The Possible Minimum Chicken Nutrient Requirements for Protecting the Environment and Improving Cost Efficiency*
- Review -

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ABSTRACT : Nitrogen and phosphorus are major nutrients in animal feeds which partially remain in the environment as pollution. In addition, nitrogen and phosphorus along with energy are the main nutrients which determine the feed cost. Any decreases in the levels of these three nutrients can contribute to reducing the pollution problem as well as the cost of feed. The nutrient requirements for chickens in the work here reported should allow for the addition of mixed enzymes (phytases, proteases, glucanases, xylanases and others). Such minimal levels of crude protein in the research results which are here reported are 16% for 0-6 weeks of age, 13.5% for 7-12 weeks of age, 11.5% for 13-18 weeks of age for layer type chicks, 13% for layer, 18% for 0-3 weeks of age broiler and 16.5% for 4-7 weeks of age broiler. These research projects have been done without adding enzyme supplements to their experimental diets.

The minimal values of phosphorus, shown as available phosphorus, are 0.25% for pullets, 0.09% for layers and 0.25% for broilers with the addition of phytase. The minimum energy requirement (metabolizable energy) for reducing the feed cost could be summarized as 2,750 kcal per kg feed for pullets, 2,800 kcal for layers and 2,700 kcal for broilers.

(**Key Words**: Environment Pollution, Nitrogen, Phosphorus, Enzymes, Crude Protein, Metabolizable Energy, Pullets, Layer, Broiler, NRC, Vitamin)

INTRODUCTION

More and more frequently attention is focused on animal production systems as one of sources of pollution affecting the quality of streams, estuaries and ground water resources. In particular, nitrogen (N) and phosphorus (P) may pollute water after application of manure or chemical fertilizer to the soils. These nutrients may be carried away as run off water after a rainfall, or they (especially N) may leach through soils into ground water. Some N becomes volatilized as ammonia and eventually contributes to acid rain that endangers forests. While both nutrients are essential for life, when the concentrations become too high in water, they endanger the ecosystem. And also N and P are the main nutrients along with energy to determine the feed cost.

In many countries on the earth, restrictions and regulations related to manure are already commonplace and regulations and legislation are increasing in several countries. Environmental control systems are revolutionizing the poultry industry. Chickens do not lay or grow or eat like they used to and we can not feed them the same way (Roland, Sr., 1994). A study (Nahm and Sung, 1995) showed that many layer rations still maintain excessive protein levels varying from 17 to 22% and excessive phosphorus contents of 0.35 to 1.27%. Poultry producers in some areas of the earth do not have any choice to select the nutrient levels for their own poultry farm because they must rely on the rations which were mixed with the imported grain by feed companies.

Low-protein and phosphorus diets offer advantages in lower cost, less excretion of nitrogen, phosphorus and other potential pollutants of the environment. They may result in greater sensitivity to dietary ammo acid excesses which might occur through unusual formulations or inadvertent supplementation of the diets with individual amino acids (Austic, 1996). Instead of the conventional feed formulation, protein and phosphorus usage in practical diets must be minimized for solving these problems, and provide added commercial amino acids and enzymes like proteases and phytases for use of biologically available amino acid and phosphorus in feeds

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that are less well digested. These formulations result in excretion of minimum amounts of nitrogen and phosphorus.

This review will discuss about the possible minimum levels of protein and phosphorus on the basis of previous research results to reduce the nitrogen and phosphorus content in the chicken manure. This could be one of the ways to contribute to preventing pollution and achieving cost efficiency, while allowing poultry producers to allow the environmental regulations and restrictions.

Addition of synthetic amino acids

A purified diet formulated on the same principles gives excellent growth in starting Coturnix quail (Blair et al., 1972). This example illustrates the validity of the concept of balanced amino acids, quantified according to the values outlined by Scott et al. (1969). Addition of certain amino acids allows for a reduction in dietary protein with no negative effect on poultry performance. These diets also help to improve the environment by reducing nitrogen excretion by poultry and reducing ammonia production from their manure (Cromwell, 1996). McNaughton (1995b) predicted the use of more synthetic amino acid, not only the use of more pounds of synthetic amino acids, but the use of more kinds of synthetic amino acids.

The use of more amino acids would result in formulating feeds that more closely approximate the minimum nutrient requirements of the bird with minimum excesses. Excesses are wasteful and may be environmentally destructive. Amino acids consisting of essential and nonessential amino acids are the building blocks of protein. Although both categories of amino acids are needed at the physiological or metabolic level, normal poultry diets contain sufficient nonessential amino acids or sufficient precursors for their synthesis; consequently, most of the emphasis in poultry nutrition is on the essential amino acids.

The use of feed grade methionine and lysine in poultry diets has been a common practice for many years. While many of the other essential amino acids have been available, their cost has restricted their use in practical diets. This, however, is changing as a result of biotechnology, such as new fermentation techniques and other new technological advances, particularly in the production of tryptophan and threonine. As a result, the price of these two amino acids has decreased in recent years and they are now being used to a limited extent in poultry diets.

Methionine or methionine hydroxyanalog (MHA) is almost universally used in poultry diets because methionine is relatively inexpensive and is generally regarded as the first limiting amino acid in poultry diets. Feed-grade lysine is produced by fermentation, using genetically engineered microorganisms. This product contains 78% lysine and is 98.5% pure. Methionine is sold as DL-methionine (99% pure) and DL-MHA (a liquid that contains 88% MHA). Feed-grade L-tryptophan (98.5% pure) and L-threonine (98.5% pure) also are produced by fermentation. In addition, lysine and tryptophan are available as a mixture that contains 15% L-tryptophan and 70% L-lysine HCL (55% L-Lysine) (This is the feed-grade lysine which is produced by fermentation formed by three firms in the U.S. and is sold as L-lysine HCL). The order of amino acid limitation in most poultry diets is methionine, lysine, threonine, tryptophan, isoleucine and arginine (Elliot, 1995). However, most feed mills use supplemental methionine and lysine, and in most cases threonine becomes the next limiting amino acid in commercial pullet and layer diets today.

