). Adjustments were made accordingly. In addition, a tentative methionine requirement for starting ducks (0.40 percent) is given on the basis of data reported by Elkin et al. (1986). Noteworthy is information published recently by Elkin et al. (1988) showing that the relative value of the D-methionine isomer was 78 percent of that of the L-isomer. Consequently, in instances where supplemental methionine is needed in duck diets, adjustments may be needed in supplemental levels of the DL-methionine sources used.

Only single papers have been published documenting the requirements of starting ducks for arginine, tryptophan, leucine, isoleucine, and valine (Chen and Shen, 1979; Wu et al., 1984; Yu and Shen, 1984). The values for these nutrients listed in Table 5-1 must therefore be viewed as tentative. The same is true of the requirement values for breeding ducks because relevant information is scarce (Cvetanov et al., 1969).

Research to determine the mineral and vitamin requirements of ducks has focused primarily on the starting period (0 to 2 or 3 weeks of age). In most instances, data on these nutrients are meager, and, with the exception of some research on dietary selenium and niacin requirements, only one report has appeared in the literature since 1980. Leclercq et al. (1990) reported that the calcium requirements of Muscovy ducks were 0.46 and 0.42 percent for age periods of 3 to 8 and 8 to 12 weeks, respectively. No information has been published recently on the calcium requirements for modern-day Pekin ducks.

TABLE 5-2 Approximate Body Weights and Feed Consumption of White Pekin Ducks to 8 Weeks of Age

Age (weeks)	Body Weight (kg)		Weekly Feed Consumption (kg)		Cumulative Feed Consumption (kg)	
	Male	Female	Male	Female	Male	Female
0	0.06	0.06	0.00	0.00	0.00	0.00
1	0.27	0.27	0.22	0.22	0.22	0.22
2	0.78	0.74	0.77	0.73	0.99	0.95
3	1.38	1.28	1.12	1.11	2.11	2.05
4	1.96	1.82	1.28	1.28	3.40	3.33
5	2.49	2.30	1.48	1.43	4.87	4.76
6	2.96	2.73	1.63	1.59	6.50	6.35
7	3.34	3.06	1.68	1.63	8.18	7.98
8	3.61	3.29	1.68	1.63	9.86	9.61

Body weight and feed consumption data for ducks from time of hatching to 8 weeks of age are given in Table 5-2.

6

Nutrient Requirements of Ring-Necked Pheasants, Japanese Quail, and Bobwhite Quail

As was true for geese and ducks, little information is available on the nutrient requirements of the game birds that are most frequently considered part of the poultry industry—Ring-necked pheasants, Japanese quail, and Bobwhite quail. Although these species do not constitute a major share of the poultry industry, there are an increasing number of specialized farms involved in their production.

RING-NECKED PHEASANTS

Information available on the nutrient requirements of the Ring-necked pheasant indicates that diets of relatively high nutrient concentrations are needed during the starting period (Table 6-1). Protein and amino acid needs, where documented (Appendix Table A-7), resemble those of turkeys. Also, pheasants are especially prone to leg disorders and abnormal feather growth when certain key nutrients such as niacin, riboflavin, choline, manganese, and zinc are inadequate (Sunde and Bird, 1957; Scott et al., 1959). Pheasant chicks are especially vulnerable to undefined dietary factors that impair leg development, and including extra zinc in diets has been shown to reduce the impact of these factors (Cook et al., 1984). A high level of calcium, as in a breeder ration, can cause leg problems and high mortality if fed to pheasant chicks (Woodard et al., 1979).

All nutrient requirements listed for female pheasants in egg production except for protein are tentative. Data presented by Monetti et al. (1982, 1985) indicate that dietary protein concentration should be maintained so that percentage of protein per megacalorie ME_n/kg of diet does not exceed 5.6.

Often, pheasants are fed diets designed to produce birds for use on game-release farms. Diets relatively high in protein and low in energy may be used to encourage the development of lean pheasants suitable for release.

JAPANESE QUAIL

Japanese quail are used for commercial specialty meat and egg production and also are valued research animals. Consequently, the nutrient requirements of Japanese quail have been documented to a greater extent than have those of other game bird species. Few definitive data have been published since 1984, when the previous edition of this report was published and

TABLE 6-1 Nutrient Requirements of Ring-Necked Pheasants as Percentages or Units per Kilogram of Diet (90 percent dry matter)

Nutrient	Unit	0 to 4 Weeks; 2,800[a]	4 to 8 Weeks; 2,800[a]	9 to 17 Weeks; 2,700[a]	Breeding; 2,800[a]
Protein and amino acids					
Protein	%	28	24	18	15
Glycine + serine	%	***1.8***	***1.55***	***1.0***	***0.50***
Linoleic Acid	%	***1.0***	***1.0***	***1.0***	***1.0***
Lysine	%	***1.5***	***1.40***	***0.8***	***0.68***
Methionine	%	***0.50***	***0.47***	***0.30***	***0.30***
Methionine + cystine	%	***1.0***	***0.93***	***0.6***	***0.60***
Protein	%	28	***24***	***18***	15
Macrominerals					
Calcium	%	1.0	***0.85***	***0.53***	***2.5***
Chlorine	%	***0.11***	***0.11***	***0.11***	***0.11***
Nonphytate phosphorus	%	0.55	***0.50***	***0.45***	***0.40***
Sodium	%	***0.15***	***0.15***	***0.15***	***0.15***
Trace minerals					
Manganese	mg	***70***	***70***	***60***	***60***
Zinc	mg	60	***60***	***60***	***60***
Water soluble vitamins					
Choline	mg	***1,430***	***1,300***	***1,000***	***1,000***
Niacin	mg	70.0	***70***	***40.0***	***30.0***
Pantothenic acid	mg	10.0	***10.0***	***10.0***	***16.0***
Riboflavin	mg	3.4	***3.4***	***3.0***	***4.0***

NOTE: Where experimental data are lacking, values typeset in bold italics represent an estimate based on values obtained for other ages or species. For nutrients not listed or those for which no values are given, see requirements of turkeys (Table 3-1) as a guide.

[a] These are typical dietary energy concentrations, expressed in kcal ME_n/kg diet.

Shim and Vohra (1984) presented a comprehensive review. Data appearing since 1984 have supported the values listed in the 1984 edition for protein (Sinha and Verma, 1984; Steigner, 1990) and for total sulfur amino acids (TSAA; Shrivastav and Panda, 1987) for the starting and growing period. In the instance of protein, however, Steigner (1990) reported that a strain of Japanese quail selected for rapid growth required a greater dietary protein concentration than did random-bred quail. Similarly, information provided by Shim and Lee (1984, 1988) and by Shim and Chen (1989) showed that the dietary requirements for lysine and TSAA for breeding quail in the 1984 edition were appropriate in relation to the stated metabolizable energy contents of the diet. The lack of data to further define requirements or to corroborate single sets of observations (Appendix Table A-8) on requirements of Japanese quail, especially breeding quail, necessitates the continued listing of a large number of tentative requirement values in Table 6-2.

TABLE 6-2 Nutrient Requirements of Japanese Quail (Coturnix) as Percentages or Units Per Kilogram of Diet (90 percent dry matter)

Nutrient	Unit	Starting and Growing; 2,900[a]	Breeding; 2,900[a]
Protein and amino acids			
Protein	%	24.0	20.0
Arginine	%	1.25	***1.26***
Glycine + serine	%	1.15	***1.17***
Histidine	%	0.36	***0.42***
Isoleucine	%	0.98	***0.90***
Leucine	%	1.69	***1.42***
Lysine	%	1.30	***1.00***
Methionine	%	0.50	0.45
Methionine + cystine	%	0.75	0.70
Phenylalanine	%	0.96	***0.78***
Phenylalanine + tyrosine	%	1.80	***1.40***
Threonine	%	1.02	***0.74***
Tryptophan	%	0.22	***0.19***
Valine	%	0.95	***0.92***
Fat			
Linoleic acid	%	***1.0***	***1.0***
Macrominerals			
Calcium	%	0.8	2.5
Chlorine	%	***0.14***	***0.14***
Magnesium	mg	300	***500***
Nonphytate phosphorus	%	0.30	***0.35***
Potassium	%	***0.4***	***0.4***
Sodium	%	0.15	***0.15***
Trace minerals			
Copper	mg	***5***	***5***
Iodine	mg	***0.3***	***0.3***
Iron	mg	***120***	***60***
Manganese	mg	***60***	***60***
Selenium	mg	***0.2***	***0.2***
Zinc	mg	25	***50***
Fat soluble vitamins			
A	IU	1,650	***3,300***
D_3	ICU	750	***900***
E	IU	***12***	***25***
K	mg	***1***	***1***
Water soluble vitamins			
B_{12}	mg	***0.003***	***0.003***
Biotin	mg	***0.3***	***0.15***
Choline	mg	***2,000***	***1,500***
Folacin	mg	***1***	***1***
Niacin	mg	40	***20***
Pantothenic acid	mg	***10***	***15***
Pyridoxine	mg	***3***	***3***
Riboflavin	mg	***4***	***4***
Thiamin	mg	***2***	***2***

NOTE: Where experimental data are lacking, values typeset in bold italics represent an estimate based on values obtained for other ages or species. For values not listed for the starting-growing periods, see requirements for turkeys (Table 3-1) as a guide.

[a] These are typical dietary energy concentrations, expressed in kcal ME_n/kg diet.

TABLE 6-3 Nutrient Requirements of Bobwhite Quail as Percentages or Units per Kilogram of Diet (90 percent dry matter)

Nutrient	Unit	0 to 6 Weeks; 2,800[a]	After 6 Weeks; 2,800[a]	Breeding; 2,800[a]
Protein and amino acids				
Protein	%	***26***	***20.0***	24.0
Methionine + cystine	%	***1.0***	***0.75***	***0.90***
Fat				
Linoleic acid	%	***1.0***	***1.0***	***1.0***
Macrominerals				
Calcium	%	0.65	***0.65***	***2.4***
Nonphytate phosphorus	%	***0.45***	***0.30***	***0.70***
Sodium	%	***0.15***	***0.15***	***0.15***
Trace minerals				
Chlorine	%	***0.11***	***0.11***	***0.11***
Iodine	mg	0.30	***0.30***	***0.30***
Water soluble vitamins				
Choline	mg	1,500.0	***1,500.0***	***1,000.0***
Niacin	mg	30.0	***30.0***	***20.0***
Pantothenic acid	mg	12.0	***9.0***	***15.0***
Riboflavin	mg	3.8	***3.0***	***4.0***

NOTE: Where experimental data are lacking, values typeset in bold italics represent an estimate based on values obtained for other ages or species. For values not listed for the starting-growing periods, see requirements for turkeys as a guide.

[a] These are typical dietary energy concentrations, expressed in kcal ME_n/kg diet.

Bobwhite Quail

The committee has made few changes in the nutrient specifications for Bobwhite quail (Table 6-3). Its reevaluation of the data (Appendix Table A-9) used to establish the previous requirements resulted in some modifications in protein, TSAA, calcium, and phosphorus recommendations for starting-growing Bobwhite quail. As with other game birds reared commercially, Bobwhite quail grown for game-release farms should be fed diets of relatively low energy content during the growing period to prevent excessive fattening.

7

Signs of Nutritional Deficiencies in Chickens and Turkeys

Clinical manifestation of nutrient deficiencies often occurs in conjunction with an alteration of normal biological processes that are unique for the nutrient. Some enzymes depend on particular vitamins and minerals for their functioning, and their activity diminishes with an inadequacy. In other instances, a particular physiological response or change in metabolite concentration may occur. This information was primarily obtained from formal experiments in which the inadequacies were definitive. Under field conditions, nutrient inadequacies are usually marginal, occasionally multiple, and often confounded with management problems or disease. To supplement physical observation of these signs, the committee has provided biochemical and physiological measurements for use in diagnosis. Table 7-1 presents a summary of the known biochemical and physiological measurements for diagnosing each nutrient deficiency. Additional information is available in the associated references.

Inadequate dietary vitamins and minerals in the chicken or turkey hen's diet are likely to reduce the egg contents accordingly and have adverse effects on embryonic development. Normal embryonic development proceeds through several events at which death of the embryo is common. The largest number of deaths occur during the transition from anaerobic to aerobic respiration with the establishment of the chorioallantois, which takes place between 3 to 4 days incubation and emergence at 18 to 21 days incubation. The same problems occur with other poultry species, and nutrient inadequacies generally accentuate death rates at these times (Couch and Ferguson, 1972).

Embryos are well developed at the end of incubation, and embryos that die as a result of nutrient deficiencies at this time may exhibit typical physical symptoms. These symptoms are assembled for each nutrient in Table 7-2. The symptoms can be similar for different nutrients, and the extent of the inadequacy may change the nature of the symptoms as well as when death occurs. Deficiency symptoms are expressed to a greater extent in growing birds than in adults. Table 7-3 gives a list of these symptoms by tissue affected, as a diagnostic aid. The table also presents information on these changes such that each can be rationalized in terms of nutrient function. References provided are not complete but are intended to be salient and most recent for cross-indexing purposes. Again, such information is usually the product of formal experimentation and not complicated by practical circumstances.

PROTEIN AND AMINO ACID DEFICIENCIES

Protein is made up of amino acids. The need for the essential amino acids determines the need for protein, and a reduction in dietary protein that results in deficiencies of several essential amino acids creates general symptoms. Productive activities suffer the most. For example, the energy used by growing birds is heavily committed to assembling the contractile elements in muscle cells but not to increasing cell number; thus protein inadequacies readily affect muscle size but not fiber number (Timson et al., 1983). Similarly, the effect of protein inadequacies on protein synthesis in the liver and oviduct is greatest with the laying hen (Muramatsu et al., 1987).

Deficiencies of individual essential amino acids usually have the same effect as when protein is deficient; however, additional symptoms may appear that characterize certain amino acids. Inadequate lysine is known to cause depigmentation of the wing feathers in Bronze turkey poults (Vohra and Kratzer, 1959) and certain colored chicks (Klain et al., 1957). A variety of abnormalities in feather development occur with deficiencies of arginine, valine, leucine, isoleucine, tryptophan, phenylalanine, and tyrosine in growing chicks (Newberne et

TABLE 7-1 Biochemical and Physiological Measurements for Diagnosis of Nutrient Deficiencies in Chickens and Turkeys

Nutrients	Biochemical and Physiological Measurements	References
Histidine	Reduced breast muscle anserine and carnosine.	Robbins et al., 1977; Amend et al., 1979
Lysine	Reduced hemoglobin and hematocrit.	Braham et al., 1961
Vitamin A	Hepatic vitamin A is indicative of a deficiency, but blood level is not. Liver xanthine dehydrogenase and kidney arginase both increase even in the first stages of a deficiency. Reduced glycogen phosphorylase in liver, and red and white muscles. Increased thyroid size and reduced T_3 and T_4.	Rogers, 1969; Nockels and Phillips, 1971; Jensen, 1974; Bruckental and Ascarelli, 1975; Nockels et al., 1984
Vitamin D	Calcium-binding protein of intestine; 1,25-$(OH)_2$-D_3 versus 24,25-$(OH)_2$-D_2 in serum (complicated by dietary calcium and phosphorus); plasma alkaline phosphatase; nonproteolipid phospholipid content of rachitic cartilage.	Bar et al., 1972; Ohmdahl and DeLuca, 1973; Morrissey et al., 1977; Boyan and Ritter, 1984; Kaetzel and Soares, 1985
Vitamin E	Superoxide dismutase; glutamic-oxaloacetictransaminase; plasma and tissue vitamin E concentration (all measurements affected by selenium as well).	Walter and Jensen, 1964; Arnold et al., 1974; Sklan et al., 1981; Sklan and Donoghue, 1982
Vitamin K	Prothrombin clotting time of plasma.	Griminger et al., 1970
Thiamin	Transketolase in erythrocytes and leucocytes; plasma pyruvic acid.	Lofland et al., 1963; Anonymous, 1977
Riboflavin	Liver xanthine dehydrogenase; erythrocyte glutathione reductase.	Chou, 1971; Lee, 1982
Niacin	Level and ratio of niacin excretion products N'-methyl-nicotinamide and N'-methyl-2-pyridone-5-carboxyamide (untested for fowl).	Darby et al., 1975
Biotin	Blood pyruvate carboxylase; ratio of C 16:1 to C 18:0 fatty acids in blood.	Edwards, 1974; Whitehead and Bannister, 1980
Pantothenic acid	Hepatic coenzyme A.	Cupo and Donaldson, 1986
Pyridoxine	Serum glutamic oxaloacetic transaminase; plasma glycine-serine ratio aspartic aminotransferase.	Daghir and Balloun, 1963; Sifri et al., 1972; Lee et al., 1976
Folacin	Dihydrofolic acid reductase in liver; serine hydroxymethyl transferase in liver.	Rabbani et al., 1973; Zamierowski and Wagner, 1977
Vitamin B_{12}	B_{12} in blood; excretion of methylmalonic acid.	Cox and White, 1962; Lau et al., 1965
Choline	Serum phospholipids.	Seifter et al., 1972
Linoleic acid	Linoleate, arachidonate, and eicosatrienoate concentrations in liver lipids.	Machlin and Gordon, 1960
Calcium	Calcium in hen's blood (but not in chick's unless deficiency is severe); intestinal calcium-binding protein (complicated by D_3 metabolites and phosphorus); turkey poults differ from chicks.	Bar et al., 1972, 1978a,b; Bar and Hurwitz, 1973
Chlorine	Hemoconcentration; alkalosis.	Leach and Nesheim, 1963; Cohen and Hurwitz, 1974; Hamilton and Thompson, 1980
Copper	Plasma ceruloplasmin; lysyl oxidase in aorta, liver, tendon, and bone; erythrocyte superoxide dismutase.	Kim and Hill, 1966; Miller and Stake, 1974; Bettger et al., 1979; Opsahl et al., 1982
Iodine	Plasma thyroxine and tri-iodothyronine.	Singh et al., 1968
Iron	Hematocrit; blood hemoglobin concentration; transferrin saturation; anemia with lipemia.	Davis et al., 1962; Waddell and Sell, 1964; Planas, 1967
Magnesium	Magnesium concentration in blood.	Sell et al., 1967; Hajj and Sell, 1969
Manganese	Chondroitin sulfate in bone; manganese concentration in bone; superoxide dismutase.	Leach, 1968; Reid et al., 1973; DeRosa et al., 1980
Phosphorus	Serum inorganic phosphorus; renal calcium-binding protein.	Miller and Stake, 1974; Bar et al., 1978a,b
Potassium	Plasma potassium; metabolic acidosis (complicated by sodium).	Burns et al., 1953; Cohen and Hurwitz, 1974
Selenium	Plasma glutathionine peroxidase.	Noguchi et al., 1973; Dean and Combs, 1981; Cantor et al., 1982
Sodium	Metabolic acidosis (complicated by potassium).	Nott and Combs, 1969; Cohen and Hurwitz, 1974
Zinc	Plasma and bone zinc; thymidine kinase; alkaline phosphatase and collagenase in bone.	Miller and Stake, 1974; Oberleas and Prasad, 1974; Starcher et al., 1980; Bettger et al., 1979

TABLE 7-2 Signs of Deficiency in the Embryo

Nutrients	Deficiency Signs	References
Vitamin A	Death at about 48 hours of incubation from failure to develop the circulatory system; abnormalities of kidneys, eyes, and skeleton.	Asmundson and Kratzer, 1952; Thompson et al., 1965; Heine et al., 1985
Vitamin D	Death at about 18 or 19 days of incubation, with malpositions, soft bones, and with a defective upper mandible prominent.	Sunde et al., 1978; Narbaitz and Tsang, 1989
Vitamin E	Early death at about 84 to 96 hours of incubation, with hemorrhaging and circulatory failure (implicated with selenium).	Card et al., 1930; Latshaw and Osman, 1974
Vitamin K	No physical deformities from a simple deficiency, nor can they be provoked by antivitamins, but mortality occurs between 18 days and hatching, with variable hemorrhaging.	Griminger, 1964; Hauschka and Reid, 1978a
Thiamin	High embryonic mortality during emergence but no obvious symptoms other than polyneuritis in those that survive.	Polin et al., 1962; Charles et al., 1972
Riboflavin	Mortality peaks at 60 hours, 14 days, and 20 days of incubation, with peaks prominent early as deficiency becomes severe. Altered limb and mandible development, dwarfism, and clubbing of down are defects expressed by embryo.	Romanoff and Bauernfeind, 1942; Landauer, 1967
Niacin	Embryo readily synthesizes sufficient niacin from tryptophan. Various bone and beak malformations occur when certain antagonists are administered during incubation.	Snell and Quarles, 1941; Landauer, 1956; Caplan, 1972
Biotin	High death rate at 19 to 21 days of incubation, and embryos have parrot beak, chondrodystrophy, several skeletal deformities, and webbing between the toes.	Cravens et al., 1994; Couch et al., 1947
Pantothenic acid	Deaths appear around 14 days of incubation, although marginal levels may delay problems until emergence. Variable subcutaneous hemorrhaging and edema; wirey down in poults.	Kratzer et al., 1955; Beer et al., 1963
Pyridoxine	Early embryonic mortality based on antivitamin use.	Landauer, 1967
Folic acid	Mortality at about 20 days of incubation. The dead generally appear normal, but many have bent tibiotarsus, syndactyly, and mandible malformations. In poults, mortality at 26 to 28 days of incubation with abnormalities of extremities and circulatory system.	Sunde et al., 1950a; Kratzer et al., 1956a
Vitamin B_{12}	Mortality at about 20 days of incubation, with atrophy of legs, edema, hemorrhaging, fatty organs, and head between thighs malposition.	Olcese et al., 1950; Ferguson et al., 1955
Manganese	Peak deaths prior to emergence. Chondrodystrophy, dwarfism, long bone shortening, head malformations, edema, and abnormal feathering are prominent.	Lyons and Insko, 1937
Zinc	Deaths prior to emergence, and the appearance of rumplessness, depletion of vertebral column, eyes underdeveloped, and missing limbs.	Kienholz et al., 1961; Turk, 1965
Copper	Deaths at early blood stage with no malformations.	Bird et al., 1963
Iodine	Prolongation of hatching time, reduced thyroid size, and incomplete abdominal closure.	Rogler et al., 1959a, b
Iron	Low hematocrit; low blood hemoglobin; poor extra-embryonic circulation in candled eggs.	Dewar et al., 1974; Morck and Austic, 1981
Selenium	High incidence of dead embryos early in incubation.	Latshaw et al., 1977

TABLE 7-3 Nutrients Associated with Various Signs of Deficiency in Growing Birds

Deficiency Signs	Descriptions	Species	Associated Nutrients
Skin lesions	Crusting and scab formation around eyes and beak	Chick, poult,	Biotin, pantothenic acid
	Bottoms of feet rough and calloused with hemorrhagic cracks	Chick, poult	Biotin, pantothenic acid
	Scaliness on feet	Chick	Zinc, niacin
	Lesions around eyes, eyelids stuck together	Chick, poult	Vitamin A
	Mouth, inflammation of oral mucosa (chicken black tongue)	Poult, chick	Niacin
Feather abnormalities	Uneven feather growth, abnormally long primary feathers, feathers not lying smoothly	Chick, poult	Protein, amino acid imbalance
	Frizzled and rough	Chick, poult	Zinc, niacin, pantothenic acid, folic acid, lysine
	Black pigmentation in breeds with red and brown feathers	Chick	Vitamin D
	Depigmentation	Chick, poult,	Copper, iron, folacin
Nervous disorders	Convulsions with head retraction	Chick, pigeon	Thiamin
Convulsions with hyperexcitability	Chick, poult, duckling	Pyridoxine	
Hyperirritability	Chick, poult, duckling	Magnesium, sodium chloride	
Characteristic fright reaction with tetanic spasms	Chick	Chloride	
Spastic cervical paralysis, neck extended with birds appearing to look down	Poult	Folacin	
Curled-toe paralysis, gross enlargement of sciatic and brachial nerves with myelin degeneration	Chick	Riboflavin	
Encephalomalacia, tetanic spasms with head retraction, hemorrhagic lesions in cerebellum	Chick	Vitamin E	
Blood and vascular system	Anemia	All poultry	
Macrocytic		Vitamin B_{12}	
Macrocytic, hyperchromic		Folacin	
Microcytic, hypochromic		Iron, copper	
Microcytic		Pyridoxine	
Hemorrhage, intramuscular, subcutaneous, internal from aortic rupture	Chick, poult	Vitamin K, copper	
Exudative diathesis	Chick, poult	Selenium, vitamin E	
Enlarged heart	Chick, poult	Copper	
Muscle	Muscular dystrophy, white areas of degeneration in skeletal muscle	Chick, duck, poult	Vitamin E, selenium
	Cardiac myopathy	Poult	Vitamin E, selenium
	Gizzard myopathy	Poult	Vitamin E, selenium
Bone disorders	Soft, easily bent bones and beak (rickets)	All poultry	Vitamin D, calcium or phosphorus deficiency or imbalance
	Hock enlargement	Poult, chick, gosling, duckling	Niacin, zinc
	Perosis	Chick, poult	Biotin, choline, vitamin B_{12}, manganese, zinc, folacin
	Bowed legs	Duck	Niacin
	Shortening and thickening of leg bones	Chick	zinc, manganese
	Curled toes	Chick	Riboflavin
Diarrhea		Chick, duck, poult	Niacin, riboflavin, biotin

NOTE: Slow growth and general lack of vigor are generally associated with malnutrition. The signs listed in this table are more specific indications of deficiencies of particular nutrients.

al., 1960; Robel, 1977; Penz and Kratzer, 1984). Chavez and Kratzer (1974) observed a foot pad dermatitis in poults when methionine was deficient, but cystine had to be adequate for the dermatitis to occur. Grau (1945) reported a tongue deformity in chicks fed a purified diet deficient in leucine, isoleucine, or phenylalanine, but these observations were not confirmed by Bragg (1953) with practical feedstuffs.

VITAMIN DEFICIENCIES

Vitamin A

Substitution of the body's secretory epithelia by keratinized surfaces is the most important change occurring with a vitamin A deficiency. Corneal, conjunctival, esophageal, and tracheal secretory membranes are all altered in chickens (Aydelotte, 1963). Mucus formation depends on vitamin A (DeLuca et al., 1971). Loss of membrane integrity, in turn, alters water retention (Lopen et al., 1973) and impairs the ability to withstand infection (Singh and Donovan, 1973; Sijtsma et al., 1989). Inadequate vitamin A also reduces the immune system's response to challenge and further contributes to disease susceptibility (Davis and Sell, 1989; Sklan et al., 1989).

The appearance of keratinized secretory surfaces is followed by a typical ataxia. Alterations in bone growth create several areas of compression on the central nervous system that cause a loss in mobility (Howell and Thompson, 1967). Inadequate vitamin A also adversely affects the pituitary-gonadal axis to create other symptoms that are not readily obvious (Fletcher, 1971). Nockels et al. (1984) reported that hypothyroidism is an early indication of vitamin A deficiency in chicks. Reductions in testes size, circulating testosterone, and fertility have been reported during vitamin A deficiency in cockerels (Padedes and Garcia, 1959; Hall et al., 1980).

Muscles in vitamin-A-deficient birds have a high level of glycogen, which cannot be readily used because phosphorylase activity is inordinately low (Nockels and Phillips, 1971; Sundeen et al., 1980). Alternatively, glucose is provided by extensive gluconeogenesis from protein (Nir and Ascarelli, 1967; Bruckental et al., 1974), and nitrogen end products increase such that deposits of uric acid appear in the kidneys and ureters (Bruckental and Ascarelli, 1975; Chandra et al., 1984).

Vitamin A in feedstuffs is labile, and concentrated supplements are normally given to ensure that the requirement is met. Misuse of these concentrates has led to occasional toxicosis problems. Skin lesions at the commissure of the beak, nose, and eyes attributable to mucus membrane hyperplastic activity have been shown to occur in chicks within 72 hours after oral dosing with 60,000 IU (Kriz and Holman, 1969). The appearance of rachitic bones together with a hyperplastic parathyroid results from the antagonism known to exist with vitamin D (Metz et al., 1985; Tang et al., 1985; Veltmann et al., 1987). Excessive vitamin A has also been shown to antagonize vitamin E (Vahl and Van't Klooster, 1987) and increase the likelihood of a deficiency when vitamin E and selenium nutriture is marginal (Combs, 1976).

Plant source feedstuffs usually provide carotenoid pigments that may be converted into vitamin A. The most favorable such pigment in this respect is β-carotene (Flegal et al., 1971), and conversion largely occurs at the intestine during absorption (Sklan, 1983). Because of the susceptibility of vitamin A sources to oxidative losses, synthetic antioxidants often are included in premixes and complete feeds (Grundboeck et al., 1977).

Vitamin D

Poultry require vitamin D to effectively use calcium. After absorption, the vitamin is hydroxylated at the 25-position in the liver and then transferred to the kidney, where the 1,25-dihydroxy metabolite is formed (Ameenuddin et al., 1985). All of the vitamin metabolites affect calcium utilization in one way or another, but the 1,25-dihydroxy-vitamin D seems to have the greatest impact. Vitamin D metabolites induce the synthesis of calcium-binding proteins in the intestine, kidney, and uterus through the efforts of vitamin D metabolites at both transcriptional and post-transcriptional levels. Calcium-binding proteins enhance calcium absorption from the intestine, recovery from the urine, and shell deposition, respectively (Coty, 1980; Jande et al., 1981; Roth et al., 1981; Clemens et al., 1988).

Vitamin D also induces the formation of osteocalcin, a protein in bone (Anonymous, 1981). Osteocalcin is believed to participate in the organic-inorganic matrix. Vitamin D is implicated by converting specific glutamic acid residues in osteocalcin to γ-carboxylglutamic acid metabolites that interact with calcium. Bone alterations associated with osteocalcin appear to be more involved with resorption and turnover when calcium is needed elsewhere in the body than growth. Presumably, vitamin D also provides proliferative signals for undifferentiated cells in the intestine (Cross and Peterlik, 1983) and pancreatic islets (Clark et al., 1987).

Vitamin D_2 represents the plant source of this vitamin and arises from the ultraviolet irradiation of ergosterol (Kobayashi and Yasumura, 1973), whereas vitamin D_3 occurs in animals upon irradiation of 7-dehydro-cholesterol in skin (Beadle, 1977). Vitamin D_3 is about 10-fold more effective with chicks than vitamin D_2 (Hurwitz et al., 1967). A large part of this difference in activity seems to involve metabolite formation in the liver, where enhanced glucuronidation of the 25-hydroxy-vitamin D_2 favors biliary excretion (Le Van et al., 1981).

Gross symptoms occurring because of a vitamin D deficiency can largely be attributed to a reduction of intestinal binding protein and lack of calcium recovered from feed (McCarthy et al., 1984). During vitamin D deficiency, growing birds develop hypocalcemia, which, in turn, stunts skeletal development through widened cartilage at epiphyses of long bones and weakened shafts (Noff et al., 1982; Long et al., 1984). For some reason, an abnormal blackening of the feathers also occurs with some pigmented chicks (Glazener and Briggs, 1948). Once the skeleton has assumed adult size, a vitaminosis D is obvious only with hens in production. Egg production and egg weight decrease while the eggshell thins as bone reserves are progressively depleted (Vohra et al., 1979).

Hens in production cyclically release estrogen from the ovary to maximize 1,25-dihydroxy-vitamin D production concurrent with eggshell formation (Castillo et al., 1979). As a result, levels of calcium-binding protein in the uterus (Navickis et al., 1979) and calcium in the medullary bone (Takahashi et al., 1983) are altered to facilitate eggshell formation. Vitamin D nutriture of the hen also influences its content in egg yolk and the subsequent need for this vitamin by the chick (Bethke et al., 1936; Griminger, 1966; Stevens and Blair, 1985).

Vitamin D removed from the yolk is metabolized by the embryo as it is by the adult, and 1,25-dihydroxy-vitamin D is the dominant metabolite (Bishop and Norman, 1975). An additional activity for this metabolite is recovery of calcium from the shell at the chorioalloic membrane to support skeletal mineralization prior to hatching (Narbaitz, 1987). The yolk sac membrane also responds to 1,25-dihydroxy-vitamin D at the same time, and a portion of the calcium from the shell is transferred into the yolk for later use upon hatching (Clark et al., 1989); however, one or more of the other metabolites must also be present if complete embryonic development and emergence from the shell is to occur (Ameenuddin et al., 1982).

The very low content of vitamin D in feedstuffs is generally ignored in feed formulation, and the complete requirement is satisfied by using concentrated premixes. Overuse of vitamin D concentrates can lead to a toxicity. High levels of 1,25-dihydroxy-vitamin D occur with a toxicosis, along with hypercalcemia and soft tissue mineralization (Morrissey et al., 1977; Ratkowski et al., 1982). Leg problems may arise with growing birds because of bone calcium loss (Cruickshank and Sim, 1987), but few obvious changes occur with hens other than a general depression in performance (Ameenuddin et al., 1986). Toxic levels of vitamin D may be transferred into the egg to create similar problems for the embryo; however, the hypercalcemia occurs from shell resorption, and bone mineralization is enhanced (Narbaitz and Fragiskos, 1984).

Vitamin D in feed may not be totally available to poultry. This vitamin is susceptible to destruction by oxidation and significant losses may occur unless supplemental antioxidants are used (Fritz et al., 1942). Also, mycotoxins in feeds interfere with the utilization of dietary vitamin D (Bird, 1978; Gedek et al., 1978; Kohler et al., 1978). Losses of vitamin D because of oxidation and poor utilization may result in a deficiency of the vitamin even though initial dietary concentrations of vitamin D substantially exceed known requirements.

Vitamin E

Vitamin E is composed of an array of tocopherols derived from plant sources that act as antioxidants within the animal. Hydrophobic areas of tissues, particularly cell membranes, are the sites of action for vitamin E (Erin et al., 1984), whereas selenium is a cofactor for complementary antioxidant activities in the aqueous portion (Xu and Diplock, 1983). Dietary vitamin E is absorbed from the intestine with fat, and its dissemination follows depletion of lipoprotein contents from circulation (Massey, 1984). In turn, tissue vitamin E content parallels feed vitamin E levels, and tissues receiving the highest proportions are intestine, liver, fat depots, and muscle (Astrup, 1979).

The amount of vitamin E needed to avoid a deficiency largely depends on the adequacy of the accompanying selenium and on circumstances presenting oxidative threats to the system. An inadequacy of both vitamin E and selenium leads to exudative diathesis, which is a subdermal accumulation of viscous blue-green-colored exudate from endothelial failures in portions of the vascular system (Scott, 1966a). Myopathies of the gizzard, heart, and, to a lesser extent, the skeletal muscles are also apparent. Skeletal muscles, particularly the breast, become more myopathic when the sulfur amino acids are also deficient. Exudative diathesis can be eliminated and most myopathies can be greatly relieved when selenium alone is increased (Combs and Scott, 1974).

Vitamin E deficiency symptoms that do not benefit from increased selenium are encephalomalacia (Hassan et al., 1985) and the susceptibility of red blood cells to hemolysis (Dobinska et al., 1982). Degeneration of the Perkinji layer of cells in the cerebellum results in nervous symptoms typified as sudden prostration with toes and legs outstretched, toes flexed, and head outstretched. High concentrations of dietary PUFA lead to increased contents in cell membranes and, in turn, the additional susceptibility to oxidative stress may enhance the possibilities of encephalomalacia (Budowski and Crawford, 1986). Other stressors such as ozone in the environment (Bartov et al., 1981) or peroxidized fat (Budowski et al., 1979) or medium-chain fatty acids (Ikumo, 1980) contained in the feed also increase the possibility of a vitamin E deficiency.

Adult fowl are less susceptible to a vitamin E deficiency than are actively growing chicks, and the symptoms differ. Males become infertile because sperm become incompetent (Friedrichsen et al., 1980). Reduced egg production and hatchability occur when both vitamin E and selenium are deficient over a prolonged period with hens (Latshaw and Osman, 1974). Although supplemental selenium can completely overcome these problems, chicks from these eggs are particularly susceptible to encephalomalacia (Bartov and Bornstein, 1980) and muscular dystrophy (Ewen and Jenkins, 1967).

Adding excessive vitamin E to feed can have adverse effects. Nockels et al. (1976) reported that feeding 8,000 IU/kg reduced body weight gain and gave a waxy appearance to the feathers. Should either vitamin D or vitamin K be marginal when high levels of vitamin E are being fed, then rachitic bones and blood clotting failures, respectively, may occur (March et al., 1973; Murphy et al., 1981; Franchini et al., 1988). However, dietary excesses approximating 100 to 500 IU/kg of feed are advantageous to the oxidative stability of broiler (Lin et al., 1989) and turkey (Sheldon, 1984) meat products.

Vitamin K

Vitamin K is used as a cofactor to synthesize γ-carboxyglutamic residues from glutamic acid in proteins located in the liver and bone. The liver protein is involved in the synthesis of several blood clotting factors, including prothrombin clotting of blood (Suttie, 1987), and the bone protein, osteocalcin, is implicated in calcification of bone matrix (Hauschka et al., 1989).

Although inadequate dietary vitamin K alters bone osteocalcin, symptoms associated with the skeletal system are not as apparent as blood clotting problems (Scott, 1966b; Hauschka and Reid, 1978b). Hemorrhaging may occur subcutaneously, intermuscularly, and internally and may lead to anemia and the appearance of hypoplastic bone marrow. A greatly extended blood clotting time may result in death from exsanguination. Vitamin K adequacy is usually measured in terms of prothrombin clotting time with decalcified plasma (Griminger et al., 1970).

Dietary vitamin K may be of three sources. Vitamin K_1, or phylloquinone, largely occurs in the leafy parts of plants. Vitamin K_2, or menaquinone, is of bacterial origin, particularly those bacterial located in the large intestine. Vitamin K_3, or menadione, has been synthesized and does not occur in nature as such. Antivitamin K compounds, whether synthetic (Lowenthal and MacFarlane, 1965) or natural (Griminger, 1987), act as anticoagulants. Menadione generally exhibits the greatest vitamin K activity (Dua and Day, 1966), except when anticoagulants are given and the converse occurs (Griminger, 1965). Dietary anticoagulants lead to vitamin K deficiency symptoms commensurate with the extent of toxicity (Veltmann et al., 1981; Bai and Krishnakumari, 1986).

Inadequate vitamin K under practical circumstances is most likely to occur during the starting period, and supplementation of the feed at this time is advantageous (Fritz, 1969). Starting feeds seldom contain forage meals, and a poorly developed intestinal microflora together with the use of antimicrobials further reduces access to the vitamin (Bornstein and Samberg, 1954). Nelson and Norris (1961a) showed that the inclusion of 0.1 percent sulfaquinoxaline increased the chick's need for supplemental vitamin K by fourfold to sevenfold.

