Getting the most out of the feed we give our livestock

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Summary

This paper identifies strategies which have the potential to increase the energy and/or nutrient yield from dietary ingredients, and provide economic benefits through different approaches to diet formulation,. It is suggested here that, on the basis of our research, amino acid requirements for both layers and broilers are over–generous, and some savings can be made by decreasing these by up to 10%. Diet formulation based on digestible amino acids in conventional ingredients, compared to total amino acids, is not necessarily cost effective. Formulating layer diets to maximise profit by using the economic optimum intake of each amino acid, which may reduce egg mass and other parameters, has several attractions particularly when egg prices are low and vary according to grade. The use of unprocessed, full–fat soybeans at up to 110 g/kg in layer diets has been shown not to depress any production parameter but may be an inexpensive source of protein and energy. The use of low protein, all grain layer diets without a protein concentrate but with the addition of synthetic amino acids has been shown to maximise production parameters and minimise nitrogen excretion. Feed enzymes are discussed, particularly feed phytase. This enzyme not only releases bound phosphorus from plant ingredients but also increases the availability of some critical minerals and amino acids. New energy systems are mentioned briefly. These have potential to allow more efficient use of the energy in feedstuffs and diets or to measure dietary energy quickly and cheaply.

Introduction

Over 20% of the dry matter of diets for livestock is undigested but most is potentially useful. A small amount of this is mineral matter and yields no energy. Of the protein ingested, normally much less than 50% is actually retained as product, i.e. lean meat or egg protein. The most efficient converter of feed to gain is the broiler chicken, but at maximum growth of about 50% of dietary protein is retained. Not only is this an inefficient use of scarce feed ingredients, it pollutes the environment. Large quantities of nitrogen, phosphorus and trace elements are voided in excreta. These enter waterways and can result in growth of algae and other plant material. Some of these algaes (e.g. blue–green) are highly toxic to humans and animals. There are therefore many good reasons why there is a need to address the question of using our feedstuffs much more efficiently.

Nutrient requirements and digestible amino acids

Requirements for nutrients, mainly amino acids, are reviewed for the various classes of livestock about every four years by organisations such as the National Research Council in the USA. These specifications are widely used in diet formulation but they may or may not be appropriate to different breeds or specific climatic conditions. Recently we (Farrell *et al*. 1999) undertook research in which we had, prior to formulation, all ingredients analysed for total amino acids and apparent metabolisable energy (AME) and also for their true amino digestibilities. Formulations were for broiler chickens and were from 100% to 91% of amino acid requirements for total and digestible amino acids. The results are shown in Table 1.

Except for feed conversion ratio (FCR) at 21 days we found no difference in the production of broiler chickens whether diets were formulated on a total or a digestible amino acid basis. Nor was there any significant difference in any production parameter between diets formulated to 100% of amino acid requirements or 90% during the starter (1–3 weeks) or finisher (3–6 weeks) phase. Although not statistically significant, there was some indication that FCR at 41 days worsened as the amino acid specifications declined from 100% to 90% of requirements, and that at each amino acid specification total amino acids were slightly better in terms of growth rate and FCR than digestible amino acids. However, feed costs per kg weight gain were if anything higher on diets formulated on a digestible rather than on a total amino acid basis. In both cases cost declined as amino acid specifications of diets decreased.

When we (Farrell *et al.* 1999) undertook similar research with laying hens, again we found no difference between formulations using total and digestible amino acids, nor between diets formulated on the basis of 97% or 90% of amino acid requirements (Table 2).

All production parameters were excellent with average hen–day production about 90% over 20 weeks of lay. However, an economic analysis of feed costs showed that only the diets with 90% of amino acid requirements were cheaper than those with 97%, and the diet formulated to 90% of digestible amino acid requirements was the least expensive ($227/tonne).

Two conclusions can be drawn from these results. First, our amino acid requirements for broilers and layers are too high even for current genotypes. There are therefore considerable savings to be made in feed costs. Second, digestible amino acids for conventional feedstuffs may provide a small saving in feed costs (see Table 2) but do not give better performance. The likely explanation is that only a very few of the commonly–used ingredients such as cottonseed meal, rapeseed meal and some meat and bone meals, particularly those that are overprocessed, have amino acid digestibilities of much less than 80 – 85%. This sort of figure has been taken into account in diet formulation, particularly when specifying amino acid allowances for both poultry and pigs. It is only when large amounts of low–quality, unconventional feedstuffs are used in diet formulation that a positive benefit may be seen in using digestible rather than total amino acids.