As more of the essential amino acids become economically and commercially available, nutritionists will include more of them into their feed formulations on a routine basis. This will allow the nutritionist to further decrease dietary crude protein levels. Care will have to be taken to ensure that the diet still provides adequate levels of the nonessential amino acids and the remaining essential amino acids.

Enzyme utilization

The addition enzyme preparations to feed for poultry is not a new concept, but is becoming more fine tuned with the production of special enzyme preparations which are specific for the substrate. Recent market research indicates that in the U. K. approximately 90-95% of all broiler diets contain feed enzymes, and on world-wide basis as much as 60-70% of wheat and barley based poultry feeds are enzyme supplemented (Wyatt and Harker, 1995).

The tremendous growth in this particular application of biotechnology to animal production has accelerated over a relatively short period (less than 5 years). These changes have come about due to more recent developments in specific enzymes designed to function optimally in the intestinal tract of the bird and are stable through the feed processing. High enzyme costs have restricted the commercial use. However, large suppliers have now developed enzymes specifically for feed application.

The feeding value of plant-based ingredients, especially cereal grains, and their use in poultry diets are influenced by the level of antinutritive compounds (e.g. non-starch polysaccharides, NSP), some examples of which are arabinoxylans and mixed-linked beta-glucans derived from the endosperm cell walls, that tend to create viscous conditions to form gels. This gel like environment can reduce normal movement and limit nutrient absorption from the intestinal tract of the bird causing the reduction of body weight and feed conversion. Viscosity of digesta impacts the digestibility of all dietary nutrients by interfering with the diffusion of pancreatic enzymes, target substrates and the end products of the digestion process. NSP levels in barley may alter and/or inhibit the bioavailability of starch, fat and protein in the digestive tract of the bird (Hesselman and Aman, 1986).

A trial looking at nutrient digestibilities at the terminal ileum has demonstrated improvements in amino acids and energy digestibility in the presence of feed enzymes (Almirall et al., 1994). Supplementing an enzyme to the wheat-based (63%) diet significantly increased ideal energy (8%) and all major limiting amino acid, ranging from 8% (lysine) to 36% (cysteine). Improvements in apparent energy digestibility of 8% would, if attributed solely to the wheat component, equate to a 12% increase in available energy of this wheat. Whereas, the improvement in fecal amino acid digestibility would equate to an increase in availability of 29% for lysine, 14% for methionine + cysteine and 28% for threonine (Wyatt and Harker, 1995).

Reducing the dry matter content of the digesta in the intestinal tract with supplemental feed enzymes has a marked impact on excreta volume and composition, resulting in a reduction in dry matter output of 12-15% (Wyatt and Harker, 1995) or 20% (Patterson, 1998). A reduction in manure output would have environmental benefits extending far beyond the broiler industry, and be particularly relevant to producers in areas of intensive animal production.

Phytic acid or phytate (myo-inosital hexaphosphate), being an essential component of all seeds, being a main storage form of phosphorus and being an antinutritial factor as well as indigestible nutrient factor, must be hydrolyzed by phytase into inorganic phosphate before it can be utilized by poultry. The phytate molecule, with its six phosphoric acid residues, usually occurs as a mixture of calcium, magnesium, potassium and zinc salts. The phytate contents of most cereals and oil seeds are about 1-3%, which accounts for 60-80% of the total phosphorus in seeds (Simell et al., 1989).

Phytate is located in different parts of different seeds. In wheat, barley, oats and rye, it is mostly in the aleurone layer (bran). In dicotyledonous seeds, including legumes and oil seeds, phytate is distributed throughout the cotyledon. Corn differs from most other grains in that about 90% of the phytate is concentrated in the germ fraction. Phytate phosphate has a limited bioavailability in poultry in that 60-75% of the phosphorus in common feed ingredients is not available for digestion by the bird. Available phosphorus values for corn and SBM (0.08 and 0.22%, respectively) indicate that phytate phosphorus utilization by poultry for these ingredients is essentially zero (NRC, 1994). Because wheat and barley contain endogenous phytase, phytate phosphorus utilization for these ingredients can range from 15 to 30% (Khalid, 1991).

Phytase (myo-inositol hexaphosphate phosphohydrolase) is a special kind of phosphotase that catalyzes the stepwise removal of inorganic or orthophosphate from phytate (Gibson and Ullah, 1990). There are two classes of phytase enzymes. Microorganisms and fungi produce 3-phytase, which first removes orthophosphate from the 3-position, while plants contain 6-phytase. Both phytases can successively remove the remaining orthophosphates which result in intermediates ranging from free myo-inositol to mono- to tetra-phosphates of inositol.

The phytase activity in feedstuffs varies depending on the ingredient (Eeckhout and de Paepe, 1994). Wheat and barley have significant phytase activity (1190 and 580 phytase units/kg, respectively) in their bran, while corn and SBM have very low phytase activities (15 and 40 phytase units/kg, respectivley).The efficacy of phytase depends on number of factors such as pH, moisture, exposure, gestro-intestinal tract retention time, phytase source as well as the calcium content of the diet. Microbial phytase has two pH optimum at pH 2.5 and pH 5.5. Plant-derived phytase has only one pH optimum in the range of pH 4-6. Plant phytase appears to undergo irreversible inactivation at pH 2.5. Investigation suggests that a minimum moisture content of 20-25% is required for phytase activity. Maximum phytase activity is achieved at a moisture content of 30%. This precludes any phytase activity in a dry mixed feed, unless the feed is mixed into a slurry (Heinzl, 1996). Phytase activity is expressed "phytase units" or FTU (FTU = fytase unit; fytase = Dutch name for phytase) per unit of feed. This unit of measurement was developed in Europe and has now been adopted worldwide. One phytase units (FTU) is the activity of phytase that generate 1 micromole of inorganic phosphorus per minute from an excess of sodium phytate at pH 5.5 and 37 degree C. Measurement of release phosphorus is done photometrically (McKnight, 1996).