Adults usually have a well-developed intestinal microflora, and vitamin K inadequacies are unusual. Vitamin K_2 is not readily absorbed from the large intestine but it is digested after coprophagy of cecal excreta (Berdanier and Griminger, 1968). The caging of hens minimizes coprophagy, and minimal amounts of vitamin K reach the egg (Cravens et al., 1941). Griminger and Brubacher (1966) observed that dietary vitamin K_3 is transferred to the yolk as vitamin K_2, but vitamin K_1 is best transferred and remains as such.

Use of vitamin K by embryos parallels that by adults. A deficiency with the embryo alters bone metabolism, but no physical deformities occur (Hauschka and Reid, 1978a). Adverse effects on blood clotting are not apparent until after hatching, when hemorrhaging and mortality occur should trauma be encountered (Griminger, 1964).

Thiamin (Vitamin B1)

Thiamin is a cofactor for several enzymes catalyzing decarboxylationand transketolation-type reactions. Although the activity of all these enzymes is depressed in a thiamin deficiency, the accrual of pyruvic acid from decreased brain pyruvic oxidase seems to manifest the most symptoms (Lofland et al., 1963). Ataxia and awkward backward flexions of the head and neck are typical nervous symptoms (Gries and Scott, 1972b). Deficient birds can rapidly detect and discriminate against feeds that do not provide the vitamin (Hughes and Wood-Gush, 1971) and are high in carbohydrate content (Thornton and Shutze, 1960).

Most complete feeds satisfy the thiamin requirement because grains and their by-products usually contain adequate amounts. Thiamin is unstable to heat at neutral and alkaline pH (Dwivedi and Arnold, 1973), and pelleting (Guo and Summers, 1969) or extrusion (Beetner et al., 1974) under these circumstances facilitates loss. Amaranth is very low in thiamin, and the level is reduced further if it is heated to destroy growth-inhibiting properties (Laovoravit et al., 1986). Inclusion of certain fish meals having enzymes capable of destroying thiamin may also decrease dietary content (Ishihara et al., 1974; Bryan et al., 1975). Use of medicants acting as a thiamin antagonist can also cause a deficiency (Ott et al., 1965; Shindo et al., 1972).

The hen transfers thiamin to the egg in proportion to dietary content (Polin et al., 1963). Although the dietary inadequacies possible under practical terms do not affect breeder flock productivity, high mortality of embryos occurs prior to hatching and chicks that hatch express a polyneuritis (Polin et al., 1962; Charles et al., 1972).

Riboflavin (Vitamin B2)

Riboflavin acts as a cofactor for many enzymes involved in oxidation-reduction. Erythrocyte glutathione reductase (Lee, 1982) and liver xanthine dehydrogenase (Chou, 1971) are two enzymes in fowl shown to need riboflavin, and their activities reflect dietary adequacy. Prior to the development of concentrated riboflavin sources, milk products were incorporated in feed to avoid deficiencies (Culton and Bird, 1940).

Riboflavin deficiencies lead to neurological problems, particularly with the sciatic and brachial nerves, where myelin degeneration, Schwann cell proliferation, and axis cylinder fragmentation have been observed (Phillips and Engel, 1938). Symptoms involving the legs of chickens appear as splay and hock resting postures, and curling of the toes occurs to a lesser extent (Wyatt et al., 1973a; Ruiz and Harms, 1988a). Turkey poults (Ruiz and Harms, 1989a) and pheasants (Scott et al., 1959) exhibit similar symptoms as the chick, whereas ducks (Fritz et al., 1939) and geese (Serafin, 1981) are more likely to have a bowing of the legs in conjunction with perosis. Goff et al. (1953) noted that increased hematocrit, increased mean corpuscular volume, decreased mean hemoglobin concentration, and a marked heterophil leucocytosis appeared in the chick prior to neurological manifestations.

Adult cockerels can endure a riboflavin-deficient feed for a prolonged period before neurological and blood problems similar to those of the growing chick appear (Arscott, 1972). Deficiency symptoms can be reversed upon riboflavin administration to adults, but correction with growing birds becomes increasingly difficult as expression progresses.

Laying hens transfer riboflavin into the yolk and albumen by hormonally induced binding proteins in the liver and oviduct, respectively (Hamazume et al., 1984). Saturation of these carriers is dependent on dietary riboflavin content (White et al., 1986), and an inadequacy is more likely to adversely affect embryonic development than harm the hen (Tarhay et al., 1975). Severe inadequacies cause death of embryos at 60 hours incubation because of circulatory system failures (Romanoff and Bauernfeind, 1942). Moderate inadequacies result in deaths at 14 days incubation, with the appearance of shortened limbs, malformed mandibles, and clubbing of the down. Marginal deficiencies further delay mortality until pipping, and symptoms are largely dwarfism with clubbed down.

Niacin

Niacin represents nicotinic acid and nicotinamide, both of which have similar activity in fowl (Ruiz and Harms, 1988b). Many enzymes in glycolysis, lipogenesis, and energy metabolism use niacin as a cofactor. Tryptophan may be converted into niacin; however, the efficiency is poor and not recommended as a substitute for diet supplementation (Ruiz and Harms, 1990).

Availability of niacin in grain and grain by-products is generally low (Manoukas et al., 1968; Yen et al., 1977); thus their contribution in determining dietary adequacy is usually ignored. Chicks at hatch have considerable tryptophan contained in the protein of the yolk; thus a niacin deficiency will not readily occur unless the feed is low for both the amino acid and the vitamin (Snell and Quarles, 1941). Briggs et al. (1943) reported that 2 weeks were required to provoke a deficiency with chicks and that an inflammation of the oral cavity and occasional poor feathering, dermatitis, and perosis—a malformation of the bones—were the primary symptoms. Turkey poults (Ruiz and Harms, 1988b), pheasants (Scott et al., 1959), ducks (Heuser and Scott, 1953), and goslings (Serafin, 1981) all expressed perosis as the primary deficiency symptom.

Biotin

Biotin acts as a cofactor for enzymes performing carboxylations. Acetyl coenzyme A carboxylase, which participates in fatty acid synthesis, and pyruvate carboxylase, which enables gluconeogenesis from intermediates in the Kreb's cycle, are both affected by biotin nutriture (Whitehead and Bannister, 1980; Watkins and Rogel, 1989). Biotin tends to concentrate in liver, kidney, and bone, the primary sites of activity of enzymes requiring this vitamin (Frigg and Torhorst, 1982). Analysis of complete feeds indicates that adequate biotin is present; however, low availability of biotin from certain grains may result in marginal concentrations in comparison with biotin requirements (Frigg, 1976).

Symptoms of a biotin deficiency are skin lesions appearing on the foot pad, shank, and toes, together with eye exfoliation and exudative dermatitis (Marusich et al., 1970). Skin lesions can be related to alterations in the fatty acid composition of associated waxes (Logani et al., 1977). Low dietary fat and the necessity for fatty acid synthesis lead to an abnormal array of fatty acids that predisposes poultry to a fatty liver and kidney syndrome (FLKS) (Whitehead and Randall, 1982). Subjecting these birds to a fast such that gluconeogenesis is accelerated precipitates a high death rate from lack of glucose (Whitehead and Siller, 1983). Tibiotarsal bones are frequently longitudinally distorted. Presumably, reduced biotin prevents ready formation of prostaglandins from essential fatty acids, and bone growth fails to respond to stresses during development (Watkins et al., 1989).

Biotin-binding proteins are found in the yolk and albumen of eggs (Bush et al., 1988). The amount of biotin associated with the yolk binding protein changes with biotin content in the feed. Hatchability is affected when the feed is deficient (White et al., 1987). Embryonic mortality because of inadequate biotin occurs largely during the last 3 days of incubation. Dwarfing, chondystrophy, and deformities of the mandibles and skeleton appear at that time (Couch et al., 1947).

Chicks hatched from breeder hens given marginal dietary biotin have increased risk of a deficiency (Whitehead et al., 1985). Provoking a deficiency is dependent on many factors, particularly those affecting supplementary biotin synthesis by microbes in the ceca and coprophagy. Caging and use of probiotics and medicants in the feed are influential in this respect (Leeson, 1982).

Pantothenic Acid

Pantothenic acid serves as a prosthetic group with coenzyme A and thereby is essential in energy metabolism. Inadequate pantothenic acid not only reduces the productive use of available energy (Beagle and Begin, 1976; Cupo and Donaldson, 1986) but also impairs detoxification mechanisms that depend upon acetylation (Kietzmann, 1981). Grains contain low concentrations of pantothenic acid, and complete feeds are usually marginal in satisfying the requirement (Southern and Baker, 1981; Ruiz and Harms, 1989b).

Deficiency symptoms are associated with the skin and nervous system of growing chicks (Gries and Scott, 1972b). Skin lesions include crusts and scabs, which first appear at the angles of the eyes and beak. Lesions on the feet are seldom and slight. Biotin deficiency symptoms are similar except lesions on the feet are more severe and appear before those on the head. Although an extensive ataxia also occurs, lesions associated with the nervous system are difficult to detect. Turkey poults present the same symptoms as chicks (Kratzer and Williams, 1948a), but poor feathering is the most prevalent deficiency sign in pheasants and quail (Scott et al., 1964).

Adult cockerels receiving inadequate pantothenic acid have reduced semen volume and fertility as well as skin lesions (Goeger and Arscott, 1984). Considerably higher levels of pantothenic acid are needed by chicken and turkey hens to maintain hatchability than for egg production (Kratzer et al., 1955; Balloun and Phillips, 1957a). Embryonic mortality occurs from about 14 days incubation or thereafter, depending on the extent of pantothenic acid inadequacy (Beer et al., 1963). Chicks that hatch are of poor quality and have variable degrees of subcutaneous hemorrhaging and edema ("stunted chick disease").

Pyridoxine (Vitamin B6)

Pyridoxine, pyridoxal, and pyridoxamine are the 3 active forms of vitamin B_6. Vitamin B_6 is a cofactor in decarboxylation and transamination reactions of amino acids. Decarboxylations lead to at least four amines that affect nervous system functioning. Transaminations of certain glycolysis and Kreb's cycle intermediates form most of the nonessential amino acids, whereas the reverse is the basis of gluconeogenesis from protein. Aspartic transaminase in the liver (Lee et al., 1976) and plasma glycine-serine ratio (Sifri et al., 1972) have been employed to evaluate vitamin B_6 nutriture.

The vitamin B_6 content of complete feeds usually satisfies most requirements (Scheiner and DeRitter, 1968). However, the vitamin availability is dependent on the digestibility of each feedstuff (Heard and Annison, 1986). The dietary requirement level may increase as dietary protein increases (Daghir and Shah, 1973), or due to the presence of linatin when linseed meal is used (Kratzer and Williams, 1948b; Klosterman et al., 1967). The inclusion of certain drugs that act as competitive inhibitors may also increase the dietary requirement (Fuller and Dunahoo, 1959).

Symptoms exhibited by vitamin-B_6-deficient chicks differ with the extent of the inadequacy (Daghir and Balloun, 1963; Gries and Scott, 1972a). A severe deficiency produces an ataxia in combination with nervousness and intermittent episodes of hyperactivity. Prominent pathological findings include hemorrhages at various locations, particularly primary wing feather follicles, and gizzard erosions. Marginal vitamin B_6 deficiencies are most likely to be expressed as a perosis because of problems with bone growth. Miller (1963) observed high proportions of pendulous crops with vitamin-B_6-deficient chicks.

Blood alterations are also typical of a vitamin B_6 inadequacy. An extreme deficiency leads to a microcytic, polychromatic hypochromic anemia in conjunction with atrophy of the spleen, thymus, and bursa of Fabricius (Asmar et al., 1968). Marginal deficiencies provoke a microcytic, normochromic polycythemia (Blalock and Thaxton, 1984), and deficient chicks show a decreased immunoglobulin M and immunoglobulin G response to antibody challenge (Blalock et al., 1984).

Although specific symptoms of vitamin B_6 deficiency are not obvious in adult chickens, deficient hens lose body weight and exhibit reduced egg production (Attar et al., 1967). Deficient hens also have relatively low serum glutamic-oxaloacetic acid transaminase activities and high serum nonprotein nitrogen levels (Attar et al., 1967). The vitamin B_6 content of eggs reflects that in the feed, and the level necessary to maintain egg production is one-half of that required for hatchability (Fuller et al., 1961). Characteristics of vitamin-B_6-deficient embryos have not been reported, but antivitamins injected into eggs cause early deaths (Landauer, 1967).

Folic acid

Folacin represents folic acid (pteroyl-γ-monoglutamic acid) and the array of extended glutamic acid conjugates. Enzymes engaged in one-carbon metabolism use folic acid as a cofactor in methyl and methylene group synthesis. Dietary folacin is absorbed and converted to the reduced form (5-methyl-tetrahydrofolic acid) by the intestine and is distributed throughout the body.

Although most complete feeds provide sufficient folic acid from their natural ingredients, marginal inadequacies are possible (Cropper and Scott, 1967). The requirement decreases with age because diminished growth rate reduces the need for deoxyribonucleic acid synthesis (Naber et al., 1957; Balek and Morse, 1976). Accentuated formation of uric acid with excessive dietary protein increases the folic acid requirement (Creek and Vasaitis, 1963), as does inadequate choline (Young et al., 1955) and serine (Rabbani et al., 1973). Use of medicants that antagonize folic acid formation by cecal microflora and management that prevents coprophagy also increases the dietary requirement (Stokstad and Jukes, 1987).

The most obvious symptom of inadequate folic acid is perosis with the chick (Daniel et al., 1946) and cervical paralysis with turkey poults (Miller and Balloun, 1967). Macrocytic anemia, abnormal nuclear bodies in erythrocytes, and numerous mitoses and hypersegmented granulocytes occur with marginal deficiencies when no physical symptoms are manifested (Maxwell et al., 1988).

Inadequate folic acid with the hen impairs the oviduct's response to estrogen and ability to form albumen (Anderson and Jackson, 1975; Burns and Jackson, 1979). More folic acid is needed to sustain hatchability than egg production; thus the embryo will suffer before the hen (Sunde et al., 1950a). High embryonic mortality occurs around 20 days of incubation, and the dead from severely depleted hens exhibit a marked bending of the tibiotarsus, and, to a lesser extent, syndactyly and deformed mandibles. Chicks that successfully emerge are stunted and have feathers that are poorly developed and abnormally pigmented (Lillie et al., 1950).

Vitamin B12 (Cobalamin)

Vitamin B_{12} is a cofactor for enzymes transferring one-carbon units and catalyzing rearrangements in the carbon skeleton of several metabolic intermediates. In fowl, vitamin-B_{12}-mediated one-carbon transfers involve methionine, serine, choline, and thymidine (Gillis and Norris, 1949; Henderson and Henderson, 1966; Langer and Kratzer, 1967), whereas the interconversion of methylmalonyl coenzyme A to succinyl coenzyme A is one of the rearrangement reactions requiring vitamin B_{12} (Ward et al., 1988).

The spleen, bone marrow, liver, kidney, and skin have high concentrations of vitamin B_{12} (Monroe et al., 1952). Although plant feedstuffs are devoid of vitamin B_{12}, its availability from animal products and cecal microflora after coprophagy makes deficiencies unlikely (Milligan et al., 1952). Deficiencies in chicks have been created by greatly increasing dietary protein content such that carbon rearrangement enzyme activities are accentuated (Rys and Koreleski, 1974; Patel and McGinnis, 1980; Ward et al., 1985). Poor feathering and mortality are the most obvious symptoms of a vitamin B_{12} deficiency, and gizzard erosions may also appear (Mushett and Ott, 1949; Milligan et al., 1952).

Yacowitz et al. (1952) fed a high-protein all-vegetable diet devoid of vitamin B_{12} to hens in cages and reported a reduction in hatchability. Olcese et al. (1950) observed that most embryonic mortality due to vitamin B_{12} deficiency in hens occurs at about 17 days of incubation, with atrophy of the leg musculature and hemorrhaging common. Ferguson et al. (1955) further observed fatty organs, dwarfing, and edema.

Choline

Choline may be synthesized in fowl; however, the extent is limited, and supplementation is necessary when demand exceeds biosynthesis capacity. Choline serves a diversity of needs, particularly as a component of phospholipids for the formation of membranes and lipoproteins. Choline also acts as a methyl donor, and its use in this respect becomes important when de novo synthesis of one-carbon units cannot meet demand.

Need for supplemental choline is the greatest with the starting bird because all facets of use are likely to be maximal (Seifter et al., 1972; Pesti et al., 1980). As growth diminishes, the necessity for choline supplementation disappears (Molitoris and Baker, 1976). Perosis is the primary symptom of a choline deficiency in chicks (Fritz et al., 1967) and turkey poults (Evans et al., 1943), whereas Bobwhite quail develop enlarged hocks and bowed legs (Serafin, 1974).

Estrogenic hormones greatly accentuate the choline need for phospholipid synthesis in the hen's liver to support yolk formation (Vigo and Vance, 1981). Supplemental choline may relieve the hepatic accumulation of fat and improve egg yolk formation (Schexnailder and Griffith, 1973; Tsigabe et al., 1988). Minimal dietary choline does not affect hatchability with either chickens (Gish et al., 1949) or turkeys (Ferguson et al., 1975), but Japanese quail and their developing embryos readily express general signs of deficiency (Latshaw and Jensen, 1971, 1972).

MINERAL DEFICIENCIES

Calcium and Phosphorus

Bone formation is highly dependent on the dietary concentrations of calcium and phosphorus as well as on adequate intake of vitamin D_3 (Hart et al., 1922; Dunn, 1924; McGowan and Emslie, 1934). Deficiency of any one of these nutrients will result in rickets. Poor growth may also be a sign of calcium or phosphorus deficiency.

Dietary excesses of either calcium or phosphorus should be avoided because such excesses can hinder the intestinal absorption of other mineral elements (Gutowska and Parkhurst, 1942; Schaible and Bandemer, 1942; Migicovsky and Emslie, 1947). The phosphorus that comes from plant products (that is, phytin) should not be depended on to fulfill the phosphorus requirement for two reasons: it is not readily available in its natural form to the bird, and it may bind calcium, zinc, iron, and manganese so as to render them unavailable (Nelson and Walker, 1964; Kratzer and Vohra, 1986).

Pullets at the beginning of the laying period undergo considerable metabolic stress associated with adjustment to the need to supply approximately 2.4 g of calcium daily to the oviduct for shell formation (Mueller et al., 1964; Hurwitz and Bar, 1971; Scott et al., 1971). Some birds mobilize large amounts of calcium from their skeleton during this period, and the bones may become so demineralized that the birds are unable to stand and appear paralyzed. The sternum and rib bones are frequently deformed, and all bones are easily broken. Dietary management to prevent this condition (generally termed "cage-layer fatigue" but more precisely described as osteoporosis) has not been devised (Roland et al., 1968).

Magnesium

When fed a diet very deficient in magnesium, chicks grow slowly for about 1 week and then stop growing and become lethargic. Chicks fed diets marginal in magnesium may grow quite well but exhibit reduced levels of plasma magnesium and symptoms of neuromuscular hyperirritability when disturbed (Almquist, 1942; Bird, 1949). Chicks show a brief convulsion and then enter a comatose state from which they usually recover, but sometimes death occurs.

A magnesium deficiency in laying hens results in a rapid decline in blood magnesium level, withdrawal of magnesium from bone, decline in egg production, and, eventually, a comatose state and death (Cox and Sell, 1967). Magnesium content and hatchability of eggs also are reduced when hens are fed magnesium-deficient diets (Sell et al., 1967; Hajj and Sell, 1969). Increasing either the calcium or the phosphorus content of the diet accentuates magnesium deficiency (Nugara and Edwards, 1963). Normally, adequate magnesium is present in the natural ingredients of practical diets to meet the requirements of poultry.

Manganese

Manganese deficiency in chicks and poults results in perosis or slipped tendon (Wilgus et al., 1937; Ringrose et al., 1939). Deficiencies of other nutrients, such as choline and biotin, may also be involved in inducing perosis (Jukes, 1940; Jukes and Bird, 1942). The usual signs of perosis are swelling and flattening of the hock joint, with subsequent slipping of the Achilles tendon from its condyles. The tibia and the tarsometatarsus may exhibit bending near the hock joint and lateral rotation. One or both legs may be affected. A shortening and thickening of the long bones of the wings and legs are also observed. The disorder, insofar as manganese is concerned, is aggravated by excess dietary calcium and phosphorus (Schaible and Bandemer, 1942).

In laying and breeding birds, manganese deficiency results in lowered egg production, reduced eggshell strength, poor hatchability, and reduced fertility. Manganese-deficient embryos exhibit shortening of the long bones, parrot beak, and wiry down (Lyons and Insko, 1937; Caskey et al., 1939).

Potassium, Sodium, and Chlorine

A deficiency of potassium results in high mortality and retarded growth of chicks and causes reduced egg production and eggshell thickness in laying hens (Ben-Dor, 1941; Gillis, 1948; Leach, 1974). It is not usually necessary to add potassium to practical feed formulations, since such formulas generally contain about 0.7 to 1.0 percent potassium.

A deficiency of sodium in chicken diets results in poor growth, increased adrenal weight, and decreased egg production (Burns et al., 1952, 1953; Nott and Combs, 1969). Frequently, sodium supplementation is minimized to reduce the moisture level in the excreta.

Signs of chlorine deficiency in chicks include poor growth, mortality, hemoconcentration, and reduced blood chlorine level (Leach and Nesheim, 1963). Chlorine-deficient chicks show a nervous condition resembling tetany and fall forward with legs extended backward when stimulated by a sharp noise.

Iodine

Iodine is necessary for the synthesis of thyroid hormones. Iodine deficiency results in goiter, which is the enlargement of the thyroid glands (Wilgus et al., 1953; Rogler et al., 1959a). The glands may increase to many times their usual size. If the deficiency is not too severe, the increased efficiency of the enlarged gland in "trapping" iodine from the bloodstream may compensate for the low dietary concentration. When this is the case, the production of thyroid hormones is normal, although the thyroid glands are enlarged.

Inadequate production of thyroid hormones results in poor growth, egg production, and egg size. Iodine deficiency in breeders results in low iodine content of the egg and, consequently, decreased hatchability and thyroid enlargement in the embryos.

Copper

Copper deficiency in poultry causes an anemia in which the red blood cells are small and low in hemoglobin (Elvehjem and Hart, 1929). Bone deformities can occur (O'Dell et al., 1961). Pigmentation of feathers in New Hampshire and Rhode Island Red chickens is reduced (Hill and Matrone, 1961). Copper is required for the activity of the enzyme needed for the cross-linking of lysine in the protein elastin (O'Dell et al., 1961; Starcher et al., 1964). Dissecting aneurism of the aorta occurs in birds deficient in copper because of the defect in elastin formation. Copper deficiency also results in marked cardiac hypertrophy (Carlton and Henderson, 1963).

Iron

Iron deficiency in chickens and turkeys causes an anemia in which the red blood cells are reduced in size and low in hemoglobin (Elvehjem and Hart, 1929). In red-feathered chickens, pigmentation does not occur when the diet is deficient in iron (Hill and Matrone, 1961; Davis et al., 1962).

Selenium

Selenium is closely associated with vitamin E and other antioxidants in practical feed formulation. The principal sign of deficiency in chicks is exudative diathesis (Creech et al., 1957; Patterson et al., 1957; Nesheim and Scott, 1958). A requirement for selenium supplementation, even in the presence of vitamin E, is demonstrated by the poor growth, muscular dystrophy, and mortality of chicks fed purified diets or diets based on grains produced on low-selenium soils (Nesheim and Scott, 1958). Selenium is required for prevention of myopathies of the gizzard and heart in turkeys (Walter and Jensen, 1963; Scott et al., 1967). Pancreatic fibrosis, with resultant reductions in the pancreatic output of lipase, trypsinogen, and chymotrypsinogen, has also been associated with selenium deficiency (Thompson and Scott, 1970; Gries and Scott, 1972c). Selenium is a structural component of glutathione peroxidase, an enzyme needed to quench peroxides generated during metabolism (Rotruck et al., 1973).

There is wide variability in the amount and availability of selenium in the soils of different geographic areas (Scott and Thompson, 1971; Scott, 1973). Consequently, cereals and plant-derived feedstuffs are variable sources of selenium. Grains from some areas contain sufficient selenium to render them toxic to chicks. The effects of toxic levels of selenium are listed in Table 8-1. The amount of supplementary selenium permissible in diets is regulated in the United States and Canada.

Zinc

Zinc has many biochemical functions. Deficiency causes retarded growth and frayed feathers (O'Dell et al., 1958; Sullivan, 1961). The extent of fraying varies from almost no feathers on the wings and tail to only slight defects in the development of some of the barbules and barbicels. The long bones of the legs and wings are shorter and thicker than normal (Kratzer et al., 1958; Morrison and Sarett, 1958; O'Dell et al., 1958). The hock joint may be enlarged. Layer and breeder diets deficient in zinc reduce egg production and hatchability (Kienholz et al., 1961).

8

Toxicity of Certain Inorganic Elements

Current information on toxic dietary levels of inorganic elements for poultry is summarized in Table 8-1. A similar summary that describes the mineral tolerances of animals has been provided by the National Research Council (1980b). Toxicity, as defined here, is any adverse effect on performance. Reduced growth rate is the most common criterion used to indicate the specific level at which a particular mineral is toxic. Although most of the information in the table was obtained from experiments in which the mineral was added in the form of an inorganic compound, organic compounds served as the source of minerals in some reports. For instance, some of the information on the toxicity of selenium was obtained by feeding seleniferous wheat.

The toxicity of a mineral is influenced by the nature of the compound in which it is present (for example, methyl mercury is much more toxic than mercuric chloride). Toxicity may also be influenced markedly by the composition of the diet, particularly with respect to other minerals and chelating agents. Selenium included in the diet at 10 ppm reduces the growth rate, but when it is fed in combination with 1,000 ppm of silver, a level as high as 40 ppm does not reduce growth (Jensen, 1975a). Copper at a level of 800 ppm in a practical turkey diet is not toxic, but 50 ppm of copper in a purified diet reduces growth. The toxicity of copper is modified by the sulfur amino acid content of the diet. Vanadium is much more toxic in a purified diet than in a practical diet, and the toxicity is increased by adding lactose to the practical diet (Hafez and Kratzer, 1976). Conversely, vanadium toxicity is reduced by including cottonseed meal in the diet (Berg, 1965; Berg and Lawrence, 1971; Sell et al., 1986a). In many instances, a high dietary level of one mineral antagonizes another element, resulting in a physiological deficiency of minerals essential for the animal. Because many different factors affect the quantity of a mineral needed to produce toxicity, diverse observations have been reported on the toxic effects of any given mineral.

TABLE 8-1 Toxic Dietary Concentrations of Inorganic Elements and Compounds for Poultry

Element or Compound	Species	Age	Chemical Form	Toxic Concentration (ppm)[a]	Toxic Effects	References
Aluminum	Chicken	Immature	$AlCl_2$	500	Reduced growth	Storer and Nelson, 1968
Aluminum	Chicken	Immature	$Al_2(SO_4)_3$	1,000	Reduced growth	Storer and Nelson, 1968
Aluminum	Chicken	Immature	$Al_2(SO_4)_3$	2,200	Rickets	Deobold and Elvehjem, 1935
Aluminum	Chicken	Mature	$Al_2(SO_4)_3$	3,000	Reduced egg production	Hussein et al., 1989
Arsenic	Chicken	Laying hen	As_2O_5	100	Reduced body weight; reduced egg production	Hermayer et al., 1977
Barium	Chicken	Immature	$BaCO_3$, $BaCl_2$	200	Reduced growth	Taucins et al., 1969
Barium	Chicken	Immature	$BaCl_2$	2,000	Death	Taucins et al., 1969
Bromine	Chicken	Immature	NaBr	5,000	Reduced growth	Doberenz et al., 1965
Cadmium	Chicken	Immature	$CdSO_4 \cdot H_2O$	25	Reduced growth	Hill et al., 1963
Cadmium	Chicken	Immature	$CdSO_4$	40	Reduced growth	Hill, 1974
Cadmium	Turkey	Immature	$CdCl_2$	20	Reduced growth	Supplee, 1961
Cadmium	Chicken	Adult	$CdSO_4$	12	Decreased egg production	Leach et al., 1979
Chlorine	Chicken	Immature	Arginine·HCL, NaCl and KCl	15,000	Reduced growth	Nesheim et al., 1964
Chromium	Chicken	Immature	K_2CrO_4	300	Reduced growth	Kunishisa et al., 1966
Chromium	Chicken	Immature	$Cr_2(SO_4)_3$	300	Reduced growth	Kunishisa et al., 1966
Chromium	Chicken	Adult	$CrCl_3 \cdot 6H_2O$	10	Egg quality	Jensen and Maurice, 1980
Cobalt	Chicken	Immature	$CoCl_2 \cdot 6H_2O$	200	Reduced growth	Hill, 1974
Cobalt	Chicken	Immature	$CoCl_2$	100	Reduced growth	Hill, 1979
Copper	Chicken	Immature	CuO	806	Reduced growth; mortality	Mehring et al., 1960
Copper	Chicken	Immature	$CuSO_4 \cdot 5H_2O$	800	Exudative diathesis; muscular dystrophy	Jensen, 1975b
Copper	Chicken	Immature	$CuSO_4 \cdot 5H_2O$	500	Reduced growth; gizzard erosion	Poupoulis and Jensen, 1976
Copper	Chicken	Immature	$CuSO_4 \cdot 5H_2O$	250	Reduced growth; gizzard erosion	Robbins and Baker, 1980a,b
Copper	Turkey	Immature	$CuSO_4 \cdot 5H_2O$	676 (practical diet)	Reduced growth	Vohra and Kratzer, 1968
Copper	Turkey	Immature	$CuSO_4 \cdot 5H_2O$	800 (purified diet)	Reduced growth	Supplee, 1964
Copper	Turkey	Immature	$CuCO_3$	50 (purified diet) 800 (practical diet not toxic)	Reduced growth	Waibel et al., 1964
Fluorine	Chicken	Immature	NaF	1,000	Reduced growth	Doberenz et al., 1965
Fluorine	Chicken	Immature	NaF	500 (similar level of F as CaF not toxic)	Reduced growth	Gardiner et al., 1959
Fluorine	Chicken	Immature	NaF	500	Reduced growth	Weber et al., 1969
Fluorine	Chicken	Immature	NaF	750	Reduced growth	Berg and Martinson, 1972
Fluorine	Chicken	Adult	NaF	1,300	Reproductive characteristics	Guenter and Hahn, 1986
Iodine	Chicken	Laying hen	KI	625	Reduced egg production, egg size, and hatchability	Arrington et al., 1967
Iron	Chicken	Immature	$Fe_2(SO_4)_3$	4,500	Rickets	Deobold and Elvehjem, 1935
Lead	Chicken	Immature	Pb acetate	1,000	Reduced growth	Damron et al., 1969
Lead	Chicken	Immature	Pb acetate	320	Lethargy, 50% mortality	Vengris and Mare, 1974
Lead	Chicken	Mature	Pb acetate	200	Reduced egg production	Edens and Garlich, 1983
Lead	Japanese quail	Mature	Pb acetate	10	Reduced egg production	Edens and Garlich, 1983
Magnesium	Chicken	Immature	MgO	5,700	Growth, skeletal development	Atteh and Leeson, 1983
Magnesium	Chicken	Immature	$MgCO_3$	6,000	Reduced growth	Chicco et al., 1967
Magnesium	Chicken	Immature	$MgCO_3$	6,400	Reduced growth; mortality	Nugara and Edwards, 1963
Magnesium	Chicken	Adult	$MgSO_4$	19,600	Reduced egg production	McWard, 1967
Magnesium	Chicken	Adult	$MgCO_3$	11,200	Reduced egg production	Stillmak and Sunde, 1971
Manganese	Chicken	Immature	$MnCl_2 \cdot 4H_2O$	4,000	Reduced growth	Southern and Baker, 1983a
Manganese	Turkey	Immature	$MnSO_4 \cdot H_2O$	4,800	Reduced growth	Vohra and Kratzer, 1968
Mercury	Chicken	Immature	$HgSO_4$, $HgCl_2$	400	Reduced growth	Hill et al., 1964
Mercury	Chicken	Immature	$HgCl_2$	250[b]	Reduced growth; mortality	Parkhurst and Thaxton, 1973
Mercury	Chicken	Immature	CH_3Hg dicyanamide	33	Reduced growth; mortality	Gardiner, 1972
Mercury	Chicken	Immature	CH_3HgCl	5	50% mortality	Soares et al., 1973
Molybdenum	Chicken	Immature	Na_2MoO_4	500	Reduced growth; mortality	Davies et al., 1960
Molybdenum	Chicken	Immature	$Na_2MoO_4 \cdot 2H_2O$	350	Reduced growth	Berg and Martinson, 1972
Molybdenum	Chicken	Laying hen	$Na_2MoO_4 \cdot 2H_2O$	500	Reduced egg production and hatchability	Lepore and Miller, 1965
Molybdenum	Turkey	Immature	$NaMoO_4$	300	Reduced growth	Kratzer, 1952
Nickel	Chicken	Immature	$NiSO_4$ or Ni acetate	500	Reduced growth	Weber and Reid, 1968

Element or Compound	Species	Age	Chemical Form	Toxic Concentration (ppm)[a]	Toxic Effects	References
Nickel	Chicken	Immature	NiCl	400	Reduced growth	Hill, 1979
Nitrate	Turkey	Immature	$NaNO_3$	900[b]	Reduced growth; mortality	Adams et al., 1967
Nitrate	Turkey	Immature	$NaNO_3$	450(N)[b]	No effect on meat color	Mugler et al., 1970
Nitrite	Chicken	Immature	KNO_2	658(N)	Decreased vitamin A in liver and thyroid enlargement	Sell and Roberts, 1963
Selenium	Chicken	Immature	Na_2SeO_3 + Se in wheat	10	Reduced growth	Carlson and Leitis, 1957
Selenium	Chicken	Immature	Na_2SeO_3	10	Reduced growth	Jensen, 1975a
Selenium	Chicken	Immature	Na_2SeO_3	20 (+1,000 Ca)	Reduced growth	Jensen, 1975a
Selenium	Chicken	Laying hen	Se in wheat	10	Reduced hatchability	Moxon and Wilson, 1944
Selenium	Chicken	Adult	Na_2SeO_3	5	Decreased hatchability	Ort and Latshaw, 1978
Silver	Chicken	Immature	$AgSO_4$	200	Reduced growth	Hill et al., 1964
Silver	Chicken	Immature	$AgNO_3$	900	Exudative diathesis (prevented by Se or vitamin E)	Peterson and Jensen, 1975a
Silver	Chicken	Immature	$AgNO_3$	900	Anemia, enlarged hearts	Peterson and Jensen, 1975b
Silver	Turkey	Immature	Ag acetate or nitrate	900	Anemia, enlarged hearts, and muscular dystrophy prevented by Cu + Se)	Jensen et al., 1974
Sodium	Chicken	Immature	Na glutamate	8,900[c]	Reduced growth	Nesheim et al., 1964
Sodium	Chicken	Laying hen	Na_2SO_4	12,000[b]	Reduced egg production	Krista et al., 1961
Sodium chloride	Chicken	Immature	NaCl	7,000[b]	Reduced growth; mortality	Krista et al., 1961
Sodium chloride	Chicken	Laying hen	NaCl	10,000[b]	Reduced egg production	Krista et al., 1961
Sodium chloride	Chicken	Adult	NaCl	40,000–60,000	Reduced egg production	Damron and Kelly, 1987
Sodium chloride	Turkey	Immature	NaCl	4,000[b]	Reduced body weight; mortality	Krista et al., 1961
Sodium chloride	Turkey	Immature	NaCl	27,000	Lung congestion; enlarged kidneys; mortality	Morrison et al., 1975
Sodium chloride	Duck	Immature	NaCl	4,000[b]	Reduced body weight	Krista et al., 1961
Sodium chloride	Turkey	Mature	NaCl	60,000	Reduced growth	Roberts, 1957
Sodium chloride	Turkey	Immature	NaCl	40,000	Reduced growth; pendulous crop	Harper and Arscott, 1962
Strontium	Chicken	Immature	$SrCO_3$	6,000	Reduced growth	Weber et al., 1968
Sulfate	Chicken	Immature	K_2SO_4, Na_2SO_4, $CaSO_4$	14,000	Reduced growth	Leach et al., 1960
Sulfate	Chicken	Laying hen	Na_2SO_4	8,100	Reduced egg production	Krista et al., 1961
Tungsten	Chicken	Immature	Sodium tungstate	500	Reduced growth	Teekell and Watts, 1959
Vanadium	Chicken	Immature	NH_4VO_3	8	Reduced growth	Berg, 1963
Vanadium	Chicken	Immature	$Ca_3(VO_4)_2$	30	Reduced growth	Romoser et al., 1961
Vanadium	Chicken	Immature	$Ca_3(VO_4)_2$	200	Mortality	Romoser et al., 1961
Vanadium	Chicken	Immature	NH_4VO_3 or $VOSO_4$	25	Reduced growth; mortality	Hathcock et al., 1964
Vanadium	Chicken	Immature	$NaVO_3$	5	Reduced growth	Hill, 1974
Vanadium	Chicken	Immature	NH_4VO_3	10	Reduced growth	Summers and Moran, 1972
Vanadium	Chicken	Laying hen	V in dicalcium phosphate	6	Depressed albumin quality	Sell et al., 1982
Vanadium	Chicken	Laying hen	NH_4VO_3	15	Depressed albumin quality	Berg et al., 1963
Vanadium	Chicken	Laying hen	NH_4VO_3	20	Depressed albumin quality; reduced body weight	Berg et al., 1963
Vanadium	Chicken	Laying hen	NH_4VO_3	30	Depressed egg production	Berg et al., 1963
Vanadium	Chicken	Laying hen	NH_4VO_3	50	Depressed hatchability	Berg et al., 1963
Zinc	Chicken	Immature	$ZnSO_4$, $ZnCO_3$	1,500	Reduced growth	Roberson and Schaible, 1960
Zinc	Chicken	Immature	ZnO	3,000	Reduced growth	Johnson et al., 1962
Zinc	Chicken	Immature	ZnO	800	Reduced growth; bone ash (sucrose-fish meal diet)	Berg and Martinson, 1972
Zinc	Chicken	Immature	$ZnSO_4$	2,000	Exudative diathesis; muscular dystrophy	Jensen, 1975b
Zinc	Chicken	Immature	$ZnSO_4$	3,000	Reduced growth (0.5 ppm Se in diet)	Jensen, 1975b
Zinc	Turkey	Immature	ZnO	4,000	Reduced growth	Vohra and Kratzer, 1968

[a] Dietary concentrations of the elements unless specified otherwise.
[b] In water.
[c] Diet low in Cl^- ion.

9

Composition of Feedstuffs Used in Poultry Diets

Feed formulation involves the judicious use of feed ingredients to supply in adequate amounts and proportions the nutrients required by poultry. Because it is impractical to analyze each batch of feedstuff for its nutrient content, reliance must be placed on feedstuff composition data that have been compiled on the basis of many laboratory analyses. Feedstuffs vary in composition. The nutrient values given in the following tables are averages reflecting the concentrations of nutrients most likely to be present in the feedstuffs commonly used in poultry feeds.

