

Using Low Energy or Low Fat Diets? – Some Practical and Theoretical Considerations.

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Introduction

Since mid 2006, the ingredient markets worldwide have been causing poultry nutritionists and producers deep concern over the cost of cereals and protein sources. While the pressure on prices in the US is well documented as competition to use corn as a substrate for bio-ethanol has become more intense, the situation outside the US is complicated due to dynamics of both the corn and wheat markets. In some cases, the day to day availability of cereals just to manufacture diets has been a concern. Faced with economic and practical pressures, the responses of nutritionists have been either to absorb the cereal price increases, look for alternative ingredients to meet the existing nutrient specifications or revise their nutrient density specifications completely. This paper addresses some of the practical and theoretical considerations to be made if nutrient density is changed in response to this dynamic ingredient economics situation.

Ingredient Economics

In addition to bio-ethanol demands in the US, the instability of cereals markets outside the US is partly being driven by demand for cereals from emerging markets in Asia such as China and India plus recent crop failures most notably for wheat in parts of Europe and Australia. Added to this complicated mix is the pressure on supply of fats and oils; many of the types previously used in animal nutrition are also valuable commodities for bio-fuel production. The fats market also has some political features because in many countries the use of specific animal fats is forbidden in poultry diets either by supply as they are a key feature of human diets, by law or by joint industry and supermarket codes of practice. This makes the list of available fats for formulation very short with often only expensive soya or maize oil combinations as unsaturated sources for young animals and palm oil based products as saturated fat sources for older animals. This creates further political pressure because of the increased deforestation in South East Asia to expand palm oil production and the loss of habitat for endangered species. This previous situation designed to give consumer satisfaction leads to nutritionally useful saturated fats produced locally not being used for local

animal feed while palm oil from the other side of the globe is transported from environmentally sensitive areas and used as its replacement.

Figure 1 shows a comparison of US corn and UK wheat prices expressed in US cents on a cents per calorie basis. While this shows the fluctuations in the US market with prices ranging by 200% in two years it also shows the increased cost of not having home grown corn in a wheat market such as the UK. This also shows the current crisis in the wheat markets; many of whom have not yet experienced a surge in bio-ethanol production such as the US has experienced. Needless to say this is casting a huge shadow over confidence in pig and poultry production in these markets.

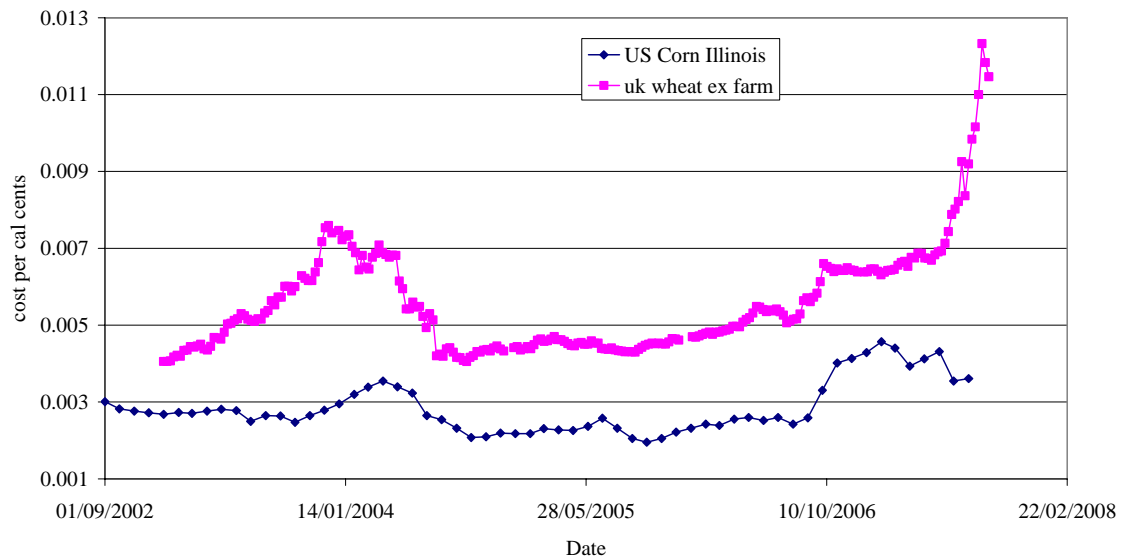


Figure 1. Comparison of costs per calorie for UK wheat and US corn (source UK wheat, Farmers Weekly, 2007; US Corn, USDA 2007). Wheat AME 3086 kcal/kg; Corn AME 3362 kcal/kg UK£ = 2.02 USD.

Nutrient Density

The term nutrient density is often used to mean different concepts including changes in caloric density (kcal/kg) alone, changes in amino acid concentrations (%) to increase amino acid intake or changes in caloric density but with constant nutrient : AME (apparent Metabolizable energy) ratios maintained at each AME concentration tested. This latter definition of nutrient density is used within this paper with increases in AME concentration implying pro rata increases in other nutrients.

Some examples of the range of typical AME concentrations the author has encountered in diets from around the world are shown in Table 1. This does not indicate amino acid: energy ratios which also vary and are not quoted as they are more commercially sensitive. These vary primarily according to the

genotype of bird used, market weights, products (live bird, portions or cut up) and ingredient availability. Turkey diets show some large differences principally between wheat based Northern Europe diets and corn based diets elsewhere.

Table 1. Typical dietary Metabolizable concentrations (AME kcal/kg)

Turkeys	USA	UK	France	Italy	Germany	Brazil
Prestarter	2900	2800	2800	2850	2750	2850
Starter	3000	2820	2900	3000	2850	3050
Grower	3250	2850	3100	3200	2950	2950
Finisher	3450	2900	3250	3350	3100	3100
Breeder	2900	2750	2800	2850	2750	2900
Broilers	USA	France*	Italy	China	Thailand	
Starter	3000	2850	3000	2900	2900	
Grower	3150	2900	3100	3000	3000	
Finisher	3250	2950	3250	3100	3100	
Breeder	2900	2750	2750	2800	2800	
	*certified <i>broilers</i>					

Responding to ingredient cost and optimising product economic performance should be the main reason for choosing energy concentrations but there are other important constraints which commercial nutritionists have to work within that can make change quite difficult to implement. One factor often encountered is the grower contract in loosely integrated organisations, particularly where growers are paid according to achieved feed conversion ratio (FCR). Changing dietary AME particularly to lower concentrations requires contracts to be amended in some cases which can create inertia. Contracts should reflect the feeding cost per bird or caloric conversion per kg live or kg meat and should not prevent the nutritionist optimising the feed programme for overall profitability of the organisation.