Supplemental microbial phytase is well known for its effectiveness in improving the availability of P in plant ingredients containing high levels of phytate P and some reports have also suggested that the availabilities of Ca, Zn and amino acid (N) are improved. Kornegay et al. (1996) reported that microbial phytase is very effective for improving the availability of phytate-P in corn and soybean meal diets, and the magnitude of the response of several measurements to added phytase is inversely related to the level of available P (and total P including phytate P) and the level of supplemental phytase added. These scientists also noted that there was a potential for improving the digestibility of amino acids and protein, and also reduced the excretion of P, Ca and Zn when diets were properly formulated with supplementing microbial phytase.

Nutrient requirements between strains of birds

To more consistently attain the genetic potential of each strain, producers should follow the nutritional and management recommendation specified by the breeder company for each strain (Elliot, 1995). Each breeder company will have a set of key performance parameters that should be monitored during the growth phase. These should include mortality (daily), feed consumption (weekly), body weights (weekly), shank lengths (weekly), house temperature (daily extremes), and water consumption (daily).

A single recommendation of each nutrient based on age does not take into consideration differences between strains of birds. Herrick and Ross (1986) reported from the trials using three different strains that there were differences in layer performances such as egg production, feed/dozen eggs, egg weight, eggshell quality, body weight gain and mortality. Leeson and Caston (1996) recently found feeding birds a lower level of crude protein had significant effects on bird performances among different strains. Their trial showed that the DeKalb and H & N strains produced less total egg mass when fed low crude protein diets, while the Babcock and Shavor strains were apparently not adversely affected by their low protein diets. The low crude protein diet did result in an overall loss of egg mass of approximately 1 kg per bird to 70 weeks of age. They showed reduced levels of dietary crude protein and available phosphorus to cause similar responses.

NUTRIENT LEVELS FOR EACH TYPE OF CHICKEN

Growing layer pullets

Recent studies have demonstrated the pullet response to dietary energy concentration under moderate and high temperature environments (Leeson and Summers, 1989). This data pointed out that less than 2,750 kcal ME/kg feed resulted in smaller pullets at 20 weeks of age. Data from these studies suggested that pullet growth was most sensitive to dietary energy concentration, and that forcing the bird to consume excessive quantities of protein has little positive effect on growth and development.

However, early growth rate (0-8 wks) is likely to be more sensitive to amino acid intake than to energy intake (Leeson, 1990). As more of the essential amino acids become economically and commercially available, nutritionists will be including more of them into' their feed formulations on a routine basis. This will allow to further decrease dietary crude protein levels. Keshavarz and Jackson (1992) showed that pullets grown on low protein diets (16%, 0-6 wks; 13.5%, 6-12 wks and 11.5% crude protein, 12-18 wks) supplemented with methionine, lysine, threomine, and arginine were only 37 g lighter at 18 weeks than control birds fed 20, 16 and 14% crude protein (CP) during the growth period.

The dietary requirement for protein is more accurately expressed as a requirement for the 22 physiologically essential amino acids. Of these 22 amino acids 10 cannot be synthesized by poultry or synthesized in inadequate amounts. Quantities to meet their metabolic needs are considered dietary essentials. The order of amino acid limitation in most poultry diets is methionine, lysine, threonine, tryptophan, isoleucine, valine and arginine (Elliot, 1995). However, care needs to be taken to ensure that the diet still provides adequate levels of the non-essential amino acids and the remaining essential amino acids. Low-protein diets providing 15% CP for starters fed to 42 days of age and 12.75% CP for growers fed to 125 days of age, eventhough these diets were supplemented with synthetic methionine, and lysine, were not adequate to support the growth rate of the Leghorn pullets when compared to growers on high-protein diets containing 20% CP for starters and 16% for growers (Leeson and Caston, 1996).

The suggested levels of the limited amino acids in table 1 are 10% higher than those of the NRC (1994) requirements, carrying a 10% margin of safety (Harms, 1987).

The present trend lowering dietary protein levels by supplementing with limited essential amino acids will tend to lower overall amino acids requirements (Austic, 1996). Each amino acid value in table 1 during each growing period is lower than those shown by Lesson and Summers (1991), Rhone-Poulenc Animal Nutrition (1993), Degussa (1995) and the requirements recommended by commercial breeder companies including Dekalb, Hy-line,

Table 1. The Possible Minimum Nutrient Requirements of Chicken as Percentages or Units per kilogram of Diet (90 percent dry matter)**

Age(wk)		Pullet			Layer	Broiler	
		0-6	7-12	13-18	18 >	0-3	4-7
ME (minimum)	Kcal/kg		2,750		2,800		
CP (exact)	%	16	13.5	11.5	13	18	16.5
Methionine	%	0.33	0.28	0.22	0.33	0.55	0.42
Lysine	%	0.94	0.66	0.50	0.76	1.32	1.19
Threonine	%	0.75	0.63	0.41	0.52	0.88	0.85
Tryptophan	%	0.19	0.15	0.12	0.18	0.22	0.20
Isoleucine	%	0.66	0.55	0.44	0.72	0.88	0.80
Valine	%	0.68	0.57	0.45	0.77	0.99	0.90
Arginine	%	1.10	0.09	0.74	0.77	1.38	1.21
Met & Cys	%	0.68	0.57	0.46	0.67	0.93	0.89
The rest of amino acids[1]							
Ca (minimum)	%		0.65		3.75	0.65	
AP (exact)	%		0.25		0.09	0.25	
The rest of minerals[2]							
Vitamina A	IU		10,000		7,380	8,840	8,113
Vitamin D_3	IU		1,800		2,440	2,811	2,568
Vitamin E	IU		25.0		7.5	17.9	15.8
Menadione (K_3)	mg		1.30		1.00	1.84	1.63
Riboflavin	mg		7.00		4.60	7.10	6.44
Niacin	mg		50.0		24.7	45.8	43.4
D-pantothenic acid	mg		10.00		7.10	12.04	10.91
Choline	mg*		1,300		1,050	1,300	1,000
Folic acid	mg		0.60		0.23	0.68	0.75
Thiamin	mg		1.0		0.7	3.0	3.0
Pyridoxine	mg		3.50		1.03	5.00	5.00
Vitamin B_{12}	µg		18.0		7.7	14.0	14.0
d-Biotin	µg*		150		100	150	150
Xanthophyll[3]							
Linoleic acid[4]							
Enzyme[5]							

[1,2,3,4] Levels of nutrients in furnished feed must meet minimum daily intake as suggested by NRC (1994).