Feedstuff composition data presented in this edition (Tables 9-1 and 9-2) were obtained from several sources, including the *United States-Canadian Tables of Feed Composition* (National Research Council, 1982), the Association of American Feed Control Officials, commercial firms, and individual scientists. In many instances, the values have been changed to reflect results of analyses of feed ingredients obtained from contemporary crop cultivars and recently employed processing methods. Additional information provided in the composition tables include nitrogen-corrected true metabolizable energy (TME_n) data for many feed ingredients and information on the true digestibility of amino acids for numerous feedstuffs. Also, equations are provided to estimate the amino acid concentration of certain ingredients on the basis of proximate analysis or on the basis of the protein content of the ingredients.

From a nutritional point of view, there is no "best" diet formula in terms of ingredients that are used. Ingredients should, therefore, be selected on the basis of availability, price, and the quality of the nutrients they contain. Certain ingredients invariably constitute the greatest part of diets, in terms of both amount and cost. Cereal grains and fats are the primary energy-supplying ingredients, and oilseed meals and animal-protein meals are used commonly as major sources of amino acids. Some important nutritional characteristics of many energy- and protein-supplying ingredients are discussed in this chapter. Sulphur, which are common contaminants in feedstuffs, and their effects are discussed in the final section.

CEREAL GRAINS

Bushel weights (bulk densities) of cereal grains are used in commerce to establish market grades and prices. Bushel weights of grains also have been used as criteria of feeding value, and in some instances this practice seems justified for poultry. For example, at standard moisture levels there is a strong relationship between bushel weight and general feeding value of oats and barley. An increase in bushel weight of these grains is a reflection of an increase in the proportion of the meaty kernel and a decrease in the proportion of fibrous hull. Thus there is a definite increase in the metabolizable energy (*ME*)—and usually protein—content of barley and oats as bushel weight increases. Similarly, there seems to be a direct relationship between the *ME* content of grain sorghum and wheat as bushel weight increases over a wide range. A relationship between bushel weight and the *ME* content of corn is not so evident. In situations in which corn, sorghum, or wheat fails to achieve maturity because of early frost or early harvest, there usually are decreases in the starchy endosperm portion of the grain and bushel weight and *ME* content are usually low. Regression equations relating the *ME* of corn to various factors such as moisture content at harvest and bushel weight have been reported (Leeson and Summers, 1975, 1976b; Leeson et al., 1977b). Ranges in bushel weight that may be encountered with different grains are shown in Table 9-3.

The feeding value of grain sorghums (milo) is markedly

TABLE 9-1 Composition (Excluding Amino Acids) of Some Feeds Commonly Used for Poultry (data on as-fed basis)

Entry Number	Feed Name Description	International Feed Number[a]	Dry Matter (%)	ME_n (kcal/kg)	TME_n (kcal/kg)	Protein (%)	Ether Extract (%)	Linoleic Acid (%)	Crude Fiber (%)	Calcium (%)	Total Phosphorus (%)	Non-phytate Phosphorus (%)	Potassium (%)	Chlorine (%)
	Alfalfa *Medicago sativa*													
01	meal dehydrated, 17% protein	1-00-023	92	1,200	1,011	17.5	2.5	0.47	24.1	1.44	0.22	0.22	2.15	0.47
02	meal dehydrated, 20% protein	1-00-024	92	1,630	—	20.0	3.6	0.58	20.2	1.67	0.28	—	2.15	0.47
03	Bakery													
	waste, dehydrated (dried bakery product)	4-00-466	92	3,862	3,696	10.5	11.7	—	1.2	0.13	0.24	—	0.35	1.23
	Barley *Hordeum vulgare*													
04	grain	4-00-549	89	2,640	2,900	11.0	1.8	0.83	5.5	0.03	0.36	0.17	0.48	0.15
05	grain, Pacific coast	4-07-939	89	2,620	—	9.2	2.0	0.85	6.4	0.05	0.32	—	0.53	0.15
	Broadbean *Vicia faba*													
06	seeds	5-09-262	87	2,431	2,339	24.0	1.4	—	7.0	0.11	0.54	—	1.2	—
	Blood													
07	meal, vat dried	5-00-380	94	2,830	—	81.1	1.6	—	0.5	0.55	0.42	—	0.18	0.27
08	meal, spray or ring dried	5-00-381	93	3,420	3,625	88.9	1.0	0.10	0.6	0.41	0.30	—	0.18	0.27
	Brewer's Grains													
09	dehydrated	5-02-141	92	2,080	—	25.3	6.2	2.94	15.3	0.29	0.52	—	0.08	0.12
	Buckwheat, common *Fagopyrum sagittatum*													
10	grain	4-00-994	88	2,660	2,755	10.8	2.5	—	10.5	0.09	0.32	0.12	0.40	0.04
	Cane Molasses—see Molasses													
	Canola *Brassica napus-Brassica campestris*													
11	seeds, meal prepressed solvent extracted, low erucic acid, low glucosinolates	5-06-145	93	2,000	2,070	38.0	3.8	—	12.0	0.68	1.17	0.30	1.29	—
	Casein													
12	dehydrated	5-01-162	93	4,130	4,134	87.2	0.8	—	0.2	0.61	1.00	1.00	0.01	—
13	precipitated dehydrated	5-20-837	92	4,118	—	85.0	0.06	—	0.2	0.68	0.82	0.82	0.01	—
	Cattle													
14	skim milk, dehydrated	5-01-175	93	2,537	—	36.1	1.0	—	0.2	1.28	1.02	1.02	1.60	0.90
	Coconut *Cocos nucifera*													
15	kernels with coats, meal solvent extracted (copra meal)	5-01-573	92	1,525	—	19.2	2.1	—	14.4	0.17	0.65	—	1.41	0.03
	Corn, Dent Yellow *Zea mays indentata*													
16	distillers' grains, dehydrated	5-28-235	94	1,972	—	27.8	9.2	—	12.0	0.10	0.40	0.39	0.17	0.07
17	distillers' grains with solubles, dehydrated	5-28-236	93	2,480	3,097	27.4	9.0	4.55	9.1	0.17	0.72	0.39	0.65	0.17
18	distillers' solubles, dehydrated	5-28-237	92	2,930	—	28.5	9.0	4.55	4.0	0.35	1.27	1.17	1.75	0.26
19	gluten, meal, 60% protein	5-28-242	90	3,720	3,811	62.0	2.5	—	1.3	—	0.50	0.14	0.35	0.05
20	gluten with bran (corn gluten feed)	5-28-243	90	1,750	2,228	21.0	2.5	—	8.0	0.40	0.80	—	0.57	0.22
21	grain	4-02-935	89	3,350	3,470	8.5	3.8	2.20	2.2	0.02	0.28	0.08	0.30	0.04
22	grits by-product (hominy feed)	4-03-011	90	2,896	3,269	10.4	8.0	3.28	5.0	0.05	0.52	—	0.59	0.05
	Cotton *Gossypium* spp.													
23	seeds, meal mechanically extracted, 41% protein (expeller)	5-01-617	93	2,320	—	40.9	3.9	2.47	12.0	0.20	1.05	—	1.19	0.04
24	seeds, meal prepressed solvent extracted, 41% protein	5-07-872	90	2,400	—	41.4	0.5	—	13.6	0.15	0.97	0.22	1.22	0.03
25	seeds, meal prepressed solvent extracted, 44% protein	5-07-873	91	1,857	2,135	44.7	1.6	—	11.1	0.15	1.25	0.37	—	—
	Feathers—see Poultry													
	Fish													
26	solubles, condensed	5-01-969	51	1,460	—	31.5	7.8	—	0.2	0.30	0.76	—	1.74	2.65
27	solubles, dehydrated	5-01-971	92	2,830	—	63.6	9.3	0.12	0.5	1.23	1.63	—	0.37	—
	Fish, Anchovy *Engraulis ringen*													
28	meal mechanically extracted	5-01-985	92	2,580	—	64.2	5.0	0.20	1.0	3.73	2.43	—	0.69	0.60
	Fish, Herring *Clupea harengus*													
29	meal mechanically extracted	5-02-000	93	3,190	—	72.3	10.0	0.15	0.7	2.29	1.70	—	1.09	0.90
	Fish, Menhaden *Brevoortia tyrannus*													
30	meal mechanically extracted	5-02-009	92	2,820	2,977	60.05	9.4	0.12	0.7	5.11	2.88	—	0.65	0.60
	Fish, White Gadidae (family)-Lophiidae (family)-Rajidae (family)													
31	meal mechanically extracted	5-02-025	91	2,593	—	62.6	4.6	0.08	0.7	7.31	3.81	—	0.83	0.50
	Gelatin													
32	process residue (gelatin by-products)	5-14-503	91	2,360	3,029	88.0	0.0	—	—	0.50	Trace	—	—	—
	Hominy Feed—see Corn													
33	Livers meal	5-00-389	92	2,860	—	65.6	15.0	—	1.4	0.56	1.25	—	—	—
	Meat													
34	meal rendered	5-00-385	92	2,195	—	54.4	7.1	0.28	2.7	8.27	4.10	—	0.60	0.91
35	with bone, meal rendered	5-00-388	93	2,150	2,495	50.4	10.0	0.36	2.8	10.30	5.10	—	1.45	0.69
	Millet Pearl *Pennisetum glaucum*													
36	grain	4-03-118	91	2,675	3,367	14.0	4.3	0.84	3.0	0.05	0.32	0.12	0.43	0.14
	Millet, Proso *Panicum miliaceum*													

Entry Number	Iron (mg/kg)	Magnesium (%)	Manganese (mg/kg)	Sodium (%)	Sulfur (%)	Copper (mg/kg)	Selenium (mg/kg)	Zinc (mg/kg)	Biotin (mg/kg)	Choline (mg/kg)	Folacin (mg/kg)	Niacin (mg/kg)	Pantothenic Acid (mg/kg)	Pyridoxine (mg/kg)	Riboflavin (mg/kg)	Thiamin (mg/kg)	Vitamin B_{12} (µg/kg)	Vitamin E (mg/kg)
01	480	0.36	30	0.09	0.17	10	0.34	24	0.30	1,401	4.2	38	25.0	6.5	13.6	3.4	4	125
02	390	0.36	42	0.09	0.43	11	0.29	25	0.33	1,419	3.3	40	34.0	8.0	15.2	5.8	4	144
03	28	0.24	65	1.14	0.02	5	—	15	0.07	923	0.2	26	8.3	4.3	1.4	2.9	—	41
04	78	0.14	18	0.04	0.15	10	0.10	30	0.15	990	0.07	55	8.0	3.0	1.8	1.9	—	20
05	110	0.12	16	0.02	0.15	8	0.10	15	0.15	1,034	0.05	48	7.0	2.9	1.6	4.0	—	20
06	70	0.13	8	0.08	—	4	—	42	0.09	1.7	—	22	3.0	—	1.6	5.5	—	1
07	2,020	0.16	5	0.32	0.32	10	0.01	4	0.08	695	0.1	29	3.0	4.4	2.6	0.4	44	—
08	3,000	0.40	6	0.33	0.32	8	—	306	0.20	280	0.4	13	5.0	4.4	1.3	0.5	44	—
09	250	0.16	38	0.26	0.31	21	0.70	98	0.96	1,723	7.1	29	8.0	0.7	1.4	0.5	—	25
10	44	0.09	34	0.05	0.14	10	—	9	—	440	—	19	12.0	—	5.5	4.0	—	—
11	159	0.64	54	—	—	10	1.00	71	0.90	6,700	2.3	160	9.5	—	3.7	5.2	—	—
12	18	0.01	4	0.01	—	4	—	33	0.05	205	0.5	1	3.0	0.4	1.5	0.5	—	—
13	17	0.01	4	0.01	—	4	—	32	0.04	208	0.5	1	2.7	0.4	1.5	0.5	—	—
14	8	0.12	2	0.51	0.32	12	0.12	39	0.33	1,393	0.62	11.5	36.4	4.1	19.1	3.7	51	9
15	—	0.31	54	0.04	—	—	—	—	—	1,089	0.30	23.8	6.5	4.4	3.5	—	—	—
16	300	0.25	22	0.09	0.43	25	0.45	55	0.49	1,180	0.9	37	11.7	4.4	5.2	1.7	—	—
17	280	0.19	24	0.48	0.30	57	0.39	80	0.78	2,637	0.9	71	11.0	2.2	8.6	2.9	—	40
18	560	0.64	74	0.26	0.37	83	0.33	85	1.10	4,842	1.1	116	21.0	10.0	17.0	6.9	3	55
19	400	0.15	4	0.02	0.43	26	1.00	33	0.15	330	0.2	55	3.0	6.2	2.2	0.3	—	24
20	460	0.29	24	0.15	0.22	48	0.10	70	0.33	1,518	0.3	66	17.0	15.0	2.4	2.0	—	15
21	45	0.12	7	0.02	0.08	3	0.03	18	0.06	620	0.4	24	4.0	7.0	1.0	3.5	—	22
22	67	0.24	15	0.08	0.03	13	0.10	3	0.13	1,155	0.3	47	8.2	11.0	2.1	8.1	—	—
23	160	0.52	23	0.04	0.40	19	0.25	64	0.60	2,753	1.0	38	10.0	5.3	5.1	6.4	—	39
24	110	0.40	20	0.04	0.31	18	—	70	0.55	2,933	2.7	40	7.0	3.0	4.0	3.3	—	15
25	—	—	—	—	—	—	—	—	—	2,685	0.9	46	14.5	—	4.7	—	—	—
26	160	0.02	14	2.62	0.12	45	2.00	38	0.18	3,519	0.02	169	35.0	12.2	14.6	5.5	347	—
27	300	0.30	50	0.3	0.40	—	—	76	0.26	5,507	0.06	271	55.0	23.8	7.7	7.4	401	—
28	220	0.24	10	0.65	0.54	9	1.36	103	0.23	4,408	0.2	100	15.0	4.0	7.1	0.1	352	4
29	140	0.15	5	0.61	0.69	6	1.93	132	0.31	5,306	0.3	93	17.0	4.0	9.9	0.1	403	22
30	440	0.16	33	0.65	0.45	11	2.10	147	0.20	3,056	0.3	55	9.0	4.0	4.9	0.5	104	7
31	181	0.18	12	0.78	0.48	6	1.62	90	0.08	3,099	0.3	59	9.9	5.9	9.1	1.7	90	9
32	—	0.05	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
33	630	—	9	—	—	89	—	—	0.02	11,311	5.5	204	29.0	—	46.3	0.2	498	—
34	440	0.58	10	1.15	0.49	10	0.42	103	0.17	2,077	0.3	57	5.0	3.0	5.5	0.2	68	1
35	490	1.12	14	0.70	0.50	2	0.25	93	0.14	1,996	0.3	46	4.1	12.8	4.4	0.8	70	1
36	25	0.16	31	0.04	0.13	22	—	13	—	793	—	53	7.8	—	1.6	6.7	—	—

Entry Number	Feed Name Description	International Feed Number[a]	Dry Matter (%)	ME_n (kcal/kg)	TME_n (kcal/kg)	Protein (%)	Ether Extract (%)	Linoleic Acid (%)	Crude Fiber (%)	Calcium (%)	Total Phosphorus (%)	Non-phytate Phosphorus (%)	Potassium (%)	Chlorine (%)
37	grain	4-03-120	90	2,898	—	11.6	3.5	—	6.1	0.03	0.30	0.14	0.43	—
	Oats *Avena sativa*													
38	grain	4-03-309	89	2,550	2,625	11.4	4.2	1.47	10.8	0.06	0.27	0.05	0.45	0.11
39	grain, Pacific coast	4-07-999	91	2,610	—	9.0	5.0	—	11.0	0.08	0.30	—	0.37	0.12
40	hulls	1-03-281	92	400	—	4.6	1.4	—	28.7	0.13	0.10	—	0.53	0.10
	Pea *Pisum* spp.													
41	seeds	5-03-600	90	2,570	2,654	23.8	1.3	—	5.5	0.11	0.42	—	1.02	0.06
	Peanut *Arachis hypogaea*													
42	kernels, meal mechanically extracted (peanut meal) (expeller)	5-03-649	90	2,500	—	42.0	7.3	1.43	12.0	0.16	0.56	—	1.15	0.03
43	kernels, meal solvent extracted (peanut meal)	5-03-650	92	2,200	2,462	50.7	1.2	0.24	10.0	0.20	0.63	0.13	1.15	0.03
	Poultry													
44	by-product, meal rendered (viscera with feet and heads)	5-03-798	93	2,950	3,120	60.0	13.0	2.54	1.5	3.00	1.70	—	0.55	0.54
45	feathers, meal hydrolyzed	5-03-795	93	2,360	3,276	81.0	7.0	—	1.0	0.33	0.55	—	0.30	0.28
	Rice *Oryza sativa*													
46	bran with germ (rice bran)	4-03-928	91	2,980	3,085	12.9	13.0	3.57	11.4	0.07	1.50	0.22	1.73	0.07
47	grain, polished and broken (brewer's rice)	4-03-932	89	2,990	3,536	8.7	0.7	—	9.8	0.08	0.08	0.03	0.13	0.08
48	polishings	4-03-943	90	3,090	—	12.2	11.0	3.58	4.1	0.05	1.31	0.14	1.06	0.11
	Rye *Secale cereale*													
49	grain	4-04-047	88	2,626	2,931	12.1	1.5	—	2.2	0.06	0.32	0.06	0.46	0.03
	Safflower *Carthamus tinctorius*													
50	seeds, meal solvent extracted	5-04-110	92	1,193	—	23.4	1.4	—	30.0	0.34	0.75	—	0.76	—
51	seeds without hulls, meal solvent extracted	5-07-959	92	1,921	—	43.0	1.3	—	13.5	0.35	1.29	0.39	1.10	0.16
	Sesame *Sesamum indicum*													
52	seeds, meal mechanically extracted (expeller)	5-04-220	93	2,210	1,978	43.8	6.5	1.90	7.0	1.99	1.37	0.34	1.20	0.06
	Sorghum *Sorghum bicolor*													
53	grain, 8-10% protein	4-20-893	87	3,288	3,376	8.8	2.9	1.13	2.3	0.04	0.30	—	0.35	0.09
54	grain, more than 10% protein	4-20-894	88	3,212	—	11.0	2.6	0.82	2.3	0.04	0.32	—	0.33	0.09
	Soybean *Glycine max*													
55	flour by-product (soybean mill feed)	4-04-594	89	720	—	13.3	1.6	—	33.0	0.37	0.19	—	1.50	0.02
56	protein concentrate, more than 70% protein	5-08-038	93	3,500	—	84.1	0.4	—	0.2	0.02	0.80	0.32	0.18	0.02
57	seeds, heat processed	5-04-597	90	3,300	2,990	37.0	18.0	8.46	5.5	0.25	0.58	—	1.61	0.03
58	seeds, meal solvent extracted	5-04-604	89	2,230	—	44.0	0.8	0.40	7.0	0.29	0.65	0.27	2.00	0.05
59	seeds without hulls, meal solvent extracted	5-04-612	90	2,440	2,485	48.5	1.0	0.40	3.9	0.27	0.62	0.22	1.98	0.05
	Sunflower, common *Helianthus annuus*													
60	seeds, meal solvent extracted	5-09-340	90	1,543	—	32.0	1.1	0.60	24.0	0.21	0.93	0.14	0.96	—
61	seeds without hulls, meal solvent extracted	5-04-739	93	2,320	2,060	45.4	2.9	1.59	12.2	0.37	1.00	0.16	1.00	0.10
	Triticale *Triticale hexaploide*													
62	grain	4-20-362	90	3,163	3,144	14.0	1.5	—	4.0	0.05	0.30	0.10	0.36	—
	Wheat *Triticum aestivum*													
63	bran	4-05-190	89	1,300	1,725	15.7	3.0	1.70	11.0	0.14	1.15	0.20	1.19	0.06
64	flour by-product, less than 4% fiber (wheat red dog)	4-05-203	88	2,568	—	15.3	3.3	—	2.6	0.04	0.49	0.14	0.51	0.14
65	flour by-product, less than 9.5% fiber (wheat middlings)	4-05-205	88	2,000	2,708	15.0	3.0	1.87	7.5	0.12	0.85	0.30	0.99	0.03
66	flour by-product, less than 7% fiber (wheat shorts)	4-05-201	88	2,162	2,061	16.5	4.6	—	6.8	0.09	0.81	—	0.93	0.07
67	grain, hard red winter	4-05-268	87	2,900	3,167	14.1	2.5	0.59	3.0	0.05	0.37	0.13	0.45	0.05
68	grain, soft white winter	4-05-337	89	3,120	—	11.5	2.5	—	3.0	0.05	0.31	—	0.42	0.05
	Whey *Bos taurus*													
69	dehydrated	4-01-182	93	1,900	693	13.0	0.8	0.01	0.2	0.97	0.76	—	1.05	1.5
70	low lactose, dehydrated (dried whey product)	4-01-186	91	2,090	—	16.0	1.0	0.01	0.3	1.95	0.98	—	3.0	1.03
	Yeast, Brewer's *Saccharomyces cerevisiae*													
71	dehydrated	7-05-527	93	1,990	2,634	44.4	1.0	—	2.7	0.12	1.40	—	1.70	0.12
	Yeast, Torula *torulopsis utilis*													
72	dehydrated	7-05-534	93	2,160	—	47.2	2.5	0.05	2.4	0.58	1.67	—	1.70	0.12

NOTE: Dash indicates that no data were available.

[a] First digit is class of feed: 1, dry forages and roughages; 2, pasture, range plants, and forages fed green; 3, silages; 4, energy feeds; 5, protein supplements; 6, minerals; 7, vitamins; 8, additives; the other five digits are the International Feed Number.

Entry Number	Iron (mg/kg)	Magnesium (%)	Manganese (mg/kg)	Sodium (%)	Sulfur (%)	Copper (mg/kg)	Selenium (mg/kg)	Zinc (mg/kg)	Biotin (mg/kg)	Choline (mg/kg)	Folacin (mg/kg)	Niacin (mg/kg)	Pantothenic Acid (mg/kg)	Pyridoxine (mg/kg)	Riboflavin (mg/kg)	Thiamin (mg/kg)	Vitamin B_{12} (μg/kg)	Vitamin E (mg/kg)
37	71	0.16	—	—	—	—	—	—	—	440	—	23	11.0	—	3.8	7.3	—	—
38	85	0.16	43	0.08	0.21	8	0.30	38	0.27	946	0.3	12	7.8	1.0	1.1	6.0	—	20
39	73	0.17	38	0.06	0.20	—	0.07	—	0.22	959	0.3	14	13.0	1.3	1.1	0.6	—	—
40	100	0.08	14	0.04	0.14	3	—	0.1	—	284	1.0	7	3.0	2.2	1.5	0.6	—	—
41	50	0.13	—	0.04	—	—	—	30	0.18	642	0.4	34	10.0	1.0	2.3	4.6	—	3
42	156	0.33	25	0.06	0.29	15	0.28	30	0.33	1,655	0.4	166	47.0	10.0	5.2	7.1	—	3
43	142	0.04	29	0.07	0.30	15	—	20	0.39	2,396	0.4	170	53.0	10.0	11.0	5.7	—	3
44	440	0.22	11	0.40	0.51	14	0.75	120	0.30	5,952	1.0	40	12.3	4.4	11.0	1.0	310	2
45	76	0.20	10	0.69	1.50	7	0.84	54	0.04	891	0.2	27	10.0	3.0	2.1	0.1	78	—
46	190	0.95	250	0.07	0.18	13	0.40	30	0.42	1,135	2.2	293	23.0	14.0	2.5	22.5	—	60
47	—	0.11	18	0.07	0.06	—	0.27	17	0.08	800	0.2	30	8.0	28.0	0.7	1.4	—	14
48	160	0.65	12	0.10	0.17	3	—	26	0.61	1,237	0.2	520	47.0	—	1.8	19.8	—	90
49	60	0.12	58	0.02	0.15	7	0.38	31	0.06	419	0.6	19	8.0	2.6	1.6	3.6	—	15
50	495	0.35	18	0.05	0.13	10	—	41	1.43	820	0.5	11	33.9	—	2.3	—	—	1
51	484	1.02	39	0.04	0.20	9	—	33	1.67	3,248	1.6	22	39.1	11.3	2.4	4.5	—	1
52	93	0.77	48	0.04	0.43	—	—	100	0.34	1,536	—	30	6.0	12.5	3.6	2.8	—	—
53	45	0.15	15	0.01	0.08	10	0.20	15	0.26	668	0.2	41	12.4	5.2	1.3	3.0	—	7
54	—	0.12	—	0.01	0.11	—	—	—	—	—	—	—	—	—	1.1	—	—	—
55	—	0.12	29	0.25	0.06	—	—	—	0.22	640	0.3	24	13.0	2.2	3.5	2.2	—	—
56	130	0.01	1	0.07	0.71	7	0.10	23	0.3	2	2.5	6	4.2	5.4	1.2	0.2	—	—
57	80	0.28	30	0.03	0.22	16	0.11	25	0.27	2,860	4.2	22	11.0	10.8	2.6	11.0	—	40
58	120	0.27	29	0.01	0.43	22	0.10	40	0.32	2,794	1.3	29	16.0	6.0	2.9	4.5	—	2
59	170	0.30	43	0.02	0.44	15	0.10	55	0.32	2,731	1.3	22	15.0	5.0	2.9	3.2	—	3
60	140	0.68	34	0.2	0.30	35	—	100	—	3,791	—	264	29.9	11.1	3.0	3.0	—	—
61	30	0.75	23	0.2	—	4	—	98	1.45	2,894	—	220	24.0	16.0	4.7	3.1	—	—
62	44	—	43	—	0.15	8	—	32	—	462	—	—	—	—	0.4	—	—	—
63	170	0.52	113	0.05	0.22	14	0.85	100	0.48	1,232	1.2	186	31.0	7.0	4.6	8.0	—	14
64	46	0.16	55	0.04	0.24	6	0.30	65	0.11	1,534	0.8	42	13.3	4.6	2.2	22.8	—	33
65	50	0.16	118	0.12	0.26	18	0.80	100	0.37	1,439	0.8	98	13.0	9.0	2.2	16.5	—	40
66	73	0.25	117	0.02	0.20	12	0.43	109	—	1,813	1.7	107	22.3	7.2	4.2	19.1	—	54
67	60	0.17	32	0.04	0.12	6	0.20	34	0.11	1,090	0.4	48	9.9	3.4	1.4	4.5	—	13
68	40	0.10	24	0.06	0.12	7	0.06	28	0.11	1,002	0.4	57	11.0	4.0	1.2	4.3	—	13
69	130	0.13	6	1.3	1.04	46	0.08	3	0.34	1,369	0.08	10	44.0	4.0	27.1	4.1	23	0.2
70	238	0.25	8	1.50	1.05	7	0.10	7	0.64	4,392	1.4	19	69.0	4.0	45.8	5.7	23	—
71	120	0.23	5	0.07	0.38	33	1.00	39	1.05	3,984	9.9	448	109.0	42.8	37.0	91.8	1	2
72	90	0.13	13	0.07	0.34	14	1.00	99	1.39	2,881	22.4	500	73.0	36.3	47.7	6.2	4	—

TABLE 9-2 Amino Acid Composition of Some Feeds Commonly Used for Poultry (data on as-fed basis)

Entry Number	Feed Name Description	International Feed Number[a]	Dry Matter (%)	Protein (%)	Arginine (%)	Glycine (%)	Serine (%)	Histidine (%)	Isoleucine (%)	Leucine (%)	Lysine (%)	Methionine (%)	Cystine (%)	Phenylalanine (%)	Tyrosine (%)	Threonine (%)	Tryptophan (%)	Valine (%)
	Alfalfa *Medicago sativa*																	
01	meal dehydrated, 17% protein	1-00-023	88.0	17.0	0.69	0.82	0.72	0.57	0.67	1.19	0.73	0.24	0.19	0.81	0.81	0.69	0.23	0.84
02	meal dehydrated, 20% protein	1-00-024	92.0	20.0	0.92	0.97	0.89	0.34	0.88	1.30	0.87	0.31	0.25	0.85	0.59	0.76	0.33	0.97
	Bakery																	
03	waste dehydrated (dried bakery product)	4-00-466	92.0	9.8	0.47	0.82	0.65	0.13	0.45	0.73	0.31	0.17	0.17	0.40	0.41	0.49	0.10	0.42
	Barley *Hordeum vulgare*																	
04	grain	4-00-549	89.0	11.0	0.52	0.44	0.46	0.27	0.37	0.76	0.40	0.18	0.24	0.56	0.35	0.37	0.14	0.52
05	grain, Pacific coast	4-07-939	89.0	9.0	0.48	0.36	0.32	0.21	0.40	0.60	0.29	0.13	0.18	0.48	0.31	0.30	0.12	0.46
	Broadbean *Vicia faba*																	
06	seeds	5-09-262	87.0	23.6	2.12	1.02	1.15	0.82	0.95	1.76	1.50	0.18	.28	1.00	0.80	0.85	0.20	1.07
	Blood																	
07	meal, vat dried	5-00-380	94.0	81.1	3.63	4.59	3.14	3.52	0.95	10.53	7.05	0.55	0.52	5.66	2.07	3.15	1.29	7.28
08	meal, spray or ring dried	5-00-381	93.0	88.9	3.62	3.95	4.25	5.33	0.98	11.32	7.88	1.09	1.03	5.85	2.63	3.92	1.35	7.53
	Brewer's Grains																	
09	dehydrated	5-02-141	92.0	25.3	1.28	1.09	0.80	0.57	1.44	2.48	0.90	0.57	0.39	1.45	1.19	0.98	0.34	1.66
	Buckwheat, Common *Fagopyrum sagittatum*																	
10	grain	4-00-994	88.0	10.8	1.02	0.71	0.41	0.26	0.37	0.56	0.61	0.20	0.20	0.44	0.21	0.46	0.19	0.54
	Canola *Brassica napus-Brassica campestris*																	
11	seeds, meal prepressed solvent extracted, low erucic acid, low glucosinolates	5-06-145	88.0	34.8	2.08	1.82	1.53	0.93	1.37	2.47	1.94	0.71	0.87	1.44	1.09	1.53	0.44	1.76
	Casein																	
12	dehydrated	5-01-162	93.0	87.2	3.61	1.79	5.81	2.78	4.82	9.00	7.99	2.65	0.21	4.96	5.37	4.29	1.05	6.46
13	precipitated dehydrated	5-20-837	92.0	85.0	3.42	1.81	5.52	2.52	4.77	8.62	7.31	2.80	0.15	4.81	5.17	4.00	0.98	5.82
	Cattle																	
14	skim milk, dehydrated	5-01-175	93.0	36.1	1.21	0.73	2.05	1.03	1.83	3.59	2.80	0.90	0.29	1.75	1.83	1.59	0.50	2.28
	Coconut *Cocos nucifena*																	
15	kernels with coats, meal solvent extracted (copra meal)	5-01-573	92.6	19.2	1.97	0.82	0.79	0.36	0.63	1.18	0.50	0.28	0.28	0.88	0.44	0.58	0.12	0.91
	Corn, Dent Yellow *Zea mays indentata*																	
16	distillers' grains, dehydrated	5-28-235	94.0	27.9	0.97	0.49	0.70	0.62	0.99	3.01	0.78	0.40	0.24	0.94	0.84	0.49	0.20	1.18
17	distillers' grains with solubles, dehydrated	5-28-236	93.0	27.2	0.98	0.57	1.61	0.66	1.00	2.20	0.75	0.60	0.40	1.20	0.74	0.92	0.19	1.30
18	distillers' solubles, dehydrated	5-28-237	92.0	28.5	1.05	1.10	1.30	0.70	1.25	2.11	0.90	0.50	0.40	1.30	0.95	1.00	0.30	1.39
19	gluten, meal, 60% protein	5-28-242	88.0	60.2	1.82	1.67	2.96	1.20	2.45	10.04	1.03	1.49	1.10	3.56	3.07	2.00	0.36	2.78
20	gluten with bran (corn gluten feed)	5-28-243	90.0	22.0	1.01	0.99	0.80	0.71	0.65	1.89	0.63	0.45	0.51	0.77	0.58	0.89	0.10	0.05
21	grain	4-02-935	88.0	8.5	0.38	0.33	0.37	0.23	0.29	1.00	0.26	0.18	0.18	0.38	0.30	0.29	0.06	0.40
22	grits by-product (hominy feed)	4-03-011	90.0	10.0	0.47	0.40	0.50	0.20	0.40	0.84	0.40	0.13	0.13	0.35	0.49	0.40	0.10	0.49
	Cotton *Gossypium* spp.																	
23	seeds, meal mechanically extracted, 41% protein (expeller)	5-01-617	91.4	41.0	4.35	1.69	1.68	1.07	1.31	2.23	1.59	0.55	0.59	2.20	1.09	1.30	0.50	1.84
24	seeds, meal direct solvent extracted, 41% protein	5-07-872	90.4	41.4	4.66	1.69	1.78	1.10	1.33	2.41	1.76	0.51	0.62	2.23	1.14	1.34	0.52	1.82
25	seeds, meal prepressed solvent extracted, 41% protein	5-07-873	89.9	41.4	4.59	1.70	1.74	1.10	1.33	2.43	1.71	0.52	0.62	2.22	1.13	1.32	0.47	1.88
	Fish																	
26	solubles, condensed	5-01-969	51.0	31.5	1.61	3.41	0.83	1.56	1.06	1.86	1.73	0.50	0.30	0.93	0.40	0.86	0.31	1.16
27	solubles, dehydrated	5-01-971	92.0	63.6	2.78	5.89	2.02	2.18	1.95	3.16	3.28	1.00	0.66	1.48	0.78	1.35	0.51	2.22
	Fish, Anchovy *Engraulis ringen*																	

Entry Number	Feed Name Description	International Feed Number[a]	Dry Matter (%)	Protein (%)	Arginine (%)	Glycine (%)	Serine (%)	Histidine (%)	Isoleucine (%)	Leucine (%)	Lysine (%)	Methionine (%)	Cystine (%)	Phenylalanine (%)	Tyrosine (%)	Threonine (%)	Tryptophan (%)	Valine (%)
28	meal mechanically extracted	5-01-985	90.0	65.0	3.81	3.68	2.51	1.59	3.06	4.98	5.07	1.95	0.65	2.75	2.22	2.82	0.78	3.46
	Fish, Herring *Clupea harengus*																	
29	meal mechanically extracted	5-02-000	92.0	72.0	4.21	4.30	2.75	1.74	3.23	5.46	5.47	2.16	0.72	2.82	2.25	3.07	0.83	3.90
	Fish, Menhaden *Brevoortia tyrannus*																	
30	meal mechanically extracted	5-02-009	92.1	61.3	3.68	4.46	2.37	1.42	2.28	4.16	4.51	1.63	0.57	2.21	1.80	2.46	0.49	2.77
	Fish, White Gadidae (family)-Lophiidae (family)-Rajidae (family)																	
31	meal mechanically extracted	5-02-025	91.0	62.2	4.02	4.42	3.06	1.34	2.72	4.36	4.53	1.68	0.75	2.28	1.83	2.57	0.67	3.02
	Gelatin																	
32	process residue (gelatin by-products)	5-14-503	91.0	88.0	7.40	20.00	2.80	0.85	1.40	3.10	3.70	0.68	0.09	1.70	0.26	1.30	0.09	1.80
	Hominy Feed—see Corn																	
	Livers																	
33	meal	5-00-389	92.0	65.6	4.14	5.57	2.49	1.47	3.09	5.28	4.80	1.22	0.89	2.89	1.69	2.48	0.59	4.13
	Meat																	
34	meal rendered	5-00-385	92.0	54.4	3.73	6.30	1.60	1.30	1.60	3.32	3.00	0.75	0.66	1.70	0.84	1.74	0.36	2.30
35	with bone, meal rendered	5-00-388	93.4	51.6	3.28	6.65	2.20	0.96	1.54	3.28	2.61	0.69	0.69	1.81	1.20	1.74	0.27	2.36
	Millet, Pearl *Peninstum glaucum*																	
36	grain	4-03-118	90.0	15.7	0.74	0.47	0.74	0.31	0.37	1.14	0.45	0.25	0.24	0.56	0.35	0.48	0.08	0.49
	Millet, Proso *Panicum miliaceum*																	
37	grain	4-03-120	87.5	9.1	0.35	0.31	0.40	0.22	0.35	1.14	0.21	0.16	0.17	0.47	0.34	0.29	0.08	0.44
	Oats *Avena sativa*																	
38	grain	4-03-309	89.0	11.4	0.79	0.50	0.40	0.24	0.52	0.89	0.50	0.18	0.22	0.59	0.53	0.43	0.16	0.68
39	grain, Pacific coast	4-07-999	91.0	9.0	0.60	0.40	0.30	0.10	0.40	0.30	0.40	0.13	0.17	0.44	0.20	0.20	0.12	0.51
40	hulls	1-03-281	92.0	4.6	0.14	0.14	0.14	0.07	0.14	0.25	0.14	0.07	0.06	0.13	0.14	0.13	0.07	0.20
	Pea *Pisum* spp.																	
41	seeds	5-03-600	88.8	23.8	2.23	1.00	1.08	0.59	0.97	1.65	1.68	0.24	0.33	1.10	0.73	0.84	0.18	1.10
	Peanut *Arachis hypogaea*																	
42	kernels, meal mechanically extracted (peanut meal) (expeller)	5-03-649	90.0	40.0	4.35	2.18	1.83	.87	1.27	2.42	1.26	0.45	0.52	1.97	1.47	1.01	0.39	1.53
43	kernels, meal solvent extracted (peanut meal)	5-03-650	91.9	49.0	5.33	2.67	2.25	1.07	1.55	2.97	1.54	0.54	0.64	2.41	1.80	1.24	0.48	1.87
	Poultry																	
44	by-product, meal rendered (viscera with feet and heads)	5-03-798	94.2	59.5	3.94	6.17	2.71	1.07	2.16	3.99	3.10	0.99	0.98	2.29	1.68	2.17	0.37	2.87
45	feathers, meal hydrolyzed	5-03-795	91.0	82.9	5.57	6.13	8.52	0.95	3.91	6.94	2.28	0.57	4.34	3.94	2.48	3.81	0.55	5.93
	Rice *Oryza sativa*																	
46	bran with germ (rice bran)	4-03-928	89.1	13.7	0.96	0.70	0.59	0.35	0.45	0.91	0.59	0.26	0.27	0.60	0.42	0.48	0.12	0.68
47	grain, polished and broken (brewer's rice)	4-03-932	89.2	10.0	0.74	0.50	0.44	0.26	0.37	0.74	0.43	0.22	0.21	0.48	0.33	0.36	0.10	0.54
48	polishings	4-03-943	90.0	12.2	0.78	0.71	1.36	0.24	0.41	0.80	0.57	0.22	0.10	0.46	0.63	0.40	0.13	0.76
	Rye *Secale cereale*																	
49	grain	4-04-047	88.0	12.1	0.53	0.49	0.52	0.26	0.47	0.70	0.42	0.17	0.19	0.56	0.26	0.36	0.11	0.56
	Safflower *Carthamus tinctorius*																	
50	seeds, meal solvent extracted	5-04-110	92.0	27.0	2.21	1.53	0.99	0.61	1.02	1.74	0.90	0.42	0.45	1.10	0.71	0.85	0.37	1.42
51	seeds without hulls, meal solvent extracted	5-07-959	92.0	43.0	3.65	2.32	—	1.07	1.56	2.46	1.27	0.68	0.70	1.75	1.07	1.30	0.59	2.33
	Sesame *Sesamum indicum*																	

Entry Number	Feed Name Description	International Feed Number[a]	Dry Matter (%)	Protein (%)	Arginine (%)	Glycine (%)	Serine (%)	Histidine (%)	Isoleucine (%)	Leucine (%)	Lysine (%)	Methionine (%)	Cystine (%)	Phenylalanine (%)	Tyrosine (%)	Threonine (%)	Tryptophan (%)	Valine (%)
52	seeds, meal mechanically extracted	5-04-220	90.0	41.0	4.68	2.04	1.72	0.99	1.51	2.68	0.91	1.22	0.72	1.93	1.48	1.40	0.62	1.91
	Sorghum *Sorghum bicolor*																	
53	grain, 8-10% protein	4-20-893	87.5	9.1	0.35	0.31	0.40	0.22	0.35	1.14	0.21	0.16	0.17	0.47	0.34	0.29	0.08	0.44
54	grain, more than 10% protein	4-20-894	88.0	10.0	0.35	0.32	0.45	0.23	0.43	1.37	0.22	0.15	0.11	0.52	0.17	0.33	0.09	0.54
	Soybean *Glycine max*																	
55	flour by-product (Soybean mill feed)	4-04-594	89.0	13.3	0.94	0.40	—	0.18	0.40	0.57	0.48	0.10	0.21	0.37	0.23	0.30	0.10	0.37
56	protein concentrate, more than 70% protein	5-08-038	93.0	84.1	6.70	3.30	5.30	2.10	4.60	6.60	5.50	0.81	0.49	4.30	3.10	3.30	0.81	4.40
57	seeds, heat processed	5-04-597	88.0	35.5	2.59	1.55	1.87	0.99	1.56	2.75	2.25	0.53	0.54	1.78	1.34	1.41	0.51	1.65
58	seeds, meal solvent extracted	5-04-604	88.2	44.0	3.14	1.90	2.29	1.17	1.96	3.39	2.69	0.62	0.66	2.16	1.91	1.72	0.74	2.07
59	seeds without hulls, meal solvent extracted	5-04-612	88.4	47.5	3.48	2.05	2.48	1.28	2.12	3.74	2.96	0.67	0.72	2.34	1.95	1.87	0.74	2.22
	Sunflower, common *Helianthus annuus*																	
60	seeds, meal solvent extracted	5-09-340	90.0	23.3	2.30	—	1.00	0.55	1.00	1.60	1.00	0.50	0.50	1.15	—	1.05	0.45	1.60
61	seeds without hulls, meal solvent extracted	5-04-739	89.8	36.8	2.85	2.03	1.49	0.87	1.43	2.22	1.24	0.80	0.64	1.66	0.91	1.29	0.41	1.74
	Triticale *Triticale hexaploide*																	
62	grain	4-20-362	88.0	11.8	0.57	0.48	0.52	0.26	0.39	0.76	0.39	0.26	0.26	0.49	0.32	0.36	0.14	0.51
	Wheat *Triticum aestivum*																	
63	bran	4-05-190	88.0	15.4	1.02	0.81	0.67	0.46	0.47	0.96	0.61	0.23	0.32	0.61	0.46	0.50	0.23	0.70
64	flour by-product, less than 4% fiber (wheat red dog)	4-05-203	88.0	15.3	0.96	0.74	0.75	0.41	0.55	1.06	0.59	0.23	0.37	0.66	0.46	0.50	0.10	0.72
65	flour by-product, less than 9.5% fiber (wheat middlings)	4-05-205	88.0	16.0	1.15	0.63	0.75	0.37	0.58	1.07	0.69	0.21	0.32	0.64	0.45	0.49	0.20	0.71
66	flour by-product, less than 7% fiber (wheat shorts)	4-05-201	88.0	16.5	1.18	0.96	0.77	0.45	0.58	1.09	0.79	0.27	0.36	0.67	0.47	0.60	0.21	0.83
67	grain, hard red winter	4-05-268	88.1	13.3	0.60	0.59	0.59	0.31	0.44	0.89	0.37	0.21	0.30	0.60	0.43	0.39	0.16	0.57
68	grain, soft white winter	4-05-337	89.0	10.2	0.40	0.49	0.55	0.20	0.42	0.59	0.31	0.15	0.22	0.45	0.39	0.32	0.12	0.44
	Whey *Bos taurus*																	
69	dehydrated	4-01-182	93.0	12.0	0.34	0.30	0.32	0.18	0.82	1.19	0.97	0.19	0.30	0.33	0.25	0.89	0.19	0.68
70	low lactose, dehydrated (dried whey product)	4-01-186	91.0	15.5	0.67	1.04	0.76	0.25	0.90	1.35	1.47	0.57	0.57	0.50	0.35	0.85	0.23	0.83
	Yeast, Brewer's *Saccharomyces cerevisiae*																	
71	dehydrated	7-05-527	93.0	44.4	2.19	2.09	—	1.07	2.14	3.19	3.23	0.70	0.50	1.81	1.49	2.06	0.49	2.32
	Yeast, Torula *Torulopsis utilis*																	
72	dehydrated	7-05-534	93.0	47.2	2.60	2.60	2.76	1.40	2.90	3.50	3.80	0.80	0.60	3.00	2.10	2.60	0.50	2.90

NOTE: Dash indicates that no data were available.