Alternative ingredients

Table 2 shows a potential list of other cereal replacement ingredients encountered in diets around the world and AME concentrations used for these ingredients. The variation in AME concentrations per ingredient noted is important as much of this is due to differences in interpretation of the same quality of ingredient rather than real differences in the true quality of ingredient. When comparing diets or nutritional recommendations from different regions or countries, it is important to compare the analysis of ingredients between nutrient databases on which these analyses are based.

What is low AME to you may not be to someone else. Virtually all alternatives to corn have lower ME concentrations and tend to have more practical problems associated with them that restrict their use or add cost to the system.

This list does not include meat meals, fish meals and whole (full fat) oilseeds which are also significant contributors to total ME in many situations. Faced with increased ingredient costs, nutritionists in most countries have little option but to use their existing repertoire of ingredients and review existing specifications to see if they still optimise the cost of production. Traditional corn based markets probably have least flexibility. The US production of corn DDGS is perhaps an exception where partial substitution between corn and corn DDGS has occurred. US corn DDGS is also finding its way into export markets and is increasingly appearing in combinations with other local ingredients.

Table 2. Alternatives to corn and wheat

Ingredient	AME kcal/kg	Practical Issues
Corn	3330 - 3390	Pellet quality
Wheat	3050 - 3200	wet litter – NSP enzymes
Barley	2640 - 2750	Litter quality - Beta glucans
Sorghum	3250 - 3300	Tannins by variety
Bakery waste	3750 - 3900	Variability by local source
Wheat middlings	2200 - 2500	Variability by local source
Fats	7500 - 8500	Quality and pellet quality
Oils	8000 - 9000	Cost and pellet quality
Corn DDGS	2400 - 2800	Handling
Rice bran	1280 - 2800	Variability – contamination
Oats	2500 - 2650	Availability
Naked oats	3350 - 3400	Availability
Tapioca	2800 - 2900	Handling and litter quality
Triticale	3100 - 3150	Litter quality - use enzymes

Another new ingredient raising interest in Northern Europe is naked oats that can be grown in climates where corn cannot be grown but has a similar AME content to corn (Macleod, 2007).

Optimum Nutrient Density – Formulation and Cost per Calorie

A possible simple framework for determining the optimum nutrient density in practice is set out as follows. On a routine basis, a commercial nutritionist should evaluate for each diet and set of ingredients costs, the nutrient density that minimises cost per calorie AME. This is a relatively easy exercise to undertake and serves to check whether the nutrient density in use differs

from that that optimises cost per calorie. Examples of such an exercise are shown in Figure 1 and 2. The are based on formulating diets for a turkey grower diet used at 9 to 12 weeks of age at a range of AME concentrations but with each diet having nutrient : AME ratios shown in Table 3.

Table 3. Nutrient : AME ratios in a turkey grower diet between 9 and 12 weeks. (g/Mcal).

Nutrient	
Lysine	4.08
Meth	1.75
M+C	3.11
Tryptophan	0.70
Threonine	2.63
Arginine	4.45
Calcium	3.93
Av. Phos	2.21
Na min	0.54
Na max	0.65
Cl min	0.63
Cl max	0.76

Example mid west costs were obtained for US ingredient price sets from August 2006 and August 2007 to compare the effect of changes in ingredient prices on cost per calorie. For the 2007 prices, the exercise was repeated first with fat prices reduced by 35% and secondly with DDGS not included. As a comparison, the same exercise was repeated for UK ingredient prices from 2005 (low prices) and November 2007 (very expensive) to provide an example for wheat based diets. All analyses include a factor for manufacturing and delivery of \$35 US or £35 UK.

Figure 1 clearly shows the increase in US costs between 2006 and 2007. However, the response of cost per calorie to increasing nutrient density is similar for both years and minimum cost per calorie is obtained at 2900 – 3000 kcal/kg versus a typical value of 3200 kcal/kg for this diet. Not permitting DDGS (previously permitted up to 20%) increases the optimum economic AME concentration by approximately 100 kcal/kg. Reducing fat costs by 35% changes the shape of the response quite dramatically with little change in cost per calorie between 2900 and 3300 kcal/kg supporting the traditional value of 3200 kcal/kg. The UK ingredient costs for a wheat based ingredient market show the expensive impact of trying to produce high energy turkey diets above 3100 kcal/kg. However, there is little change in the pattern of response between 2005 and 2007 with a typical value for this diet of 2900 kcal/kg. However, the UK costs per calorie are almost twice those in the US.

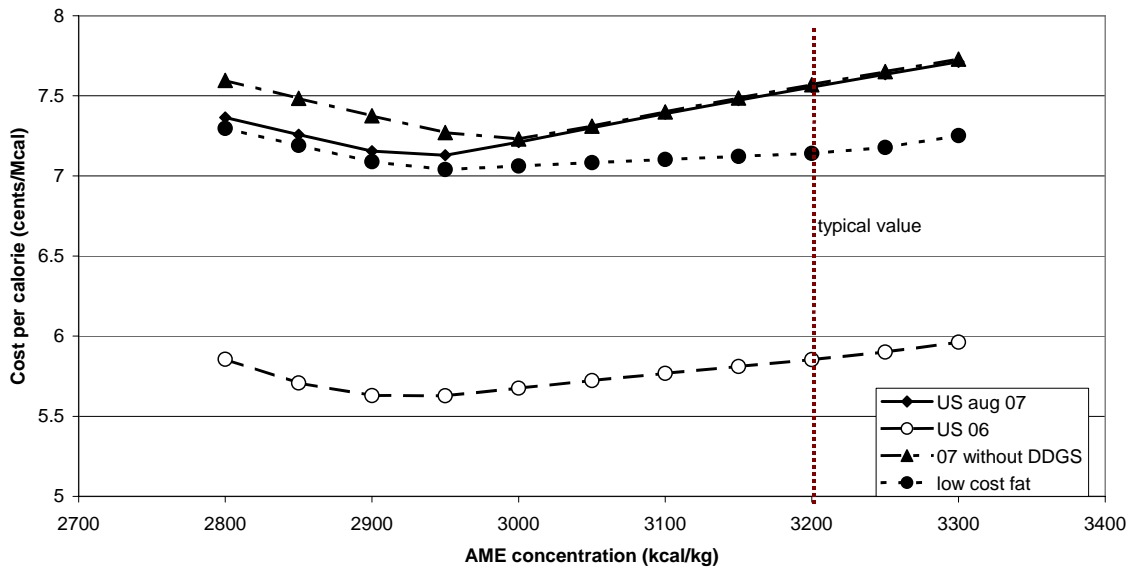


Figure 1. A comparison of cost per calorie for US ingredient costs in 2006 and 2007 for a range of AME concentrations at constant nutrient : AME ratios