Table 1 Bodyweight and feed conversion ratio (FCR) of broilers (sexes combined) given diets formulated on a total (T) or digestible (D) amino acid basis and to 91–100% of specifications.

			%	Bodyweight (g/bird) 21 d	FCR 21 d	Bodyweight (g/bird) 42 d	FCR 42 d	Feed costs (¢/kg gain)
Diet	1	T	100	726	1.39^{bc}	2192	1.78	59.7
	2	T	97	728	1.39^{c}	2192	1.79	58.9
	3	T	94	726	1.41^{abc}	2205	1.81	58.5
	4	T	91	714	1.43^{a}	2167	1.81	56.9
	5	D	100	717	1.41^{abc}	2163	1.80	60.5
	6	D	97	706	1.43^{ab}	2165	1.81	58.9
	7	D	94	711	1.42^{abc}	2142	1.81	57.6
	8	D	91	701	1.45^{a}	2134	1.87	56.5
SEM				10.1	0.013	19.4	0.029	
Probability				0.45	0.045	0.152	0.010	

Table 2 Egg production, egg weight, egg mass, feed intake and feed conversion ratio, and specific gravity are given for each of the four diets formulated on a total or digestible amino acid basis and to 97% or 90% of specifications.

	Total		Digestible		Probability
	97%	90%	97%	90%	
Egg production (%)	90.9	87.3	89.8	89.0	0.24
Feed intake (g/d)	106.8	105.9	108.5	107.6	0.53
Egg weight (g)	61.5	61.3	61.7	61.5	0.94
Egg mass (g/d)	55.8	53.5	55.4	55.8	0.25
Feed conversion ratio (g/g)	1.92	2.00	1.98	1.99	0.24
Specific gravity	1.087	1.088	1.088	1.087	0.64
Weight change (kg)	0.204	0.187	0.186	0.520	0.70
Ingredient cost ($/tonne)	253	243	247	227	
Feed cost/kg eggs (¢)	48.6	48.6	48.9	45.1	

Formulating diets to maximise profit

Until recently diets were formulated to maximise bird performance at least cost. This concept is different from maximising profit and considers economic aspects of formulation and the level of production that it will sustain. Computer driven models have been designed in which nutrient specifications can be varied to yield an economically optimum output (Mannion 1998). The basis of the program is that feed intake for a flock of layers will vary depending on several factors, e.g. shed temperature, strain of bird, rate of lay. Feed intake is predicted by the computer program and then daily amino acid allowances are estimated. The marginal cost of each amino acid is calculated, i.e. ¢/mg increase and the marginal revenue from egg output, i.e. ¢/g increase. The egg output sustained by the economic optimum intake of each amino acid will vary between amino acids, and these outputs are calculated by the program. The first limiting amino acid is identified and the intakes of the other amino acids are reduced accordingly to a level that will support the same egg output as that sustained by the first limiting amino acid. It follows that if very large eggs do not command the price that is required to produce a high proportion of these by the laying flock then size can be reduced by limiting the dietary amino acid supply, of methionine for example.

Roland (1998) and Ahmad *et al.* (1997) have developed an econometric feeding and management program in which egg, protein and energy prices dictate nutrient requirements. Roland's approach is less complex than that of Mannion's in that only the total sulfur amino acids (TSSA) are considered since these are normally first–limiting in typical layer diets in the United States. Depending on the price of eggs and the premiums given to the different grades, a saving of 2¢/dozen or more is possible using the econometric approach to feeding. A disadvantage of this program is that it is based on corn/soybean diets and this may have to be modified for other ingredients.