[3] A minimum of xanthophyll should be used based on yolk color demand of the market area.

[5] Exogenous enzyme complex combining with phytases, proteases, -glucanase, xylanases and others is required for applying the nutrient requirements on this table.

ME : metabolizable energy, CP : crude protein, AP : available phosphorus.

* The same amount of NRC (1994) requirement.

** Based on data from 15 scientific publications (Huran, 1984; Leeson and Summers, 1989; Lettner and Preining, 1991; Keshavarz and Jackson, 1992; Summers, 1993; BASF, 1994; NRC, 1994; Baker, 1995; Contor, 1995; Schutte and Pack, 1995; Gorden and Roland, Sr., 1996; Kidd and Kerr, 1996; Lesson, 1996; Roland, Sr., 1996; McKnight, 1997).

ISA, Avian Farms and Arbor Acres (The Korean Poultry Research, 1995). The suggested amino acid values by Harms (1989) were higher than values in table 1 except for lysine. Recommended amino acid values for pullets in each stage by the Nutrient Requirement for Poultry of Japan (NRPJ, 1984) and Heart-Land Lysine (1990) are lower than the values in table 1, eventhough recommended values of Heart-Land Lysine were given as the digestible amino acid values. Betram and Schmidtborn (1984) suggested the higher values of sulfur-containing amino acid (methionine, methionine+cystine) than values in table 1, with lower values for the rest of the amino acids. The connection between NRC diets and actual production rations are only in time, not in fact and NRC (1994) nutrient requirements are designed to be minimum, not a real diet (Anon, 1994). Each amino acid values in table 1 for pullets was developed on the basis of the NRC (1994), which requires the modification of each value to apply to a real diet in a practical environment.

It is commercially recommended that there is 1.00% calcium and 0.5% available phosphorus in all pullet diets. However, Schoner and Hoppe (1992) indicated that no adverse effect on weight gain and phosphorus (P) utilization in broilers due to increase in dietary calcium (Ca) (6.0-9.0 g/kg) could be measured when 500 units of phytase activity were added to a diet which had a basal P content of 5.5g per kg. They also showed that a further reduction in the P content of diet from 5.5 to 5.0g at the same Ca and phytase levels reduced live mass of broiler. Simons et al. (1990) reported that chicks fed phytase had 40% less phosphorus in excreta as compared to chicks receiving phosphorus from a mixture of dicalcium phosphate and mono-ammonium phosphate. Calcium retention and dry matter (DM) digestibility were improved when phytase was added to broiler diets (Kornegay et al., 1996). Supplemental microbial phytase is well known for its effectiveness in improving the availability of P in plant ingredients containing high levels of phytate P, and this report has also suggested that the availabilities of Ca, Zn and amino acid (and N) are also improved (Kornegay, 1996a). Most of the scientists' data were generated with a diet based on corn and soybean meal. Kornegay et al. (1996) confirmed that microbial phytase was very effective for improving the availability of phytase P in corn and soybean meal diets. They also showed that the magnitude of the response of several measurements to added phytase was inversely related to the level of available P (and total P to include phytate P) and to the level or amount of supplemental phytase added. They calculated that P equivalency of 1 g of P ranged from 467 to 922 unit of phytase, and these equations could be used to estimate the equivalent amount of inorganic P released over a range of 250 to 1,000 units of phytase/kg of diet.

Very few research projects have attempted to determine the requirements of calcium and phosphorus for the layer pullets with phytase supplementation, since phytase supplementation increases the availability of calcium and phosphorus for broilers (table 1). The research report of BASF (McKnight, 1997) provided that the AP level could be reduced up to 0.25% with phytase supplementation in the broiler diet without any performance differences from the 0.45% AP of the control diet. Nutrient requirement tables from several sources including NRC (1994) suggest the same or very similar levels of calcium and phosphorus requirements between pullets and broilers(Read the section for broilers).

The National Research Council vitamin requirements are expressed in terms of the minimum amount required to prevent deficiency symptoms as evidenced by strict scientific research. Optimum nutrition occurs only when poultry makes efficient use of nutrients in the feed for growth, health, reproduction and survival (McNaughton, 1990). Optimal vitamin requirements are the vitamin levels required by an animal to prevent marginal (undetected) deficiencies and inadequacies to allow optimal health and performance. Low dietary crude protein and phosphorus levels in poultry diets are possible when optimal vitamin requirements are maintained which would allow starter and growing pullets to remain healthy during this stressful period. Waldroup (1996) pointed out that many values in the NRC (1994) nutrient requirements are based upon research done more than 40 years ago with animals of markedly different productive potential than existing today, and this is particularly true with requirements for most vitamins and trace minerals.

Vitamin addition levels should be based on field experience. Unfortunately, very little extensive research has been conducted at levels in which vitamins are used (Shurson et al., 1996). For practical purposes, vitamin values recommended by BASF (1994) in table 1 were selected because these values are the average levels which feed manufacturers use in their rations for pullets under the field conditions.