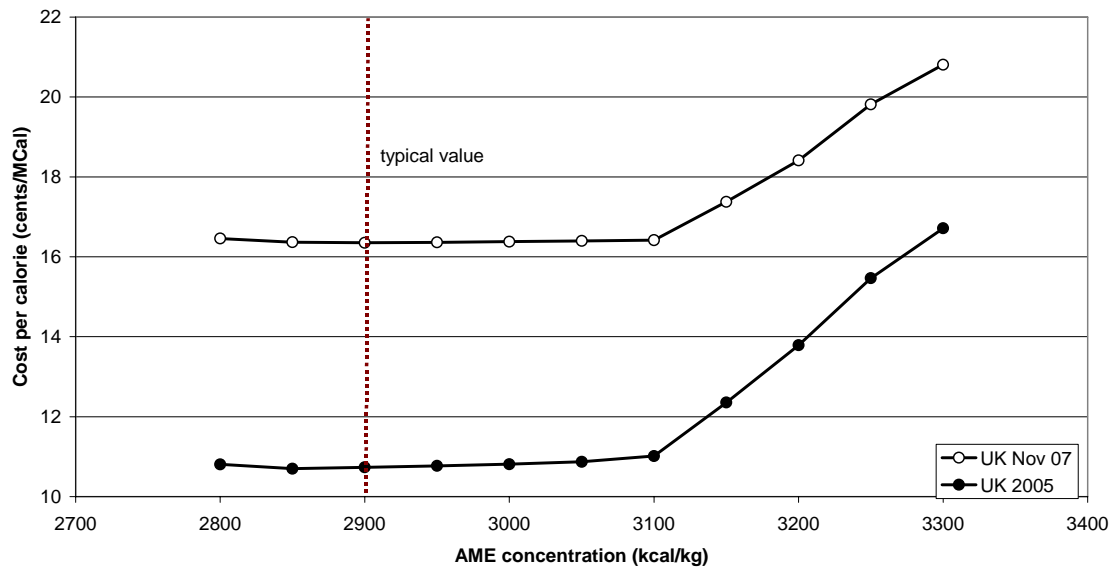


Figure 2. A comparison of cost per calorie for UK ingredient costs in 2005 and 2007 for a range of AME concentrations at constant nutrient : AME ratios

This analysis serves as an example for one diet only and the results are not intended as definitive recommendations. It is surprising visiting nutritionists around the world how infrequently nutrient density is challenged. The intention here is to encourage nutritionists to do the exercise themselves for

their own ingredient costs as limits such as maximum fat mixing or spraying capacity, pellet quality limitations and manufacturing costs and transport cost will impact their results.

It is likely with increasing fat costs and limited availability plus substitution between corn and DDGS, the optimum AME concentration to minimise cost per calorie in future is likely to be lower than traditional values, especially for turkey diets in North Carolina.

Various modelling techniques have been suggested to automatically calculate optimum nutrient density to minimise feed cost or maximise margins. As an example, Guevara (2004) has suggested determining the optimum caloric density using nonlinear programming techniques incorporating predictive broiler performance quadratic equations. It is also possible to configure least cost formulation software to formulate to achieve the optimum caloric density by setting nutrients and requirements as nutrient : AME ratios and setting cost per calorie as a formulation constraint. While these techniques are useful and rapid, for commercial nutritionists working with a feed mill with ever changing practical and commercial constraints, it is important to understand clearly how local ingredient constraints and prices influence the outcome of an exercise of the type shown in Figure 1.

Besides ingredient cost factors, changes in genotype may over a longer period influence the AME concentration that minimises cost per calorie. It can be hypothesised that the combination of selection for both improved feed conversion (which reduces feed intake to achieve target slaughter weight) and increased breast growth potential means modern genotypes will require higher nutrient : AME ratios in order to achieve their optimum nutrient intakes. The elegant work of Havenstein *et al.* (2003 a and b) showed the impact of feeding the modern broiler and a strain with 1957 genetic potential on 1957 and 2001 specification diets. There was a significant strain x diet interaction with the modern strain having both significantly lower growth rate and breast meat yield when fed the 1957 diet indicating the nutrient requirements for maximum growth in the modern genotype had increased over time in comparison to those for the older genotype. As an example of more subtle genotypic differences, Kidd *et al.* (2004) examined the response of three strains of broiler with different growth, feed intake and breast growth potentials to increased threonine intake. Depending on the method of determination, these data only show subtle but economically important differences in the optimum threonine inclusion rates according to strain.

Practical data to indicate this hypothesis is correct and is influencing worldwide commercial broiler diets are limited. Interestingly, Figure 3 shows lysine concentrations are increasing as shown by the global average lysine content determined by analysis of broiler diets (Degussa, 2007). Regression analysis suggests percent lysine concentrations are increasing by 0.017, 0.011 and 0.020 per year. It must be noted that these increased lysine concentrations are a response to improvements in genotype growth and

efficiency is an assumption. Partly it may reflect the move in some markets from whole bird to further processing. It must be noted also that these data do not show corresponding AME concentrations while in contrast to lysine, the corresponding analyses for other amino acids do not show clear annual improvements.

Similar global data are not available for turkeys but from my experience, I would not expect similar increases in amino acid content to be seen in turkey diets. This is despite genotypes also being selected for improved feed conversion and breast growth potential. Increasing nutrient : AME ratios at each stage of growth will require more space in the formula for protein sources such as soya. This will increase the demand for increasingly expensive energy dense materials such as corn and fats and oils which may mean cost per calorie is minimised at lower AME concentrations. Formulating to lower AME concentration but incorporating higher nutrient : AME ratios may be a correlated effect of genotypic improvement.