Although more complex, this same approach can be used for providing diets for broiler chickens. The most critical stage for meeting the chick's nutrient requirements is during the first seven days. During this time chicks will eat only very small quantities of feed relative to total lifetime consumption, and will use the feed very efficiently. Feed manufacturers would therefore be well advised to keep the very high quality ingredients for this phase (0–7 days) and reduce diet specifications after that time and start to introduce the poorer–quality, less expensive feedstuffs. This strategy will allow much greater usage of locally–available feedingstuffs and byproducts. Under certain circumstances, broiler growth rate may be reduced such that they do not reach their target weight in the minimum time. This factor may be less important and more economical than providing diets that are expensive and of high nutrient specifications, allowing broilers to reach their target bodyweight in minimum time. It is also possible to reduce mortality; there are often fewer deaths in slower–growing broilers and carcasses are often leaner.

Leeson *et al.* (1992) demonstrated the remarkable capacity of broilers aged 35 days to increase feed intake in response to diet dilution, i.e. reducing AME content without altering performance. This allows a high inclusion of low quality feedstuffs for the last week of growth (Table 3).

Low protein diets

It is known that the crude protein in feed grains is of poor quality in that it does not have the correct balance of the essential amino acids to support good growth and egg production. To balance these amino acids expensive protein concentrates, such as fish meal, soybean meal or grain legumes, must be added to improve production. The result is an oversupply of several amino acids and wastage of protein. On average, only about 30–35% of dietary protein is retained by broilers and layers. There is therefore an opportunity to utilise more efficiently the protein in grains through the use of free amino acids. Some of these are now economically priced and widely available; others will be available commercially when demand increases. Several researchers have been examining the use of low protein diets in layers with limited success (Keshavaraz and Jackson 1992; Summers 1993).

Table 3 Effect of reducing the energy content of broiler diets by dilution (Leeson *et al.* 1992).

Diet AME	Growth rate (g/bird)		Breast weight (g)	
(MJ/kg)	42–49 d	35–49 d	42 d	49d
13.4	625	1275	323	421
12.1	581	1225	326	436
10.7	571	1182	330	409
9.4	599	1209	328	428
8.1	629	1209	322	412
6.7	620	1199	318	414

We have been examining the use of low protein diets in layers. Shown in Table 4 are the results over 20 weeks of lay (Farrell *et al.* 1998). Although all of the diets contained some protein concentrate, diet 3 contained only 39 g sunflower meal/kg but still gave similar production to the other groups. All production parameters were similar to the control diet (170 CP/kg). It should be noted that other essential amino acids such as free threonine and tryptophan were added to some diets.

In a second experiment, some diets were formulated without any protein concentrate. The results in Table 5 demonstrate unequivocally that, provided the diets contain adequate amounts of the essential amino acids, bird performance on diets containing only cereal grains with small amounts of cereal byproducts will give excellent production without depressing egg size. The addition of glutamic acid to diet 3 did not change bird performance on that diet. All diets contained adequate amounts of minerals and vitamins. The substantial savings in dietary protein associated with its better utilisation in cereal grains, together with the reduced excretion of nitrogen by the birds, can only benefit the industry and the environment. N excretion was significantly less on the four low–protein diets compared to the control diet (Table 5). Once all of the important amino acids become economically priced then these sorts of diets will be commercially available.

Raw soybeans

Full fat soybeans are a rich source of crude protein (390 g/kg) and oil (180 g/kg) but they contain antinutritional and toxic factors, particularly trypsin inhibitors. It is therefore necessary to heat–treat the beans before feeding them to pigs and poultry. This is expensive. Broiler chickens and piglets are particularly sensitive to these inhibitors and it is common practice to pass the beans through an extruder. This utilises friction to generate sufficient heat to destroy the trypsin inhibitors in the beans. R. Perez–Maldonado, P. Mannion and D.J. Farrell (unpublished data, 1999) have demonstrated a reduction in broiler growth rate and poorer feed efficiency even when fed a variety (Kti) of soybeans selected for reduced trypsin inhibitor activity. However when we included in diets this variety and a commercial variety of full–fat soybean and fed them to groups of 30 Isa brown laying hens at 70 and 110 g/kg diet, no such depression in egg production or egg weight was seen (Table 6). However there was a tendency (P=0.08) for egg production to be reduced on the untreated raw soybean diet at 7% inclusion, and egg mass was also lowest on this diet. Feed intake was lowest on this diet. The Kti diets performed particularly well, and with one exception, egg mass was not different from that on the control diet (1). This was not so for the raw soybean based diets (2-5).