[a] First digit is class of feed: 1, dry forages and roughages; 2, pasture, range plants, and forages fed green; 3, silages; 4, energy feeds; 5, protein supplements; 6, minerals; 7, vitamins; 8, additives; the other five digits are the International Feed Number.

influenced by the tannin content of the grain. Development of high-tannin or "bird-resistant" varieties has allowed increased production of sorghum in areas where bird predation had previously limited yields; however, the presence of tannins in these cultivars may reduce their nutritional value. Tannins cause a binding and precipitation of dietary proteins and digestive enzymes (Butler et al., 1984) and may reduce both the amino acid (Armstrong et al., 1974) and the energy digestibility

TABLE 9-3 Ranges in Weights per Unit of Volume for Selected Feedstuffs at Standard Moisture

Feedstuffs	Pounds per Bushel	Kilograms per Hectoliter	Moisture (%)
Barley	36–48	45–62	16.0
Corn	46–56	59–72	15.5
Oats	22–40	28–52	16.0
Sorghum (milo)	51–57	66–74	15.5
Soybeans	49–56	63–72	13.0
Wheat	45–63	58–81	15.5

(Gous et al., 1982) of the diet. The *ME* of grain sorghums can be predicted from their tannin content by the following equation (Gous et al., 1982):

$$ME_n \text{ (kcal/kg)} = 3{,}152 - 358 \text{ (\% tannic acid).}$$

Although wheat was once considered too expensive for use in animal feeds, increased production in recent years has resulted in more extensive use in poultry diets. In general, wheat has about 90 percent of the *ME* value of corn. The protein and amino acid composition varies widely and is influenced by genetic and environmental factors. Most wheat varieties have been developed for various baking properties, although some breeders have developed varieties designed primarily for animal feeds (Bowyer and Waldroup, 1987). The nutrient sources in wheat are easily digested (McNab and Shannon, 1974). Feeding trials with broilers, layers, and turkeys indicate that wheat can be effectively used to provide a major portion of the energy in these diets (Waldroup et al., 1967; Lillie and Denton, 1968; Petersen, 1969). But because wheat has no carotenoid pigments, adjustment is made when skin or yolk pigment must be maintained.

One vitamin that must be considered with wheat feeding is biotin. Although the total biotin content in wheat exceeds that in corn, the biological availability in wheat is low (Frigg, 1976). A condition known as fatty liver and kidney syndrome (FLKS) has frequently been observed in all species of poultry when wheat is used extensively. Biotin supplementation should be considered when wheat provides more than 50 percent of the cereal grain.

Notwithstanding differences in bushel weight, the protein content of grains (dry matter basis) often varies a great deal from batch to batch. This variation may be the result of genetic constitution, soil fertility, time of harvest, and other factors. The protein concentration of grains can be determined readily for feed formulation purposes. It should be recognized, however, that the amino acid composition of protein in a specific grain does not remain constant as protein concentration changes. In some instances, the concentrations of essential amino acids in protein increase, but, in other instances, they decrease. For example, there is a marked inverse relationship between the protein content of wheat or sorghum grain and the lysine concentration in the protein. As protein content increases, lysine in the protein decreases. This relationship is most prominent within cultivars of wheat and sorghum grains and is the result of a shift among the major proteins within these grains, whereby the proportion of prolamine (low in lysine) increases at the expense of other proteins high in lysine. Certain other amino acids (such as arginine, methionine, and cystine) may be affected similarly. An inverse relationship between protein content and concentration of certain essential amino acids in the protein also has been reported for cultivars of barley, corn, oats, and rice. The alterations in amino acid composition with increasing protein concentration generally are less with these grains than with wheat and milo.

Recently, much research has been focused on the selection of cultivars of grains in which the concentrations of both protein and selected amino acids within the protein may be increased. Examples include high-lysine corn and high-protein barley. The quantities of these grains available for feeding to poultry are limited at the present time.

PROTEIN SUPPLEMENTS

A number of the feedstuffs used to supply supplementary protein to poultry diets may contain naturally occurring toxic or potentially toxic compounds. In many instances, the nutritive value of the protein supplement can be markedly influenced by the method used in processing the protein supplement.

Cottonseed Meal

Cottonseed meal, for example, may contain gossypol pigments. Free gossypol forms complexes with iron in the feed, intestinal tract, blood, and egg yolk, leading to possible iron deficiency or to discoloration of the yolk. Under extreme heat during processing, the gossypol may also form complexes with lysine, severely reducing the digestibility. The amount of gossypol present in cottonseed meal is variable and depends on the cultivar and the manufacturing procedures. In general, meals produced by the prepress solvent method are lowest in free gossypol, have greater lysine digestibility, and are the preferred meal for poultry (Phelps, 1966). Gossypol adversely affects the bird, with younger birds being less tolerant than older birds. Hens consuming gossypol may lay eggs with olive-discolored yolks, with the incidence related to the amount of free gossypol consumed. The discoloration may be evident in the newly laid egg, but it more often becomes apparent after storage. Addition of soluble iron salts to bind the free gossypol may enable the use of cottonseed meals, where this is economically feasible (Waldroup, 1981). The presence of cyclopropenoid fatty acids and gossypol in cottonseed meals and oil may also cause a pinkish color in the egg whites.

Rapeseed Meals

Rapeseed meals manufactured from many varieties of rapeseed contain goitrogenic, or progoitrogenic, compounds (glucosinolates) at sufficiently high concentrations to reduce growth rate and egg production when fed to poultry. Canadian plant geneticists have been successful in developing rapeseed cultivars, called canola, that contain negligible quantities of glucosinolates in the seed. Meals manufactured from these cultivars are called canola meal.

Inclusion of rapeseed meals in the diet of brown-egg layers sometimes results in the production of eggs with a "fishy" or off-flavor taint. This taint is due to the presence of excess amounts of trimethylamine (TMA) in the yolk. Deposition of TMA in yolks by certain strains of chickens is due to the presence of an autosomal semidominant gene that has variable expression depending upon various environmental factors including the inclusion rate of rapeseed meal. Although some brown-egg strains carry this trait, white-egg strains do not. This genetic defect reduces the synthesis of TMA oxidase enzyme, leading to increased quantities of TMA in the metabolic pool. Rapeseed contains variable levels of sinapine, a potent inhibitor of TMA oxidase. Low-glucosinolate cultivars have less drastic effects on egg taint but do not completely correct the situation. Therefore care should be taken in feeding rapeseed or canola meals to hens that produce brown-shelled eggs.

Soybean Meal

Soybeans contain compounds that inhibit the activity of the proteolytic enzyme trypsin (Read and Haas, 1938). They also contain other antinutrients, including hemagglutinins or lectins, which contribute to growth depression (Ham et al., 1945; Chernick et al., 1948; Coates et al., 1970; Liener, 1980). Ingestion of the antitryptic substances induces enlargement of the pancreas.

The trypsin inhibitor is inactivated by heat treatment of soybean meal. The heat treatment must be carefully controlled because overheating can result in deterioration of protein quality. On the basis of the assumption that the urease enzyme in raw soybeans is denatured at approximately the same rate as the trypsin inhibitor, and because it is easier to determine urease activity than trypsin inhibitor, urease assays (Caskey and Knapp, 1944) have generally been used by the feed industry in monitoring soybean meal quality. However, some studies indicate that there is not a direct relationship between the activities of the two enzymes (Albrecht et al., 1966) and that the rates of destruction of urease and the trypsin inhibitor are not equal under different processing conditions (McNaughton and Reece, 1980).

The feed industry in the United States has long used a maximum urease rise of 0.2 pH units as the standard for processing soybean meal for all types of livestock feeds. However, studies show that meals with a urease value up to 0.50 pH units are acceptable in poultry feeds (Glista and Scott, 1950; Wright, 1968; De Schrijver, 1977; Waldroup et al., 1985a). Damage to the protein from overheating the soybean meal is more serious when dietary lysine concentrations are marginal, and heat damage may be monitored by measuring the solubility of the protein, either by the Kjeldahl or by the dye-binding method (Dale and Araba, 1987; Kratzer et al., 1990).

High level usage of soybean meal in poultry diets has been linked to the incidence of foot pad dermatitis (Jensen et al., 1970). The exact cause of this is not known. Soybean meal contains relatively high levels of potassium, which may increase litter moisture and thus result in sticky litter. In addition, the carbohydrate fraction of soybean meal is poorly digestible (Parsons et al., 1980; Pierson et al., 1980) and may serve as a substrate for increased bacterial activity in the litter.

Animal Protein Sources

Animal protein sources—meat meals, fish meals, blood meal, and feather meal—are subject to variation as a result of manufacturing conditions and the nature of the raw material from which they are processed. Excessive and/or prolonged heating during drying will lower digestibility and cause some loss of essential amino acids. Proteins of hide, scales, hair, feathers, and bone are not easily digested and contain high concentrations of keratin and/or collagenous proteins. The latter will result in relatively low concentrations of tryptophan in the product. The use of certain lots of fish meal may result in the development of a condition known as gizzard erosion (Janssen, 1971), a disease manifested primarily by ulcerations of the lining of the gizzard. A substance known as gizzerosine has been isolated from samples of fish meal known to induce gizzard erosion and has been shown to possess the same gizzard-erosion-producing properties (Okazaki et al., 1983). To date, however, the exact level of gizzerosine necessary to induce gizzard erosion cannot be stated, since other factors (notably excess levels of copper sulfate) may precipitate or exacerbate the condition.

Fish meal may result in the development of off-flavors in poultry meat (Fry et al., 1965) or eggs (Holdas and May, 1966; Koehler and Bearse, 1975). The quantity of fish meal required to produce off-flavors is influenced primarily by the oil content of the meal, length of time fed, degree of rancidity of the oil, and holding time and temperature of the egg or carcass. Thus it is not possible to state a universal level of fish meal that will not result in the development of off-flavors.

ESTIMATING THE AMINO ACID COMPOSITION OF FEEDSTUFFS

Many factors influence the amino acid composition of grains and protein supplements. For accurate and economical feed formulation, it is desirable to know the amino acid composition of the actual ingredient to be used in the diet. However, it is generally not feasible to analyze all samples of feed ingredients prior to their use in feeds. Therefore research has been conducted at several laboratories using regression analysis to estimate the amino acid composition of selected feed ingredients from their proximate composition (Ward, 1989). An equation for estimating the amino acid content of feedstuffs related to changes in protein content is presented in Table 9-4 and an equation for estimating amino acid content from other proximate components is shown in Table 9-5. These equations represent different approaches that provide similar answers. No attempts have been made to compare the results obtained from using both sets of equations on a common set of samples.

Knowledge of the availability of amino acids in feedstuffs is important for consistent formulation of diets that meet the birds' amino acid requirements. The amounts of amino acids that are available to the animal are often much lower than the quantity contained in feedstuffs. Many factors affect the availability of amino acids. Undenatured proteins vary markedly in their digestibility. For example, feathers and most connective

TABLE 9-4 Estimation of Amino Acids from Protein Content of Feed Ingredients

Ingredients	Percentage Dry Matter	Percentage Crude Protein	Regression Factors	Methionine	Methionine + Cystine	Lysine	Threonine	Tryptophan	Arginine
Alfalfa meal,	88	16.3	a	–0.079	–0.052	0.013	–0.041	0.002	–0.119
Medicago sativa			b	0.0191	0.0282	0.0410	0.0436	0.0138	0.0474
Corn,	88	8.5	a	0.015	0.073	0.057	0.014	0.041	0.091
Zea mays			b	0.0192	0.0345	0.0224	0.0336	0.0026	0.0353
Corn gluten feed	88	18.8	a	0.101	–0.281	–0.055	–0.024		–1.394
			b	0.0106	0.0527	0.0302	0.0358	—	0.1142
Milo,	88	9.0	a	0.038	0.084	0.094	0.029	0.004	0.089
Sorghum vulgare			b	0.0135	0.0276	0.0121	0.0296	0.0103	0.0286
Canola meal,	88	34.8	a	0.177	0.140	1.133	0.250	0.081	.510
Brassica campestris			b	0.0157	0.0419	0.0231	0.0377	0.0105	0.0499
Rice bran	88	12.6	a	–0.044	–0.001	0.011	0.051	—	0.40
			b	0.0241	0.0423	0.0466	0.0366	—	0.1112
Soybean meal,	88	45.8	a	0.127	0.157	–0.252	0.203	–0.041	–0.543
Soya hispida			b	0.0111	0.0255	0.0665	·0.0344	0.0144	0.0844
Sunflower meal,	88	33.0	a	–0.107	–0.048	0.259	–0.051	–0.055	–0.559
Helianthus annuus			b	0.0255	0.0419	0.0265	0.0380	0.0134	0.0965
Triticale	88	11.8	a	0.024	0.069	0.140	0.047	—	0.046
			b	0.0147	0.0332	0.0209	0.0264	—	0.0447
Wheat,	88	12.9	a	–0.009	0.042	0.094	0.026	0.307	0.022
Triticum			b	0.0163	0.0343	0.0194	0.0264	0.0087	0.0445
Wheat bran	88	15.4	a	–0.087	–0.034	0.070	–0.206	—	0.020
			b	0.0208	0.0738	0.0353	0.0340	—	0.0649
Field beans,	88	25.4	a	–0.074	–0.009	0.306	0.335	0.101	–1.918
Vicia faba			b	0.0106	0.0205	0.0518	0.0220	0.0045	0.1653
Cottonseed meal,	88	37.4	a	0.153	0.044	0.158	0.142	—	0.466
Gossypium herbaceum			b	0.0127	0.0323	0.0364	0.0291	—	0.1157
Fish meal	91	63.8	a	–0.909	–10.059	–2.706	–10.083	–0.492	–0.456
			b	0.0420	0.0540	0.1181	0.0588	0.0184	0.0652
Meat and bone meal	91	47.9	a	–0.416	–0.960	–0.867	–0.822	–0.405	0.773
			b	0.0215	0.0423	0.0671	0.0483	0.0139	0.0539
Field peas,	88	21.1	a	0.157	0.371	–0.213	0.431	0.065	–1.224
Pisum arvense			b	0.0021	0.0063	0.0800	0.0171	0.0058	0.1453
Poultry by-product meal	91	58.4	a	–0.743	—	–3.221	1.158	—	–1.263
			b	0.0291	—	0.1057	0.0184	—	0.0879
Poultry by-product meal, feather rich	91	56.7	a	0.374	–0.187	0.222	0.323	—	–0.175
			b	0.0039	0.0549	0.0311	0.0391	—	0.0668
Barley,	88	10.7	a	0.024	0.051	0.109	0.072	0.015	0.033
Hordeum vulgare			b	0.0141	0.0328	0.0256	0.0266	0.0104	0.0438
Lupine seeds,	88	31.8	a	–0.064	0.176	0.411	–0.188	0.096	0.223
Lupinus spp.			b	0.0090	0.0163	0.0334	0.0398	0.0049	0.0947

NOTE: To estimate amino acid content, fit the equation $y = a + bx$, where x is the level of crude protein in the sample, a is the intercept, and b is the regression coefficient. Dash indicates that no coefficients were available.

Source: The Amino Acid Composition of Feedstuffs, 1990. Allendale, N.J.: DeGussa Corporation.

TABLE 9-5 Estimation of Amino Acid Composition of Feed Ingredients from Proximate Components

Ingredients	Regression Factor	Methionine	Methionine + Cystine	Lysine	Threonine	Tryptophan	Arginine
Lupin beans	Intercept	0.21996	0.95037	1.4019	0.25777	0.04185	0.7692
	Protein	–[a]	–	0.018	0.02099	0.010	0.11352
	Moisture	-0.00306	-0.01326	-0.03354	-0.01034	–	-0.05846
	Fat	0.0076	–	–	0.04113	–	–
	Fiber	-0.00219	-0.01262	-0.0142	–	–	–
	Ash	–	–	–	–	–	-0.17185
Milo	Intercept	0.0557	0.0859	0.2753	0.0593	0.142	0.2664
	Protein	0.0126	0.0282	0.0097	0.0238	0.014	0.0163
	Moisture	–	–	–	–	0.0116	0.0092
	Fat	–	–	-0.0392	–	-0.07	–
	Fiber	–	0.0142	-0.0227	-0.014	–	-0.0238
	Ash	–	-0.0237	0.0353	0.0318	-0.0637	0.0741
Meat and bone	Intercept	0.7048	-1.1187	4.7627	-0.0022	-1.7233	5.4562
meal	Protein	0.0098	0.0458	–	0.0384	0.0229	–
	Moisture	-0.0299	0.0372	-0.09	–	0.0562	-0.0916
	Fat	0.012	–	–	–	0.0266	-0.0565
	Fiber	0.0555	–	–	–	0.1311	–
	Ash	-0.0224	–	-0.0629	-0.0099	–	-0.0246
Poultry by-product	Intercept	-9.1947	8.587	-12.066	7.8878	0.8287	0.1536
	Protein	0.1019	-0.0311	0.149	–	–	0.0627
	Moisture	0.1013	-0.0403	–	–	-0.0159	0.0423
	Fat	0.1438	-0.149	0.2488	-0.2065	–	–
	Fiber	–	–	–	0.244	-0.055	–
	Ash	0.0801	-0.1338	0.1535	0.1618	-0.0079	–
Poultry by-	Intercept	0.9628	7.3812	11.8668	1.6665	0.0981	2.4219
product (crude	Protein	-0.0162	-0.0361	-0.0936	0.0137	–	0.0306
protein = 54–62%)	Moisture	-0.0675	-0.1187	–	-0.042	–	–
	Fat	0.0681	-0.1102	–	–	0.0257	
	Fiber	0.0623	–	–	–	–	-0.0601
	Ash	–	-0.0761	-0.1299	-0.0212	0.0172	
Field peas	Intercept	0.12772	0.18461	0.1614	0.39919	0.09402	-0.91679
	Protein	0.01941	0.04412	0.03032	-0.01403	0.12596	
	Moisture	-0.00895	–	–	–	-0.02906	0.06947
	Fat	–	-0.05672	-0.11144	0.06006	–	–
	Fiber	-0.01017	-0.01301	0.02799	0.01807	–	–
	Ash	0.09637	–	0.12756	-0.10471	0.24338	-0.21985
Rice bran (full-fat)	Intercept	0.0315	0.1517	-0.1305	0.0202	0.0594	-0.0312
	Protein	0.0135	0.0274	0.0313	0.0246	0.0042	0.0433
	Moisture	–	–	–	0.0024	–	–
	Fat	–	-0.0033	–	–	–	–
	Fiber	–	-0.0046	–	0.0045	–	–
	Ash	-0.0018	-0.0039	0.0061	0.001	0.0051	–
Soybean meal	Intercept	0.1754	0.1902	-0.113	1.5584	-0.201	1.0221
(crude protein	Protein	0.0079	0.0179	0.0579	0.0159	0.0222	0.0678
=44–48%)	Moisture	–	–	–	-0.0289	–	–
	Fat	–	–	–	-0.0366	–	–
	Fiber	–	–	–	-0.0277	–	–
	Ash	0.0221	0.0624	0.0665	–	-0.0241	-0.1132
Sunflower meal	Intercept	-0.0452	0.04425	1.1555	0.31712	-0.35379	-0.52833
	Protein	0.01905	0.03874	0.0157	0.02928	0.02035	0.09468
	Moisture	0.01612	0.00023	0.00358			
	Fat	–	–	–	-0.04026	0.00528	–
	Fiber	–	–	-0.01197	–	0.0001	–
	Ash	–	–	-0.03554	–	–	–
Wheat	Intercept	0.196	0.0074	0.3902	0.0717	0.0582	0.381
	Protein	0.0098	0.0582	0.0137	0.0336	0.0047	0.0221
	Moisture	-0.0086	-0.0054	-0.0195	-0.0068	–	-0.0176
	Fat	–	0.0435	0.0812	0.0545	-0.0142	0.0154
	Fiber	-0.0412	-0.0195	0.0163	0.0628	–	–
	Ash	-0.0032	-0.0285	-0.0144	-0.0173	–	-0.0016
Bakery by-product	Intercept	0.0315	0.1517	-0.1305	0.0202	0.0594	-0.0312
	Protein	0.0315	0.0274	0.0313	0.0246	0.0042	0.0433
	Moisture	–	–	–	0.0024	–	–
	Fat	–	-0.0033	–	–	–	–
	Fiber	–	-0.0046	0.0045	–	–	–
	Ash	-0.0018	-0.0039	0.0061	0.001	0.0051	–

Ingredients	Regression Factor	Methionine	Methionine + Cystine	Lysine	Threonine	Tryptophan	Arginine
Barley	Intercept	0.03751	-0.0319	0.05149	0.05491	0.00596	-0.019
	Protein	0.01311	0.02881	0.01975	0.02713	0.01053	0.0339
	Moisture	–	–	0.01235	–	–	0.01762
	Fat	–	0.02886	–	–	–	–
	Fiber	–	0.01549	–	–	–	–
	Ash	–	–	–	–	–	–
Corn	Intercept	0.11324	0.05313	-0.10041	-0.05593	0.26305	-0.03611
	Protein	0.01123	0.02982	0.04573	0.02275	–	0.05484
	Moisture	–	–	–	0.00678	-0.01334	–
	Fat	–	–	–	0.01593	–	–
	Fiber	–	–	–	0.00963	–	–
	Ash	–	–	–	–	–	–
Corn gluten meal	Intercept	0.47972	-0.05128	-1.68796	-1.42473	-3.55835	-1.03918
	Protein	0.02256	0.05079	0.04201	0.05376	0.06078	0.04928
	Moisture	-0.01619	-0.02883	0.01719	–	–	0.00518
	Fat	-0.00898	-0.00663	-0.00561	0.00337	-0.00604	-0.00384
	Fiber	-0.05844	–	0.12073	0.12052	0.22955	0.04866
	Ash	0.00788	0.00546	–	-0.00359	0.01117	-0.0058
Fish meal	Intercept	8.8912	5.0029	2.2017	4.4545	-0.3998	3.6336
	Protein	0.02597	–	0.055	–	0.0124	0.02564
	Moisture	–	-0.0651	0.06728	-0.0358	–	-0.0331
	Fat	–	-0.0702	–	-0.03662	0.0241	–
	Fiber	-0.3727	–	-0.7517	-0.182	-0.1369	-0.2596
	Ash	-0.0272	-0.0754	-0.0566	-0.0612	0.009	-0.0482

NOTE: To estimate amino acid, insert values shown for specific amino acid into the following equation: y = intercept + b_1(% protein) + b_2(% moisture) + b_3(% fat) + b_4(% fiber) + b_5(% ash), where the b, etc., represent the regression coefficients listed in each column. Dash indicates that no coefficients were available.

Sources: This information is drawn from three reports published in 1986 by Monsanto: Amino Acids in Feed Ingredients and Their Predictability. Monsanto Nutrition Update, vols. 4:2, 4:3, and 4:4. St. Louis, Mo.: Monsanto Company.

tissues contain high concentrations of cystine and disulfide bonding, which increase the stability of the protein and resistance to digestive enzymes. Antinutritional factors such as tannins in sorghum and trypsin inhibitors in soybeans reduce the availability of amino acids. Much of the latter adverse effect is due to increases in endogenous amino acid losses. The negative effects of undenatured protein structure and antinutritional factors can usually be reduced or totally eliminated by heat processing. Although some processing is needed to increase the availability of amino acids in many feedstuffs, adverse processing conditions such as excessive pressure and heat can reduce availability. These factors are particularly critical for animal protein meals since substantial processing or cooking is required during manufacturing. Lysine and cystine are two of the amino acids most affected by processing conditions.

True digestibility coefficients for amino acids in 30 feedstuffs are shown in Table 9-6. The values were determined by the precision-fed cockerel assay described by Sibbald (1986) or a modification thereof. The three primary sources of the digestibility values used to compile the data of Table 9-6 were Sibbald (1986), Green (1987), and Parsons (1990a), with data from other published reports also included. The assay was originally developed for determination of true *ME* (Sibbald, 1976) and later extended to determination of amino acid digestibility (Likuski and Dorrell, 1978; Sibbald, 1979). The basic procedure consists of subjecting adult male birds to fasting for 24 to 48 hours, followed by crop-intubation of 30 to 50 g of the test feedstuff and quantitative collection of excreta for 48 hours. Additional cockerels are either subjected to fasting or given a nitrogen-free diet during the assay period to estimate endogenous amino acid excretion. A large number of data have been generated by using this assay during the last 10 years, and the results seem to be reasonably consistent among different laboratories.

A large portion of the data used to derive the coefficients in Table 9-6 were determined with cecectomized birds; however, data from studies with conventional birds were also included. Cecectomy removes the majority of the hindgut area in poultry and eliminates most of the potentially confounding effects of the hindgut microflora on amino acid excretion. The surgical procedure is simple, and several laboratories are currently using the technique. Digestibility coefficients determined with cecectomized birds are often lower than those determined with conventional birds.

Determination of amino acid digestibility by analysis of the ideal contents has also been used to a limited extent. The two primary approaches used in these studies have been (1) removal of the ideal contents immediately following slaughter (Summers and Robblee, 1985) and (2) collection of intestinal digesta via a cannula placed in the terminal ileum (Thomas and Crissey, 1983; Raharjo and Farrell, 1984).

Entry Number	Feed Name Description	International Feed Number[a]	Dry Matter (%)	Protein (%)	Arginine (%)	Glycine (%)	Serine (%)	Histidine (%)	Isoleucine (%)	Leucine (%)	Lysine (%)	Methionine (%)	Cystine (%)	Phenylalanine (%)	Tyrosine (%)	Threonine (%)	Tryptophan (%)	Valine (%)
52	seeds, meal mechanically extracted	5-04-220	90.0	41.0	4.68	2.04	1.72	0.99	1.51	2.68	0.91	1.22	0.72	1.93	1.48	1.40	0.62	1.91
	Sorghum *Sorghum bicolor*																	
53	grain, 8-10% protein	4-20-893	87.5	9.1	0.35	0.31	0.40	0.22	0.35	1.14	0.21	0.16	0.17	0.47	0.34	0.29	0.08	0.44
54	grain, more than 10% protein	4-20-894	88.0	10.0	0.35	0.32	0.45	0.23	0.43	1.37	0.22	0.15	0.11	0.52	0.17	0.33	0.09	0.54
	Soybean *Glycine max*																	
55	flour by-product (Soybean mill feed)	4-04-594	89.0	13.3	0.94	0.40	—	0.18	0.40	0.57	0.48	0.10	0.21	0.37	0.23	0.30	0.10	0.37
56	protein concentrate, more than 70% protein	5-08-038	93.0	84.1	6.70	3.30	5.30	2.10	4.60	6.60	5.50	0.81	0.49	4.30	3.10	3.30	0.81	4.40
57	seeds, heat processed	5-04-597	88.0	35.5	2.59	1.55	1.87	0.99	1.56	2.75	2.25	0.53	0.54	1.78	1.34	1.41	0.51	1.65
58	seeds, meal solvent extracted	5-04-604	88.2	44.0	3.14	1.90	2.29	1.17	1.96	3.39	2.69	0.62	0.66	2.16	1.91	1.72	0.74	2.07
59	seeds without hulls, meal solvent extracted	5-04-612	88.4	47.5	3.48	2.05	2.48	1.28	2.12	3.74	2.96	0.67	0.72	2.34	1.95	1.87	0.74	2.22
	Sunflower, common *Helianthus annuus*																	
60	seeds, meal solvent extracted	5-09-340	90.0	23.3	2.30	—	1.00	0.55	1.00	1.60	1.00	0.50	0.50	1.15	—	1.05	0.45	1.60
61	seeds without hulls, meal solvent extracted	5-04-739	89.8	36.8	2.85	2.03	1.49	0.87	1.43	2.22	1.24	0.80	0.64	1.66	0.91	1.29	0.41	1.74
	Triticale *Triticale hexaploide*																	
62	grain	4-20-362	88.0	11.8	0.57	0.48	0.52	0.26	0.39	0.76	0.39	0.26	0.26	0.49	0.32	0.36	0.14	0.51
	Wheat *Triticum aestivum*																	
63	bran	4-05-190	88.0	15.4	1.02	0.81	0.67	0.46	0.47	0.96	0.61	0.23	0.32	0.61	0.46	0.50	0.23	0.70
64	flour by-product, less than 4% fiber (wheat red dog)	4-05-203	88.0	15.3	0.96	0.74	0.75	0.41	0.55	1.06	0.59	0.23	0.37	0.66	0.46	0.50	0.10	0.72
65	flour by-product, less than 9.5% fiber (wheat middlings)	4-05-205	88.0	16.0	1.15	0.63	0.75	0.37	0.58	1.07	0.69	0.21	0.32	0.64	0.45	0.49	0.20	0.71
66	flour by-product, less than 7% fiber (wheat shorts)	4-05-201	88.0	16.5	1.18	0.96	0.77	0.45	0.58	1.09	0.79	0.27	0.36	0.67	0.47	0.60	0.21	0.83
67	grain, hard red winter	4-05-268	88.1	13.3	0.60	0.59	0.59	0.31	0.44	0.89	0.37	0.21	0.30	0.60	0.43	0.39	0.16	0.57
68	grain, soft white winter	4-05-337	89.0	10.2	0.40	0.49	0.55	0.20	0.42	0.59	0.31	0.15	0.22	0.45	0.39	0.32	0.12	0.44
	Whey *Bos taurus*																	
69	dehydrated	4-01-182	93.0	12.0	0.34	0.30	0.32	0.18	0.82	1.19	0.97	0.19	0.30	0.33	0.25	0.89	0.19	0.68
70	low lactose, dehydrated (dried whey product)	4-01-186	91.0	15.5	0.67	1.04	0.76	0.25	0.90	1.35	1.47	0.57	0.57	0.50	0.35	0.85	0.23	0.83
	Yeast, Brewer's *Saccharomyces cerevisiae*																	
71	dehydrated	7-05-527	93.0	44.4	2.19	2.09	—	1.07	2.14	3.19	3.23	0.70	0.50	1.81	1.49	2.06	0.49	2.32
	Yeast, Torula *Torulopsis utilis*																	
72	dehydrated	7-05-534	93.0	47.2	2.60	2.60	2.76	1.40	2.90	3.50	3.80	0.80	0.60	3.00	2.10	2.60	0.50	2.90

NOTE: Dash indicates that no data were available.

[a] First digit is class of feed: 1, dry forages and roughages; 2, pasture, range plants, and forages fed green; 3, silages; 4, energy feeds; 5, protein supplements; 6, minerals; 7, vitamins; 8, additives; the other five digits are the International Feed Number.

It is generally accepted that digestible amino acid values are more indicative of relative nutritional value among feedstuffs than are total amino acid concentration values. However, the application of digestibility values in practical feed formulation is sometimes confusing because the amino acid requirements listed in the tables herein are expressed as total amino acid concentration in the diet. There is little or no published research on the digestible amino acid requirements of poultry species. Therefore a review of 28 published studies on the lysine and methionine plus cystine requirements of broilers, turkeys, and laying hens was recently conducted to calculate digestible amino acid requirements indirectly (Parsons, 1990b). First, the amino acid digestibility coefficients in Table 9-6 were used to calculate the digestible amino acid content of the basal diet feed ingredients used in the requirement studies. The digestible amino acid content of the basal diet was then added to the amount of supplemental crystalline amino acid (100 percent available) needed to meet the requirement; this sum was considered to be the digestible amino acid requirement. The results of these calculations for the 28 studies were consistent and indicated that the calculated digestible amino acid requirements were 8 to 10 percent lower than the determined total amino acid requirements.

Amino Acid Supplements

Individual amino acids are frequently included as ingredients in diets of poultry. DL-methionine and L-lysine are most commonly used in commercial diets and other amino acids may be used in semipurified and purified diets. The protein equivalents and estimated ME_ns of 20 amino acids are presented in Table 9-7. This information should be useful in formulating poultry diets.

TABLE 9-7 Nitrogen Concentration, Crude Protein Equivalents, and Nitrogen-Corrected Metabolizable Energy Values for Amino Acids

Amino Acid	Nitrogen (%)	Crude Protein Equivalent (g/100 g) of Amino Acid	Metabolizable Energy (kcal/kg)[a]
Alanine	15.72	98.25	3,060
Arginine	32.16	201.00	2,940
Asparagine	21.20	132.50	1,760
Aspartic acid	10.52	65.75	2,020
Cystine	11.66	72.88	2,060
Glutamic acid	9.52	59.50	2,880
Glutamine	19.17	119.81	2,630
Glycine	18.66	116.62	1,570
Histidine	27.08	169.25	2,410
Isoleucine	10.68	66.75	5,650
Leucine	10.67	66.69	5,640
Lysine	19.16	119.75	4,600
Methionine	9.39	58.69	3,680
Phenylalanine	8.48	53.00	6,030
Proline	12.17	76.06	3,980
Serine	13.33	83.31	2,210
Threonine	11.76	73.50	3,150
Tryptophan	13.72	85.75	5,460
Tyrosine	7.73	48.31	5,240
Valine	11.96	74.75	4,990

[a] Assuming 100 percent digestibility and conversion of nitrogen to uric acid (including urea in the case of arginine).