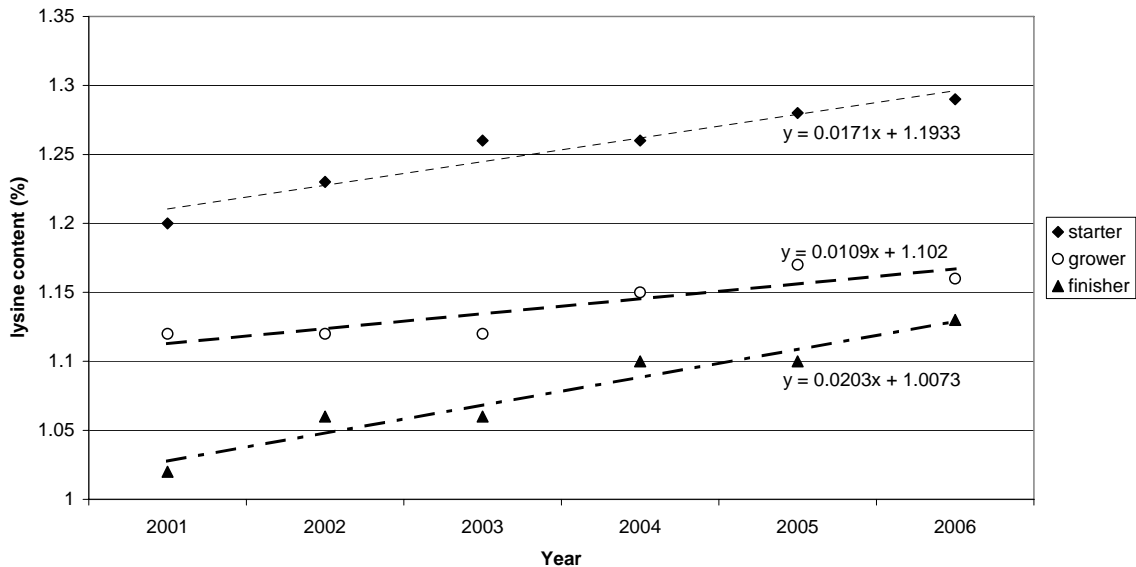


Figure 3. Trends in annual lysine concentration in broiler diets (Degussa, 2007)

Optimum Nutrient Density – Physical Performance

Example trial

The next stage in the framework of predicting the optimum nutrient density is to ask whether physical performance is affected by changing AME concentration while maintaining constant nutrient : AME ratios.

For turkeys, this was the subject of a series of trials (BUT unpublished, 1995 and 1997). Diets were produced for the Grower 1 phase onwards that

reflected the low AME concentrations for low nutrient density diets such as the UK, high AME diets for high nutrient density diets such as Italy and the US (see Table 3) and an intermediate density produced by blending the low and high ranges. Nutrient : AME ratios were calculated to be the same for each series of diets (note - amino acids were expressed on a total basis).

In a preliminary trial, heavy medium strain males were grown using the low and high density programmes (see Table 4).

Table 3. Example of dietary specifications for nutrient density trials

Period	Age (d)	AME (kcal/kg)			Nutrient :AME ratios	
		low	med	high	Lys:Mcal	Met+Cys:Mcal
Prestarter	0 - 28	2829			6.54	4.28
Starter	28 - 43	2857			5.64	3.89
Grower 1	43 - 67	2895	3066	3243	4.81	3.63
Grower 2	67 - 95	2895	3099	3291	3.87	3.06
Finisher	94 - 134	2908	3111	3315	3.27	2.83

Table 4. Effect of nutrient density on performance of heavy medium turkey males at 141d (BUT 1995). (see Table 3 for description of terms high and low).

	High	Low
Body weight (kg)	17.7	17.1
Breast (% live)	28.8	28.9
Breast skin (% live)	5.7	5.4
Abdominal fat (% live)	1.7	1.5
Breast weight (kg)	5.1	4.9

This trial showed that despite having the same nutrient : AME ratios, there was a growth response to increased nutrient density. However, percentage of breast was not improved and there was some evidence of increased fatness associated with this growth response to increased nutrient density.

A further trial using heavy strain males compared low, medium and high nutrient density programmes (see Table 5). Diets were wheat based with AME concentration increased by using added fat. AME concentration was constrained in the high nutrient density diets to ensure pellet quality was similar for each nutrient density.

Again, there was a growth response to increased nutrient density in this trial. However, fatness was increased while breast meat percentage decreased. As with the preliminary trial, breast weight did not show the same responses as body weight to increased nutrient density. Feed intake declined linearly with increase dietary AME concentration; there was almost a perfect isocaloric

adjustment as AME intake increased by 1.6% and 2.0% for the medium and high density programmes.

In terms of biological efficiency, the high nutrient density programme was most efficient. However, in terms of economic efficiency, the optimum programme depends on whether the assessment is made on feed cost per kg live or per kg breast meat and on local ingredient costs. Figure 4 summarizes the effect of increased AME concentration on body weight and feed intake with both traits showing linear responses.

Table 5. Effect of nutrient density on performance of heavy turkey males at 134d (BUT 1997). (see Table 3 for description of terms low, medium and high).

results 0 - 134d	Low	Medium	High
weighted average AME (kcal/kg)	2895	3075	3248
Body weight (kg)	18.53	19.09	19.51
Feed conversion ratio	2.92	2.71	2.62
Caloric conversion (kcal/g)	8.45	8.33	8.19
AME intake (kcal/d)	1169	1187	1192
Breast (% live)	27.77	27.66	26.95
Breast weight (kg)	5.15	5.28	5.26
Abdominal fat (% live)	1.28	1.47	1.83
Feed : breast	10.51	9.79	9.35
calories : breast (kcal/g)	30.41	30.12	30.36

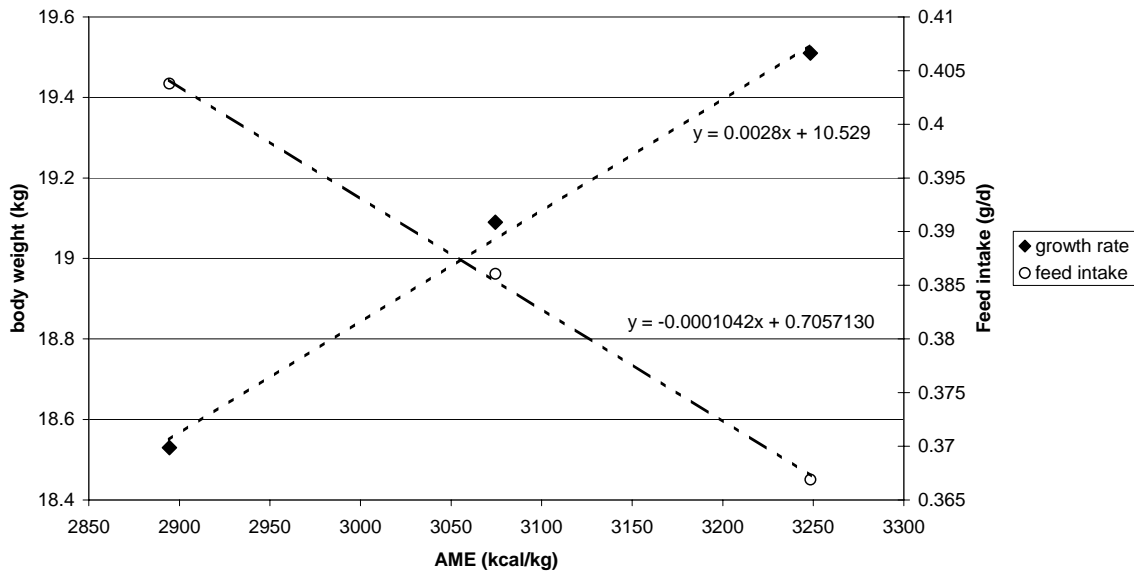


Figure 4. Effect of AME concentration on body weight and feed intake of heavy male turkeys to 134d.