The numbers indicated in table 1 are considered very high compared with those of NRC (1994) table but are still lower than the recommended values by Hoffman-La Roche in a review paper written by Shurson et al. (1996) and even lower than those for starters and growers suggested by Leeson and Summers (1991) other than values for vitamins A, D_3, B_2, and B_{12}. Interestingly enough, all values in table 1 were much lower than values recommended for chick starters by Germans and Europeans, and still lower than values recommended for replacement chickens suggested by Germans and Europeans (Gropp, 1994) except for riboflavin and pyridoxine. The choline and biotin values provided in table 1 were offered from NRC (1994). These contents are more than the recommendation of Germans (750 mg/kg and 80~120 μg/kg) and Europeans (1,000 mg/kg and 100 μg/kg), while lower than those for starter (1,600 mg/kg and 200 μg/kg) and for growing chickens (1,400 mg/kg and 150 μg/kg) in Leeson and Summers (1991), respectively. The results of comparing these values suggests that vitamin values for starter chicks and replacement chickens need not to be divided to provide for optimal health and performance of chicks fed the low dietary crude protein and phosphorus levels during this stressful period.

Vitamins only represent 0.5% of the weight and 1.5% of the cost of complete chicken feeds (Coelho, 1994), and the higher levels indicated would allow the producer to save time and investment of mixing two different types of vitamin mixes, one for starter chicks and one for replacement chickens.

Layers

As energy intake increases, there is a dramatic increase in egg production, particularly when protein intake is very low (Lesson, 1990). In this study egg production increased from 45% to 85% when energy intake increased from 185 to 312 kcal per day for birds consuming 13.1g CP per day. Summers and Lesson (1989) indicated that the average daily energy intake was from 185-312 kcal ME/bird from 18 to 61 weeks of age and protein intake varied from 13 to 21 g/bird/day. These scientists recommended 2,800 kcal ME/kg which was a higher level than values given by the NRPJ (1984) and Rhone-Poulenc Animal Nutrition (1993) and lower than the recommendations of most commercial layer production companies as well as NRC (1994).

Many egg producers attach great importance to dietary crude protein content. It is possible that the protein requirement is much lower, providing dietary amino acid levels are maintained. Reducing crude protein could limit the amount of excess nitrogen excreted. Belyavin (1992) reported that there were no significant differences for any of the performance characteristics in the diet containing 14% crude protein, with supplementing amino acids added at the level of 0.78% lysine and 0.36% methionine can lead to as good a physical performance as a diet containing 17% crude protein. All diets in this research were fed ad libitum and the trial was conducted over the period of 20-76 weeks of age. Crude protein can be reduced to a concentration of 13% in the diet without negatively affecting percent production (Summers, 1993). This study showed that the N-excretion could be cut by approximately 30-40%, compared to diets with 17 or 19% crude protein. At 15% crude protein or less, there was a tendency towards a reduced egg weight. Whether or not an adequate supply of the essential amino acids was always secured in the experiments, cannot be deduced from the results.

Scientists compared the performance parameters of laying hens fed complete diets with either conventional or reduced crude protein levels, being 16.7% vs. 14.1% CP (Schutte et al., 1983), 16.5% vs. 14% CP (Van Weerden et al., 1984), 17.5% vs. 15.5% CP (Scholtyssek et al., 1991), 17.6% vs. 14.9% CP (Harms and Russel, 1993), and 18% vs. 13% CP (Lettner and Preining, 1991). These research results did not show any differences in the production rate between the conventional protein levels and the reduced protein levels with the supplemented amino acids. Schutte et al. (1994) and Bertram et al. (1995) compared the performance parameters of laying hens fed complete diets with either conventional or reduced crude protein levels. The crude protein levels of the standard rations in these trials ranged from 17 to 18% and contained the major limiting amino acids in the following concentrations : methionine 0.4%, methionine plus cystine 0.65-0.70%, and lysine 0.70-0.90%. The content of limiting amino acids in the low protein diets (13.3-15.5%) was adjusted to the levels of the "normal" crude protein content by the incorporation of crystalline amino acids. The performance criteria of the birds after feeding both complete diets show that under current commercial conditions the utilization of dietary protein can be considerably enhanced by feeding protein-reduced rations supplemented with methionine and lysine. In these ways laying performance and daily egg mass production are maintained for the protein-reduced, supplemented diets. The feed conversion ratio showed a slight, but not significant, upward trend in some cases. However, the use of low-protein amino acid-supplemented diets (14, 13 and 12% crude protein supplemented with methionine, lysine, tryptophan and isoleucine for age periods of 18-34, 34-50 and 50-66 weeks) during the laying period failed to produce a comparable performance to those fed the protein levels (18, 16.5 and 15% for similar age periods) that are typically used in commercial practice (Keshavarz, 1991). Keshavarz (1997) also provided the results of another trial that 16.5, 15.5, 14.5 and 13.5% protein for 20 to 36, 36 to 48, 48 to 60 and 60 to 72 weeks of age did not influence layers' overall performance for the entire laying period. In this research the levels of total sulfur amino acids were maintained at 0.59% and the minimum level of lysine was 0.68% in the laying rations.

Recently Leeson and Caston (1996) reported that four egg-type strains of layers had no significant differences in performance when fed varying levels of crude protein in their diets. In their experiment, each strain of pullets was fed diets of 16.8 % crude protein or 14.4 % crude protein supplemented with methionine and lysine. Strain affected body weight and feed intake. At 70 weeks of age, egg production and egg mass were similar for the four strains. However, egg mass on the low protein amino-acid fortified diet was almost one kilogram (2.2 pounds) less for the 52 weeks of the experiment. And the strain with the lightest body weight at 18 weeks of age was heaviest at 70 weeks.