TABLE 9-8 Average Fatty Acid Composition of Some Feeds Commonly Used for Poultry (data on as-fed basis)

Entry Number	Feed Name Description	International Feed Number	Dry Matter (%)	Ether Extract (%)	Selected Fatty Acids, Percentage of Feed							
					$C_{12:0}$	$C_{14:0}$	$C_{16:0}$	$C_{16:1}$	$C_{18:0}$	$C_{18:1}$	$C_{18:2}$	$C_{18:3}$
01	Alfalfa, meal dehydrated, 17% protein	1-00-023	92	2.0	0.01	0.01	0.57	0.05	0.08	0.13	0.37	0.78
02	Barley, grain	5-00-549	89	1.08	0.01	—	0.49	0.02	0.03	0.37	0.78	0.08
03	Corn, dent yellow, distillers' solubles, dehydrated	5-28-237	92	9.0	—	—	1.80	0.07	0.09	2.25	4.77	0.02
04	Corn, dent yellow, grain	4-02-935	89	3.8	—	—	0.62	—	0.10	1.17	1.82	0.09
05	Corn, dent yellow, grits by-product (hominy feed)	4-03-011	90	6.9	—	—	0.97	—	0.14	1.94	3.75	0.10
06	Corn, dent yellow, gluten, meal	5-28-241	90	2.5	—	—	0.50	—	0.06	0.61	1.16	—
07	Cotton, seeds, meal solvent extracted, 41% protein	5-01-621	93	3.9	—	0.02	1.22	—	0.02	0.53	2.46	0.03
08	Fish, menhaden, meal mechanically extracted	5-02-009	92	9.4	0.01	1.15	3.61	1.58	0.57	1.96	0.14	0.08
09	Meat with bone, meal rendered	5-00-388	93	8.6	—	0.22	2.36	0.44	1.42	3.74	0.31	—
10	Oats, grain	4-03-309	89	4.2	—	0.05	0.93	0,04	0.05	1.60	1.47	0.09
11	Peanut, kernels, meal mechanically extracted (expeller)	5-03-649	90	7.3	—	—	1.52	0.08	0.23	3.32	1.43	—
12	Poultry, feathers, meal hydrolyzed	5-03-795	93	3.3	0.01	0.06	0.99	0.19	0.48	0.98	0.43	—
13	Sorghum, milo, grain	4-04-444	89	2.8	—	—	0.56	0.15	0.03	0.89	1.13	0.06
14	Soybean, seeds without hulls, meal solvent extracted	5-04-612	90	1.0	—	—	0.24	0.01	0.05	0.16	0.47	0.07
15	Wheat, grain	5-05-211	87	1.9	—	—	0.46	0.08	0.03	0.44	0.81	0.11
16	Wheat, middlings	4-05-205	88	3.0	—	—	0.61	—	—	0.58	1.70	0.12

NOTE: Dash indicates that no data were available for these values.
SOURCE: Fatty acid composition data obtained from Edwards (1964).

CHARACTERISTICS OF DIETARY FATS

As discussed in Chapter 1, dietary fats vary appreciably in composition and in their contributions to nutrition of poultry. The fatty acid composition of some ingredients commonly used in poultry diets is presented in Table 9-8. Selected characteristics of supplemental fats (including combined moisture, insolubles, and unsaponifiables content), fatty acid composition, and experimentally determined ME_n values are shown in Table 9-9. This information provides an overview of the different fats that have been evaluated experimentally and some of the conditions under which they were evaluated. For comparative purposes, ME_n values of specific carbohydrates are also listed in Table 9-9.

MACROMINERAL SUPPLEMENTS

Concentrated sources of calcium, phosphorus, sodium, potassium, and magnesium are often used to achieve desired dietary concentrations of specific macrominerals. These mineral sources contain other elements of potential nutritional importance, including chlorine, fluorine, sulfur,

TABLE 9-9 Characteristics and Metabolizable Energy of Various Sources of Fats and Selected Carbohydrates Occurring in Feed

MIU[a] (%)	Fatty Acids (% free)	Selected Fatty Acids, Percentage of Total Fatty Acids: 16:0	16:1	18:0	18:1	18:2	18:3	Nature of Sample	Energy Content "As Fed": kcal ME/kg	Methodology[b]	Data Reference
								Animal Tallows			
2.2	4.8	26.9	3.3	17.4	41.5	7.5	0.1	Commercial	6,020-7,690	ME_n chicks 10-20%	Sibbald et al., 1961
—	—	35.4	2.7	36.5	24.5	0.9	—	Beef	7,268-7,780	ME_n poults 10%	Whitehead and Fisher, 1975
—	—	22.9	2.8	24.2	40.9	0.6	1.1	Commercial	7,601	ME_n chicks 3-10%	Guirguis, 1976
—	—	25.7	4.2	22.7	37.0	2.5	0.3	Beef	7,920	*TME* 15%	Sibbald, 1978b
—		26.2	2.4	25.1	39.6	3.2	0.5	Commercial	8,460-10,640	ME_n-*TME* regression	Muztar et al., 1981
1.7	9.6	25.2	4.4	19.7	39.3	8.9	—	Commercial	8,083-8,387	ME_n-*TME* chick, 7%	Lessire et al., 1982
0.3	4.3	26.1	5.1	25.2	37.4	1.9	—	Beef	6,683-6,916		
0.5	2.4	25.8	3.7	18.1	42.1	4.6	—	Commercial	6,808-8,551	ME_n poults 2-8 weeks	Sell et al., 1986b
2.9	19.1	25.5	4.0	19.3	40.0	4.9	<0.1	Commercial	6,633-9,353	ME_n chicks 2-6%	Wiseman et al., 1986
4.0	15.5	22.0	3.6	13.1	49.6	8.4	1.7	Commercial A	6,258	ME_n chicks 9%	Huyghebaert et al., 1988
3.6	16.5	22.5	3.0	16.0	47.9	7.0	1.6	B	6,709		
4.1	6.0	19.9	1.5	14.0	47.2	12.7	1.7	C	6,060		
3.5	1.6	22.0	2.7	15.8	47.6	8.7	1.9	D	7,628		
3.0	10.2	21.2	5.9	15.5	45.4	9.6	1.2	E	7,148		
5.9	65.1	36.2	0.9	9.6	44.1	8.2	—	Soap stocks	4,900		
								Animal-Vegetable Blends			
0.9	2.6	19.0	1.7	10.7	34.3	27.8	3.8	Tallow-crude soy	8,110-8,820	ME_n chicks 10%	Sibbald et al., 1961
0.8	13.6	19.8	1.6	10.3	34.4	29.9	6.3	Tallow-crude soy	7,660	ME_n chicks 10%	Sibbald et al., 1962
0.7	13.8	19.4	1.5	10.3	34.8	29.5	6.4	Tallow-refined soy	7,830		
1.5	49.2	24.7	2.3	9.6	34.6	21.9	0.5	Tallow-soap stocks	8,490		
—	—	25.9	4.1	13.4	42.7	8.4	0.5	Commercial-feed grade	9,340	*TME* 15%	Sibbald and Kramer, 1977
—	—	21.1	2.1	16.2	41.3	10.3	0.6	Commercial-edible	9,360		
—	—	16.8	2.2	10.3	47.6	12.1	4.6	Tallow-crude canola	8,710		
—	—	20.8	2.1	11.1	31.7	27.8	3.3	Tallow-crude soy	9,700		
—	—	20.9	2.1	10.4	32.2	30.5	0.4	Tallow-refined corn	9,570		
—	—	29.5	2.1	13.7	37.3	10.6	1.1	Tallow-soap stocks	8,850		
—	—	17.2	1.3	9.5	51.1	13.7	3.2	Lard-crude canola	10,000		
—	—	15.9	1.6	13.5	50.2	9.9	3.2	Tallow-crude canola	9,140		
3.6	61.0	21.0	1.4	6.0	25.4	38.6	4.2	Commercial	7,114-8,924	ME_n poults 2-8 weeks	Sell et al., 1986b
0.9	36.3	17.7	1.0	12.5	34.5	31.2	3.9	Beef A-crude soy	7,571	ME_n chicks 9%	Huyghebaert et al., 1988
0.8	36.2	16.0	3.1	12.2	32.4	31.0	3.9	Beef B-crude soy	7,788		
1.7	68.7	23.9	0.5	6.9	34.1	32.6		Animal soap stock-soy; soap stock	5,834		
								Canola Oil			
—	—	4.9	0.4	1.9	61.0	18.8	7.7	Crude oil	9,210	*TME* 15%	Sibbald and Kramer, 1977
—	—	9.9	0.4	4.8	52.4	22.4	7.5	Soap stock	7,780-8,930	ME_n-*TME* regression	Muztar et al., 1981
								Coconut Oil			
—	—	8.2	0.4	3.0	5.7	1.8	—	24 oils, MCFA = 57%	—	—	Weihrauch et al., 1977
—	—	12.8	—	2.9	13.7	23.1	—	Undefined, MCFA[c] = 34%	8,812	ME_n chicks 9%	Veen et al., 1974
								Corn Oil			
—	—	12.2	0.5	0.7	24.7	60.5	1.4	Refined	9,639-10,811	ME_n poults 10%	Whitehead and Fisher, 1975
—	—	8-19	<0.5	0.5-4.0	19-50	34-62	<2.0	Commercial range	—	—	Spencer et al., 1976
—	—	12.4	0.1	1.9	26.9	57.0	0.7	Refined	9,870	*TME* 15%	Sibbald and Kramer, 1977
—	—	—	—	—	—	—	—	Refined	9,660-9,210	*TME* 15%	Dale and Fuller, 1981
								Cottonseed Oil			
8.2	78	30.1	0.2	4.1	29.8	29.5	3.0	Soap stock A	—	—	Waldroup and Tollett, 1972
6.5	67	25.8	0.4	2.2	19.8	47.1	3.0	B	—	—	
9.0	70	25.4	0.4	2.9	19.3	47.8	3.3	C	—	—	
14.1	83	23.4	0.3	1.8	21.3	47.3	5.1	D	—	—	
32.1	21	23.7	0.3	2.6	20.3	49.1	3.0	E	—	—	
—	—	17-29	0.5-1.5	1.0-4.0	13-44	33-58	0.1-2.1	Commercial range	—	—	Spencer et al., 1976
								Fish Oil			
—	—	—	—	—	—	—	—	Menhaden	8,450	ME_n chicks 4-12%	Cuppett and Soares, 1972
—	—	18.6	5.8	4.8	18.5	24.1	1.3	Hydrogenated	6,800	ME_n chicks 9%	Veen et al., 1974
—	—	19-24	11-18	2-3	10-23	0.9-1.7	0.4-1.7	Menhaden range	—	—	Stansby, 1981
—	—	10-19	6-12	0.7-2.1	9-26	0.1-2.9	0-1.1	Herring range	—	—	

MIU[a] (%)	Fatty Acids (% free)	Selected Fatty Acids, Percentage of Total Fatty Acids						Nature of Sample	Energy Content "As Fed"		Data Reference
		16:0	16:1	18:0	18:1	18:2	18:3		kcal ME/kg	Methodology[b]	
—	—	17	13	3	10	1	—	Raw anchovy	—	—	De Koning et al., 1986
								Lard			
—	—	28.7	2.1	19.6	40.9	8.7	—	Edible	9,114-9,854	ME_n poults 10%	Whitehead and Fisher, 1975
—	—	24.4	3.4	14.2	40.2	0.4	—	Edible	9,060	*TME* 15%	Sibbald, 1978
—	—	20-32	1.7-5.0	5-24	35-62	3-16	<1.5	Commercial range	—	—	Spencer et al., 1976
—	—	28.9	2.2	16.9	38.0	9.7	0.2	Edible	9,390	*TME* 15%	Sibbald and Kramer, 1977
0.2	0.1	26.6	3.1	15.8	42.4	9.1	<0.1	Edible	9,926-10,236	ME_n chicks 2-6%	Wiseman et al., 1986
1.1	0.2	22.4	2.1	17.7	46.1	8.0	2.1	Edible A	7,337	ME_n chicks 9%	Huyghebaert et al., 1988
0.7	0.1	21.2	5.3	17.0	44.8	9.3	1.1	B	7,356		
								Palm Oil			
—	—	27.3	0.5	6.1	58.5	11.4	1.3	*E. guineenis*	—	—	Clegg, 1973
—	100	46.4	0.2	5.0	38.7	6.9	0.1	Fatty acid composite	7,710	*TME* 15%	Sibbald and Kramer, 1977
1.8	0.2	40.7	0.3	5.2	41.6	11.4	—	Refined oil	5,800	ME_n chicks 9%	Huyghebaert et al., 1988
1.8	1.0	38.0	1.5	5.5	44.3	9.0	—	Used in cooking	5,302	—	
								Peanut Oil			
—	—	6-16	<1.0	1.3-6.5	36-72	13-45	<1.0	Commercial range	—	—	Spencer et al. 1976
								Poultry Fat			
5.2	18.0	—	—	—	—	—	—	Commercial	10,186	ME_n chicks 14%	Cullen et al., 1962
0.7	0.7	21.6	4.8	7.2	42.3	23.0	—	Commercial A	8,625-8,916	ME_n-*TME* chick 7%	Lessire et al., 1982
3.9	0.5	18.1	5.9	4.6	46.2	23.3	1.1	B	9,360	*TME* 7%	
								Safflower Oil			
—	—	2-10	<0.5	1-10	7-42	55-81	<1.0	Commercial range	—	—	Spencer et al., 1976
								Soybean Oil			
1.4	0.6	11.3	0.3	3.9	27.2	49.8	7.5	Crude	8,650-8,020	ME_n chicks 10-20%	Sibbald et al., 1961
0.3	0.7	11.3	0.1	4.9	28.2	50.2	5.6	Crude	8,370	ME_n chicks 20%	Sibbald et al., 1962
1.3	12.2	21.0	0.3	4.5	17.1	45.9	1.8	Dried gums	6,440		
0.8	13.5	20.1	0.8	4.4	17.0	40.6	0.9	Lecithins	—	—	
—	—	7-12	<0.5	2.0-5.5	19-30	48-58	4-10	Commercial range	—	—	Spencer et al., 1976
—	—	12.2	0.1	3.2	26.0	51.6	6.3	Crude	9,510	*TME* 15%	Sibbald and Kramer, 1977
2.0	1.3	10.6	<0.1	3.9	25.1	52.1	7.0	Refined	9,687-10,212	ME_n chicks 2-6%	Wiseman et al., 1986
1.8	0.1	11.6	—	3.9	19.8	57.9	6.8	Refined	8,375	ME_n chick 9%	Huyghebaert et al., 1988
3.6	1.5	9.8	—	3.7	24.3	55.0	7.2	Crude	8,795	—	
4.2	72.3	7.9	—	4.1	24.0	56.9	7.1	Soap stocks	6,111	—	
4.0	1.1	28.5	—	5.0	35.8	28.0	2.7	Used in cooking	6,309	—	
								Sunflower Oil			
—	—	3-10	<1.0	1-10	14-65	20-75	<0.7	Commercial range	—	—	Spencer et al., 1976
—	—	6.7	0.1	4.3	27.4	57.1	3.7	Refined	9,659	ME_n, chick 2-8%	Guirguis, 1976
—	—	2-4	—	3-5	80-87	4-9	—	High 18:1 cultivars	—	—	Purdy, 1986
								Carbohydrates			
—	—	—	—	—	—	—	—	Starch	4,070	ME_n	Naber and Touchburn, 1969
—	—	—	—	—	—	—	—	Sucrose	3,900	?	Janssen et al., 1972
—	—	—	—	—	—	—	—	Glucose	3,730	*TME*	Sibbald, 1977
—	—	—	—	—	—	—	—	Glucose	2,831-3,327	ME_n hen 0-9% fat	Mateos and Sell, 1980
—	—	—	—	—	—	—	—	Fructose	2,809-3,305		
—	—	—	—	—	—	—	—	Glucose:fructose (50:50)	2,798-3,209	—	
—	—	—	—	—	—	—	—	Maltose	2,868-3,326	—	
—	—	—	—	—	—	—	—	Starch	2,918-3,396	—	
—	—	—	—	—	—	—	—	Sucrose	2,512-3,063	—	

NOTE: Dash indicates that no data were available.

[a] Moisture, ether insolubles, and unsaponifiable matter contents as a percentage of the fat.

[b] ME_n is apparent metabolizable energy corrected for nitrogen retention; *TME* is true metabolizable energy using the rooster unless otherwise stated, and level(s) of fat used in the test diet. Some *ME* values are not corrected for nitrogen retention, particularly those prior to 1970.

[c] Medium-chain fatty acid contributions (8:0 + 10:0 + 12:0).

TABLE 9-10 Element Concentrations in Common Mineral Sources (data on as-fed basis)

Entry Number	Feed Name Description	International Feed No.	Calcium (%)	Phosphorus (%)	Sodium (%)	Potassium (%)	Magnesium (%)	Chlorine (%)	Fluorine (%)	Sulfur (%)	Iron (mg/kg)	Copper (mg/kg)	Manganese (mg/kg)	Zinc (mg/kg)
01	Bone meal, steamed	6-00-400	29.8	12.5	0.04	0.2	0.3	—	—	2.4	—	16	30	100
02	Calcium carbonate, $CaCO_3$	6-01-069	38.0	0.0	0.02	0.06	0.05	—	0.00	—	300	24	300	2
03	Calcium phosphate, dibasic from defluorinated phosphoric acid	6-01-080	22.0	18.7	0.06	0.1	0.6	0.013	0.18	1.11	10,000	10	300	100
04	Calcium phosphate, mono-dibasic	6-26-137	16.0	21.0	0.06	0.07	0.6	—	0.15	1.2	9,000	15	300	200
05	Calcium sulfate, dihydrate, $CaSO_4{\cdot}2H_2O$	6-01-090	22.6	—	—	—	—	—	—	18.1	—	—	—	—
06	Limestone, ground	6-02-632	38.0	—	0.05	0.1	2.1	0.03	<0.0025	—	2,000	—	—	—
07	Magnesium oxide, MgO	6-02-756	3.0	0.03	0.015	0.02	55.0	0.02	0.02	0.04	6,000	10	—	10
08	Meat with bone, meal rendered	5-00-388	10.3	5.1	0.7	1.3	1.1	0.7	—	0.5	490	2	14	93
09	Oyster, shells, ground	6-03-481	38.0	0.1	0.2	0.1	0.3	0.01	—	—	500	—	400	—
11	Phosphate, defluorinated	6-01-780	32.0	18.0	4.9	0.1	0.4	—	0.18	—	8,000	20	250	60
10	Phosphate, rock curacao, ground	6-05-586	34.0	14.0	0.2	—	0.8	—	0.53	—	3,500	—	—	—
12	Phosphate, rock, soft	6-03-947	17.0	9.0	0.10	0.30	0.35	0.007	1.25	0.31	15,000	64	39	90
13	Potassium chloride, KCl	6-03-755	0.05	—	1.0	50.5	0.34	47.3	—	0.45	600	7	7	9
14	Potassium and magnesium sulfate	6-06-177	0.06	—	0.76	18.5	11.6	1.25	0.001	22.3	100	2	20	9
15	Potassium sulfate, K_2SO_4	6-08-098	0.15	—	0.09	41.0	0.6	1.5	—	17.9	700	—	10	—
16	Sodium carbonate, Na_2CO_3	6-12-316	—	—	43.39	—	—	—	—	—	—	—	—	—
17	Sodium bicarbonate, $NaHCO_3$	6-04-272	—	—	27.0	—	—	—	—	—	—	—	—	—
18	Sodium chloride, NaCl (common salt)	6-04-152	0.3	—	39.0	—	0.005	60.0	—	0.2	50	—	—	—
19	Sodium phosphate, dibasic, from furnaced phosphoric acid, Na_2HPO_4	6-04-286	—	20.8	31.0	—	—	—	—	—	—	—	—	—
20	Sodium phosphate, monobasic, $NaH_2PO_4{\cdot}H_2O$	6-04-288	—	21.8	16.2	—	—	—	—	—	—	—	—	—
21	Sodium sulfate, decahydrate, $Na_2SO_4{\cdot}10H_2O$	6-04-291	—	—	13.8	—	—	—	—	9.7	—	—	—	—
22	Phosphoric acid, H_3PO_4	6-03-707	0.08	23.7	0.05	0.02	0.45	—	0.19	1.1	12,000	10	400	100

NOTE: The mineral supplements used as feed supplements are not chemically pure compounds, and the composition may vary substantially among sources. The supplier's analysis should be used if it is available. Dashes indicate that no data were available.

iron, copper, manganese, and zinc. The concentration of these elements contained in selected macromineral supplements is shown in Table 9-10.

MYCOTOXINS

Mycotoxins are toxic compounds produced by fungi. Most mycotoxins cause health problems for animals by entry through the feed, although they may also be water- or air-borne. Given the appropriate conditions, fungi will grow on grain and oilseeds prior to harvest. Wet conditions and warm temperatures favor the growth of fungi (Diener et el., 1987). Stresses such as drought, insect infestation, and plant disease often make the crop susceptible to fungal growth. Some fungi will then produce mycotoxins, which remain with the grain and oilseeds after harvest.

Mycotoxins in feed ingredients are difficult to economically remove or destroy. One method for detoxification of one class of mycotoxins—aflatoxins—is ammoniation of ingredients. Ammoniation was effective in destroying aflatoxin in peanut meal and cottonseed meal (Gardner et al., 1971) and in corn (Hughes et al., 1979). A second procedure for reducing the effect of aflatoxins is the use of dietary adsorbents. Including sodium calcium aluminosilicate in the diet at a level of 0.5 percent is effective in reducing the effect of aflatoxins on the growth of chickens (Kubena et al., 1990).

Conditions that are favorable for fungal growth and mycotoxin production may also occur while ingredients are in storage. The best way to prevent this problem is to keep the moisture level of ingredients low enough to inhibit fungal growth. In some instances, antifungal additives may be used to prevent fungal growth in feed or ingredients.

Several classes of mycotoxins are known to cause economic losses in poultry. The first to be identified was aflatoxins. These are produced by some strains of the fungi *Aspergillus flavus, A. paraciticus* , and *A. nomius*. Aflatoxins have been labeled B_1, B_2, G_1, and G_2. Conditions appropriate for the production of aflatoxin are more commonly encountered in the southeastern or central part of the United States or where the leaf canopy maintains high moisture content at the plant level.

Aflatoxins can produce a variety of effects. Broilers show decreased growth and increased kilogram feed:gain ratios when fed 2.5 mg of aflatoxin per kilogram but not when fed 1.25 mg/kg (Smith and

Hamilton, 1970). When hens were fed diets with approximately 90 mg of aflatoxin per kilogram, egg production decreased quickly and a high rate of mortality ensued (Hamilton, 1971). At a level of 1.5 mg/kg feed, aflatoxins caused fatty livers, necrosis, and bile duct hyperplasia (Carnaghan et al., 1966). Hematological responses such as lowered serum protein, reduced hemoglobin, and lower levels of serum triglycerides, phospholipids, and cholesterol result from moderate aflatoxin doses (Tung et al., 1972).

Fusarium moniliforme is a fungus that may grow on grains. It is found to produce a thiaminase causing thiamin deficiency in chicks (Fritz et al., 1973). Mortality is increased if additional thiamin is not supplied in contaminated diets. Corn shown to contain *F. moniliforme* causes substantial mortality when fed to ducklings (Jeschke et al., 1987).

Tricothecenes constitute another group of fungal compounds that may decrease the performance of poultry. These compounds may be produced by several genera of fungi but are most commonly metabolites of *Fusarium* . Laboratory studies have shown that T-2 toxin at levels up to 20 mg/kg of diet may decrease weight gain and egg production (Wyatt et al., 1973b, 1975). Oral lesions and digestive disturbances are caused by toxic concentrations of T-2.

Other tricothecenes produced by *Fusarium* are deoxynivalenol (DON), nivalenol, and diacetylnivalenol. These toxins appear to be more toxic to swine, in which they may cause vomiting and feed refusal (Morehouse, 1985), than to poultry. Adverse effects of *Fusarium* toxins on turkey reproduction have been reported (Allen et al., 1983).

Mycotoxins such as ochratoxin A and zearalenone have also been identified and may cause deleterious effects on poultry. A review of their effects was done by the Council for Agricultural Science and Technology (1989).

10

Standard Reference Diets for Chicks

Many laboratories that use Leghorn- or meat-type chicks for studies in animal behavior, biochemistry, microbiology, nutrition, pathology, physiology, and toxicology need nutritionally complete standard reference diets. The use of standard reference diets that are well defined facilitates more valid comparison of information obtained from experiments conducted within and among laboratories. The diets shown in Table 10-1 have been used successfully in various laboratories and are presented as guides to those requiring such formulations. The isolated soybean protein, casein, and chemically defined diets contain some mineral and vitamin supplements not normally needed in practical diets.

Dextrose (glucose·H_2O) rather than starch should be used in diets consisting primarily of purified intact proteins (such as isolated soy protein and casein) to obtain improved performance. Diets containing substantial quantities of dextrose and crystalline amino acids should be stored under refrigeration to minimize Maillard or Browning reactions. These chemically defined diets are intended for short-term use (1 to 3 weeks) and will not support maximum growth over an extended period of time.

TABLE 10-1 Formulas for Reference Diets for Chicks

Ingredient	Practical Diet[a]	Soy Isolate Diet[b]	Chemically Casein Diet[c]	Chemically Defined Diet I[d]	Defined Diet II[e]
Ground yellow corn (8.8% protein)(g/kg)	580	—	—	—	—
Soybean meal (48.5% protein)(g/kg)	350	—	—	—	—
Isolated soybean protein (g/kg)	—	250	—	—	—
Casein (g/kg)	—	—	200	—	—
DL-Methionine (g/kg)	2.5	6	5	—	—
L-Arginine (g/kg)	—	—	10	—	—
Glycine (g/kg)	—	4	20	—	—
Crystalline amino acids (g/kg)	—	—	—	204.8[f]	286[g]
Corn oil (g/kg)	30	40	30	50–150	150
Starch (g/kg)	6.5–1 kg	—	—	558–1 kg	205
Dextrose (g/kg)	—	6.08–1 kg	678–1 kg	—	—
Sucrose (g/kg)	—	—	—	154	
Cellulose (g/kg)	—	30	—	30	30
Sawdust (g/kg)	—	—	—	—	100
Choline chloride (100%) (g/kg)	0.75	2	2	2	1.625
Thiamin HCl (mg/kg)	1.8	15	20	20	1.6
Riboflavin (mg/kg)	3.6	15	10	10	5
Calcium pantothenate (mg/kg)	10	20	30	30	15
Niacin (mg/kg)	25	50	50	50	35
Pyridoxine HCl (mg/kg)	3	7.8	6	6	6
Folacin (mg/kg)	0.55	6	4	4	1.5
Biotin (mg/kg)	0.15	0.6	0.6	0.6	0.1
Vitamin B_{12} (mg/kg)	0.0	0.02	0.04	0.04	0.03
Inositol (mg/kg)	—	—	100	100	100
Para-aminobenzoic acid (mg/kg)	—	—	2	2	2
Ascorbic acid (mg/kg)	—	—	250	250	—
Vitamin A (IU/kg)	1,500	4,500	5,200	5,200	1,880
Vitamin D_3 (ICU/kg)	400	450	600	600	375
Vitamin E (IU/kg)	10	50	20	20	31.3
Vitamin K (mg/kg)	0.55	1.5	2	2	1.3
Antioxidant (mg/kg)[h]	125	100	—	12-5	—
Iodized salt (g/kg)	5	—	—	—	—
NaCl (g/kg)	—	6	8.8	8.8	2.75
$CaCO_3$ (g/kg)	10	14.8	3	3	15
$CaHPO_4 \cdot 2H_2O$ (g/kg)	20	20.7	—	—	30
$Ca_3(PO_4)_2$ (g/kg)	—	—	28	28	—
$MgSO_4 \cdot 7H_2O$ (g/kg)	—	6	3.5	3.5	—
$MgCO_3$ (g/kg)	—	—	—	—	2.38
KH_2PO_4 (g/kg)	—	10	9	9	—
K_2CO_3 (g/kg)	—	—	—	—	5.25
$NaHCO_3$ (g/kg)	—	—	—	—	5
$Al(OH)_3$ (g/kg)	—	—	—	—	5
KCl (g/kg)	—	1	—	—	—
$MnSO_4 \cdot H_2O$ (mg/kg)	170	350	650	650	—
$MnCO_3$ (mg/kg)	—	—	—	—	91.5
$ZnSO_4 \cdot H_2O$ (mg/kg)	110	—	—	—	—
$ZnCO_3$ (mg/kg)	—	150	100	100	—
ZnO (mg/kg)	—	—	—	—	25
$Fe_2(SO_4)_3 \cdot 7H_2O$	—	500	—	—	250
Ferric citrate (mg/kg)	500	—	500	500	—
$CuSO_4 \cdot 5H_2O$ (mg/kg)	16	30	20	20	15.5
Na_2SeO_3 (mg/kg)	0.2	0.2	0.2	0.2	0.23
KI (mg/kg)	—	—	40	40	—
KIO_3 (mg/kg)	—	2	—	—	0.6
$CoCl_2$ (mg/kg)	—	1.7	—	—	—
$CoSO_4 \cdot 7H_2O$ (mg/kg)	—	—	1	1	1
H_3BO_3 (mg/kg)	—	—	9	9	9
$Na_2MoO_4 \cdot 2H_2O$ (mg/kg)	—	8.3	9	9	2.5

NOTE: Dash indicates a zero value for the ingredient.

[a] National Research Council (1977).

[b] Scott et al., 1982.

[c] Halpin and Baker, 1986.

[d] Baker et al., 1979. The vitamin mix shown in the table differs slightly from the one in the cited reference because of modification in recent years.

[e] Blair et al., 1977.

[f] 11.5 g L-arginine • HCl, 4.5 g L-histidine HCl • H_2O, 11.4 g L-lysine HCl, 4.5 g L-tyrosine, 1.5 g L-tryptophan, 5 g L-phenylalanine, 3.5 g DL-methionine, 3.5 g L-cystine, 6.5 g L-threonine, 10 g L-leucine, 6 g L-isoleucine, 6.9 g L-valine, 6 g glycine, 4 g L-proline, 120 g L-glutamic acid.

[g] 16.9 g L-arginine, 14.1 g glycine, 5.6 g L-histidine, 11.3 g L-isoleucine, 19.7 g L-leucine, 17.6 g L-lysine • HCl, 7.8 g DL-methionine, 2.0 g L-cystine, 9.9 g L-phenylalanine, 9.9 g L-tyrosine, 2.8 g L-tryptophan, 9.9 g L-threonine, 12.1 g L-valine, 36.2 g L-aspartic acid, 100 g L-glutamic acid, 9.9 g L-proline.

[h] Ethoxyquin or butylated hydroxy toluene.

Appendixes

TABLE A–1 Documentation of Nutrient Requirements of Starting and Growing Leghorn—Type Chickens

Nutrient and Estimated Requirement	Age Period (Days)	Response Criteria	Breed	References
Protein, %				
20	0–14	Growth	White Leghorn	Grau and Kamei, 1950
21.1	0–42	Growth	White Leghorn and Rhode Island Red	Edwards et al., 1956
14–20	84–140	Growth	White Leghorn	McNaughton et al., 1977b
15–18	0–42	Growth	White Leghorn	McNaughton et al., 1977b
12	0–56	Growth	White Leghorn	Leeson and Summers, 1979
16	56–84	Growth	White Leghorn	Leeson and Summers, 1979
19	84–104	Growth	White Leghorn	Leeson and Summers, 1979
14 and 21	56–140	Growth	White Leghorn	Douglas and Harms, 1982
12 or 13.6	0–42	Growth	Commercial brown-egg layers	Maurice et al., 1982
16 or 13.6	42–140	Growth	Commercial brown-egg layers	Maurice et al., 1982
18	0–28	Growth of muscle fiber	White Leghorn	Timson et al., 1983
18	0–42	Growth	White Leghorn	Keshavarz, 1984
12	42–140	Growth	White Leghorn	Keshavarz, 1984
16.5	140–504	Laying	White Leghorn	Keshavarz, 1984
22	0–28	Growth	White Leghorn	Leeson and Summers, 1984
18	0–140	Growth	White Leghorn	Chi, 1985
Isoleucine, %				
0.5	8–18	Growth	White Leghorn	Mori and Okumura, 1984
Leucine, %				
1.2	8–18	Growth	White Leghorn	Mori and Okumura, 1984
Lysine, %				
0.9–1.1	0–42	Growth	White Leghorn	Edwards et al., 1956
0.94	1–21	Growth, feed efficiency	White Leghorn	Chung et al., 1973
0.70	35–49	Growth, feed efficiency	White Leghorn	Chung et al., 1973
<0.5	56–98	Growth	White Leghorn	Berg, 1976
<0.45	98–147	Growth	White Leghorn	Berg, 1976
0.68	0–504	Growth, egg production	White Leghorn	Keshavarz, 1984
Methionine, %				
0.8	0–14	Growth	White Leghorn	Grau and Kamei, 1950
Methionine and cystine, %				
0.8	0–14	Growth	White Leghorn	Grau and Kamei, 1950
0.59	0–504	Growth, laying	White Leghorn	Keshavarz, 1984
0.45	0–42	Growth	White Leghorn	Chi, 1985
Threonine, %				
0.72	7–21	Growth, feed efficiency	White Leghorn	Davis and Austic, 1982
Valine, %				
0.8	8–18	Growth	White Leghorn	Mori and Okumura, 1984
Requirements for essential amino acids described in review papers	Various	Growth	Primarily White Leghorn	Almquist, 1952
Requirements for essential amino acids described in review papers	Various	Growth	White Leghorn	Waldroup et al., 1980
Requirements for essential amino acids described in review papers	Various	Growth, egg production	White Leghorn	Harms, 1984
Calcium				
0.78	0–153	Growth	White Leghorn	Hamilton and Cipera, 1981
3.19	154–439	Egg production	White Leghorn	Hamilton and Cipera, 1981
0.89	35–126	Growth	White Leghorn	Classen and Scott, 1982
2.08	12–154	Growth, subsequent egg production	White Leghorn	Classen and Scott, 1982
3.50	177–225	Egg production	White Leghorn	Classen and Scott, 1982
2.0–3.5	At 133 to 4th egg	Growth, bone development	White Leghorn	Leeson et al., 1986
0.8	98–140	Growth, subsequent egg production	White Leghorn	Keshavarz, 1987
3.5	98–140	Egg production	White Leghorn	Keshavarz, 1987
3.55	140–420	Egg production	White Leghorn	Keshavarz, 1987
4.0	>112	Egg production	White Leghorn	Leeson and Summers, 1987b
Nonphytate phosphorus, %				
0.4–0.6	7–28	Growth	White Leghorn	Gillis et al., 1949
0.25–0.30	0–140	Growth	Brown-egg layers	Carew and Foss, 1980
0.31	112–140	Growth	White Leghorn	Douglas and Harms, 1986

Nutrient and Estimated Requirement	Age Period (Days)	Response Criteria	Breed	References
Potassium, %				
0.20–0.24	0–28	Growth, bone calcification	White Leghorn	Gillis, 1948
Sodium, %				
0.10–0.30	0–28	Growth	White Leghorn	Burns et al., 1953
0.13	0–21	Growth	White Rock	Hurwitz et al., 1973
0.15	0–140	Growth	White Leghorn	Manning and McGinnis, 1980
Chlorine, %				
0.13	0–14	Growth, feed efficiency	Broiler Strain	Nam and McGinnis, 1981
Sodium chloride, %				
0.25	0–140	Growth, sexual maturity	White Leghorn	Leeson and Summers, 1980
Magnesium, mg/kg				
300	0–28	Deficiency, neuropathy	White Leghorn	Bird, 1949
250	0–28	Growth	Broiler strain	Gardiner et al., 1960
594	0–21	Growth	White Rock	Nugara and Edwards, 1963
Manganese, mg/kg				
50	0–140	Growth, perosis	New Hampshire	Gallup and Norris, 1939a
20	0–28	Growth	White Leghorn	Watson et al., 1971
Zinc, mg/kg				
35	0–42	Growth, feathering, bone development	White Rock	O'Dell et al., 1958
20	0–42	Growth	White Rock	Edwards et al., 1959
20	To 1st egg	Growth, feed efficiency	White Leghorn	Rahman et al., 1961
78	0–7	Growth, feathering	White Leghorn	Sunde, 1972
52	7–21	Growth, feathering	White Leghorn	Sunde, 1972
Iron, mg/kg				
40	0–56	Growth	Rhode Island Red	Hill and Matrone, 1961
4	0–56	Growth	Rhode Island Red	Hill and Matrone, 1961
56	0–21	Growth, feed efficiency	Broiler strain	Waddell and Sell, 1964
75–80	0–28	Growth	New Hampshire	Davis et al., 1968
Copper, mg/kg				
4	0–56	Growth	Rhode Island Red	Hill and Matrone, 1961
Iodine, mg/kg				
0.300	0–56	Growth, thyoid histology	White Leghorn and Broiler strains	Creek et al., 1957
0.400	0–56	Growth, thyoid histology	White Leghorn and Broiler strains	Creek et al., 1957
0.075	0–35	Growth	Broiler strain	Rogler and Parker, 1978
Selenium, mg/kg				
0.01 to 0.05, depending on dietary concentration of Vitamin E	0–24	Growth	Plymouth Rock	Thompson and Scott, 1969
0.01 to 0.05, depending on dietary concentration of Vitamin E	0–14	Growth	Plymouth Rock	Gries and Scott, 1972c
Vitamin A, IU/kg				
800–1600	0–56	Growth, absence of deficiency signs	White Leghorn	Record et al., 1937
1,200–2,000	70–84	Curative feeding	White Leghorn	Record et al., 1937
2,650	0–189	Growth	White Leghorn	Taylor and Russell, 1947
1,760–7,000	0–56	Growth	White Leghorn	Thornton and Whittet, 1962
4,400	0–113	Growth, E. *acervulina* resistance	White Leghorn	Coles et al., 1970
Vitamin D_3 IU/kg				
180	0–84	Growth, bone development	Brown-egg layers	Baird and Greene, 1935
132	0–21	Growth, bone development	Broiler strain	McNaughton et al., 1977a
198	0–21	Growth, bone development	Broiler strain	McNaughton et al., 1977a
500	Adults	Egg production, shell quality	Various strains	Ameenuddin et al., 1985