Economic analysis

Local costs were estimated for each programme by formulating diets to meet the nutrient constraints of each programme using local ingredients and local costs. Costs sets used were examples of US and UK for 1997 (when soya was very expensive) and US and UK (peak replacement prices) for 2007 (Table 6).

The UK example is included as it shows the impact of a wheat based system. This shows that despite improved body weight and FCR, there is no economic justification for medium or high nutrient density programmes to minimize feed cost per kg live or per kg breast meat. This reinforces the argument that FCR is not always an accurate predictor of economic performance. Interpretation of the US costs is more complex as the least cost nutrient density varies by year and whether the assessment is on a live bird or breast meat basis. For the 1997 costs, feed cost per kg live was optimized at the high nutrient density justifying commercial practice at that time. However, feed cost per kg breast was optimized at the medium nutrient density. In contrast, the 2007 costs showed the low nutrient density programme gave lowest feed cost per kg live and per kg breast.

It was also noted in this and the preliminary trial that the low nutrient density programme produced wetter litter that required frequent bedding with clean shavings. The high nutrient density programme required little bedding after 100 days and litter volume in these trial pens as judged by depth of litter was lower. The bedding use was unfortunately not recorded but bedding and litter removal costs are increasingly expensive management considerations. The cost and impact of these items on a litter management programme should be included to provide a whole system assessment of the effects of changes in nutrient density. A sudden increase in litter disposal volume caused by changing nutrient density may make a nutritionist very unpopular with production managers!

Two practical points arise from personal experience discussing these findings with commercial producers. First, there is consensus that optimum nutrient density varies according to region, country and time and best practice dictates this is reviewed especially where a wide range of ingredients are available or ingredient prices are volatile. Secondly, when some organizations have performed nutrient density trials in commercial practice, the responses to nutrient density were inconsistent and different to those shown in Table 5 reinforcing the view that individual companies need to keep challenging their own feed programmes and not rely on external data. Extrapolating turkey pen trial results to commercial practice often presents a number of issues. The impact of other feed intake factors such as physical

feed quality, temperature and stocking density confounds the responses observed in commercial practice.

Table 6. Feed cost per kg live bird and kg breast for heavy male turkeys using results in Table 5 and ingredient costs for 1997 and 2002 for the UK and USA.

	Low	Medium	High
body weight (kg)	18.53	19.09	19.51
FCR	2.92	2.71	2.52
feed cost per kg live (US cents/kg)			
UK 1997	1.15	1.17	1.54
US 1997	0.65	0.61	0.61
UK 2007	1.37	1.41	1.49
US 2007	0.59	0.61	0.63
Breast (% live)	27.77	27.66	26.95
feed cost per kg breast (US cents/kg)			
UK 1997	4.13	4.22	5.74
US 1997	2.33	2.20	2.25
UK 2007	4.93	5.11	5.53
US 2007	2.14	2.19	2.35

Published response data

The nutrient density responses reported above were achieved using diets where AME concentration was increased primarily by increasing fat content of the diet. Plavnik *et al.* (1997a) conducted similar trials in broilers and turkeys to investigate the effect of increasing nutrient density by increasing carbohydrate or fat concentration at the expense of dietary fibre. In these trials, the responses to dietary AME were similar for carbohydrate and fat indicating additivity of fat and carbohydrate calories across the range of AME concentrations tested for both species. For turkeys, the responses to dietary AME were linear up to the highest AME tested (3250 kcal/kg). In broilers, there was evidence of non linear effects of AME concentration on weight gain and feed efficiency with asymptotic responses, especially between 1 and 4 weeks of age when body weight gain was significantly depressed below 2900 kcal/kg.

From a review of the literature, other similar research can be classified into reports where responses of body weight to nutrient density were observed

(Pesti *et al.*, 1983; Jackson *et al.*, 1982; Guevara, 2004; Araujo *et al.*, 2005) trials were no response was observed (Waldroup *et al.*, 1990; Veldkamp *et al.*, 2005) or trials with a negative response (Lemme *et al.*, 2005). This parallels some of the variable commercial experience with nutrient density research.

The classic study of the effects of dietary AME concentration on performance by Fisher and Wilson (1974) analyzed the results of 160 experiments and for experiments where a significant growth response to AME was observed, they produced an estimate of +0.33 g/d per 100 kcal AME/kg while carcass fat increased by 0.16% per 100 kcal AME/kg. This increase in carcass fatness was considered to be independent of the level of inclusion of added fat.

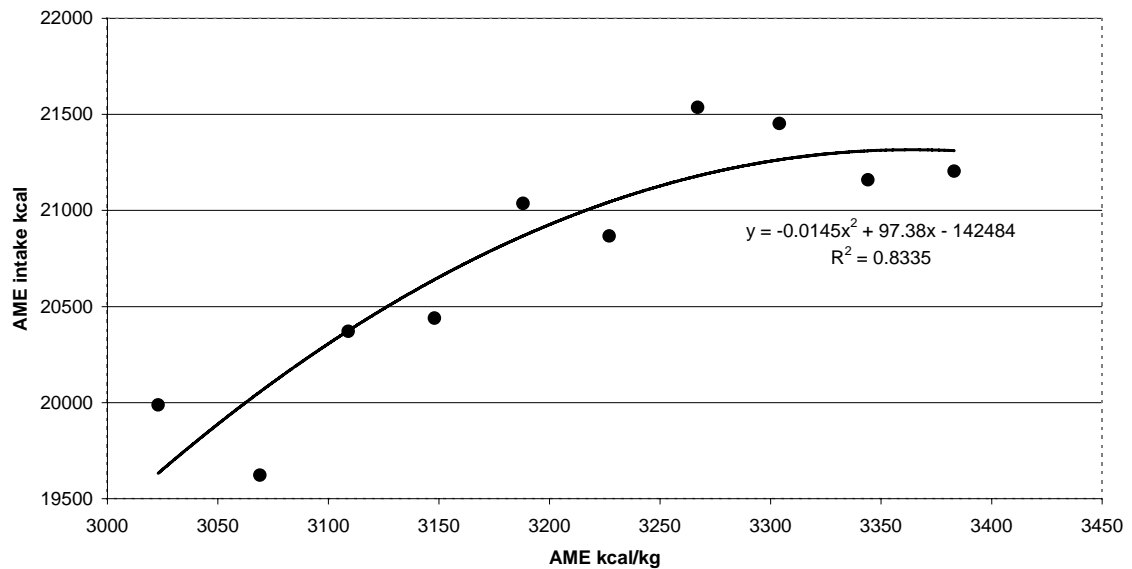


Figure 6. Effect of AME concentration on AME intake to 56d for heavy broilers (Saleh *et al.*, (2004).