The amino acid values for layers in table 1, which are 10% higher than those of the NRC (1994) requirements, are at considerably lower levels than those given by several commercial breeder companies (Dekalb, Hy-line brown layer, ISA brown, Hy-line W-77 White Layer, Avian Farm, and Arbor Acres adapted from The Korean Poultry Research, 1995). However, further research is required for the proper levels of the limited amino acids with the reduced protein content in the commercial layer farm. As enzymes and more synthetic amino acids become justified, their use in layer's diets may provide a means of reducing pollution (Belyavin, 1992). Each limited amino acid in table 1 was lower or higher than the levels of Belyavin (1992; methionine, 0.36%; lysine, 0.78%; methionine & cystine, 0.67%) and the values, 0.52 % (threonine), 0.18% (tryptophan), 0.68% (isoleucine) and 0.92% (arginine), were provided by Rhone-Poulenc Animal Nutrition (1993), Harms (1989) and Russell and Harms (1997), indicating a balance on the basis of 17% crude protein. This was the control diet in the Belyavin (1992) research and was recommended for light and semi-heavy body weight as well as low and high environmental temperatures. These limited amino acid values are higher than values of NRC (1994), the NRPJ (1984), those provided by Lesson and Summers (1991), and offered by Bertram and Scimidtborn (1984).

The level of phosphorus in feed influences egg shell quality and egg production (Keshavarz, 1990). The results of short- and long- term performance were reduced ($p < 0.05$) and mortality was increased ($p < 0.05$) due to consumption of a diet containing 6.5% calcium and a marginal level of available phosphorus (0.2%). The results of digestion trials (Keshavarz, 1987a, b) indicated that calcium and phosphorus retention were reduced due to increasing the dietary levels of calcium. However, increasing the dietary levels of phosphorus did not influence ($p > 0.05$) the retention of calcium or phosphorus. Because of disposal and environmental concerns over the amounts of phosphorus in the manure, one experiment with four egg-type strains of layers recently was conducted by Leeson and Caston (1996). In this experiment starting with pullets at 18 weeks of age, diets had available phosphorus levels of 0.41, 0.34 or 0.27 %. Egg production and total egg mass were similar for all strains. Dietary phosphorus had no effect on body weight or feed intake, although there were consistent strain effects on these parameters.

Simons and Versteegh (1993) fed laying hens a low available phosphorus (0.06% AP) diet supplemented with graded levels of monocalcium phosphate (MCP) or phytase from 24 to 52 weeks of age and measured laying performance, eggshell quality, skeletal quality and phosphorus excretion. Phosphorus deficiency symptoms observed with the negative control diet were completely compensated by the lowest levels of MCP supplementation and by the lowest level of phytase (200 FTU/kg, FTU = fytase unit). Phosphorus excretion via manure increased when MCP was added to the diet and decreased when phytase was added to the diet. Phosphorus excretion of the groups with phytase averaged 40% less than the groups receiving MCP. Roland, Sr. (1996) conducted a trial with sixteen hundred pullets (21 weeks of age), which were divided into 10 groups and fed diets containing 0.1, 0.2, 0.3, 0.4 and 0.5% AP, with and without 300 FTU of phytase. In this trial, dietary energy, protein and calcium were maintained at 2,819 ME kcal/kg, 16.6% and 4.0%, respectively. Hens fed diets containing 0.1% AP maintained production equal to other treatments for 11 weeks. However, during week 12, egg production and feed consumption decreased in hens fed 0.1% AP and by week 17, production had dropped to 60% vs. 87% for hens in other treatments. The addition of phytase to the diet containing 0.1% AP completely prevented the adverse effects. Another phytase trial (Roland, Sr., 1996) was conducted with two other groups of hens (Hy-Line and Delta). Diets containing 0.3% AP (control) and 0.09% AP were fed with and without phytase. In the trial with Hy-Line W36 hens, production dropped within 3 to 4 weeks but phytase completely prevented the drop. Feed consumption decreased but phytase prevented it. Egg weight also dropped but phytase prevented it. The same results were obtained with Dekalb (Delta) hens.

Because low calcium levels increase phosphorus excretion and low phosphorus levels increase calcium excretion, a proper ratio of calcium and phosphorus must be maintained in order to satisfy the hens requirement of either nutrient (Gordon and Roland, Sr., 1996). How much calcium should be fed to optimize the phosphorus requirement? There are many complex factors that influence calcium and phosphorus requirements as follows (Gordon and Roland, Sr., 1996). 1. calcium level, 2. particle size of $CaCO_3$, 3. cage density, 4. accuracy of P feed ingredient analysis, 5. accuracy of feed intake value, 6. accuracy of availability values, 7. variation in individual feed intake, 8. variation in average feed intake, 9. flock uniformity 10. vitamin D_3, 11. strain of bird, 12. dietary chloride level, 13. environmental temperature, 14. method of formulation and feeding, 15. age at sexual maturity, 16. feed intake, 17. variation in phytate P utilization, 18. transition time from pre-lay to lay diet. Still few parts about calcium and phosphorus requirement have been discussed in several research reports and the levels recommended must be continued to be used until more knowledge is obtained. The new Hy-Line (1995) management guide increased their maximum calcium level from 3.85 to 4.4% and reduced their protein.

The vitamin values of layers in table 1 were recommended for commercial layers as being adequate for production performance, health, feed conversion, reproduction and survival under the commercial production conditions, as used by commercial feed manufacturers (BASF, 1994). These values were higher than those of the NRC (1994) recommendation but include pyridoxine (2.5 mg/kg feed in NRC versus 1.03 mg/kg feed in BASF recommendation table) and folic acid (0.25 mg/kg feed in NRC versus 0.23 mg/kg feed in BASF table). All of the values except vitamin D and Vitamin B_2 are lower than the recommendation of Lesson and summer (1991).

All the values of vitamin recommendations for layers in table 1 remain lower than the recommendations of Germany or Europe, with the exception of the higher values of pyridoxine, folic acid and biotin than the European recommendations (European recommendations are lower than German recommendation in vitamin recommendations for layers). The choline levels in table 1 were given by the NRC (1994), showing lower recommendation values than Lesson and Summers (1991), and higher than the value of Miles et al. (1986).