Nutrient and Estimated Requirement	Age Period (Days)	Response Criteria	Breed	References
Vitamin E, IU/kg				
60	Various	To prevent exudative diathesis, encephalomalacia, muscular degeneration	Various strains	Machlin and Gordon, 1962
30–50	0–35	Growth	White Rock	Combs and Scott, 1974
Vitamin K, mg/kg				
0.524–0.528	0–28	Growth	White Rock	Nelson and Norris, 1960
0.515	0–84	Growth	White Rock	Nelson and Norris, 1961a
0.524–0.528	0–28	Growth	White Rock	Nelson and Norris, 1961b
Riboflavin, mg/kg				
3.5 decreasing to 1.0	0–7	Growth	White Leghorn	Heuser et al., 1938
3.5 decreasing to 1.0	49–56	Growth	White Leghorn	Heuser et al., 1938
3	0–56	Growth, prevention of curled toe paralysis	White Leghorn	Bethke and Record, 1942
2.3	0–42	Growth, prevention of curled toe paralysis	White Leghorn	Bootwalla and Harms, 1990
Pantothenic acid, mg/kg				
6	0–42	Growth	White Leghorn	Bauernfeind et al., 1942
6.6	0–150	Growth, egg quality, hatchability	New Hampshire	Balloun and Phillips, 1957b
4.8	0–42	Growth	White Leghorn	Bootwalla and Harms, 1991
Niacin, mg/kg				
28	0–56	Growth	Barred Plymouth Rock	Childs et al., 1952
1.8	42–77	Growth	White Leghorn	Sunde, 1955
17.5–20	0–28	Growth	White Leghorn	Patterson et al., 1956
Vitamin B_{12}, mg/kg				
4.4	0–77	Growth	White Leghorn	Davis and Briggs, 1951
27	0–23	Growth	White Leghorn	Ott, 1951
2.5	0–42	Growth	White Leghorn	Miller et al., 1956
10	0–21	Growth	White Leghorn	Patel and McGinnis, 1980
Choline, mg/kg				
2,000	0–147	Growth, egg production	White Leghorn	Nesheim et al., 1971
1,000	0–126	Growth	White Leghorn	Tsiagbe et al., 1982
Biotin, µg/kg				
260	0–18	Growth, feed efficiency	Broiler strain	Anderson and Warnick, 1970
Folic Acid, mg/kg				
0.80	0–35	Growth, feed efficiency	White Leghorn	March and Biely, 1955
0.30	0–28	Growth	Broiler strain	Young et al., 1955
0.33 to 1.45, depending on protein level	0–35	Growth	New Hampshire	March and Biely, 1956
0.30	0–18	Growth	Broiler strain	Creek and Vasaitis, 1963
Thiamine, mg/kg				
0.6–0.8	0–35	Growth	White Leghorn	Arnold and Elvehjem, 1938
0.88	0–28	Growth	White Leghorn	Thornton, 1960
0.88	0–28	Gain, feed efficiency	White Leghorn	Thornton and Shutze, 1960
Pyridoxine, mg/kg				
2.8–3.0	0–28	Growth	White Leghorn	Briggs et al., 1942
5.7	0–56	Growth	White Plymouth Rock	Fuller and Kifer, 1959
5	0–21	Growth	Broiler strain	Kazemi and Kratzer, 1980

TABLE A–2 Documentation of Nutrient Requirements of Leghorn—Type Chickens in Egg Production

Nutrient and Estimated Requirement	Age Period (Weeks)	Response Criteria	Breed	References
Protein, g/bird daily				
14.9	24–60	Egg yield	White Leghorn	Balloun and Speers, 1969
14	24–72	Egg yield	White Leghorn	Thayer et al., 1974
15	20–72	Egg yield	White Leghorn	Proudfoot et al., 1988
Arginine, mg/bird daily				
400	Not specified	Egg yield	White Leghorn	Adkins et al., 1962
Isoleucine, mg/bird daily				
475	Not specified	Egg yield	White Leghorn	Bray, 1969
650	Not specified	Egg yield	White Leghorn	Gous et al., 1987
Lysine, mg/bird daily				
690	22–42	Egg yield	White Leghorn	Nathanael and Sell, 1980
650	24–72	Egg yield	White Leghorn	Latshaw, 1981
620	20–72	Egg yield	White Leghorn	Proudfoot et al., 1988
Methionine + cystine, mg/bird daily				
500	20 from onset of lay	Egg yield	White Leghorn	Reid and Weber, 1973
530	24–72	Egg yield	White Leghorn	Latshaw, 1981
Threonine, mg/bird daily				
400	Not specified	Egg yield	White Leghorn	Adkins et al., 1958
Tryptophan, mg/bird daily				
165	20–76	Egg yield	White Leghorn	Wethli and Morris, 1978
239	20–76	Egg yield	Rhode Island Red	Ohtani et al., 1989
Valine, %				
0.64	Not specified	Egg yield	Crossbreds	Hurwitz and Bornstein, 1978
Linoleic acid, %				
2.0	22–54	Egg production	White Leghorn	Menge, 1970
1.0	22–54	Egg weight	White Leghorn	Menge, 1970
1.0	22–54	Hatch	White Leghorn	Menge, 1970
0.9	20–72	Egg weight	White Leghorn	Whitehead, 1981
Calcium, g/bird daily				
3.12	48–55	Egg production, shell strength	White Leghorn	Atteh and Leeson, 1983
3.15	24–72	Egg production	White Leghorn	Scheideler and Sell, 1986
>2.8	54–58	Egg production, shell strength	White Leghorn	Austic and Keshavarz, 1988
Nonphytate Phosphorus, mg/bird daily				
215	28–36	Egg production	White Leghorn	Miles et al., 1983
250	21–32	Egg production	White Leghorn	Said and Sullivan, 1985
250	35–51	Egg production	White Leghorn	Sell et al., 1987
>150	52–72	Egg production	White Leghorn	Sell et al., 1987
Potassium, %				
0.10	12	Egg production, egg weight, shell thickness	White Leghorn	Leach, 1974
Sodium, mg/bird daily				
140–150	20–48	Egg production, feed conversion	White Leghorn	Reid, 1977
130	21–45	Egg yield	Medium weight brown-egg layers	Sauveur and Mongin, 1978
Chlorine, mg/bird daily				
132	Not specified	Egg production	White Leghorn	Vogt, 1977
Magnesium, mg/kg				
350	25–31	Egg production, egg weight	White Leghorn	Cox and Sell, 1967
900	Not specified	Egg production	White Leghorn	Edwards and Nugara, 1968
355	30–38	Egg production, hatchability	White Leghorn	Hajj and Sell, 1969
Managenese, mg/kg				
>13	21–33	Egg production, hatchability	New Hampshire	Gallup and Norris, 1939b
20	22	Egg production, egg weight, shell quality	White Leghorn	Cox and Balloun, 1969
>7	17–23	Shell quality	White Leghorn	Longstaff and Hill, 1971
Zinc, mg/kg				
28	22–72	Egg yield, hatchability	White Leghorn	Stahl et al., 1986
54	Not specified	Feather condition of progeny	White Leghorn	Stahl et al., 1986
Iron, mg/kg				
45	Not specified	Hematocrit	White Leghorn	Morck and Austic, 1981
55	Not specified	Hatchability	White Leghorn	Morck and Austic, 1981

Nutrient and Estimated Requirement	Age Period (Weeks)	Response Criteria	Breed	References
Copper, mg/kg				
>1	44–48	Shell quality	White Leghorn	Baumgartner et al., 1978
<2.5	44–48	Shell quality	White Leghorn	Baumgartner et al., 1978
Iodine, µg/kg				
35	4–45	Hatchability	White Leghorn	Rogler et al., 1959a
>75	4–45	Embryonic thyroid	White Leghorn	Rogler et al., 1959b
Selenium, mg/kg				
0.05	32–56	Egg production	White Leghorn	Latshaw et al., 1977
0.05	32–57	Egg production, hatchability	White Leghorn	Combs and Scott, 1979
Vitamin A, IU/kg				
3,520	26–70	Egg production, blood spots, hatchability	White Leghorn	Hill et al., 1961
2,750	20–64	Egg production, fertility, hatchability	White Leghorn	Reid et al., 1965
Vitamin D_3, IU/kg				
150	21–34	Egg production, shell quality, fertility, hatchability	White Leghorn	Abdurahim et al., 1979
250	30–46	Egg production, shell quality	White Leghorn	Shen et al., 1981
Vitamin E, IU/kg				
12	Not specified	Hatchability	White Leghorn	Jensen and McGinnis, 1960
41 in presence of oxidized fat	Not specified	Hatchability	White Leghorn	Olson et al., 1962
Vitamin K, mg/kg				
>1.0	Not specified	Hatchability	White Leghorn	Griminger, 1964
Riboflavin, mg/kg				
2.5	30–45	Egg production	White Leghorn	Petersen et al., 1947a
3.6	30–45	Hatchability, chick quality	White Leghorn	Petersen et al., 1947b
Pantothenic acid, mg/kg				
6.5	Not specified	Hatchability	White Leghorn	Gillis et al., 1948
7	Not specified	Hatchability	New Hampshire	Balloun and Phillips, 1957a
1.9	28–53	Egg production	White Leghorn	Beer et al., 1963
4.9	28–53	Hatchability	White Leghorn	Beer et al., 1963
8.9	28–53	Viability of progeny	White Leghorn	Beer et al., 1963
Niacin, mg/kg				
9	Not specified	Egg production, hatchability	White Leghorn	Ringrose et al., 1965
11	Not specified	Egg production, hatchability	White Leghorn	Ringrose et al., 1965
<21	41–57	Egg yield, hatchability	White Leghorn	Ouart et al., 1987
Vitamin B_{12}, *µg/kg*				
1.0	22–35	Hatchability	White Leghorn	Mariakulandai and McGinnis, 1953
1–2	Not specified	Hatchability	New Hampshire	Johnson, 1954
0.5–1.0	Not specified	Hatchability	White Leghorn	Chin et al., 1958
Choline, mg/kg				
1,050	50–66	Egg yield	White Leghorn	Miles et al., 1986
<1,480	45–57	Egg yield	White Leghorn	Parsons and Leeper, 1984
1,000	32–52	Egg yield	White Leghorn	Keshavarz and Austic, 1985
Biotin, mg/kg				
0.10	19–73	Egg production	White Leghorn	Whitehead, 1980
Folic acid, mg/kg				
0.5	44–55	Egg production, hatchability	White Leghorn	Sunde et al., 1950a,b
0.2	Not specified	Hatchability	White Leghorn	Couch and German, 1950
Thiamin, mg/kg				
0.68	Not specified	Hatchability	White Leghorn	Polin et al., 1963
Pyridoxine, mg/kg				
2.5	Not specified	Egg production, hatchability	White Leghorn	Cravens et al., 1946
2.3	Not specified	Egg production, hatchability	White Leghorn	Fuller et al., 1961
4.5	Not specified	Egg production, hatchability	White Leghorn	Fuller et al., 1961

TABLE A-3 Documentation of Nutrient Requirements of Starting and Growing Market Broilers

Nutrient and Estimated Requirement	Age Period (Days)	Response Criteria	Breed	References
Arginine, %				
1.2	10–20	Growth	Not specified	Almquist, 1947
≤1.11	7–21	Growth, feed efficiency	New Hampshire × Columbian	Snyder et al., 1956
≤0.85	7–28	Growth, feed efficiency	Barred Plymouth Rock	Krautmann et al., 1957
1.08	7–14	Growth, feed efficiency	Not specified	Klain et al., 1960
0.92	7–21	Growth, feed efficiency nitrogen balance (adjusted to 23% crude protein diet	White Plymouth Rock × Light Sussex	Lewis et al., 1963
1.10	7–14	Growth, feed efficiency	New Hampshire × Columbian	Dean and Scott, 1965
0.78	7–14	Growth, feed efficiency	New Hampshire × Columbian	Allen and Baker, 1972
0.85	7–21	Growth, feed efficiency	Broiler strain	Hewitt and Lewis, 1972
≤0.76	14–28	Growth, feed efficiency	Not specified	Woodham and Deans, 1975
1.13, males	28–49	Growth, feed efficiency, feather loss	Hubbard × Hubbard	Kessler and Thomas, 1976
0.98, females	28–49	Growth, feed efficiency, feather loss	Hubbard × Hubbard	Kessler and Thomas, 1976
1.33	7–14	Computer model	Not specified	Hurwitz et al., 1978
1.19	14–21	Computer model	Not specified	Hurwitz et al., 1978
1.16	21–28	Computer model	Not specified	Hurwitz et al., 1978
1.10	28–35	Computer model	Not specified	Hurwitz et al., 1978
0.99	35–42	Computer model	Not specified	Hurwitz et al., 1978
0.96	42–49	Computer model	Not specified	Hurwitz et al., 1978
1.05	49–56	Computer model	Not specified	Hurwitz et al., 1978
1.4	1–28	Growth, feed efficiency	Broiler strain	Burton and Waldroup, 1979
1.25	8–29	Growth, feed efficiency	Vedette ISA	Alimentation Equilibree Commentri, 1981
0.91	29–50	Growth, feed efficiency	Vedette ISA	Alimentation Equilibree Commentri, 1981
1.25	0–21	Growth, feed efficiency	Peterson × Arbor Acre	Cuca and Jensen, 1990
Glycine + serine, %				
1.6	8–16	Growth, feed efficiency	New Hampshire × Columbian	Dean and Scott, 1965
≤0.3	8–16	Growth, feed efficiency	New Hampshire × Columbian	Baker et al., 1968
0.5–1.0	1–10	Growth, feed efficiency	Cobb	Coon et al., 1974
≤1.8	1–23	Growth, feed efficiency	Not specified	Ngo and Coon, 1976
0.60	8–16	Growth, feed efficiency	New Hampshire × Columbian	Baker et al., 1979
Histidine, %				
0.4	8–13 or 15	Growth, feed efficiency	New Hampshire × Columbian	Klain et al., 1960
0.3	8–16	Growth, feed efficiency	New Hampshire × Columbian	Dean and Scott, 1965
≤0.34	14–28	Total protein efficiency	Ross	Woodham and Deans, 1975
0.33	8–16	Growth, feed efficiency	New Hampshire × Columbian	Baker et al., 1979
0.32	8–22	Growth	New Hampshire × Columbian	Han et al., 1991
Isoleucine, %				
0.60	10–24	Growth	Not specified	Almquist, 1947
0.73	8–15	Growth	New Hampshire × Columbian	Klain et al., 1960
0.80	8–16	Growth	New Hampshire × Columbian	Dean and Scott, 1965
≤0.52	7–21	Growth, plasma amino acid levels	Not specified	D'Mello, 1974
0.48	14–28	Total protein efficiency	Ross	Woodham and Deans, 1975
0.60	8–16	Growth, feed efficiency	New Hampshire × Columbian	Baker et. al., 1979
0.81	7–21	Growth, feed efficiency	Ross × Arbor Acre	Farran and Thomas, 1990
Leucine, %				
1.4	10 or 24	Growth	Not specified	Almquist, 1947
1.68	8–13 or 15	Growth, feed efficiency	New Hampshire × Columbian	Klain et. al., 1960
1.2	8–16	Growth, feed efficiency	New Hampshire × Columbian	Dean and Scott, 1965
1.10	7–21	Growth, plasma amino acid levels	Not specified	D'Mello, 1974
≤1.05	14–28	Total protein efficiency	Ross	Woodham and Deans, 1975
1.00	8–16	Growth, feed efficiency	New Hampshire × Columbian	Baker et al., 1979
1.16	7–21	Growth, feed efficiency	Ross × Arbor Acre	Farran and Thomas, 1990
Lysine, %				
0.90	2–14	Growth	Not specified	Almquist and Mecchi, 1942
0.96	14–28	Growth	Not specified	Grau et al., 1946
0.90	10–20	Growth	Not specified	Almquist, 1947
1.00	0–42	Growth	Rhode Island Red × White Leghorn	Milligan et al., 1951
0.72	56–63	Growth, feed efficiency	Rhode Island Red	Bird, 1953
1.10	1–28	Growth, feed efficiency	Rhode Island Red × Barred Plymouth Rock	Edwards et al., 1956
1.01	7–14	Growth, feed efficiency	Not specified	Klain et al., 1960
0.83	7–14	Growth, feed efficiency, plasma amino acids	New Hampshire × Columbian	Zimmerman and Scott, 1965

Nutrient and Estimated Requirement	Age Period (Days)	Response Criteria	Breed	References
0.70	14–21	Growth, feed efficiency, plasma amino acids	New Hampshire × Columbian	Zimmerman and Scott, 1965
0.67	21–28	Growth, feed efficiency, plasma amino acids	New Hampshire × Columbian	Zimmerman and Scott, 1965
0.59	28–35	Growth, feed efficiency, plasma amino acids	New Hampshire × Columbian	Zimmerman and Scott, 1965
0.92	35–56	Growth, feed efficiency	Broiler strain	Bornstein, 1970
0.85	7–21	Growth, feed efficiency	Broiler strain	Hewitt and Lewis, 1972
1.05	14–28	Growth, feed efficiency	New Hampshire × Columbian	Boomgaardt and Baker, 1973a
1.06	14–21	Growth, feed efficiency	New Hampshire × Columbian	Boomgaardt and Baker, 1973b
0.92	42–56	Growth, feed efficiency	New Hampshire × Columbian	Boomgaardt and Baker, 1973b
0.68	49–63	Growth, feed efficiency	Broiler strain	Twining et al., 1973
1.12	7–14	Growth, feed efficiency	Not specified	Woodham and Deans, 1975
0.64, females	49–63	Growth, feed efficiency	Vantress × Arbor Acre	Thomas et al., 1977
0.69, males	49–63	Growth, feed efficiency	Vantress × Arbor Acre	Thomas et al., 1977
1.18	7–14	Computer model	Not specified	Hurwitz et al., 1978
1.00	14–21	Computer model	Not specified	Hurwitz et al., 1978
0.95	21–28	Computer model	Not specified	Hurwitz et al., 1978
0.87	28–35	Computer model	Not specified	Hurwitz et al., 1978
0.78	35–42	Computer model	Not specified	Hurwitz et al., 1978
0.76	42–49	Computer model	Not specified	Hurwitz et al., 1978
0.84	49–56	Computer model	Not specified	Hurwitz et al., 1978
1.10	14–28	Growth, feed efficiency	Broiler strain	McNaughton et al., 1978
1.18	1–21	Growth, feed efficiency	Broiler strain	Attia and Latshaw, 1979
1.10	1–28	Growth, feed efficiency	Broiler strain	Burton and Waldroup, 1979
0.99	35–42	Growth, feed efficiency	Cornish × White Plymouth Rock	Holsheimer, 1981
Methionine, %				
0.50	10–20	Growth	Not specified	Almquist, 1947
0.45	7–14	Growth, feed efficiency	New Hampshire × Columbian	Dean and Scott, 1965
0.18	7–14	Growth, feed efficiency	Not specified	Klain et al., 1960
0.39	7–21	Growth, feed efficiency	Broiler strain	Hewitt and Lewis, 1972
0.39	7–14	Computer model	Not specified	Hurwitz et al., 1978
0.34	14–21	Computer model	Not specified	Hurwitz et al., 1978
0.34	21–28	Computer model	Not specified	Hurwitz et al., 1978
0.31	28–35	Computer model	Not specified	Hurwitz et al., 1978
0.27	35–42	Computer model	Not specified	Hurwitz et al., 1978
0.27	42–49	Computer model	Not specified	Hurwitz et al., 1978
0.29	49–56	Computer model	Not specified	Hurwitz et al., 1978
0.57	1–21	Growth, feed efficiency	Cobb	Waldroup et al., 1979
0.44	8–21	Growth, feed efficiency	New Hampshire × Columbian	Robbins and Baker, 1980a
0.46	1–14	Growth, feed efficiency, feathering	White Mountain × Hubbard	Moran, 1981
0.36, males	35–56	Growth, feed efficiency	White Mountain × Hubbard	Moran, 1981
0.29, females	35–49	Growth, feed efficiency	White Mountain × Hubbard	Moran, 1981
0.49	7–21	Growth, feed efficiency	Broiler strain	Thomas et al., 1985
0.55	1–21	Growth, feed efficiency	Broiler strain	Tillman and Pesti, 1985
Methionine + cystine, %				
0.90	10–20	Growth	Not specified	Almquist, 1947
0.80	7–14	Growth, feed efficiency	New Hampshire × Columbian	Dean and Scott, 1960
0.47	7–14	Growth, feed efficiency	New Hampshire × Columbian	Klain et al., 1960
0.70	0–42	Feed efficiency	Vantress × New Hampshire	Nelson et al., 1960
0.81	0–28	Feed efficiency	Vantress × New Hampshire	Nelson et al., 1960
0.5	28–56	Growth	Hubbard	Adams et al., 1962
>0.6–<0.7	28–56	Feed efficiency	Hubbard	Adams et al., 1963
0.81	0–35	Growth, feed efficiency	Cornish × White Plymouth Rock	Bornstein and Lipstein, 1964
0.90	0–35	Growth, feed efficiency	Cornish × White Plymouth Rock	Bornstein and Lipstein, 1964
0.67	35–56	Growth, feed efficiency	Cornish × White Plymouth Rock	Bornstein and Lipstein, 1966
0.60	7–14	Growth, feed efficiency	New Hampshire × Columbian	Graber et al., 1971
0.63	35–42	Growth, feed efficiency	New Hampshire × Columbian	Graber et al., 1971
0.65	49–56	Growth, feed efficiency	New Hampshire × Columbian	Graber et al., 1971
0.79	7–21	Growth, feed efficiency	Broiler strain	Hewitt and Lewis, 1972
0.70	14–21	Growth, feed efficiency	New Hampshire × Columbian	Boomgaardt and Baker, 1973b
0.51	42–56	Growth, feed efficiency	New Hampshire × Columbian	Boomgaardt and Baker, 1973b
0.92	8–21	Growth, feed efficiency, nitrogen retention	New Hampshire × Columbian	Boomgaardt and Baker, 1973c
0.58	14–28	Growth, feed efficiency	Not specified	Woodham and Deans, 1975
0.93	0–28	Growth, feed efficiency	Cobb	Murillo et al., 1976
0.61	35–49	Computer model	Not specified	Hurwitz et al., 1978
0.84	7–14	Computer model	Not specified	Hurwitz et al., 1978
0.78	14–21	Computer model	Not specified	Hurwitz et al., 1978
0.79	21–28	Computer model	Not specified	Hurwitz et al., 1978

Nutrient and Estimated Requirement	Age Period (Days)	Response Criteria	Breed	References
0.76	28–35	Computer model	Not specified	Hurwitz et al., 1978
0.68	35–42	Computer model	Not specified	Hurwitz et al., 1978
0.69	42–49	Computer model	Not specified	Hurwitz et al., 1978
0.39	49–56	Computer model	Not specified	Hurwitz et al., 1978
0.86	1–21	Growth, feed efficiency	Broiler strain	Attia and Latshaw, 1979
0.90	1–21	Growth, feed efficiency	Cobb	Waldroup et al., 1979
0.80	8–21	Growth, feed efficiency	New Hampshire × Columbian	Robbins and Baker, 1980a
0.52	8–21	Growth, feed efficiency	New Hampshire × Columbian	Robbins and Baker, 1980a
0.55	8–21	Growth, feed efficiency	Hubbard	Robbins and Baker, 1980b
0.57	8–16	Growth, feed efficiency	New Hampshire × Columbian	Willis and Baker, 1980
0.70	35–42	Growth, feed efficiency	Cornish × White Plymouth Rock	Holsheimer, 1981
0.87, males	1–14	Growth, feed efficiency, feathering	White Mountain × Hubbard	Moran, 1981
0.92, females	1–14	Growth, feed efficiency, feathering	White Mountain × Hubbard	Moran, 1981
0.81, males	35–52	Growth, feed efficiency, feathering	White Mountain × Hubbard	Moran, 1981
0.82	1–21	Growth, feed efficiency	Cobb	Wheeler and Latshaw, 1981
>0.70–<0.76	21–42	Growth, feed efficiency	Cobb	Wheeler and Latshaw, 1981
0.65	8–16	Growth, feed efficiency	New Hampshire × Columbian	Willis and Baker, 1981a
0.50	7–17	Growth, feed efficiency	New Hampshire × Columbian	Baker et al., 1983
0.87	7–24	Growth, feed efficiency	New Hampshire × Columbian	Baker et al., 1983
0.80	1–21	Growth, feed efficiency	Hubbard	Mitchell and Robbins, 1983
0.72	21–42	Growth, feed efficiency	Hubbard	Mitchell and Robbins, 1983
0.77	7–21	Growth, feed efficiency	Broiler strain	Thomas et al., 1985
0.78	21–42	Growth, feed efficiency, carcass fat	Peterson × Arbor Acres	Jensen et al., 1989
Phenylalanine + tyrosine, %				
1.6	10–20 or 40	Growth	Not specified	Almquist, 1947
≤1.0	4–10	Growth, feed efficiency	New Hampshire × Columbian	Fisher et al., 1957
1.30	8–13 or 15	Growth, feed efficiency	New Hampshire × Columbian	Klain et al., 1960
1.31	8–16	Growth, feed efficiency	New Hampshire × Columbian	Dean and Scott, 1965
0.87	8–14	Growth, feed efficiency	New Hampshire × Columbian	Sasse and Baker, 1972
1.09–1.12	14–28	Total protein efficiency	Ross	Woodham and Deans, 1975
0.95	8–16	Growth, feed efficiency	New Hampshire × Columbian	Baker et al., 1979
Threonine, %				
0.60	10–20	Growth, feed efficiency	Not specified	Almquist, 1947
0.45	1–14	Growth, feed efficiency	White Leghorn	Grau, 1947
0.55–0.60	7–21	Growth, feed efficiency	Barred Plymouth Rock	Krautmann et al., 1958
0.58	7–14	Growth, feed efficiency	Not specified	Klain et al., 1960
0.65	7–14	Growth, feed efficiency	New Hampshire × Columbian	Dean and Scott, 1965
0.70	1–18	Growth, feed efficiency	New Hampshire × White Leghorn	Bhargava et al., 1971
0.53	7–21	Growth, feed efficiency	Broiler strain	Hewitt and Lewis, 1972
0.52	14–28	Growth, feed efficiency	Not specified	Woodham and Deans, 1975
0.80	7–14	Computer model	Not specified	Hurwitz et al., 1978
0.71	14–21	Computer model	Not specified	Hurwitz et al., 1978
0.71	21–28	Computer model	Not specified	Hurwitz et al., 1978
0.67	28–35	Computer model	Not specified	Hurwitz et al., 1978
0.60	35–42	Computer model	Not specified	Hurwitz et al., 1978
0.60	42–49	Computer model	Not specified	Hurwitz et al., 1978
0.64	49–56	Computer model	Not specified	Hurwitz et al., 1978
0.73–0.75	1–21	Growth, feed efficiency	ISA JV 715	Uzu, 1986
0.68	22–42	Growth, feed efficiency	ISA JV 715	Uzu, 1986
0.85	3–14	Growth, feed efficiency (adjusted to 23% crude protein	Peterson	Robbins, 1987
0.72, males	7–21	Growth, feed efficiency	Broiler strain	Thomas et al., 1987
0.67, females	7–21	Growth, feed efficiency	Broiler strain	Thomas et al., 1987
0.79	1–27	Growth, feed efficiency	Hybro	Bertram et al., 1988
0.79	7–20	Growth, feed efficiency	Vantress × Arbor Acres	Smith and Waldroup, 1988a
0.70–0.77	1–14	Growth, feed efficiency	Broiler strain	Austic and Rangel-Lugo, 1989
Tryptophan, %				
0.25	10–20	Growth	Not specified	Almquist, 1947
0.18	10–24	Growth, feed efficiency	New Hampshire × White Leghorn	Wilkening et al., 1947
0.143	10–20	Growth, feed efficiency	New Hampshire × Columbian	Griminger et al., 1956
0.17	7–14	Growth, feed efficiency	Not specified	Klain et al., 1960
0.225	7–14	Growth, feed efficiency	New Hampshire × Columbian	Dean and Scott, 1965
0.20	8–14	Growth, feed efficiency (adjusted to 23% CP	New Hampshire × Columbian	Boomgaardt and Baker, 1971
0.17	7–21	Growth, feed efficiency	Broiler strain	Hewitt and Lewis, 1972

Nutrient and Estimated Requirement	Age Period (Days)	Response Criteria	Breed	References
≤0.14	14–28	Growth, feed efficiency	Not specified	Woodham and Deans, 1975
0.179	28–49	Growth, feed efficiency, feather scores	Arbor Acres	Hunchar and Thomas, 1976
0.163	7–14	Computer model	Not specified	Hurwitz et al., 1978
0.144	14–21	Computer model	Not specified	Hurwitz et al., 1978
0.141	21–28	Computer model	Not specified	Hurwitz et al., 1978
0.134	28–35	Computer model	Not specified	Hurwitz et al., 1978
0.118	35–42	Computer model	Not specified	Hurwitz et al., 1978
0.122	42–49	Computer model	Not specified	Hurwitz et al., 1978
0.128	49–56	Computer model	Not specified	Hurwitz et al., 1978
0.17	7–56	Growth	Cobb	Freeman, 1979
0.24	0–7	Growth, feed efficiency	Cobb	Freeman, 1979
0.19	7–34	Growth, feed efficiency	Lohmann	Steinhart and Kirchgessner, 1984
≤0.16	7–20	Growth, feed efficiency	Vantress × Arbor Acres	Smith and Waldroup, 1988b
0.22	8–22	Growth	New Hampshire × Columbian	Han et al., 1991
Valine, %				
0.80	10–20 or 24	Growth	Not specified	Almquist, 1947
0.83	8–13 or 15	Growth, feed efficiency	New Hampshire × Columbian	Klain et al., 1960
0.82	8–16	Growth, feed efficiency	New Hampshire × Columbian	Dean and Scott, 1965
0.75	7–21	Growth, plasma amino acid levels	Not specified	D'Mello, 1974
0.69–0.71	14–28	Total protein efficiency	Ross	Woodham and Deans, 1975
0.69	8–16	Growth, feed efficiency	New Hampshire × Columbian	Baker et al., 1979
>0.72	21–42	Feed efficiency, abdominal fat	Broiler strain	Mendonca and Jensen, 1989a
0.90	7–21	Growth, feed efficiency	Ross × Arbor Acres	Farran and Thomas, 1990
Proline, %				
≤0.5	9–15	Growth, feed efficiency	New Hampshire × Columbian	Green et al., 1962
0.4–0.8	8–14	Growth	New Hampshire × Columbian	Graber et al., 1970
0.40	8–16	Growth, feed efficiency	New Hampshire × Columbian	Baker et al., 1979
Linoleic, %				
	Varied cited in a review	Growth, tissue triene: tetraene ratio	Various	Balnave, 1970
Calcium, %				
0.90	29–56	Growth, feed efficiency	Broiler strain	Waldroup et al., 1963a
0.74	0–28	Growth, bone ash	Vantress × Arbor Acres	Twining et al., 1965
0.80	42–56	Growth, feed efficiency, bone ash	Vantress × Arbor Acres	Twining et al., 1965
0.80	28–56	Growth, feed efficiency, tibia ash, bone breaking force	Broiler strain	Waldroup et al., 1974a
1.30	0–21	Maximum toe ash	White Cornish × White Plymouth Rock	Yoshida and Hoshii, 1982a
1.18	21–56	Maximum toe ash	White Cornish × White Plymouth Rock	Yoshida and Hoshii, 1982b
Nonphytate phosphorus, %				
0.43	0–21	Growth, bone ash	New Hampshire × White Leghorn	O'Rourke et al., 1952
0.35	14–35	Growth, bone ash	New Hampshire × White Leghorn	O'Rourke et al., 1952
0.27	28–70	Growth, bone ash	New Hampshire × White Leghorn	O'Rourke et al., 1952
0.45	0–28	Growth, bone ash	Various	Almquist, 1954
0.55	0–21	Growth, bone ash	New Hampshire × White Leghorn	O'Rourke et al., 1955
0.33	28–70	Growth, bone ash	New Hampshire × White Leghorn	O'Rourke et al., 1955
0.45	0–28	Growth, bone ash, serum alkaline phosphates	Rhode Island Red	Gardiner, 1962
0.45	0–28	Growth, bone ash	Vantress × White Plymouth Rock	Waldroup et al., 1962
0.24	28–56	Growth, feed efficiency	Broiler strain	Waldroup et al., 1963a
0.39	0–28	Growth, bone ash	Broiler strain	Waldroup et al., 1963b
0.35	0–28	Growth, feed efficiency	Vantress × Arbor Acres	Twining et al., 1965
0.24	42–56	Growth, feed efficiency, bone ash	Vantress × Arbor Acres	Twining et al., 1965
0.43	0–21	Growth, bone ash	White Plymouth Rock	Fritz et al., 1969
0.24	28–56	Growth, feed efficiency, tibia ash, bone breaking force	Broiler strain	Waldroup et al., 1974a
0.53	0–28	Maximum bone ash	Broiler strain	Waldroup et al., 1975
0.35	28–56	Growth, feed efficiency	Hubbard	Sauveur, 1978
0.50	0–28	Growth, feed efficiency, bone ash	Broiler strain	El Boushy, 1979
0.50	8–22	Growth, feed efficiency, tibia ash	New Hampshire × Columbian	Willis and Baker, 1981b
0.75	0–21	Maximum toe ash	White Cornish × White Plymouth Rock	Yoshida and Hoshii, 1982a
0.35	21–56	Maximum toe ash	White Cornish × White Plymouth Rock	Yoshida and Hoshii, 1982b

Nutrient and Estimated Requirement	Age Period (Days)	Response Criteria	Breed	References
0.38	0–28	Growth, toe ash	Hubbard	Nys et al., 1983
0.29	35–53	Growth, feed efficiency, tibia ash, bone length	Broiler strain	Tortuero and Diez Tardon, 1983
Potassium, %				
0.25–0.30	13–41	Growth, mortality	Vantress × Plymouth Rock	Leach et al., 1959
Sodium, %				
0.11–0.20	1–28	Growth, feed efficiency	New Hampshire × Columbian	McWard and Scott, 1961a
0.13	7–23	Growth, blood pH	White Rock	Hurwitz et al., 1973
0.07	49–63	Growth, blood pH	White Rock	Hurwitz et al., 1974
>0.23	1–21	Growth	Broiler strain	Ross, 1977
0.2–0.25	7–21	Growth	Cobb × Hubbard	Ross, 1979
0.35	1–21	Growth	Peterson × Hubbard	Edwards, 1984
Chlorine, %				
0.315–0.340	2–28	Growth, mortality, blood chlorine	White Plymouth Rock	Leach and Nesheim, 1963
0.13	7–23	Growth, blood pH	White Rock	Hurwitz et al., 1973
0.07	49–63	Growth, blood pH	White Rock	Hurwitz et al., 1973
0.12	1–21	Growth, mortality	Ross	Gardiner and Dewar, 1976
0.42	1–21	Growth	Peterson × Hubbard	Edwards, 1984
Magnesium, mg/kg				
350–400	7–24	Growth	Not specified	Almquist, 1947
100–300	1–21	Growth, mortality	White Plymouth Rock	Edwards et al., 1960
250	1–28	Growth, blood magnesium, mortality	Vantress × Hubbard	Gardner et al., 1960
200	1–14	Growth, mortality	New Hampshire × Columbian	McWard and Scott, 1961b
577	1–21	Growth, mortality, bone magnesium	White Plymouth Rock	Nugara and Edwards, 1963
≤350	1–27	Growth, feed efficiency	New Hampshire × Columbian	Baker and Molitoris, 1975
Manganese, mg/kg				
50	1–42	Growth, perosis	New Hampshire	Gallup and Norris, 1939a
14	8–22	Growth	New Hampshire × Columbian	Southern and Baker, 1983a
Zinc, mg/kg				
35	12–26	Growth, feed efficiency	White Plymouth Rock	Morrison and Sarett, 1958
35	1–42	Growth, bone integrity	White Rock or Cornish × White Rock	O'Dell et al., 1958
30	1–28	Growth	White Meteor × White Rock	Roberson and Shaible, 1958
47–57	1–14	Growth, tibia ash	White Rock	Edwards et al., 1959
>52	1–28	Growth leg deformity	New Hampshire × Connecticut	Lease et al., 1960
>40 mg	1–28	Growth, hock enlargement	White Plymouth Rock	Zeigler et al., 1961
14	8–22	Growth	New Hampshire × Columbian	Southern and Baker, 1983b
18	1–21	Growth	Broiler strain	Dewar and Downie, 1984
>45	8–22	Tibia zinc	New Hampshire × Columbian	Wedekind et al., 1990
Iron, mg/kg				
56	7–21	Growth, blood hemoglobin, liver iron	Not specified	Waddel and Sell, 1964
75–80	1–28	Growth, blood hemoglobin	New Hampshire and Plymouth Rock	Davis et al., 1968
80	1–21	Growth, blood hemoglobin, packed cell volume	Not specified	McNaughton and Day, 1979
40	8–22	Growth, blood hemoglobin, hematocrit	New Hampshire × Columbian	Southern and Baker, 1982
Copper, mg/kg				
8	1–21	Growth, blood hemoglobin, packed cell volume	Not specified	McNaughton and Day, 1979
Iodine, mg/kg				
0.3–0.4	28–56	Growth, thyroid histology	Barred Plymouth Rock	Creek et al., 1957
Selenium, mg/kg				
>0.02 mg	1–24	Mortality, exudative diathesis	Plymouth Rock × Vantress	Thompson and Scott, 1969
0.1 mg	1–31	Pancreatic degeneration and fibrosis	White Plymouth Rock × Vantress	Gries and Scott, 1972c
>0.1 mg	1–63	Growth, glutathione peroxidase activity	Hubbard	Binnerts and El Boushy, 1985
0.14–0.17	1–21	Growth, plasma thyroid hormones	Hubbard and Arbor Acre	Jensen et al., 1986
Vitamin A, IU/kg				
2,200	Varied	Growth	Various	Almquist, 1953
1,320	1–28	Growth, feed efficiency	Columbian Rock	Olsen et al., 1959
≤1,100	7–63	Growth	Not specified	Marusich and Bauernfeind, 1963
900	1–56	Growth, incidence of coccidiosis	Broiler strain	Ogunmodede, 1981
Vitamin D_3, IU/kg				
200–396	1–28	Growth	Not specified	Waldroup et al., 1963a
198	1–28	Growth, tibia ash	Not specified	Waldroup et al., 1965
200	1–54	Growth, tibia ash	Not specified	Biely and March, 1967
≤200	1–14	Growth, bone mineralization	Not specified	McAuliffe et al., 1976