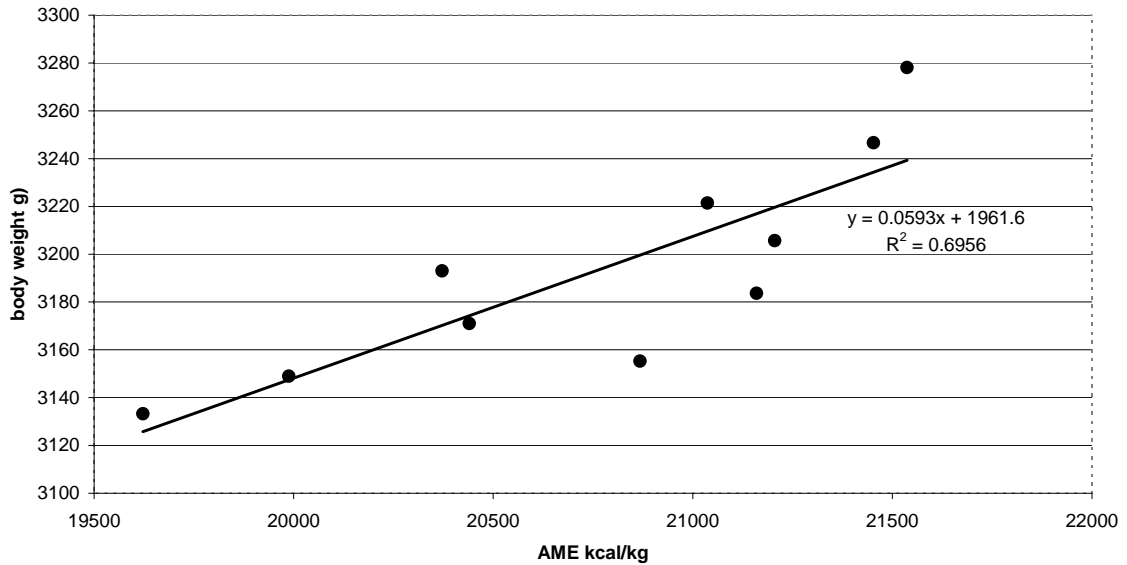


Figure 7. Relationship between AME intake and body weight at 56d for heavy broilers (Saleh *et al.*, 2004).

A typical example of a recent comprehensive broiler nutrient density trial is summarized in Figures 5 and 6 (Saleh *et al.*, 2004). This trial shows a quadratic response of body weight with reduced body weight using high AME greater than 3300 kcal/kg and reduced feed intake at these high AME concentrations. Breast meat yield was variable with evidence of a parabolic shaped response.

Broilers did not show evidence of achieving isocaloric consumption (Figure 6) as AME concentration increased. AME intake increased as AME concentration increased to 3250 kcal/kg. There was a strong correlation between body weight and AME intake (Figure 7). From practical experience, the effect of increased nutrient density on growth performance is more reliable (i.e. linear to higher AME concentrations) for turkeys than broilers providing pellet quality is maintained. Practical guides are 2 g/d per 100 calories for heavy turkey males to 140 days and 0.5 - 1 g/d for modern broilers up to 3250 kcal/kg AME.

The recent turkey work of Veldkamp *et al.* (2005) also demonstrated no interaction for body weight between dietary AME and ambient temperature but for feed intake there was a significant interaction especially at earlier ages with feed intake significantly depressed at low AME and high temperature. In agreement with the results reported in Table 5, breast meat yield was also significantly reduced by increased AME concentration.

More recent broiler data (Dozier *et al.*, 2007) also confirms that for heavy broilers reduced AME concentration in the finisher period tended to improve breast meat yield which was more sensitive to amino acid intake than AME concentration. For broilers, Lemme *et al.*, 2005 also showed highest breast

meat yields with a low AME (2709, 2858 and 2903 kcal/kg) programme for starter, grower and finisher diets respectively. This study also compared the growth response to methionine and cystine (met + cys) intake at each dietary AME concentration. Integrating the responses to met + cys intake for each level of AME indicated one common growth response curve independent of AME concentration (Figure 5). A similar conclusion was made for turkeys with a common response curve to increased met + cys intake in 12 to 16 week old male turkeys at low and medium AME concentrations (BUT unpublished, 1994).

However, in contrast to most other turkey trials, dietary AME had no effect on growth or breast meat yield in this trial. These trials, where the plateau of the growth response to amino acid intake was unaffected by AME concentration, both support the hypothesis that amino acid response curves can be calculated independently of AME concentration. The key question is whether this statement is valid when the asymptote or plateau (maximum growth rate) in the growth response to increased amino acid intake is significantly reduced by AME concentration which indicates that AME intake is limiting growth.