Table 4 Major dietary ingredients in low–protein layer diets and bird performance (Experiment 1).

Diet	1	2†	3	4‡	5	SEM
Major ingredients (g/kg)						
Sorghum			166			
Maize	264	570	250	630	Control	
Barley	264			116		
Wheat	264		261			
Soybean meal (45% CP)		90		115		
Mill run		206	100			
Sunflower meal (32% CP)			39			
Protein concentrate	81					
Tallow	15	4	6			
D–L methionine	2.3	2.1	2.6	2.5		
L–lysine	4.2		5.4	3.1		
Crude protein (g/kg)	129	139	119	122	170	
Layer performance (n = 25) over 12 weeks						
Egg no (%)	88.1	85.0	87.2	88.2	86.7	1.56
Egg weight (g)	53.5	54.6	53.5	53.3	53.8	0.55
Egg mass (g)	47.0	46.4	46.7	48.9	46.7	0.98
Feed intake (g/d)	114.9	118.5	118.3	118.5	119.1	2.50
Feed efficiency (g/g)	2.46	2.60	2.56	2.45	2.57	0.070

† Diet 2 of Summers (1993); ‡ Diet 5 of Keshavarez and Jackson (1992).

Table 5 Major ingredients in low–protein diets (g/kg) and bird performance (Experiment 2).

Diet	Control	2	3	4	5	SEM
Major ingredients (g/kg)						
Wheat	(conventional ingredients)	757	487	477	500	
Sorghum			300	300	300	
Rice pollard		40	53	51		
Millrun		60				
Rice hulls			24	25	7	
Soybean meal					20	
Sunflower meal					40	
Glutamic acid				8.5		
Crude protein (g/kg)	175	145	137	139	142	
Layer performance (n = 40) over 16 weeks						
Hen-day production (%)	86	89	86	86	89	1.90
Egg weight (g)	61.9	61.1	61.0	60.8	60.6	1.86
Egg mass (g/d)	53.4	54.4	52.2	53.0	54.0	1.36
Feed intake (g/d)	126^{a}	123^{a}	117^{b}	117^{b}	122^{a}	2.39
Feed efficiency (g/g)	2.40^{a}	2.27^{b}	2.25^{b}	2.26^{b}	2.28^{b}	0.0553
W excretion (g/kg)	61.7^{a}	49.0^{b}	48.0^{b}	44.1^{b}	47.7^{b}	2.56

†Value with different superscripts are significantly different.

Table 6 Mean production parameters over 19 weeks of groups of 30 Isabrown hens initially 29 weeks of age and given diets with full–fat soybeans subjected to various treatments.

	Soybean	(g/kg)	Treatment	Feed intake (g/d)	Egg production (%)	Egg weight (g)	Egg mass (g)
1	Full fat		extruded	124.8^{a}	94.0	63.6	59.8^{a}
2	Raw	70	none	110.7^{d}	88.7	61.7	54.7^{c}
3	Raw	70	steam	116.3^{c}	89.2	62.2	56.4^{bc}
4	Raw	110	none	121.9^{ab}	93.5	63.1	59.0^{ab}
5	Raw	110	steam	115.2^{cd}	92.4	61.5	56.8^{bc}
6	Kti†	70	none	117.8^{bc}	91.9	63.7	58.7^{ab}
7	Kti	70	steam	115.6^{cd}	90.8	62.6	56.7^{bc}
8	Kti	110	none	117.5^{bc}	92.2	63.2	58.3^{ab}
9	Kti	110	steam	117.8^{bc}	93.3	63.1	58.8^{ab}
	SEM			2.66	1.99	0.84	1.34
	Probability			0.00	0.08	0.089	0.004

†Selected for reduced trypsin inhibitor activity.

Feed enzymes

Non starch polysaccharides

Because substantial amounts of dry matter are passed out in faeces of livestock, partly because they do not have the necessary enzymes in their digestive tract or in insufficient concentrations, feed enzymes have received much attention. They are used routinely in conjunction with several different grains (i.e. wheat, barley and rye) because these are high in the non starch polysaccharides (NSP) which can increase gut viscosity. It is the soluble NSP that are the most serious offenders.