Nutrient and Estimated Requirement	Age Period (Days)	Response Criteria	Breed	References
198	1–21	Growth, tibia ash	Not specified	McNaughton et al., 1977a
400	1–56	Growth, tibia ash	Not specified	Lofton and Soares, 1986
Vitamin E, IU/kg				
15–24	1–28	Prevention of encephalomalacia	Barred Plymouth Rock × Rhode Island Red	Singsen et al., 1955
5–60	Varied, cited in a review	Encephalomalacia exudative diathesis, muscular degeneration	Various	Machlin and Gordon, 1962
5.4–7.4	2–33	Mortality, incidence of encephalomalacia	White Rock	Bartov and Bornstein, 1972
30–50	1–14 and 1–35	Growth, peroxidation in hepatic microsomes	Vantress × Plymouth Rock	Combs and Scott, 1974
Vitamin K, mg/kg				
0.588	1–14	Prothrombin time	White Plymouth Rock	Nelson and Norris, 1960
0.479	1–28	Prothrombin time	White Plymouth Rock	Nelson and Norris, 1960
0.515	1–84	Prothrombin time	White Plymouth Rock	Nelson and Norris, 1961a
0.500	1–14	Prothrombin time	White Plymouth Rock	Nelson and Norris, 1961b
0.370	1–28	Prothrombin time	White Plymouth Rock	Nelson and Norris, 1961b
Riboflavin, mg/kg				
2.5	1–56	Growth	Barred Rock × New Hampshire	Bethke and Record, 1942
3.0	14–42	Growth, feed efficiency	White Wyandotte	Bolton, 1944
3.0–3.5	14–42	Growth	White Wyandotte	Bolton, 1947
2.3	1–56	Growth	Hubbard × Arbor Acres	Wyatt et al., 1973a
5.1	1–56	Growth	Harco	Ogunmodede, 1977
3.6	1–21	Growth, feed efficiency	Cobb and Cobb × Arbor Acres	Ruiz and Harms, 1988b
2.6	8–22	Growth, leg paralysis	New Hampshire × Columbian	Chung and Baker, 1990
Pantothenic acid, mg/kg				
14	Not specified	Growth	Not specified	Jukes, 1939
10	Not specified	Growth	Not specified	Jukes and McElroy, 1943
5	Not specified	Growth	New Hampshire × Columbian	Staten et al., 1980
Niacin, mg/kg				
26–28	7–42	Growth, perosis	Barred Plymouth Rock	Childs et al., 1952
37	1–21	Growth	White Cornish	Yoshida et al., 1966
20	7–20	Growth, incidence of tongue lesions	New Hampshire × Columbian	Baker et al., 1973
≤22	8–50	Growth, feed efficiency	New Hampshire × Columbian	Yen et al., 1977
>55 mg	1–53	Growth, feed efficiency	Not specified	Waldroup et al., 1985b
28–36	1–21	Growth, leg disorders	Cobb	Ruiz and Harms, 1988
32	1–21	Growth, leg disorders	Arbor Acres × Cobb	Ruiz et al., 1990
≤22 mg	21–49	Growth	Cobb	Ruiz and Harms, 1990
Vitamin B_{12}, mg/kg				
0.01	7–29	Growth, energetic efficiency	Dominant White × White Plymouth Rock	Looi and Renner, 1974
≤0.01 mg	1–28	Growth, feed efficiency	Sussex × White Rock	Rys and Koreleski, 1974
Choline, mg/kg				
1,000	14–42	Growth, perosis	Barred Plymouth Rock	West et al., 1951
1,540–1,760	1–56	Growth, feed efficiency	White Rock	Quillen et al., 1961
1119	1–21	Growth	White Rock	Fritz et al., 1967
358	44–55	Growth	New Hampshire × Columbian	Molitoris and Baker, 1976
800	7–28	Growth	White Rock	Lipstein et al., 1977
≤1,171	7–35	Growth, perosis	Not specified	Derilo and Balnave, 1980
1,910–4,100	1–21	Growth, feed efficiency	Not specified	Pesti et al., 1980
1,200	8–25	Growth	New Hampshire × Columbian	Baker et al., 1983
625	8–17	Growth	New Hampshire × Columbian	Lowry et al., 1987
>1,300	1–21	Growth, feed efficiency	Not specified	Tsiagbe et al., 1987
Biotin, mg/kg				
>0.26 mg	1–25	Growth, mortality, leg abnormalities	Not specified	Anderson and Warnick, 1970
0.14	1–24	Growth, mortality due to fatty kidney liver syndrome	Not specified	Payne et al., 1974
0.14–0.18	1–35	Growth	Ross	Whitehead and Bannister, 1980
≤0.17–0.18	1–56	Incidence of fatty liver and kidney syndrome	Ross	Whitehead and Randall, 1982
≤0.20	1–21	Growth, leg disorders, dermatitis	Hubbard	Watkins, 1988
Folic acid, mg/kg				
≤0.5	1–28	Growth	Not specified	Saxena et al., 1954
≤0.3	1–21 and 1–28	Growth, perosis	Rhode Island Red × White Plymouth Rock	Young et al., 1955
0.40–0.65 mg	1–35	Growth	New Hampshire	March and Biely, 1956

Nutrient and Estimated Requirement	Age Period (Days)	Response Criteria	Breed	References
0.3–0.45 mg	1–20	Growth, perosis	Arbor Acres	Creek and Vasaitis, 1963
0.34–0.49 mg	1–28	Growth, leg abnormalities	Not specified	Saxena et al., 1954
Thiamin, mg/kg				
0.75	3–28	Growth, polyneuritis	New Hampshire × Delaware	Thornton 1960
1.0–1.3	Not specified	Growth, feed efficiency	New Hampshire × Delaware	Thornton and Shutze 1960
Pyridoxine, mg/kg				
3–5	12–42	Growth, perosis, anemia, dermatitis	White Rock	Hogan et al. 1941
2	7–28	Growth, feed efficiency	Not specified	Kratzer et al., 1947
<5.7	1–56	Growth, feed efficiency	White Plymouth Rock	Fuller and Kifer, 1959
3.3	1–14	Growth	White Plymouth Rock	Fuller and Dunahoo, 1959
2.2–2.6	1–28	Growth, gizzard erosion, serum glutamic oxaloacetic transaminase	Vantress × Arbor Acre	Daghir and Balloun, 1963
2.8–3.6	1–14 or 35	Growth, feed efficiency	Not specified	Kirchgessner and Friesecke, 1963
3	Not specified	Growth, feed efficiency	Not specified	Maier and Kirchgessner, 1968
>3.1	7–28	Growth, serum aspartate aminotransferase	Not specified	Daghir and Shah, 1973
3.2–3.4	1–28	Growth, perosis	White Plymouth Rock × Vantress	Gries and Scott, 1972a
≤1.0	1–20	Growth, feed efficiency	Ross	Lee et al., 1976
1.1	8–17	Growth	New Hampshire × Columbian	Yen et al., 1976
1.75	3–49	Growth, plasma amino acids	Not specified	aboaysha and Kratzer, 1979
1.3–2.7	1–21	Growth	Not specified	Kazemi and Kratzer, 1980
≤1.48	1–49	Growth	Not specified	Blalock et al., 1984

TABLE A-4 Documentation of Nutrient Requirements of Broiler Breeder Pullets and Hens

Nutrient and Estimated Requirement	Age Period (Weeks)	Response Criteria	Breed	References
Protein, g/bird daily				
20	24–52	Egg production, egg weight, body weight, liveability	Cobb	Waldroup et al., 1976b
15.6–16.5	Not specified	Estimated by model	Not specified	Bornstein et al., 1979
19.5	21–64	Egg production, egg weight, fertility	Marshall	Pearson and Herron, 1981
23.1	31–60	Egg yield	Tetra	Jeroch et al., 1982
19	19–40	Body weight, skeletal growth egg production, egg weight, hatchability	Hubbard	Spratt and Leeson, 1987
18–19	31–60	Egg production, egg weight, body weight, egg quality, hatchability	Tetra	Schloffel et al., 1988
Arginine, mg/bird daily				
1,111	Peak egg production	Body weight, egg mass	Mathematical model	Waldroup et al., 1976c
1,111	Peak egg production	Body weight, egg mass	Mathematical model	Bornstein et al., 1979
<1,226 mg	24–64	Egg production, egg weight, fertility, hatchability, egg specific gravity	Cobb	Wilson and Harms, 1984
Histidine, mg/bird daily				
209	Peak egg production	Body weight, egg mass	Mathematical model	Waldroup et al., 1976c
200	Peak egg production	Body weight, egg mass	Mathematical model	Bornstein et al., 1979
Isoleucine, mg/bird daily				
853	Peak egg production	Body weight, egg mass	Mathematical model	Waldroup et al., 1976c
850	Peak egg production	Body weight, egg mass	Mathematical model	Bornstein et al., 1979
Leucine, mg/bird daily				
1,247	Peak egg production	Body weight, egg mass	Mathematical model	Waldroup et al., 1976c
1,250	Peak egg production	Body weight, egg mass	Mathematical model	Bornstein et al., 1979
Lysine, mg/bird daily				
773	Peak egg production	Body weight, egg mass	Mathematical model	Waldroup et al., 1976c
760	Peak egg production	Body weight, egg mass	Mathematical model	Bornstein et al., 1979
<808	24–64	Egg production, egg weight, fertility, hatchability, egg specific gravity	Cobb	Wilson and Harms, 1984
Methionine, mg/bird daily				
558	Peak egg production	Body weight, egg mass	Mathematical model	Waldroup et al., 1976c
570	Peak egg production	Body weight, egg mass	Mathematical model	Bornstein et al., 1979
400	24–64	Egg production, body weight, fertility, hatchability	Cobb	Harms and Wilson, 1980
Methionine + cystine, mg/bird daily				
819	Peak egg production	Body weight, egg mass	Mathematical model	Waldroup et al., 1976c
830	Peak egg production	Body weight, egg mass	Mathematical model	Bornstein et al., 1979
723	24–64	Egg production, egg weight, fertility, hatchability	Cobb	Harms and Wilson, 1980
<682	24–64	Egg production, egg weight, fertility, hatchability, egg specific gravity	Cobb	Wilson and Harms, 1984
694	Peak egg production	Nitrogen balance	Tetra	Halle et al., 1984
Phenylalanine + tyrosine mg/bird daily				
1,126	Peak egg production	Body weight, egg mass	Mathematical model	Waldroup et al., 1976c
1,110	Peak egg production	Body weight, egg mass	Mathematical model	Bornstein et al., 1979
Phenylalanine, mg/bird daily				
610	Peak egg production	Body weight, egg mass	Mathematical model	Bornstein et al., 1979
Threonine, mg/bird daily				
717	Peak egg production	Body weight, egg mass	Mathematical model	Waldroup et al., 1976c
720	Peak egg production	Body weight, egg mass	Mathematical model	Bornstein et al., 1979
Tryptophan, mg/bird daily				
189	Peak egg production	Body weight, egg mass	Mathematical model	Waldroup et al., 1976c
190	Peak egg production	Body weight, egg mass	Mathematical model	Bornstein et al., 1979
<223 mg	24–64	Egg production, egg weight, fertility, hatchability, egg specific gravity	Cobb	Wilson and Harms, 1984
Valine, mg/bird daily				
979	Peak egg production	Body weight, egg mass	Mathematical model	Waldroup et al., 1976c
920	Peak egg production	Body weight, egg mass	Mathematical model	Bornstein et al., 1979
Calcium, g/bird daily				
3.91	26–53	Egg production, egg specific gravity, hatchability	Cobb	Wilson et al., 1980
Nonphytate phosphorus, mg/bird daily				
338	26–53	Egg production, egg specific gravity, hatchability	Cobb	Wilson et al., 1980

Nutrient and Estimated Requirement	Age Period (Weeks)	Response Criteria	Breed	References
Sodium, mg/bird daily				
<154	32–64	Egg production egg weight, fertility, egg specific gravity, hatchability	Cobb	Damron et al., 1983
Chlorine, mg/bird daily				
208	32–60	Egg production, egg weight, hatchability	Cobb	Harms and Wilson, 1984
Biotin, µg/bird daily				
16	20–58	Egg production, egg weight, hatchability	Marshall	Whitehead et al., 1985

TABLE A-5 Documentation of Nutrient Requirements of Broiler Breeder Males

Nutrient and Estimated Requirement	Age Period (Days)	Response Criteria	Breed	References
Metabolizable energy, kcal/bird daily				
400	28–40	Body weight, fertility, hatchability, chick production, testes weight	Broiler strain	McCartney and Brown, 1980
458	30–54	Body weight, fertility, hatchability, chick production, testes weight	Broiler strain	Brown and McCartney, 1983
346	30–46	Body weight, fertility, hatchability, chick production, testes weight	Hubbard	Brown and McCartney, 1986
358	30–60	Body weight, semen volume, sperm cells, fertility	Broiler strain	Buckner et al., 1986
Protein, %				
12.4	7–21	Development of testes, subsequent fertility	Peterson	Wilson et al., 1971
12–14	4–53	Weight gain, semen volume and concentration testes weight	Broiler strain	Wilson et al., 1987a
9	6–53	Weight gain, semen volume and concentration testes weight	Broiler strain	Wilson et al., 1987b
15	1–4	Fertility 24–27 weeks	Hubbard	Vaughters et al., 1987
Protein, g/bird daily				
10–14	20–60	Semen production	Hubbard	Buckner and Savage, 1986
Calcium, %				
<0.2	36–60	Semen volume, sperm concentration, dead sperm, fertility, hatchability	White Leghorn	Wilson et al., 1969
Calcium, mg/bird daily				
7.98	44–56	Weight gain, blood parameters, bone constituents	White Leghorn	Norris et al., 1972
<500	Not specified	Reproductive parameters	Broiler strains	Kappleman et al., 1982
Nonphytate phosphorus, %				
0.1	44–56	Weight gain, blood parameters, bone constituents	White Leghorn	Norris et al., 1972
Nonphytate phosphorus, mg/bird daily				
110	32–40	Semen volume	Arbor Acres, cage males	Bootwalla and Harms, 1989

TABLE A-6 Documentation of Nutrient Requirements of Turkeys

Nutrient and Estimated Requirement	Age Period (Days)	Response Criteria	Breed	References
Protein, %				
28	0–7	Growth	Bronze, both sexes	Lloyd et al., 1949
20	0–4	Growth	Jersey Buff, both sexes	Baldini et al., 1954
20	8–16	Growth	Large White, both sexes	Carter et al., 1957
28	0–8	Growth	Bronze, both sexes	Atkinson et al., 1957
25–32	0–6	Growth	Bronze, both sexes	Balloun et al., 1959
18	8–12	Growth	Bronze, females	Jensen et al., 1965
16	12–16	Growth	Bronze, females	Jensen et al., 1965
14	16–20	Growth	Bronze, females	Jensen et al., 1965
22	8–12	Growth	Large White, males	Summers et al., 1968
18	12–16	Growth	Large White, males	Summers et al., 1968
14	16–20	Growth	Large White, males	Summers et al., 1968
24	8–10	Growth	Large White, females	Summers et al., 1968
20	10–12	Growth	Large White, females	Summers et al., 1968
18	12–14	Growth	Large White, females	Summers et al., 1968
24	6–12	Growth	Large White, males	Eberst et al., 1972
30	0–7	Growth	Large White, males	Herz et al., 1975a
22	7–13	Growth	Large White, males	Herz et al., 1975b
30	0–4	Growth	Large White, males	Richter et al., 1980
21.3	10	Growth	Large White, males	Potter et al., 1981
19.5	14	Growth	Large White, males	Potter et al., 1981
17.6	18	Growth	Large White, males	Potter et al., 1981
21.7	10	Growth	Large White, females	Potter et al., 1981
18.4	14	Growth	Large White, females	Potter et al., 1981
15.0	18	Growth	Large White, females	Potter et al., 1981
20	5–14	Growth, carcass composition	Large White, both sexes	Richter and Prinz, 1980
26	4–10	Growth, carcass quality	Small White, both sexes	Salmon, 1984
20	10–13	Growth, carcass quality	Small White, males	Salmon, 1984
18	10–13	Growth, carcass quality	Small White, females	Salmon, 1984
Arginine, %				
1.60	0–3	Growth	Bronze, both sexes	Almquist, 1952
1.90	1–3	Growth	Bronze, both sexes	Dunkelgod et al., 1970
1.60	1–3	Growth	Bronze and Large White, both sexes	Warnick and Anderson, 1973
1.75	1–3	Growth	Large White, males	D'Mello and Emmans, 1975
1.59	0–4	Carcass content plus maintenance	Large White, males, mathematical model	Hurwitz et al., 1983a
1.32	4–8	Carcass content plus maintenance	Large White, males, mathematical model	Hurwitz et al., 1983a
1.02	8–12	Carcass content plus maintenance	Large White, males, mathematical model	Hurwitz et al., 1983a
0.80	12–16	Carcass content plus maintenance	Large White, males, mathematical model	Hurwitz et al., 1983a
0.63	16–20	Carcass content plus maintenance	Large White, males, mathematical model	Hurwitz et al., 1983a
0.47	20–24	Carcass content plus maintenance	Large White, males, mathematical model	Hurwitz et al., 1983a
Glycine, %				
0.90	0–3	Growth	Bronze, both sexes	Kratzer and Williams, 1948a
Histidine, %				
0.58	1–3	Growth	Bronze, both sexes	Warnick and Anderson, 1973
0.53	0–4	Carcass content plus maintenance	Large White, males, mathematical model	Hurwitz et al., 1983
0.42	4–8	Carcass content plus maintenance	Large White, males, mathematical model	Hurwitz et al., 1983
0.30	8–12	Carcass content plus maintenance	Large White, males, mathematical model	Hurwitz et al., 1983
0.23	12–16	Carcass content plus maintenance	Large White, males, mathematical model	Hurwitz et al., 1983
0.18	16–20	Carcass content plus maintenance	Large White, males mathematical model	Hurwitz et al., 1983
0.12	20–24	Carcass content plus maintenance	Large White, males, mathematical model	Hurwitz et al., 1983

Nutrient and Estimated Requirement	Age Period (Days)	Response Criteria	Breed	References
Isoleucine, %				
0.80	0–3	Growth	Bronze, both sexes	Kratzer et al., 1952
1.10	1–3	Growth	Bronze, both sexes	Warnick and Anderson, 1973
0.84	1–3	Growth	Large White, males	D'Mello, 1975
1.03	0–4	Carcass content plus maintenance	Large White, males, mathematical model	Hurwitz et al., 1983
0.86	4–8	Carcass content plus maintenance	Large White, males, mathematical model	Hurwitz et al., 1983
0.67	8–12	Carcass content plus maintenance	Large White, males, mathematical model	Hurwitz et al., 1983
0.53	12–16	Carcass content plus maintenance	Large White, males, mathematical model	Hurwitz et al., 1983
0.42	16–20	Carcass content plus maintenance	Large White, males, mathematical model	Hurwitz et al., 1983
0.31	20–24	Carcass content plus maintenance	Large White, males, mathematical model	Hurwitz et al., 1983
Leucine, %				
1.86	1–3	Growth	Bronze, both sexes	Warnick and Anderson, 1973
1.42	1–3	Growth	Large White, males	D'Mello, 1975
1.96	0–4	Carcass content plus maintenance	Large White, males, mathematical model	Hurwitz et al., 1983
1.62	4–8	Carcass content plus maintenance	Large White, males, mathematical model	Hurwitz et al., 1983
1.23	8–12	Carcass content plus maintenance	Large White, males, mathematical model	Hurwitz et al., 1983
0.96	12–16	Carcass content plus maintenance	Large White, males, mathematical model	Hurwitz et al., 1983
0.74	16–20	Carcass content plus maintenance	Large White, males, mathematical model	Hurwitz et al., 1983
0.53	20–24	Carcass content plus maintenance	Large White, males, mathematical model	Hurwitz et al., 1983
Lysine, %				
1.5	0–4	Growth	Bronze, both sexes	Almquist, 1952
0.96	4–8	Growth	Bronze, both sexes	Kratzer et al., 1956b
0.85	8–12	Growth	Bronze, both sexes	Kratzer et al., 1956b
0.76	14–18	Growth	Bronze, both sexes	Kratzer et al., 1956b
0.56	16–19	Growth	Bronze, both sexes	Kratzer et al., 1956b
0.60	20–23	Growth	Bronze, both sexes	Kratzer et al., 1956b
1.55	0–6	Growth	Bronze, both sexes	Balloun and Phillips, 1957b
1.60	0–3	Growth	Large White, both sexes	Kummero et al., 1971
1.68	1–3	Growth	Bronze, both sexes	Warnick and Anderson, 1973
1.50	0–4	Growth	Large White, males	Tuttle and Balloun, 1974
1.40	4–8	Growth	Large White, males	Tuttle and Balloun, 1974
1.12	8–12	Growth	Large White, males	Tuttle and Balloun, 1974
1.55	1–3	Growth	Large White, males	D'Mello and Emmans, 1975
0.96	12–16	Growth	Large White, males	Jensen et al., 1976
0.76	16–20	Growth	Large White, males	Jensen et al., 1976
1.4	8–12	Growth	Large White, both sexes	Potter et al., 1981
1.2	12–16	Growth	Large White, both sexes	Potter et al., 1981
0.9	11–20	Growth	Large White, both sexes	Potter et al., 1981
1.42	0–4	Carcass content plus maintenance	Large White, males, mathematical model	Hurwitz et al., 1983
1.12	4–8	Carcass content plus maintenance	Large White, males, mathematical model	Hurwitz et al., 1983
0.81	8–12	Carcass content plus maintenance	Large White, males, mathematical model	Hurwitz et al., 1983
0.63	12–16	Carcass content plus maintenance	Large White, males, mathematical model	Hurwitz et al., 1983
0.49	16–20	Carcass content plus maintenance	Large White, males, mathematical model	Hurwitz et al., 1983
0.32	20–24	Carcass content plus maintenance	Large White, males, mathematical model	Hurwitz et al., 1983
Methionine, %				
0.55	Starting	Growth	Bronze, both sexes	Almquist, 1952
0.56	0–6	Growth	Jersey Buff, both sexes	Baldini et al., 1957

Nutrient and Estimated Requirement	Age Period (Days)	Response Criteria	Breed	References
0.6	0–3	Growth, foot pad dermatitis	Large White, males	Murillo and Jensen, 1976a
0.4	8–12	Growth, feed efficiency	Large White, males	Murillo and Jensen, 1976b
0.46	1–4	Growth	Large White, males	Behrends and Waibel, 1980
0.30	8–12	Growth	Large White, males	Behrends and Waibel, 1980
0.19	16–20	Growth	Large White, males	Behrends and Waibel, 1980
0.51	0–4	Carcass content plus maintenance	Large White, males, mathematical model	Hurwitz et al., 1983
0.41	4–8	Carcass content plus maintenance	Large White, males, mathematical model	Hurwitz et al., 1983
0.31	8–12	Carcass content plus maintenance	Large White, males, mathematical model	Hurwitz et al., 1983
0.24	12–16	Carcass content plus maintenance	Large White, males, mathematical model	Hurwitz et al., 1983
0.20	16–20	Carcass content plus maintenance	Large White, males, mathematical model	Hurwitz et al., 1983
0.15	20–24	Carcass content plus maintenance	Large White, males, mathematical model	Hurwitz et al., 1983
Methionine + cystine, %				
0.90	0–4	Growth	Bronze, both sexes	Almquist, 1952
0.79	0–3	Growth	Large White, both sexes	Kummero et al., 1971
1.04	1–3	Growth	Bronze, both sexes	Warnick and Anderson, 1973
1.05	0–3	Growth, foot pad dermatitis	Large White, both sexes	Murillo and Jensen, 1976a
0.82	8–12	Growth, feed efficiency	Large White, males	Murillo and Jensen, 1976b
0.83	1–3	Growth	Large White, males	D'Mello, 1976
1.10	0–4	Growth	Medium White, males	Potter and Shelton, 1979
1.00	4–8	Growth	Medium White, males	Potter and Shelton, 1979
0.93	8–12	Growth	Medium White, both sexes	Potter and Shelton, 1980
0.75	12–16	Growth	Medium White, both sexes	Potter and Shelton, 1980
1.01	1–4	Growth	Large White, males	Behrends and Waibel, 1980
0.71	8–12	Growth	Large White, males	Behrends and Waibel, 1980
0.48	16–20	Growth	Large White, males	Behrends and Waibel, 1980
1.05	0–4	Carcass content plus maintenance	Large White, males, mathematical model	Hurwitz et al., 1983
0.93	4–8	Carcass content plus maintenance	Large White, males, mathematical model	Hurwitz et al., 1983
0.76	8–12	Carcass content plus maintenance	Large White, males, mathematical model	Hurwitz et al., 1983
0.60	12–16	Carcass content plus maintenance	Large White, males, mathematical model	Hurwitz et al., 1983
0.48	16–20	Carcass content plus maintenance	Large White, males, mathematical model	Hurwitz et al., 1983
0.38	20–24	Carcass content plus maintenance	Large White, males, mathematical model	Hurwitz et al., 1983
1.15	0–4	Growth, feed efficiency	Large White, both sexes	Schutte et al., 1986
1.05	4–8	Growth, feed efficiency	Large White, both sexes	Schutte et al., 1986
Phenylalanine +tyrosine, %				
1.60	1–2	Growth	Large White, males	Dunkelgod et al., 1970
1.80	1–3	Growth	Bronze, both sexes	Warnick and Anderson, 1973
1.72	0–4	Carcass content plus maintenance	Large White, males, mathematical model	Hurwitz et al., 1983
1.43	4–8	Carcass content plus maintenance	Large White, males, mathematical model	Hurwitz et al., 1983
1.09	8–12	Carcass content plus maintenance	Large White, males, mathematical model	Hurwitz et al., 1983
0.86	12–16	Carcass content plus maintenance	Large White, males, mathematical model	Hurwitz et al., 1983
0.67	16–20	Carcass content plus maintenance	Large White, males, mathematical model	Hurwitz et al., 1983
0.49	20–24	Carcass content plus maintenance	Large White, males, mathematical model	Hurwitz et al., 1983
Phenylalanine, %				
0.83	1–2	Growth	Large White, males	Dunkelgod et al., 1970
1.05	0–4	Carcass content plus maintenance	Large White, males, mathematical model	Hurwitz et al., 1983

Nutrient and Estimated Requirement	Age Period (Days)	Response Criteria	Breed	References
0.88	4 – 8	Carcass content plus maintenance	Large White, males, mathematical model	Hurwitz et al., 1983
0.67	8 – 12	Carcass content plus maintenance	Large White, males, mathematical model	Hurwitz et al., 1983
0.53	12 – 16	Carcass content plus maintenance	Large White, males, mathematical model	Hurwitz et al., 1983
0.41	16 – 20	Carcass content plus maintenance	Large White, males, mathematical model	Hurwitz et al., 1983
0.30	20 – 24	Carcass content plus maintenance	Large White, males, mathematical model	Hurwitz et al., 1983
Threonine, %				
1.10	1 – 2	Growth	Large White, males	Dunkelgod et al., 1970
1.00	1 – 3	Growth	Bronze, both sexes	Warnick and Anderson, 1973
0.94	1 – 3	Growth	Large White, males	D'Mello, 1976
1.14	0 – 4	Carcass content plus maintenance	Large White, males, mathematical model	Hurwitz et al., 1983
0.94	4 – 8	Carcass content plus maintenance	Large White, males, mathematical model	Hurwitz et al., 1983
0.72	8 – 12	Carcass content plus maintenance	Large White, males, mathematical model	Hurwitz et al., 1983
0.56	12 – 16	Carcass content plus maintenance	Large White, males, mathematical model	Hurwitz et al., 1983
0.44	16 – 20	Carcass content plus maintenance	Large White, males, mathematical model	Hurwitz et al., 1983
0.32	20 – 24	Carcass content plus maintenance	Large White, males, mathematical model	Hurwitz et al., 1983
Tryptophan, %				
0.26	0 – 4	Growth	Bronze, both sexes	Almquist, 1952
0.37	1 – 2	Growth	Large White, males	Dunkelgod et al., 1970
0.26	1 – 3	Growth	Bronze, both sexes	Warnick and Anderson, 1973
0.21	0 – 4	Carcass content plus maintenance	Large White, males, mathematical model	Hurwitz et al., 1983
0.17	4 – 8	Carcass content plus maintenance	Large White, males, mathematical model	Hurwitz et al., 1983
0.13	8 – 12	Carcass content plus maintenance	Large White, males, mathematical model	Hurwitz et al., 1983
0.11	12 – 16	Carcass content plus maintenance	Large White, males, mathematical model	Hurwitz et al., 1983
0.08	16 – 20	Carcass content plus maintenance	Large White, males, mathematical model	Hurwitz et al., 1983
0.06	20 – 24	Carcass content plus maintenance	Large White, males, mathematical model	Hurwitz et al., 1983
Valine, %				
1.38	1 – 2	Growth	Large White, males	Dunkelgod et al., 1970
1.20	1 – 3	Growth	Bronze, both sexes	Warnick and Anderson, 1973
1.21	1 – 3	Growth	Large White, males	D'Mello, 1975
1.34	0 – 4	Carcass content plus maintenance	Large White, males, mathematical model	Hurwitz et al., 1983
1.13	4 – 8	Carcass content plus maintenance	Large White, males, mathematical model	Hurwitz et al., 1983
0.88	8 – 12	Carcass content plus maintenance	Large White, males, mathematical model	Hurwitz et al., 1983
0.69	12 – 16	Carcass content plus maintenance	Large White, males, mathematical model	Hurwitz et al., 1983
0.53	16 – 20	Carcass content plus maintenance	Large White, males, mathematical model	Hurwitz et al., 1983
0.40	20 – 24	Carcass content plus maintenance	Large White, males, mathematical model	Hurwitz et al., 1983
Linoleic, %				
1.00	0 – 3	Growth	Large White and Bronze, both sexes	Ketola et al., 1973
Calcium, %				
1.7	0 – 3	Bone ash	Bronze, both sexes	Motzok and Slinger, 1948
1.5	0 – 4	Bone ash	Small White, both sexes	Wilcox et al., 1953

Nutrient and Estimated Requirement	Age Period (Days)	Response Criteria	Breed	References
0.6	8–24	Growth, toe ash	Bronze, both sexes	Nelson et al., 1961
1.0	0–8	Growth, toe ash	Large White, both sexes	Slinger et al., 1961
0.7	8–20	Growth, toe ash	Bronze, both sexes	Sullivan, 1961
0.81	0–8	Growth, toe ash	Bronze, both sexes	Formica et al., 1962
0.83	8–23, 25	Growth, toe ash	Bronze, both sexes	Formica et al., 1962
Nonphytate phosphorus, %				
0.6	0–4	Growth	Bronze and Small White, both sexes	Almquist, 1954
0.5	8–20	Growth, bone ash	Bronze, both sexes	Sullivan, 1960
0.35	9–16	Growth, toe ash	Bronze × White Holland, both sexes	Day and Dilworth, 1962
0.21	17–24	Growth, toe ash	Bronze × White Holland, both sexes	Day and Dilworth, 1962
0.50	0–3	Bone ash	Large White, males	Bailey et al., 1986
0.6–0.8	0–4	Growth, bone ash	Large White, males	Stevens et al., 1986
Potassium, %				
0.6	0–2	Growth	Medium White, both sexes	Supplee and Combs, 1959
0.35	0–4	Growth	Bronze, both sexes	Sullivan, 1963
0.6	0–4	Growth	Large White, both sexes	Chavez and Kratzer, 1973
0.8	0–4	Growth, tissue potassium	Large White, both sexes	Smith et al., 1973
Sodium, %				
0.20	0–4	Growth	Bronze, both sexes	Kumpost and Sullivan, 1966
0.25	0–4	Body, plasma composition	Large White, both sexes	Pang et al., 1978
0.17	0–3	Growth	Large White, both sexes	Harms, 1982
0.17	0–3	Growth	Large White, both sexes	Harms and Miles, 1983
0.12	42–48	Poult yield	Large White, females	Harms et al., 1985
Chlorine, %				
0.15	0–4	Growth	Large White, both sexes	Kubicek and Sullivan, 1973
0.12	32–50	Maximum shell strength, poult yield	Large White, females	Harms et al., 1983
Magnesium, mg/kg				
475	0–4	Alleviate deficiency symptoms	Bronze, both sexes	Sullivan, 1964
Manganese, mg/kg				
30	0–8	Growth, alleviation of perosis	Bronze, both sexes	Ringrose et al., 1939
22	0–5	Growth, tissue levels	Large White, males	Woerpel and Balloun, 1964
60	0–4	Growth	Bronze, both sexes	Kealy and Sullivan, 1966
Zinc, mg/kg				
66	0–3	Growth, deficiency symptoms	Bronze, both sexes	Kratzer et al., 1958
70	0–4	Growth, deficiency symptoms	Bronze, both sexes	Sullivan, 1961
63	0–3	Growth, deficiency symptoms	Medium White, both sexes	Supplee et al., 1961
41	0–3	Growth, blood level	Large White, both sexes	Dewar and Downie, 1984
Selenium, mg/kg				
0.28	0–4	Gizzard myopathy	Bronze, both sexes	Scott et al., 1965
0.20	0–5	Gizzard myopathy	Large White, both sexes	Cantor and Moorehead, 1977
0.23	18–38	Hatchability, poult mortality	Large White, both sexes	Cantor et al., 1978
Vitamin A, IU/kg				
5,065	0–4	Growth	Bronze, both sexes	Almquist, 1953
2,642	30–48	Poult yield	Large White, females	Stoewsand and Scott, 1961
5,280	0–8	Maintain liver levels of vitamin A	Large White, both sexes	
4,721	0–12	Growth, liver storage of vitamin A	Large White, both sexes	Couch et al., 1971
2,000	0–12	Growth	Large White, males	Prinz et al., 1983
5,000	0–12	Growth, liver storage of vitamin A	Large White, males	Prinz et al., 1986
Vitamin D, IU/kg				
700	0–12	Growth	Bronze, both sexes	Baird and Greene, 1935
800	0–4	Growth, bone ash	Small White, both sexes	Hammond, 1941
2,000	0–4	Growth, bone ash	Large White, both sexes	Sanford and Jukes, 1944
300	0–4	Growth, bone ash	Large White, both sexes	Stadelman et al., 1950
1,100	0–4	Growth, toe ash	Large White, both sexes	Neagle et al., 1968
Vitamin E, IU/kg				
11	0–4	Growth, gizzard myopathy	Bronze, both sexes	Scott et al., 1965
50	0–4	Gizzard myopathy	Large White, both sexes	Cantor and Moorehead, 1977
275	16–19	Meat oxidative stability	Large White, females	Sheldon, 1984
Vitamin K, mg/kg				
1.76	0–4	Prothrombin time	Bronze, both sexes	Griminger, 1957

Nutrient and Estimated Requirement	Age Period (Days)	Response Criteria	Breed	References
Riboflavin, mg/kg				
2.7	0–6	Growth, deficiency symptoms	Bronze, both sexes	Patrick et al., 1944
3.75	0–4	Growth, deficiency symptoms	Bronze, both sexes	Bird et al., 1946
4.0	0–6	Growth, deficiency symptoms	Bronze and Large White, both sexes	Jukes et al., 1947
4.0	0–3	Erythrocyte glutathione reductase and liver flavin	Medium White, both sexes	Lee, 1982
>3.50	0–3	Growth, leg paralysis	Large White, both sexes	Ruiz and Harms, 1989a
Pantothenic acid, mg/kg				
10.5	1–3	Growth, dermatitis	Bronze, both sexes	Kratzer and Williams, 1948b
<8.6	0–3	Growth	Large White, both sexes	Ruiz and Harms, 1989b
Niacin, mg/kg				
71.5	0–2	Growth, enlarged hocks	Bronze, both sexes	Scott, 1953
21	4–12	Growth, leg disorders	Large White, both sexes	Christmas et al., 1986
44	0–3	Growth, leg disorders	Large White, both sexes	Ruiz and Harms, 1989b
Vitamin B_{12}, mg/kg				
0.002–0.010	0–4	Growth	Bronze, both sexes	Sherwood and Sloan, 1954
0.003	0–6	Growth	Small White, both sexes	Johnson, 1955
Choline, mg/kg				
2,000	0–2	Perosis	Not specified	Jukes, 1940
1,900	0–6	Perosis	Not specified	Evans, 1943
2,300	10–24	Growth	Bronze, females	Slinger et al., 1946
<1,490	0–3	Growth	Large White, both sexes	Harms and Miles, 1984
<1,250	4–8	Growth	Large and Medium White, both sexes	Blair et al., 1986
Biotin, mg/kg				
0.284	0–3	Growth, deficiency symptoms	Bronze, both sexes	Jensen and Martinson, 1969
0.275–0.324	0–3	Growth, deficiency symptoms	Bronze, both sexes	Dobson, 1970
0.225–0.275	0–3	Growth, deficiency symptoms	Bronze, both sexes	Dobson, 1970
0.220	0–8	Growth	Large White, males	Krueger et al., 1976
Folic acid, mg/kg				
0.8	0–6	Growth, anemia prevention	Bronze, both sexes	Jukes et al., 1947
2.0	0–3	Growth, cervical paralysis	Jersey Buff, both sexes	Russell et al., 1947
Thiamin, mg/kg				
2.0	0–3	Growth, symptoms of deficiency	Bronze, both sexes	Robenalt, 1960
1.6–2.0	0–3	Growth	Bronze, both sexes	Sullivan et al., 1967
Pyridoxine, mg/kg				
2.0–3.0	0–3	Growth	Not specified	Kratzer et al., 1947
3.9–4.4	0–4	Growth, survival	Bronze, both sexes	Sullivan et al., 1967

TABLE A-7 Documentation of Nutrient Requirements of Turkey Breeders

Nutrient and Estimated Requirement	Age Period (Days)	Response Criteria	Breed	References
Protein, %				
15	32–52	Poult yield	Large White, females	Jensen and McGinnis, 1961
15	30–48	Poult yield	Large and Small White, females	Atkinson et al., 1970
10	30–46	Poult yield	Large White, females	Minear et al., 1972
18	32–48	Poult yield egg weight	Large White, females	Menge et al., 1979
14	17–20	Egg production	Large White, females	Meyer et al., 1980a
14	20–32	Egg production	Large White, females	Meyer et al., 1980a
12	12–28	Semen production	Large White, males	Meyer et al., 1980b
14	28–56	Egg production	Large White, females	Meyer et al., 1980a
10	30–41	Poult yield	Large White, females	Meyer et al., 1980b
8	28–53	Semen production	Large White, males	Cecil, 1982
16	32–48	Poult yield	Large White, females	Bougon et al., 1985
Protein, g/bird daily				
26	32–60	Poult yield	Small White, females	Jackson et al., 1974
Linoleic acid, %				
1.21	24–55	Egg production, hatchability	Large White, females	Cooper and Barnett, 1968
1.1	30–55	Poult yield	Large White, females	Whitehead and Herron, 1988
Calcium, %				
1.75	26–54	Poult yield	Bronze, females	Jensen et al., 1963
2.0	30–48	Poult yield	Large White, females	Balloun and Miller, 1964b
1.9	30–47	Egg production	Bronze, females	Atkinson et al., 1967a
2.66	30–47	Egg production	Large White, females	Atkinson et al., 1967a
3.19	30–47	Egg production	Bronze, females	Atkinson et al., 1967a
2.25	30–46	Poult yield	Large White, females	Arends et al., 1967
1.2	0–4	Growth	Large White, males	Neagle et al., 1968
2.5	33–53	Poult yield	Small White, males	Potter et al., 1974
2.55	30–50	Poult yield	Large White, females	Waldroup et al., 1974b
Nonphytate phosphorus, %				
0.42	30–42	Poult yield	Small White, females	Ferguson et al., 1974
0.30	30–50	Poult yield	Large White, females	Waldroup et al., 1974
0.55	30–45	Poult yield	Small White, females	Atkinson et al., 1976
0.30	30–50	Fertility	Medium White, females	Slaugh et al., 1989
Manganese, mg/kg				
60	30–46	Poult yield	Bronze, females	Atkinson et al., 1967b
Vitamin A, IU/kg				
2,200–3,520	30–48	Hatchability, poult survival	Bronze, females	Jensen, 1965
Vitamin D, IU/kg				
1,000	32–40	Poult yield	Bronze, females	Wilhelm et al., 1941
<750	31–40	Poult yield	Large White, females	Kramer and Waibel, 1978
300–400	41–53	Poult yield	Large White, females	Kramer and Waibel, 1978
900	29–35	Adequate poult yield but inadequate liver storage	Large White, females	Stevens et al., 1984
Vitamin E, IU/kg				
24	32–54	Poult yield	Bronze, females	Jensen and McGinnis, 1957
Riboflavin, mg/kg				
3.50	Not specified	Poult yield	Bronze, females	Boucher et al., 1942
Pantothenic acid, mg/kg				
16.0	Various	Poult yield, survival	Bronze, females	Kratzer et al., 1955
Niacin, mg/kg				
23.6	32–48	Egg weight, poult yield	Large White, females	Harms et al., 1988
Choline, mg/kg				
<990	32–46	Poult yield	Bronze and Large White, females	Balloun and Miller, 1964a
<1,230	32–54	Poult yield	Small White, females	Ferguson et al., 1975
Biotin, mg/kg				
>0.105	30–46	Poult yield	Large White, females	Waibel et al., 1969
<0.150	Not specified	Poult yield	Large and Medium White, females	Arends et al., 1971
0.160	27–34	Egg biotin (albumen)	Medium White, females	White et al., 1987
Folic acid, mg/kg				
0.7	32–48	Poult yield	Bronze, females	Kratzer et al., 1956a
1.23	32–48	Poult yield, survival	Large White, females	Miller and Balloun, 1967