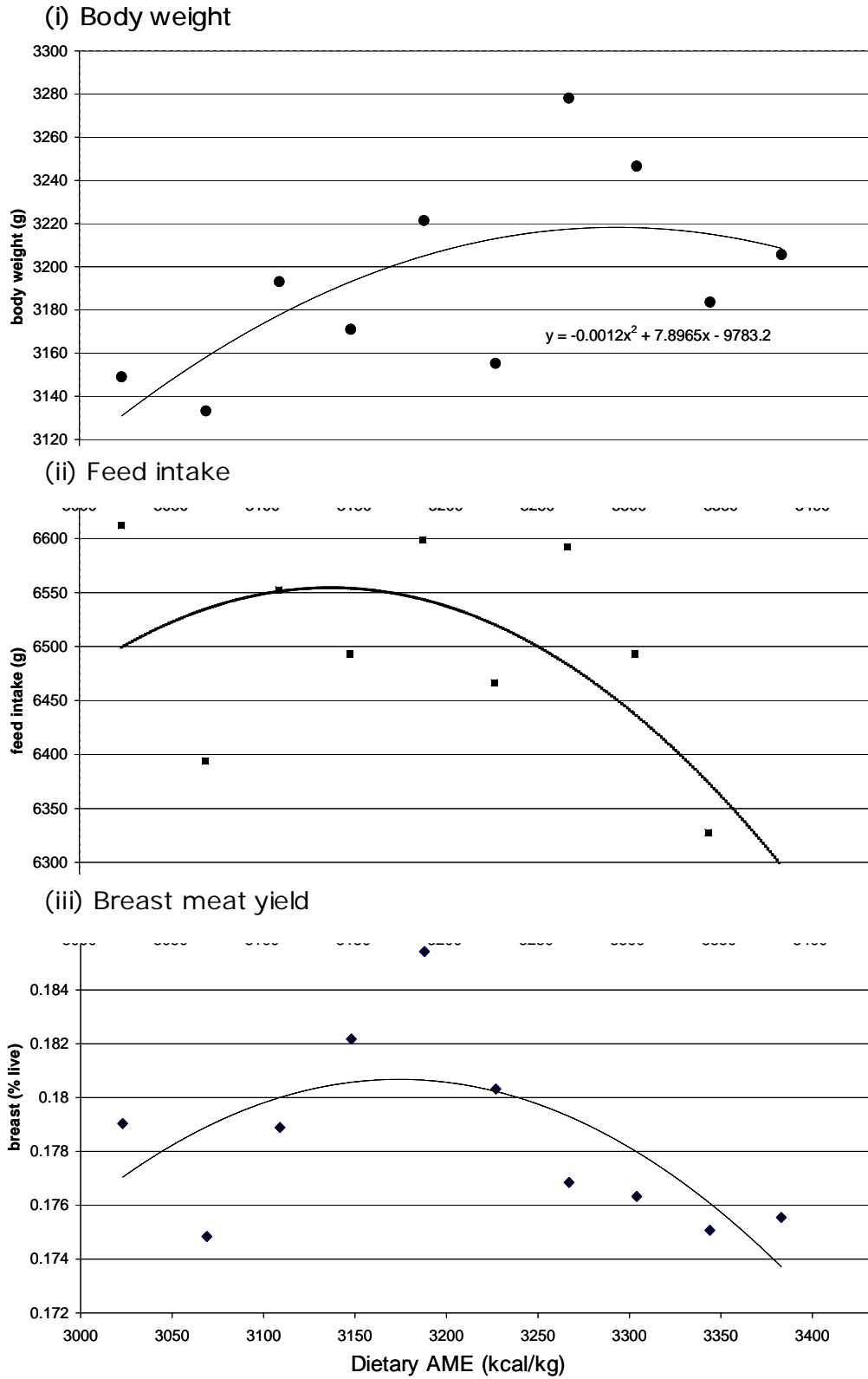


Figure 5. Effect of dietary AME concentration on body weight (56 d), feed intake (56d) and breast meat percentage (63 d) (Saleh *et al.*, 2004).

Physical form of the feed

One of the confounding practical problems when investigating nutrient density is the effect on pellet quality of changing AME concentration. Indeed, Saleh *et al.* (2004) comment that pellet quality was highly variable for the diets above 3200 kcal/kg shown in Figures 5, 6 and 7 and pellet quality may explain the non linear effects of increased AME concentration on feed intake and AME intake. Low AME diets tend to contain more wheat and less fat and therefore should have high pellet quality whereas high AME diets tend to be corn based high fat diets with greater risk of poor pellet quality. Pellet quality statistics (where pellets are used) are not reported in many nutrient density trials but may possibly explain most of the variation in response outlined previously. Part of the feed intake response may also be due to feed spillage with low pellet quality especially for heavy turkey males which complicates analysis of the data.

An example of the effect of feed form on the response of broilers between 21 and 39 days to (low) dietary AME concentrations is shown in Figure 8 (Leclerq, 1988). The slope of the growth response for mash was almost twice that for pellets (0.0104 versus 0.0053 g/d per kcal/kg). However, in a comprehensive series of trials, Plavnik *et al.*, (1997b) showed no significant difference for broilers between the linear growth responses to AME concentration for mash versus pelleted diets albeit the slope of the mash response was numerically steeper. Pelleted diets increased growth and abdominal fatness. For diets where mash was made using reground pellets, the growth responses to AME for mash and pellet diets were also not significantly different. For turkeys, the responses to AME concentration for pellets and mash diets were also both linear with similar slope coefficients when AME was varied using carbohydrate. However, when AME concentration was varied using added fat, the slope of the response to AME for pelleted diets was significantly reduced in a similar pattern to the broiler data in Figure 8. The authors concluded this effect resulted from the confounding effect of added fat on pellet quality in high AME diets. This observation is most apparent from personal experience when comparing feed conversion results in commercial practice, especially between turkey producers who use diets with AME concentrations greater than 3300 kcal/kg where pellet quality can vary dramatically between different feed mills.

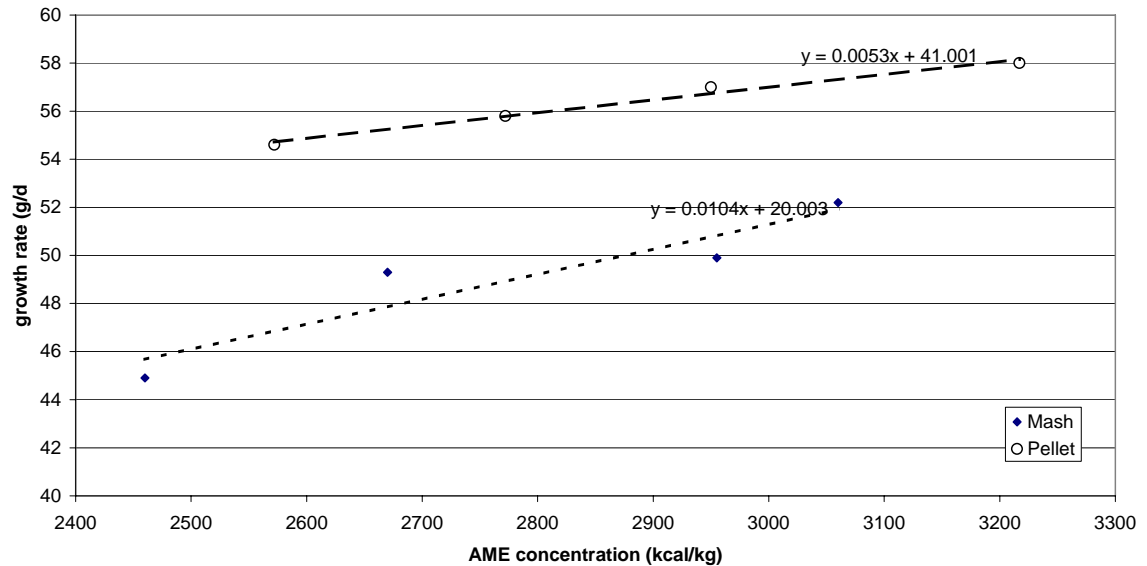


Figure 8. Responses of broilers to increasing dietary AME concentration fed either mash or pelleted diets (Leclerq, 1988)

As an aside, increasing diet costs, capital and electrical energy costs during manufacture are causing some feed producers to question the economic benefit of pelleting broiler diets. In particular, in some countries with high energy costs, two questions are often posed:

- (i) is a coarse mash (especially using roller grinding) a viable alternative for modern broilers?
- (ii) can pellet production be more cost effective in terms of both manufacturing costs and feed efficiency at lower nutrient density?