Broilers

Large amounts of energy can promote better feed efficiency and optimize growth, but can also increase metabolic problems such as ascites, leg weakness and sudden death syndrome. Some researchers have shown that the broiler may adapt to lower-energy diets and just eat more to make up the difference. Leeson (1996) indicated that growth rate of the male broiler is independent of diet energy level and that the bird will adjust intake so as to maintain almost constant energy intake. He said that broilers do not eat to near physical capacity when offered conventional diets, but the bird has the ability to increase its intake when energy levels in its diet are reduced. In one of their experiments, male broilers were fed single-stage diets that provided 2,700, 2,900, 3,100 or 3,300 kcal ME/kg through day 49. All diets contained 21% CP with 1.20% lysine and 0.58% methionine. Results showed that there was a small reduction in live weight and carcass weight between the highest and lowest energy level used, although bodyweight was not changed significantly between energy levels. Birds that were fed diets containing less ME tended to eat more.

Various research trials have been done to restrict either protein levels or restrict feed intake during part or all of the feeding program in broiler production. A trial was designed to test the effect of early protein restriction on broiler performance (Scheideler, 1989). The control diet was formulated to 100% of NRC (1984) recommended levels of protein and amino acids. The second diet was formulated to 80% of NRC-recommend levels of protein and essential amino acids while the third diet was formulated to 80% of NRC levels of total protein, but 100% of NRC-recommended levels of essential amino acids. The experimental diets were fed to the chicks from day one to three weeks of age. At three weeks all birds were placed on the same control diet. Both restricted diets resulted in body weights that were significantly less than the control diet at six weeks of age. Skinner et al. (1991) provided different research results about nutrient restriction. They found that feeding a starter diet containing only 75% of the NRC (1994) amino acid requirements will reduce growth rate during the starting period. When the birds are placed on 100% of the NRC (1994) amino acid requirements for the grower and finishing periods they actually grow faster than birds fed a comparable control feeding program and they exhibited fewer leg problems and fewer heart attacks. They reported the research results from a different trial when a diet diluted with 50% ground oat hulls was fed during the starter period and the birds achieved the same as, or even more weight than control-fed birds at 49 days of age, with an improved feed and nutrient efficiency.

Huran (1984) demonstrated that the low-protein rations of 16 and 20% crude protein level in the growing periods of 0-20 and 21-49 days could successfully bring male and female body weights in 49 days to broiler market weight. Both male and female birds are able to perform quite well with low protein diets containing low amino acid levels (18% CP for starter, 18% CP for grower and 16% CP for finisher) as well as on high protein diets (22% CP for starter, 20% CP for grower and 16% CP for finisher) (Leeson and Summers, 1991). These research results showed that the female is slightly smaller at 42 days, and there is a general trend for inferior feed efficiency with the low protein diets. For males, 42 day body weight was not affected, although again feed efficiency was slightly inferior.

The protein requirement of the bird can be expressed more correctly as a requirement per each essential amino acid and a total requirement for non-essential amino acids which is related to a minimal concentration in crude protein. On the basis of this concept, one attempt was conducted with two different protein levels (19.5% CP and 16.5% CP) with birds aged from 4 to 7 weeks (Uzu, 1982). The low protein diet (16.5% CP) with the addition of methionine and lysine or threonine, lysine and methionine resulted in the feed consumption level identical to and growth performance even higher than that of the control diet (19.5% CP). In fact there was no crude protein level specified as a minimum (Baker, 1995). Baker (1995) suggested to drive the appropriate protein minimum by using the amino acid to lysine ratio.

The amino acid values in table 1 are cited from the NRC (1994) amino acid requirements after adding 10% for a safety margin (Harms, 1987), except for increasing lysine value from 1.10% to 1.20% for 1-21 days old, threonine value from 0.74% to 0.78% for 21-42 days old and isoleucine value from 0.72% to 0.85% for 5-43 days old (9.0 g/kg from 15 to 23 days of age and 8.0 g/kg from 33 to 43 days of age) (Schutte and Pack, 1995; Kidd and Kerr, 1996). Kidd and Kerr (1996) reported that increasing dietary lysine from 1.10 to 1.20% from 1 to 18 days in broilers ($p < 0.001$), improved weight gain (453 g versus 488 g) and feed gain (1.39 versus 1.33). No interactions between lysine and threonine were observed. They found out that the NRC (1994) lysine requirement for 1 to 21 day old chicks is too low and the 1 to 18 day lysine requirement for chicks is at least 1.20% of diet. They also provided research results that showed the low protein diet containing 0.78% total threonine, supported growth performance and carcass yield that was equal to, or not significantly different from the high protein diet and that broilers fed low protein diets require the addition of synthetic threonine, in addition to additions of synthetic sulfur amino acid and lysine.

In a report on ascites, sudden death syndrome (SDS) and leg problems, Summers (1994, 1996) presented data that suggested that increased levels of dietary methionine and lysine, while having little effect on weight gain or feed : gain ratio, could significantly increase the incidence of ascites, SDS and leg problems. In this test, conducted with male broilers, the birds of 0-6 weeks of age were fed a commercial-type diet (0.88% of total sulfur amino acid and 1.21% of lysine) or the same diet supplemented with an additional 0.2% DL-methionine, or 0.45% L-lysine HCl or with the methionine plus lysine supplementation. McNaughton (1995a) and Whitehead (1995) have indicated that ascites, SDS and leg problems occur in particular situations such as high energy rations (i.e., more than 3250 kcal/kg), high salt rations (i.e., more than 0.6% salt) and other inadequacies of management as well as environment situations.

Amino acid values in table 1 are elevated to be quite a bit higher than values shown in the NRPJ (1984), the Rhone-Poulenc Animal Nutrition (1993), Lesson and Summers (1991), and the Korean Poultry Research (1995). However, the methionine values of table 1 were lower than those in the NRPJ (1984) and Heart-land Lysine (1990). Amino acid values provided by Avian Farms (1995) were lower than values of amino acid in table 1 for 0-3 weeks but higher for 4-7 weeks. Adding 10% safety margins to each amino acid in table 1 resulted in higher values, especially in total sulfur amino acid.