Not only do the NSP have a negative effect on feed utilisation, they may also create management problems, largely as a result of wet excreta. In broilers, there may be hock burns and breast blisters, downgrading of carcasses, increased mortality, respiratory problems, susceptibility to disease and reduced bird performance. In layers, there may be wet droppings that attract flies and rodents and give large numbers of unsaleable, dirty eggs. High viscosity may reduce gut peristalsis and as a consequence reduce fat digestion, particularly tallow which requires greater emulsification than vegetable oil (Bedford 1996).

Grains of low viscosity, such as maize and sorghum, do not normally respond to viscosity–reducing feed enzymes because of low levels of soluble NSP. However there are some enzyme products that have been used successfully in maize/soybean meal diets (Creswell *et al.* 1998). The production of hens on diets formulated to high (HS) or medium (MS) nutrient specifications based on maize, wheat pollard and soybean meal with a commercial enzyme product designed for low viscous grains is shown in Table 7. There was a significant response to enzyme addition on the diet with medium nutrient specifications (5% lower than HS) for egg production, egg weight and egg mass. This suggests not only an improvement in energy yield but also in amino acid digestibility.

Generally speaking, many feed enzymes give a production response only when nutrient needs are under–specified and particularly in diets of low nutrient density. This can be translated into additional yield of energy and improved availability of amino acids. Adams (1998) suggests that feed formulaters increase the AME of one tonne of feed by an additional 500 MJ when a feed enzyme is included. This figure is probably generous.

Phytate

Much of the phosphorus in plant ingredients is in a bound form and is poorly available to non-ruminant livestock, although this varies due to source, species and age of animal. Feed phytases are commercially available and used to release bound phosphorus. This in turn enables less P to be added to diets and less excreted into the environment.

Feed phytase not only increased the availability of phosphorus in diets based on sorghum and soybean meal but also increased the retention of other minerals and may increase the AME of diets given to ducklings and chickens (Farrell *et al.* 1993). Ravindran *et al.* (1998) showed that when a feed phytase was added to diets containing wheat, sorghum, soybean meal and wheat pollard and with different amounts of phytic acid P, there was a significant increase in AME of 5.6%, but only with those diets with adequate amounts of available P (4.5 g/kg). Phytase also improved ileal nitrogen digestibility and that of some essential amino acids. These additional benefits are in the order of $3 per tonne of feed (P. Selle, BASF, *pers. comm.* 1998).

Farrell and Martin (1998) have recently shown that feed phytase was effective in increasing growth rate of ducklings given diets with and without rice bran and inadequate (1 g) or adequate (3 g) in inorganic P/kg with and without rice bran (Table 8). Interestingly, only the diet with 200 g rice bran/kg and 3 g inorganic P showed no significant improvement in growth rate or feed intake. The greatest response was seen on the basal diet. This contained sorghum, wheat and soybean meal.

Further work by Cabahug *et al.* (1999) has shown the consistent improvement in mean amino acid digestibility measured in the ileum of ingredients when a feed phytase is added to the diet (Table 9).

A major concern is time of application of feed enzymes. Heat treatment and other factors unquestionably reduce enzyme stability (Pickford 1992). At 90°C some enzymes have little biological activity and at 80°C efficacy may be reduced by about 50%. Although successful attempts have been made to reduce effects of high temperature on feed enzyme stability (Pettersson and Rasmussen 1997) through coating for example, the long–term solution is likely to be post–pelleting application in liquid form, particularly if annular gap expanders are more commonly used.

Energy: systems and measurement

Provision of energy in feed ingredients for livestock is normally the most expensive component when formulating diets. Currently the two systems in general use are digestible energy (DE) for pigs and apparent metabolisable energy (AME) for poultry. Neither of these

Table 7 Responses of laying hens on diets formulated to high (HS) or medium (MS) nutrient specifications with (+) and without (–) a feed enzyme.