TABLE A-8 Documentation of Nutrient Requirements of Geese

Nutrient and Estimated Requirement	Age Period (Days)	Response Criteria	Breed	References
Protein, %				
24	0–6	Growth	White Chinese	Roberson and Francis, 1963a
12	6–16	Growth	White Chinese	Roberson and Francis, 1963a
24	0–4	Growth	White Chinese	Roberson and Francis, 1963b
16	4–12	Growth	White Chinese	Roberson and Francis, 1963b
20	0–4	Growth, feathering	Embden	Allen, 1981
16	4–6	Growth, feathering	Embden	Allen, 1981
14	4–9	Growth, feathering	Embden	Allen, 1981
18.2	0–2	Growth, feed efficiency	Not specified	Nitsan et al., 1983
12.0	2–7	Growth, feed efficiency	Not specified	Nitsan et al., 1983
18	0–3	Growth, carcass yield, carcass composition	Embden	Summers et al., 1987
16	0–9	Growth, carcass yield, carcass composition	Embden	Summers et al., 1987
Lysine, %				
0.90	1–2 and 3–7	Growth	White Chinese	Roberson and Francis, 1966
1.10	0–4	Growth	Not specified	Mateova et al., 1980
0.85	4–8	Growth	Not specified	Mateova et al., 1980
1.07	0–2	Growth, feed efficiency	Not specified	Nitsan et al., 1983
0.60	2–7	Growth, feed efficiency	Not specified	Nistan et al., 1983
Methionine, %				
0.40	0–3	Growth, feed efficiency, carcass composition	White Italian	Znaniecke et al., 1975
0.29	0–2	Growth, feed efficiency	Not specified	Nitsan et al., 1983
0.15	2–7	Growth, feed efficiency	Not specified	Nitsan et al., 1983
Methionine + cystine, %				
0.73	0–3	Growth, feed efficiency, carcass composition	White Italian	Znaniecka et al., 1975
0.58	0–2	Growth, feed efficiency	Not specified	Nitsan et al., 1983
0.47	2–7	Growth, feed efficiency	Not specified	Nitsan et al., 1983
Calcium, %				
0.4	0–4 and 0–6	Growth, bone ash	Pilgrim	Aitken et al., 1958
Total phosphorus, %				
0.46	0–4 and 0–6	Growth, bone ash	Pilgrim	Aitken et al., 1958
Riboflavin, mg/kg				
3.8	0–2	Growth	Embden	Serafin, 1981
Pantothenic acid, mg/kg				
12.6	0–3	Growth, mortality	Embden	Serafin, 1981
Niacin, mg/kg				
66	0–3	Growth, perosis	Not specified	Battig et al., 1953
31.2	0–3	Growth	Embden	Serafin, 1981
Choline, mg/kg				
1530	0–3	Growth, perosis	Embden	Serafin, 1981
Choline, niacin, folic acid				
Not determined but estimates obtained	0–2	Growth, liveability	Toulouse	Briggs et al., 1953

TABLE A-9 Documentation of Nutrient Requirements of Ducks

Nutrient and Estimated Requirement	Age Period (Days)	Response Criteria	Breed	References
Protein, %				
22	0–2	Growth	White Pekin	Dean, 1972a
16	2–7	Growth	White Pekin	Dean, 1972a
18	0–2	Growth	White Pekin	Wilson, 1975
16	2 to market	Growth	White Pekin	Wilson, 1975
19	0–2	Growth	White Pekin	Siregar et al., 1982
16	3–8	Growth	White Pekin	Siregar et al., 1982
Arginine, %				
1.08	1–3	Growth, feed efficiency	Mule	Chen and Shen, 1979
Isoleucine, %				
0.63	1–3	Growth, feed efficiency	Mule	Yu and Shen, 1984
Leucine, %				
1.26	1–3	Growth, feed efficiency	Mule	Yu and Shen, 1984
Lysine, %				
0.60	Fattening	Growth	Not specified	Jeroch and Hennig, 1965
0.90	0–8	Growth, Plasma lysine	Pekin	Gazo et al., 1970
0.64	3–6	Growth	Muscovy	Leclerq and Carville,1977
0.55	6–10	Growth	Muscovy	Leclerq and Carville, 1977
1.06	1–3	Growth, feed efficiency	Mule	Chen and Shen, 1979
<0.70	1–7	Growth, feed efficiency	Pekin	Adams et al., 1983
Methionine, %				
0.45	0–1.5	Growth	Pekin	Dean, 1967
0.30	3–6	Growth	Muscovy	Leclerq and de Carville, 1977a
0.25	6–10	Growth	Muscovy	Leclerq and de Carville, 1977a
0.40	0–2	Growth	Pekin	Elkin et al., 1986
Methionine + cystine, %				
0.60	0–1.5	Growth	Pekin	Dean, 1967
0.60	3–6	Growth	Muscovy	Leclerq and de Carville, 1977a
0.55	6–10	Growth	Muscovy	Leclerq and de Carville, 1977a
0.70	0–2	Growth	Pekin	Elkin et al., 1986
Tryptophan, %				
0.23	1–3	Growth, feed efficiency	Mule	Wu et al., 1984
Valine, %				
0.78	1–3	Growth, feed efficiency	Mule	Yu and Shen, 1984
Calcium, %				
0.56	0–8	Growth, feed efficiency, bone ash	Pekin	Dean et al., 1967
0.58	Ducklings	Growth, bone ash	Pekin	Dean, 1972b
1.00	Ducklings	Growth	Taiwan	Su, 1977
3.75	Sexually mature	Egg production	Taiwan	Su, 1977
Nonphytate phosphorus, %				
0.60	0–4	Growth, bone ash	Pekin	Dean, 1972a
1.05	Sexually mature	Egg production	Taiwan	Su, 1977
0.40	0–3	Growth	Muscovy	Leclerq and de Carville, 1979
0.22	3–6	Growth	Muscovy	Leclerq and de Carville, 1979
0.18	6–10	Growth	Muscovy	Leclerq and de Carville, 1979
0.34	0–3	Growth, bone ash	Mule	Lin and Shen, 1979
Sodium chlorine, %				
0.14	0–7	Growth, liveability	Pekin	Dean, 1972a
0.12	0–7	Growth, liveability	Pekin	Dean, 1972a
Magnesium, mg/kg				
500	0–2	Growth, brain alkaline phosphatase	Pekin	Van Reen and Pearson, 1953
Manganese, mg/kg				
50	0–3	Growth	Mule	Wu and Shen, 1978
Zinc, mg/kg				
68	0–3	Growth	Mule	Wu and Shen, 1978
Selenium, mg/kg				
0.14	0–7	Growth, liveability, glutathione peroxidase	Pekin	Dean and Combs, 1981
0.20	0–7	Growth liveability glutathione peroxidase	Pekin	Dean and Combs, 1981
Vitamin D_3, IU/kg				
300	0–3	Bone ash	Pekin	Fritz et al., 1941
400	0–3	Bone ash	Pekin and Indian Runner	Motzok and branion, 1946

Nutrient and Estimated Requirement	Age Period (Days)	Response Criteria	Breed	References
Vitamin E, IU/kg				
9	0–4	Myopathy of heart muscle and smooth muscle of intestines	Pekin	Jager, 1972
Vitamin K, mg/kg				
0.5	0–2	Prothrombin time	Pekin	Dean, 1972
Riboflavin, mg/kg				
3	0–7	Growth	Pekin	Fritz et al., 1939
4	0.5–2	Growth	Pekin	Hegsted and Perry, 1948
Pantothenic acid, mg/kg				
11	0.5–2	Growth	Pekin	Hegsted and Perry, 1948
Niacin, mg/kg				
52	0–2	Growth, leg development	Pekin	Heuser and Scott, 1953
45	0–3	Growth, feed efficiency	Mule	Wu et al., 1984
Pyridoxine, mg/kg				
2.5	0.5–3 or longer	Growth, hemoglobin, hematocrit	Pekin	Hegsted and Rao, 1945

TABLE A-10 Documentation of Nutrient Requirements of Pheasants

Nutrient and Estimated Requirement	Age Period (Days)	Response Criteria	Breed	References
Metabolizable energy, kcal/kg				
2,700	Sexually mature	Egg production, egg weight, feed efficiency, mortality	Ring–neck	Monetti et al., 1982
Protein, %				
26	0 – 3	Growth	Ring–neck	Scott et al., 1954
24	3 – 5	Growth	Ring–neck	Scott et al., 1954
26	0 – 4	Growth, feed efficiency	Ring–neck	Scott et al., 1963
24	0 – 8	Growth, feathering, liveability	Chinese	Woodard et al., 1977
20	8 – 16	Growth, feathering, liveability	Chinese	Woodard et al., 1977
12	After 16	Growth, feathering, liveability	Chinese	Woodard et al., 1977
28	0 – 4	Growth	Ring–neck	Fuentes, 1981
28	0 – 4	Growth, feed efficiency	Ring–neck	Warner et al., 1982
19	8 – 17	Growth, feathering, feed efficiency, liveability	Ring–neck	Cain et al., 1984
15	Sexually mature	Egg production, fertility, hatchability	Ring–neck	Monetti et al., 1985
Methionine, %				
0.48	0 – 4	Growth	Ring–neck	Fuentes, 1981
Methionine + cystine, %				
0.94	0 – 4	Growth	Ring–neck	Fuentes, 1981
Calcium, %				
0.93	0 – 5	Growth, bone ash	Ring–neck	Scott et al., 1958a
0.53	5 – 14	Growth, bone ash	Ring–neck	Scott et al., 1958a
0.90	0 – 5	Growth, bone ash	Ring–neck	Hinkson et al., 1971
1.2	0 – 8	Growth, bone ash	Ring–neck	Reynnells, 1979
2.1	Sexually mature	Egg production, shell quality, bone ash	Ring–neck	Reynnells, 1979
2.0	Sexually mature	Egg production, fertility, hatchability, body weight	Ring–neck	Wise and Ewins, 1980
Total phosphorus, %				
0.98	0 – 4	Growth, bone ash	Ring–neck	Sunde and Bird, 1956
0.7	0 – 5	Growth, bone ash	Ring–neck	Scott et al., 1958a
0.48	5 – 14	Growth, bone ash	Ring–neck	Scott et al., 1958a
Nonphytate phosphorus, %				
0.6	0 – 8	Growth, bone ash	Ring–neck	Reynnells, 1979
0.6	Sexually mature	Egg production bone ash	Ring–neck	Reynnells, 1979
Sodium, %				
0.22	0 – 4	Growth, liveability	Ring–neck	Scott et al., 1960
Manganese, mg/kg				
70	0 – 5	Growth, bone development	Ring–neck	Scott et al., 1959
Zinc, mg/kg				
62	0 – 5	Growth, feather and bone development	Ring–neck	Scott et al., 1959
120	0 – 3	Growth, feather development	Ring–neck	Cook et al., 1984
Vitamin D_3, IU/kg				
1,500	0 – 5	Growth, bone ash	Ring–neck	Scott et al., 1958a
Riboflavin, mg/kg				
3.4	0 – 5	Growth, feather and bone development	Ring–neck	Scott et al., 1959
Pantothenic acid, mg/kg				
10	0 – 4	Growth, feather and bone development	Ring–neck	Scott et al., 1964
Niacin, mg/kg				
50	0 – 4	Growth, bone development	Ring–neck	Sunde and Bird, 1957
70	0 – 5	Growth, feathering and bone development	Ring–neck	Scott et al., 1959
Choline, mg/kg				
1,430	0 – 5	Growth, feather and bone development	Ring–neck	Scott et al., 1959

TABLE A-11 Documentation of Nutrient Requirements of Japanese Quail

Nutrient and Estimated Requirement	Age Period (Days)	Response Criteria	References
Protein, %			
24	0–35	Growth, protein retention	Weber and Reid, 1967
24	0–42	Growth	Lepore and Marks, 1971
26	0–35	Growth, feed efficiency	Vogt, 1969
25	0–28	Growth	Vohra and Roudybush, 1971
20	Sexually mature	Egg production, egg weight, feed efficiency	Begin and Insko, 1972
20	Sexually mature	Egg production	Lee et al., 1977
28.4	Sexually mature	Egg production	Sakurai, 1979
16	Sexually mature, peak egg production	Egg production, egg yield, body weight	Allen and Young, 1980
24	Sexually mature	Not specified	Sakurai, 1981
20	Sexually mature	Egg production	Shim and Lee, 1982
24	0–28	Growth, carcass characteristics	Steigner, 1990
Arginine, %			
1.25	0–10	Growth	Young et al., 1978
1.13	Sexually mature	Egg production, body weight, egg weight	Allen and Young, 1980
Glycine, %			
1.74	0–21	Growth	Svacha et al., 1970
1.17	21–35	Growth	Svacha et al., 1970
Glycine + serine, %			
1.14	0–10	Growth	Young et al., 1978
Histidine, %			
0.36	0–10	Growth	Young et al., 1978
0.38	Sexually mature	Egg production, body weight, egg weight	Allen and Young, 1980
Isoleucine, %			
0.98	0–10	Growth	Young et al., 1978
0.81	Sexually mature	Egg production, body weight, egg yield	Allen and Young, 1980
Leucine, %			
1.69	0–10	Growth	Young et al., 1978
1.28	Sexually mature	Egg production, body weight, egg weight	Allen and Young, 1980
Lysine, %			
1.37	0–21	Growth	Svacha et al., 1970
1.2	21–35	Growth	Svacha et al., 1970
1.15	0–10	Growth	Young et al., 1978
0.86	Sexually mature	Egg production	Allen and Young, 1980
0.97	Sexually mature	Egg production	Shim and Lee, 1984
Methionine, %			
0.43	0–10	Growth	Young et al., 1978
0.37	Sexually mature	Egg production, body weight, egg yield	Allen and Young, 1980
0.48	0–35	Growth, feed efficiency, feather development, carcass yield	Shrivastav and Panda, 1987
0.27	Sexually mature	Egg production	Shim and Lee, 1988
0.39	Sexually mature	Egg production, feather loss	Shim and Lee, 1989
Methionine + cystine, %			
0.74	0–21	Growth	Svacha et al., 1970
0.72	21–35	Growth	Svacha et al., 1970
0.72	0–10	Growth	Young et al., 1978
0.68	Sexually mature	Egg production, body weight, egg yield	Allen and Young, 1980
0.75	0–35	Growth, feed efficiency, feather development, carcass yield	Shrivastav and Panda, 1987
0.72	Sexually mature	Egg production	Shim and Lee, 1988
0.71	Sexually mature	Egg production, feather loss	Shim and Chen, 1989
Phenylalanine + tyrosine, %			
1.79	0–10	Growth	Young et al., 1978
1.25	Sexually mature	Egg production, body weight, egg yield	Allen and Young, 1980
Threonine, %			
1.02	0–10	Growth	Young et al., 1978
0.67	Sexually mature	Egg production, body weight, egg yield	Allen and Young, 1980
Tryptophan, %			
0.22	0–10	Growth	Young et al., 1978
0.17	Sexually mature	Egg production, body weight, egg yield	Allen and Young, 1980
Valine, %			
0.95	0–10	Growth	Young et al., 1978
0.83	Sexually mature	Egg production, body weight, egg yield	Allen and Young, 1980

Nutrient and Estimated Requirement	Age Period (Days)	Response Criteria	References
Calcium, %			
2.5	Sexually mature	Egg production, hatchability	Nelson et al., 1964
0.80	0–14	Growth, bone ash, calcium and phosphorus retention	Consuegra and Anderson, 1967
0.48	14–28	Growth, bone ash, calcium and phosphorus retention	Consuegra and Anderson, 1967
0.44	0–35	Growth, feed efficiency, bone ash, liveability	Miller, 1967
0.70	0–21	Growth, bone ash	Bisoi et al., 1980
Nonphytate phosphorus, %			
0.6	Sexually mature	Egg production, hatchability	Nelson et al., 1964
0.30	0–28	Growth, bone ash, calcium and phosphorus retention	Consuegra and Anderson, 1967
0.3	0–21	Growth, bone ash	Bisoi et al., 1980
Sodium chlorine, %			
0.15	0–28	Growth	Scott et al., 1960
0.10	8–35	Growth, liveability, adrenal weight	Lumijarvi and Vohra, 1976
Magnesium, mg/kg			
300	0–14	Growth, liveability, hemoglobin, tibia ash	Harland et al., 1976
150 mg	0–14	Growth, liveability	Vohra, 1972b
Iron, mg/kg			
120	0–28	Growth, hemoglobin, feathering, bone ash	Harland et al., 1973
Copper, mg/kg			
<5	0–28	Growth, hemoglobin, feathering, bone ash	Harland et al., 1973
Manganese, mg/kg			
<12	0–28	Growth, hemoglobin, feathering, bone ash	Harland et al., 1973
Zinc, mg/kg			
25	0–28	Growth, feathering, tibia ash, liveability	Spivey-Fox and Jacobs, 1967
Selenium, mg/kg			
0.1	0–42	Growth, liveability	Thompson and Scott, 1967
Iodine, mg/kg			
0.3	0–28	Growth, thyroid weight	Scott et al., 1960
Vitamin A, IU/kg			
1,650	7–56	Growth, liveability	Shellenberger and Lee, 1966
3,300	Sexually mature	Hatchability	Shellenberger and Lee, 1966
825	0–14	Growth	Ramachandran and Arscott, 1974
1,000	0–10	Growth, liver vitamin A	Parrish and Al-Hasani, 1983
3,200	Sexually mature	Hatchability, liveability, vitamin A in yolk	Parrish and Al-Hasani, 1983
Vitamin D, IU/kg			
480	0–21	Bone ash, plasma calcium	Shue, 1967
750	0–14	Growth	Ramachandran and Arscott, 1974
Thiamine, mg/kg			
6	0–14	Growth	Ramachandran and Arscott, 1974
1.2	0–35	Growth, liveability	Mak and Vohra, 1982
Niacin, mg/kg			
40	0–14	Growth	Ramachandran and Arscott, 1974
15	0–35	Growth, viability	Mak and Vohra, 1982
Pantothenic acid, mg/kg			
40	0–7	Growth, feather development, dermatitis	Spivey-Fox et al., 1966
10	7–35	Growth, feather development, dermatitis	Spivey-Fox et al., 1966
10	0–35	Growth, feather development	Cutler and Vohra, 1967
15	Sexually mature	Fertility, hatchability	Cutler and Vohra, 1967
23	0–14	Growth	Ramachandran and Arscott, 1974
Riboflavin, mg/kg			
8	0–14	Growth	Ramachandran and Arscott, 1974
2	0–35	Growth, viability	Mak and Vohra, 1982
Choline, mg/kg			
2,500	0–28	Growth, feed efficiency	Vogt, 1970
2,090	Sexually mature	Egg weight	Latshaw and Jensen, 1971
1,045–2,090	Sexually mature	Body weight, liver lipids	Latshaw and Jensen, 1972
1,300	0–14	Growth	Ramachandran and Arscott, 1974
Folacin, mg/kg			
0.36	Not specified	Growth, liveability	Wong et al., 1977
Pyridoxine, mg/kg			
6	0–14	Growth	Ramachandran and Arscott, 1974
1,25	0–35	Growth, viability	Mak and Vohra, 1982

TABLE A-12 Documentation of Nutrient Requirements of Bobwhite Quail

Nutrient and Estimated Requirement	Age Period (Days)	Response Criteria	References
Metabolizable energy, kcal/kg			
2,850–3,170	0–5	Growth, energy consumption, feed efficiency	Wilson et al., 1977
Protein, %			
28	0–8	Growth, liveability	Baldini et al., 1950
20	0–6	Growth, liveability	Baldini et al., 1953
26.5	0–4	Growth, feed efficiency, feathering	Scott et al., 1963
28	0–6	Growth	Andrews et al., 1973
20	6–9	Growth	Andrews et al., 1973
26	0–5	Growth, feed efficiency	Serafin, 1977
24	0–5	Growth, feed efficiency	Serafin, 1982
Methionine + cystine, %			
1.0	0–5	Growth	Serafin, 1982
Calcium, %			
0.65	0–6	Growth, liveability, bone ash	Wilson et al., 1972
2.3	Sexually mature	Egg production, eggshell thickness, fertility, hatchability	Dewitt et al., 1949
2.4	Sexually mature	Egg production, eggshell thickness, fertility	Cain et al., 1982
Nonphytate phosphorus, %			
0.8	Sexually mature	Egg production, fertility, hatchability, liveability of offspring	Dewitt et al., 1949
0.40	0–6	Growth, liveability, tibia ash	Scott et al., 1958b
0.28	6–12	Growth, liveability, bone ash	Scott et al., 1958b
0.45	0–6	Growth, liveability, bone ash	Wilson et al., 1972
0.35	0–6	Growth, bone ash	Powell et al., 1974
>0.70	Sexually mature	Egg production, egg shell thickness, fertility	Cain et al., 1982
Vitamin A, IU/kg			
8,800	0–10	Growth, liveability	Nestler, 1946
13,200	Sexually mature	Reproduction, survival of offspring	Nestler, 1946
Riboflavin, mg/kg			
3.8	0–5	Growth, feed efficiency, liveability	Serafin, 1974
Pantothenic acid, mg/kg			
10	0–4	Growth, liveability, feathering, leg development	Scott et al., 1964
12.6	0–5	Growth, feed efficiency, liveability	Serafin, 1974
Niacin, mg/kg			
31	0–5	Growth, feed efficiency, liveability	Serafin, 1974
Choline, mg/kg			
1,500	0–5	Growth, feed efficiency, liveability	Serafin, 1974

TABLE B–1 Estimating the Energy Value (kcal/kg dry matter) of Feed Ingredients from Proximate Composition (components as percentage of ingredient unless otherwise noted)

Ingredient	Prediction Equation	Reference
Cereal grains and milling by-products		
Corn grain	$ME_n = 36.21 \times CP + 85.44 \times EE + 37.26 \times NFE$	Janssen, 1989
Sorghum (tannin <0.4%)	$ME_n = 31.02 \times CP + 77.03 \times EE + 37.67 \times NFE$	Janssen, 1989
Sorghum (tannin >1.0%)	$ME_n = 21.98 \times CP + 54.75 \times EE + 35.18 \times NFE$	Janssen, 1989
Sorghum	$ME = 3{,}152 - 357.79 \times \text{tannic acid}$	Gous et al., 1982
Sorghum	$ME_n = 38.55 \times DM - 394.59 \times \text{tannic acid}$	Janssen, 1989
Sorghum	$ME = 3{,}062 + 887 \times CF - 202.5 \times (CF)^2$	Moir and Connor, 1977
Sorghum	$ME = 4{,}412 - 90.34 \times ADF$	Moir and Connor, 1977
Sorghum	$ME = 3{,}773 + 65.73 \times APF - 3.272 \times (APF)^2$	Moir and Connor, 1977
Triticale	$ME_n = 34.49 \times CP + 62.16 \times EE + 35.61 \times NFE$	Janssen, 1989
Wheat	$ME_n = 34.92 \times CP + 63.1 \times EE + 36.42 \times NFE$	Janssen, 1989
Polished rice, rice polishings	$ME_n = 46.7 \times DM - 46.7 \times \text{ash} - 69.55 \times CP + 42.95 \times EE - 81.95 \times CF$	Janssen, 1989
Rice bran, solvent extracted	$ME_n = 46.7 \times DM - 46.7 \times \text{ash} - 69.54 \times CP + 42.94 \times EE - 81.95 \times CF$	Janssen, 1989
Rice products	$ME_n = 4{,}759 - 88.6 \times CP - 127.7 \times CF + 52.1 \times EE$	Janssen et al., 1979
Bakery by-product	$ME_n = 34.49 \times CP + 76.1 \times EE + 37.67 \times NFE$	Janssen, 1989
Dried bakery products	$TME_n = 4{,}340 - 100 \times CF - 40 \times \text{ash} - 30 \times CP + 10 \times EE$	Dale et al., 1990
Wheat middlings, wheat bran	$ME_n = 40.1 \times DM - 40.1 \times \text{ash} - 165.39 \times CF$	Janssen, 1989
Wheat and wheat products (feeds in meal form)	$ME_n = 3{,}985 - 205 \times CF$	Janssen et al., 1979
Wheat and wheat products (feeds in pellet form)	$ME_n = 3{,}926 - 181 \times CF$	Janssen et al., 1979
Barley and barley products	$ME_n = 3{,}078 - 90.4 \times CF + 9.2 \times STA$	Janssen et al., 1979
Oats and oat products	$ME_n = 2{,}970 - 59.7 \times CF + 116.9 \times EE$	Janssen et al., 1979
Starch industry by-products		
Corn wet-milling by-products	$ME_n = 4{,}240 - 34.4 \times CP - 159.6 \times CF + 13.5 \times EE$	Janssen et al., 1979
Corn gluten meal (65% crude protein)	$ME_n = 40.94 \times CP + 88.17 \times EE + 33.13 \times NFE$	Janssen, 1989
Corn gluten meal (40% crude protein)	$ME_n = 36.64 \times CP + 73.3 \times EE + 25.67 \times NFE$	Janssen, 1989
Corn gluten feed (20% crude protein)	$ME_n = 42.35 \times DM - 42.35 \times \text{ash} - 23.74 \times CP + 28.03 \times EE - 165.72 \times CF$	Janssen, 1989
Sugar industry products		
Beet or cane molasses	$ME_n = 40.01 \times SUG$	Janssen, 1989
Sugar	$ME_n = 38.96 \times SUG$	Janssen, 1989
Distillers by-products		
Brewer's dried grains, corn distillers' dried solubles, corn distillers' dried grains, corn distillers' dried grains plus solubles	$ME_n = 39.15 \times DM - 39.15 \times \text{ash} - 9.72 \times CP - 63.81 \times CF$	Janssen, 1989
Yeast, torula	$ME_n = 34.06 \times CP + 40.82 \times EE + 26.91 \times NFE$	Janssen, 1989
Dried roots		
Sweet potatoes (dried)	$ME_n = 8.62 \times CP + 50.12 \times EE + 37.67 \times NFE$	Janssen, 1989
Tapioca meal (e.g., cassava)	$ME_n = 39.14 \times DM - 39.14 \times \text{ash} - 82.78 \times CF$	Janssen, 1989
Tapioca meal (e.g., cassava)	$ME_n = 4{,}054 - 43.4 \times \text{ash} - 103 \times CF$	Janssen et al., 1979
Oilseeds, oilseed meals, and by-products		
Cottonseed meal, expeller or solvent	$ME_n = 21.26 \times DM + 47.13 \times EE - 30.85 \times CF$	Janssen, 1989
Cottonseed products	$ME_n = 2{,}153 - 31.8 \times CF + 43.5 \times EE$	Janssen et al., 1979
Peanut meal, expeller or solvent	$ME_n = 29.68 \times DM + 60.95 \times EE - 60.87 \times CF$	Janssen, 1989
Peanut products	$ME_n = 3{,}072 - 39.1 \times \text{ash} - 47.6 \times CF + 63.7 \times EE$	Janssen et al., 1979
Rapeseed meal, solvent, high glucose	$ME_n = 29.73 \times CP + 46.39 \times EE + 7.87 \times NFE$	Janssen, 1989
Rapeseed meal, solvent, double zero	$ME_n = 32.76 \times CP + 64.96 \times EE + 13.24 \times NFE$	Janssen, 1989
Soybean meal, expeller	$ME_n = 37.5 \times CP + 70.52 \times EE + 14.9 \times NFE$	Janssen, 1989
Soybean meal, solvent	$ME_n = 37.5 \times CP + 46.39 \times EE + 14.9 \times NFE$	Janssen, 1989
Soybean meal (solvent or expeller process)	$ME_n = 2{,}702 - 57.4 \times CF + 72.0 \times EE$	Janssen et al., 1979
Soybeans, heat treated, meal	$ME_n = 36.63 \times CP + 77.96 \times EE + 19.87 \times NFE$	Janssen, 1989
Soybeans, heat treated, pellet	$ME_n = 38.79 \times CP + 87.24 \times EE + 18.22 \times NFE$	Janssen, 1989
Full-fat soybeans (feeds in meal form)	$ME_n = 2{,}769 - 59.1 \times CF + 62.1 \times EE$	Janssen et al., 1979
Full-fat soybeans (feeds in pellet form)	$ME_n = 2{,}636 - 55.7 \times CF + 82.5 \times EE$	Janssen et al., 1979
Sunflower seeds, unextracted	$ME_n = 36.64 \times CP + 89.07 \times EE + 4.97 \times NFE$	Janssen, 1989
Sunflower products	$ME_n = 3{,}999 - 189 \times \text{ash} - 58.5 \times CF + 59.5 \times EE$	Janssen et al., 1979
Sunflower, expeller, with hulls	$ME_n = 26.7 \times DM + 77.2 \times EE - 51.22 \times CF$	Janssen, 1989
Sunflower, expeller or solvent, decorticated	$ME_n = 6.28 \times DM - 6.28 \times \text{ash} + 25.38 \times CP\ 62.62 \times EE$	Janssen, 1989

Ingredient	Prediction Equation	Reference
Products of animal origin		
Skim milk powder	$ME_n = 40.94 \times CP + 77.96 \times EE + 19.04 \times NFE$	Janssen, 1989
Whey, dried, low lactose	$ME_n = 38.79 \times CP + 77.96 \times EE + 19.04 \times NFE$	Janssen, 1989
Meat and bone meal	$ME_n = 33.94 \times DM = 45.77 \times \text{ash} + 59.99 \times EE$	Janssen, 1989
Fish meal (60%, 65%, 67% crude protein)	$ME_n = 35.87 \times DM - 34.08 \times \text{ash} + 42.09 \times EE$	Janssen, 1989
Herring meal, Norwegian	$ME_n = 35.87 \times DM - 34.08 \times \text{ash} + 42.09 \times EE$	Janssen, 1989
Blood meal, spray dried	$ME_n = 34.49 \times CP + 64.96 \times EE$	Janssen, 1989
Blood meal, drum dried	$ME_n = 31.88 \times CP + 60.32 \times EE$	Janssen, 1989
Feather meal (pepsin dig ≧ 80%)	$ME_n = 33.2 \times CP + 57.53 \times EE$	Janssen, 1989
Poultry offal meal	$ME_n = 31.02 \times CP + 74.23 \times EE$	Janssen, 1989
Poultry offal meal, high-fat	$ME_n = 31.02 \times CP + 78.87 \times EE$	Janssen, 1989
Poultry by-product meal	$TME_n = -725 + 0.841 \times GE$ (kcal/kg dry matter)	Pesti et al., 1986
Poultry by-product meal	$TME_n = 4{,}070 - 142 \times \text{calcium}$	Pesti et al., 1986
Poultry by-product meal	$TME_n = 4{,}330 - 61 \times \text{ash}$	Pesti et al., 1986
Poultry by-product meal	$TME_n = 5{,}060 - 263 \times \text{ash} + 491 \times \text{calcium}$	Pesti et al., 1986
Poultry by-product meal	$TME_n = 479 + 89 \times CP - 1{,}094 \times \text{phosphorus}$	Pesti et al., 1986
Poultry by-product meal	$TME_n = 11{,}340 - 103 \times CP - 327 \times \text{calcium}$	Pesti et al., 1986
Poultry by-product meal	$TME_n = 934 - 69 \times CP - 110 \times \text{ash}$	Pesti et al., 1986
Poultry by-product meal	$TME_n = 561 - 154 \times \text{calcium} - 622 \times \text{phosphorus}$	Pesti et al., 1986
Poultry by-product meal	$TME_n = 556 - 63 \times \text{ash} - 506 \times \text{phosphorus}$	Pesti et al., 1986
Fat products from Dutch renderers	$ME_n = 20{,}041 - 23.0 \times IV - 319.1 \times C16:0 - 153.4 \times C18:0$	Janssen et al., 1979
Fats and oils	$ME_n = 8{,}227 - 10{,}318(-1{,}1685[\text{Unsaturated:Saturated ratio}])$	Ketels and DeGroote, 1989
All fats and oils	$ME_n = 28{,}119 - 235.8\,(C18:1 + C18:2) - 6.4\,(C16{:}0) - 310.9\,(C18:0) + 0.726\,(IV \times FR_1) - 0.0000379\,(IV[FR_1 + \text{FFA}])^2$	Huyghebaert et al., 1988
Vegetable oils (free fatty acid <50%)	$ME_n = -10{,}147.94 + 188.28\,IV + 155.09\,FR_1 - 1.6709\,(IV \times FR_1)$	Huyghebaert et al., 1988
Vegetable oils (free fatty acid >50%)	$ME_n = 1{,}804 + 29.7084\,IV + 29.302\,FR_1$	Huyghebaert et al., 1988
Animal fats (free fatty acid <40%)	$ME_n = 126{,}694 + 1645\,IV + 838.4\,C16:0 - 215.3\,C18:0 + 746.61\,FR_1 + 356.12\,(FR_1 + FFA) - 14.83\,(IV \times FR_1)$	Huyghebaert et al., 1988
Animal fats (free fatty acid >40%)	$ME_n = -9{,}865 + 194.1\,IV + 300.1\,C18{:}0$	Huyghebaert et al., 1988

NOTE: Abbreviations used above are as follows: *GE* = gross energy; *ME* = metabolizable energy; ME_n = nitrogen-corrected metabolizable energy; TME_n = nitrogen-corrected true metabolizable energy; *CP* = % crude protein; *EE* = % ether extract; *CF* = % crude fiber; *NFE* = % nitrogen-free extract; *ADF* = % acid detergent fiber; *APF* = % Acid-pepsin fiber; *STA* = % starch; *SUG* = % sugar; *IV* = iodine value; C16 : 0 = % palmitic acid; C18 : 0 = % stearic acid; C18:1 = % oleic acid; C18 : 2 = % linoleic acid; *FFA* = % free fatty acid, calculated as oleic acid equivalents; FR_1 = first fraction from a column chromatography separation that contains the practically unaltered triglycerides plus other apolar components; and *DM* = dry matter.

TABLE C–1 Conversion reactors—Weights and Measures

Units	Multiplied by the Factor Below Equals	Units	Multiplied by the Factor Below Equals	Units
lb	453.6	g	0.002205	lb
lb	0.4536	kg	2.205	lb
oz	28.35	g	0.035273	oz
kg	1,000	g	0.001	kg
kg	1,000,000	mg	0.000001	kg
g	1,000	mg	0.001	g
g	1,000,000	mcg (or µg)	0.001	mg
g	10^9	ng (nanogram)	10^{-9}	g
g	10^{12}	pg (picogram)	10^{-12}	g
mg	1,000	mcg (or µg)	0.001	mg
mg/kg[a]	0.0001	%	10,000	mg/kg
ppm	0.0001	%	10,000	ppm
gal (U.S.)	3.785	liters	0.2642	gal (U.S.gal (Brit.)
4.546	liters	0.220	gal (Brit.bu (bushel)	0.3525 hl
(hectoliter)	2.837	bu		
cal (calorie)	4.184	j (joule)	0.239	cal
kcal (kilocalorie)	1,000	cal	0.001	kcal
Mcal (megacalorie)	1,000,000	cal	0.000001	Mcal
Mcal	1,000	kcal	0.001	Mcal

[a] 100 ppm = 100 mg/kg = 0.010 percent; thus converting 0.0002 percent = 2 ppm = 2 mg/kg.

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Authors

F. Howard Kratzer is professor emeritus of avian science at the University of California at Davis, from where he received his Ph.D. in animal nutrition. His many concurrent positions include a visiting professorship at the University of Sydney (Australia), and the Federal University of Rio Grande do Sol (Brazil). His research interests are poultry nutrition, amino acid requirements of chickens and turkeys, vitamin needs and functions, minerals and mineral availability, and growth inhibitors.

J. David Latshaw is professor of poultry science at Ohio State University, where he has taught since 1970. He received his Ph.D. in nutrition from Washington State University. Research areas of major interest to him are factors influencing feed intake in poultry, and interaction of diet and growth efficiency.

Steven L. Leeson currently is a professor of poultry science at the University of Guelph (Canada). He received his Ph.D. in poultry nutrition from the University of Nottingham (England). His research areas are feeding programs for leghorn birds, interaction of nutrient supply from feed and body reserves, and energy evaluation of ingredients.

Edwin T. Moran, Jr., previously a professor at the University of Guelph (Canada), Moran has been professor of animal nutrition at Auburn University since 1986. He received his Ph.D. in animal nutrition from Washington State University. His research experience includes influence of nutrition and management on broiler yields, amino acid availability and performance, and feedstuff evaluation in broiler production.

Carl M. Parsons currently is assistant professor of animal science at the University of Illinois at Urbana-Champaign. He received his Ph.D. in animal science from Virginia Polytech Institute and State University. Research interests include poultry production and management with emphasis in the field of nutrition, and improved nutritional efficiency for production of poultry meat and eggs, particularly with respect to protein utilization.

Jerry L. Sell (*Chair*) is professor of animal nutrition at Iowa State University, where he has taught since 1976, and from where he received his Ph.D. in poultry nutrition. His major areas of research are energy efficiency of chickens and turkeys, and metabolism of minerals.

Park W. Waldroup is professor of poultry nutrition at the University of Arkansas at Fayetteville. He received his Ph.D. in nutritional biochemistry from the University of Florida. Among his research interests are studies concerned with nutrient requirements of poultry in terms of nutrient balance and interrelationships of nutrients, and effects of processing on nutritive value of feed.

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