Mcknight (1996) summarized that phytase addition improved phosphorus (total) utilization from an average of 47% to an average of 64% in the practical broiler diets. Contor (1995) conducted a trial to compare the broiler diet containing 0.45% AP and 0.92% calcium to the basal diet (calcium = 0.65%, available phosphorus = 0.27%) supplemented with 1,200 units/kg of phytase (A. niger phosphates or yeast acid phosphotase or A. niger phytase). There were no differences among these treatments in weight gain, feed intake and feed conversion.

The magnitude of the response to added phytase is proportionally related to the phosphorus retention rate in the broiler body and inversely related to the phosphorus excretion, eventhough it did not appears as a straight line on their figure (Kornegayk, 1996a). McKnight (1997) recommended 500 μg/kg of phytase (Natuphos) to replace 0.1% AP and 0.1% calcium, with 300 μg/kg of phytase replacing 0.1% AP and 0.1% calcium for broiler grower and finisher diets. 1,200 μg/kg of phytase in the broiler diet (calcium = 0.65%, AP = 0.27%) resulted in the same broiler performances the diet supplied with 0.45 % AP and 0.92% calcium (Contor, 1995). According to McKnight (1997), the research results of BASF showed that the AP level could be reduced up to 0.25% with phytase supplementation in the broiler diet, which did not cause any performance differences from the 0.45% AP of the control diet.

Thirteen vitamins are added to practical poultry rations. NRC (1994) poultry requirement for vitamins is only a minimum like other nutrients and NRC'S (1994) minimum nutrient requirements are not designed to be the real level found in the diet. They are abstract, and sometimes theoretical guesses (Anon, 1994).

The best evidence of the impact of vitamin addition on animal performance is illustrated in a series of trials comparing the highest vitamin supplementation (top 5%) with consecutive lower supplementation levels (top 25%, average industry, bottom 25% and NRC) in broilers based on an industry survey conducted by BASF in 1994 (BASF, 1994). Each decrease in vitamin supplementation led to a significant ($p < 0.05$) decrease in performance measured by weight, feed efficiency and mortality.

The NRC (1994) published requirements are generally lower than the average values used by most nutritionists, except for thiamin and biotin. These two vitamins are being gradually increased by most nutritionists. The most striking difference between the NRC and field requirements are in vitamin A and D. NRC (1994) values are 25-50% lower than field requirements (Coelho, 1994). table 1 recommends vitamin levels for starter and grower broilers which were suggested by BASF (1994). These values are average commercial vitamin fortification for broilers based on an industry survey conducted by BASF in 1994 (BASF, 1994), which show much higher levels than the NRC (1994) recommendation levels. However, they are much lower than European commercial average recommendations (Gropp, 1994). For example European average recommendations (broiler starter/grower) for vitamins A, D_3 and K are 12,000 IU/kg, 4,000 IU/kg and 4 mg/kg, respectively while US average commercial vitamin fortification for broiler starters are 8,840 IU/kg, 2,811 IU/kg and 1.85 mg/kg, respectively, maintaining the same trends of each value for the rest of the other vitamins. Interestingly, the recommended values of BASF (1994) for thiamin, pyridoxine and biotin are lower than values recommended by the NRC (1994) while maintaining less than half values for biotin recommendations providing 0.08 mg/kg and 0.07 mg/kg for broiler starters and growers of US average commercial fortification compared to 0.2 mg/kg for broiler starter/grower of European average commercial fortification. However, the recommended value for thiamin is a reflection of the German minimum values of which figures for the pyridoxine supplementation of broiler diets in Germany from 1 to 7.3 mg/kg.

Methyl groups such as choline and methionine are essential in the diet, but interest in their use lagged because many researches thought growing birds could synthesize sufficient choline from normal rations to fulfill requirement (Sunde, 1982). Sunde (1982) suggested that 868 mg/kg were sufficient in broiler diets, while higher levels, including levels up to 3,906 mg/kg, did not produce sufficiently different performance. Surprisingly, German poultry diets provide the minimum figure of choline chloride too. The maximum values for broiler starter/grower are 750 (1,000) mg/kg in Germany (Europe). The level of choline for broiler starter/growers did not appear in the BASF (1994) table.

Under stress conditions, vitamin E requirements for broiler were definitely increased to 300 mg/kg feed in heat stress and 150-300 mg/kg feed in moderate E. coli infections when supplying with vitamin E acetate (Fletcher and Tappel, 1973). Murphy et al. (1981) reported that vitamin E fed to broiler chickens at 100 IU/kg of feed apparently interferes with vitamin D utilization.

The vitamin values recommended in table 1 still remain at lower levels compared to those of vitamin supplement companies like Hoffman-La Roche and BASF (Shurson et al, 1996), with these values being higher than most values recommended by Leeson and Summers (1991) except vitamin D_3, riboflavin, vitamin B_{12} and pyridoxine. Vitamin values in table 1 provide the average commercial vitamin fortification for broiler starter/grower based on industry survey in US mostly, with two vitamins (thiamin, and pyridoxine) being from Europe and two vitamins (choline and biotin) from NRC (1994).

CONCLUSION

Restrictions and regulations related to manure disposal from the animal production systems are already commonplace in many countries, while regulations and legislation pertaining to this problem are pending in other countries. In particular, nitrogen (N) and phosphorus (P) may pollute water after application of animal manure or chemical fertilizer to the soils.

Low-protein and lower phosphorus diets offer advantages in lower costs and less excretion of nitrogen, phosphorus and other potential pollutants of the environment. Instead of the conventional feed formulations, the levels of protein and phosphorus in the ration should be reduced while supplementing synthetic amino acids and enzymes like proteases and phytases. This would allow biologically available amino acids and phosphorus in feeds that are less well digested to be better utilized.

Vitamin contents in table 1 of this review are 1-6 times higher than those of the NRC (1994). Vitamin cost does not significantly affect feed cost, but vitamins are nutrients which contribute to increasing the utilization of protein and phosphorus, thereby minimizing pollution and increasing the metabolic efficiency of chickens.

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