Treatments	HS diet		MS diet		Enzyme effect
	E-	E+	E-	E+	(P<)
Egg prod. per hen day (%)	77.6[a†]	78.7[a]	70.7[b]	75.6[a]	0.04
Egg prod. per hen housed (%)	75.3	78.0	69.4	74.3	-
Egg weight (g)	67.2[a]	67.0[a]	64.6[b]	67.1[a]	0.03
Egg mass (g/d)	52.1[a]	52.7[a]a	45.7[b]	50.7[a]	0.02
Feed intake (g/d)	114.7[b]	113.0[b]	115.0[ab]	117.3[a]	0.55
FCR (g feed/g egg)	2.20[a]	2.14[a]	2.52[b]	2.31[a]	0.05
Mortality (%)	4	2	4	2	-

[†]Values in the same row with a common superscript are not different ($P<0.05$).

systems accommodates the variation in the availability of dietary energy which depends on the source (i.e. carbohydrate, fat and protein) and the purposes for which this energy will be used (i.e. maintenance, fat and protein deposition in lean tissue, in egg albumin or in milk). Over 50 years ago Fraps recognised that absorbed energy was utilised quite differently for these different purposes and proposed the Productive Energy System for poultry (Fraps 1944; Fraps and Carlyle 1942). Because of normal biological variability and the fact that AME is such a repeatable measurement, the AME system has persisted to the present day as the basis of poultry diet formulation.

Recently Emmans (1994) published complete details of a new energy system which he has developed with colleagues over the past 15 years. This system is known as the Effective Energy System and can be used for all domestic livestock species. Like any 'net energy' system, it is quite complex and unlikely to be adopted universally as the feeding system of choice. However it does allow much more precise formulation of diets and therefore much more efficient utilisation of feedstuffs. The basic concept of the system is that an animal expends a constant amount of energy (heat) to accomplish various biochemical transactions associated with the processing of its feed on the one hand and the transformation of the end–products after digestion of the feed into maintenance and growth (fat and protein accretion) for broiler chickens on the other hand. The effective energy system considers protein, not in terms of amino acids, and fat (or lipid) not in terms of fatty acids but only in terms of energy (heat of combustion). A difficulty lies in the concept that the heat increment of growth depends on the proportion of lean and fat in the tissue gain as well as the components in the feed that will achieve this gain.

Table 8 The effects of rice bran-based diets supplemented with inorganic P (P_i) at 1 or 3 g/kg without (–) or with (+) a microbial feed phytase on bodyweight gain (g/bird/d), feed intake (g/bird/d) and feed conversion ratio (FCR, g/g) of ducklings grown from 2–19 d of age.

Rice bran	P_i	Phytase	Gain	Feed intake	FCR
0	1	-	44.2^{d†}	71.7^{f}	1.62^{e}
		+	52.6^{a}	88.1^{cd}	1.67^{de}
200	1	-	50.2^{bc}	84.7^{de}	1.69^{cd}
		+	53.1^{a}	93.5^{a}	1.76^{ab}
200	3	-	53.5^{a}	90.1^{abc}	1.68^{d}
		+	53.6^{a}	90.2^{abc}	1.68^{d}
400	1	-	49.0^{cd}	88.6^{bc}	1.81^{a}
		+	51.6^{ab}	91.9^{ab}	1.78^{ab}
400	3	-	47.3^{d}	83.4^{eg}	1.76^{ab}
		+	50.0^{bc}	87.0^{cdg}	1.74^{bc}
	LSD	(P = 0.05)	2.26	3.62	0.06

†Means within columns with no common superscripts (a–f) are significantly different (P< 0.05).

Table 9 Improvement in mean apparent ileal digestibility (%) of 15 amino acids and % increase in lysine and threonine alone in ingredients with (+) and without a feed phytase (–) (Cabahug *et al.* 1999).

	15 amino acids		Lysine	Threonine
Phytase	-	+	(% increase)	
Wheat	77.7	84.6	10.9	15.7
Sorghum	74.7	79.4	3.7	8.8
Maize	78.0	80.4	3.2	6.7
Soybean meal	82.2	85.5	4.0	8.0
Canola meal	78.7	80.7	0.9	4.1
Cottonseed meal	70.8	74.2	4.7	6.9
Sunflower meal	76.7	80.2	5.7	5.5
Millrun	70.8	73.4	2.4	6.1
Rice pollard	62.1	66.9	5.1	7.1

The starting point of the Effective Energy System is AME_n (corrected to zero nitrogen (n) balance); from this are subtracted (1) the energy required by the bird to 'process' (i.e. ingest, digest and excrete) the dry matter of the feed; (2) the energy required to digest and utilise the crude protein in the diet; and (3) the energy required to process the dietary fat. There are two coefficients that are used for fat, one for the fat in the diet that is used directly and efficiently for the synthesis of tissue fat, and the other for tissue fat that is formed from other substrates (energetically more expensive).

Like any energy system there are two components: (1) the effective energy content of the feedstuff or diet, and (2) the effective energy requirements of the broiler chicken.

In terms of energy requirements of the bird, there are three energy costs: (1) maintenance, a requirement that is based on the amount of lean tissue in the body at any given time; (2) protein retention; and (3) fat retention. The latter two need a precise knowledge of how much fat and protein are deposited daily in broiler growth. The equation can be simplified for requirement (kJ/day) to

$$\text{Maintenance heat} + 50 \text{ protein retention (g)} + 56 \text{ fat retention (g)}$$

There is a need to have detailed information on the genotype of the broilers, particularly their mature bodyweight and composition (lean and fat).

Rapid measurement of metabolisable energy

I have already mentioned that the current energy system now used for poultry is AME. Despite its inadequacies, it is likely to continue to be used for some time. The classical method of measurement of AME takes considerable time. It involves measurement of feed intake and excreta voided for 4–5 days once birds have adapted to the diet for about 3 days. There are also substantial quantities of feed needed and excreta to be dried. Sibbald (1986) developed a method in which starved cockerels are force–fed about 50 g of a pure feedstuff and the excreta collected over the next 48 hours. However there is a need to correct the excreta by subtracting the energy of droppings voided by starved, similar birds or birds given a solution of glucose. This yields a true metabolisable energy (TME) value. This method was criticised by Farrell (1981) on the grounds that it is doubtful whether the force–feeding method using a tube into the crop to deliver the 50 g of feed will be accepted much longer on animal welfare grounds.

Farrell (1978) and Farrell *et al.* (1991) have developed a rapid method in which adult birds are trained to consume their daily feed allowance (about 100 g) in one hour. The cockerels are starved for about 30 hours, then fed for one hour and excreta collected for the next 42 hours. Because feed intake is much greater than the 50 g force–fed the birds in Sibbald's method, there is no need to make a correction for endogenous excreta and the result is an AME value and not a TME value. Thus the energy value conforms with the universally accepted energy system (AME) for poultry. The advantage of this rapid method is that precise AME values can be obtained within a matter of days rather than weeks thereby allowing very accurate diet formulation with known AME value for the ingredients.

A recent experiment was designed to see if adult cockerels could be used for laying hens as the assay bird. AME of three grain based diets were compared when measurements were made with cockerels and hens.

It can be seen from Table 10 that in two out of three grains there was good agreement between the standard method of determination with hens and our rapid method with cockerels. There is no explanation as to why sorghum B gave a higher value of 1 MJ for hens than for cockerels. A major advantage of adult cockerels is that they are in zero nitrogen balance such that AME = AME_n and no nitrogen analysis is therefore necessary.

Concluding remarks

As we move into the next millennium, there will be continued growth in the world's population, increased demand for livestock products and greater competition for food to feed our livestock. Although projected growth in the Asian region has slowed down for economic reasons (Farrell 1998), the long–term predictions indicate that our feed resources may be the limiting factor in attempts to meet animal protein demand (Farrell 1997).

Table 10 A comparison of AME_n values (± SEM) made on the same three diets with adult hens using the conventional 4–day method and with adult cockerels using the rapid method of Farrell *et al.* (1991).

Diet	AME_n MJ/kg DM		
(Grain base)	Hens	Cockerels	SEM
Sorghum A	14.85	14.47	0.182
Sorghum B	15.50†	14.40	0.092
Barley	13.64	13.60	0.090

†Significantly different (P = 0.05).

This paper has identified a number of ways in which we can extract more nutrients from feedstuffs, balance more accurately our diets, utilise energy in feeds more efficiently, and measure that energy more accurately and quickly. For these initiatives to be used in the commercial world, those that formulate our diets and feed our livestock must work more closely with scientists and technical staff to bring these innovations to fruition and ensure their practical application.

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