In the UK, pelleting and conditioning for a broiler finisher type diet represent about 5% of delivered diet cost for a turkey diet (T Hiley, personal communication). This may be an underestimate as the restriction on mill capacity from producing pellets could allow an increase in capacity if mash production was considered allowing fixed costs to be spread over an increased tonnage. However, the need for conditioning as a means of microbial control is a complicating factor. If market weight can be achieved at less than 5% penalty in lost feed efficiency in this example, then coarse mash may be a viable economic alternative. The results of Greenwood *et al.*, 2005 (at peak performance using 1.05% digestible lysine) for mash indicate a 6% reduction in growth rate for mash based feeds versus pellets while Lemme *et al.* (2006) suggest 6.7% reduction in growth rate for a coarse mash. Unless growth retardation is an objective of the feed programme economic calculations suggest (from pen trials results) that pellets are still justified economically for the UK example but are under review elsewhere.

In other cases and especially in tropical conditions, costs of pelleting to obtain reliable pellet quality are prohibitive so pelleting is not economically attractive and this impacts the choice on nutrient density. However, reducing nutrient density and therefore increasing the total feed required due to increased feed intake may incur some hidden manufacturing costs that cannot be ignored. If, for example, a mill is working at full capacity (which is the case many commercial mills) and nutrient density is decreased by 10% then increasing production by 10% may not be practical without significant capital expenditure. Increasing the transport capacity by 10% may also be prohibitive. Changing ingredient specification and fat inclusion rate may affect throughput rate which again impacts capacity and cost.

Moritz *et al.* (2003) assessed the effect of nutrient density when moisture additions up to 5% were made during processing feed to improve pellet quality. The results showed no effect on AME concentration (2986 versus 3143 kcal/kg) on body weight independent of moisture addition between 3 and 6 weeks of age but the lower AME programme reduced feed efficiency. However, adding 5% moisture to the low energy diet improved feed efficiency to the same level as seen with the higher AME control diet. The authors associated with improvements in pellet quality. The suggestion from this trial is that reducing nutrient density and investing in improved pellet quality may be a cost effective strategy.

If part of the growth response to increased nutrient density is caused by pellet quality effects, then the results of Greenwood *et al.* (2005) are relevant to the debate on adjusting amino acid requirements as AME concentration increases (Figure 9). Their results suggest the main effect of feed form on the growth response to lysine intake from 16 to 30 d was on the plateau phase of the response, presumably because feed form reduces growth by restricting AME intake. Optimum amino acid intake could therefore be predicted if for example, the magnitude of the effect of pellet quality on growth rate was estimated. As an example, for responses shown in Figure 9 using the lysine intakes at maximum growth rate in the quadratic functions fitted to these data and applying similar functions to AME intake (not shown), the lysine : AME ratio for maximum growth rate are 3.15 and 3.29 g/Mcal for mash and pellets, respectively. This supports the view that amino acid recommendations should be adjusted when growth is depressed by specific feed intake factors.

However, in practice the effects of pellet quality and nutrient density are likely to be working against each other in a kind of pellet positive / density negative swing effect where poor pellet quality depresses AME intake at high AME concentrations while low AME concentrations depresses AME intake due to bulk intake constraints as implied by Saleh *et al.* (2004). This is discussed in more detail by McKinney and Teeter (2004) who assign a so called 'caloric value' to pelleting in an attempt to balance these opposing effects.

Amino acid responses

Earlier in this paper, it was stated that amino acid responses are unaffected for broilers and turkeys by changes in AME concentration. An important proviso is that this statement arises from studies where AME concentration had no or little effect on the plateau of the amino acid growth response.

In those countries that use lower AME diets for turkeys such as Germany and the UK, the ratios of amino acids : AME tend to be higher than the US using high AME diets. This may be due to the use of different turkey strains, high pellet quality or ingredient digestibility effects (corn versus wheat) but this may also reflect the traditional importance of least feed cost per kg breast meat.

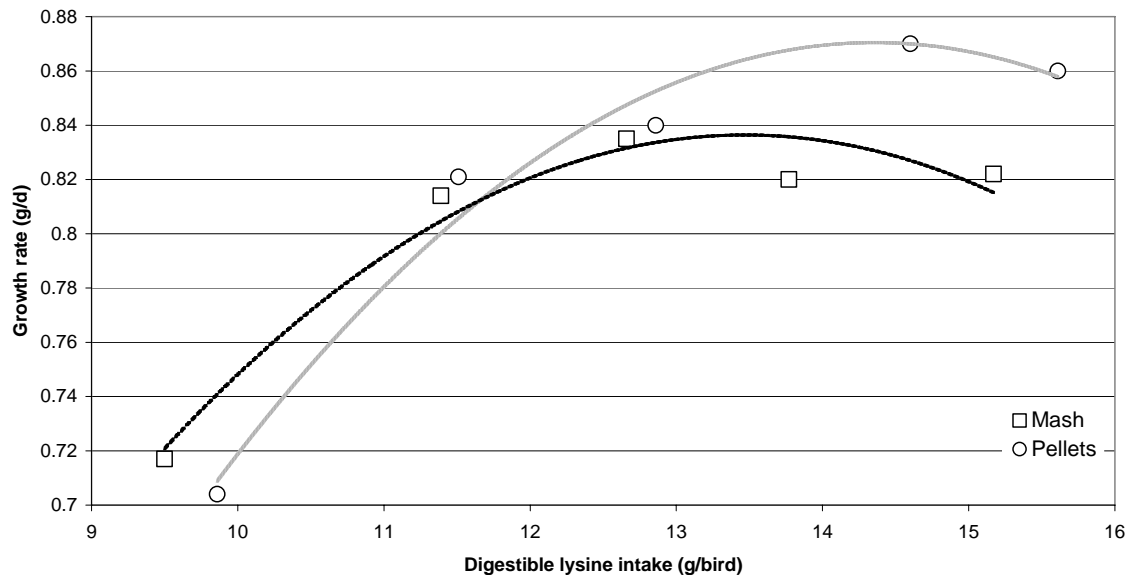


Figure 9. Effect of physical form of the feed on the response of broilers to increased digestible lysine intake from 16 to 30 d (Greenwood *et al.* 2005).

For broilers though, some nutritionists in countries that use low AME diets (<3000 kcal/kg), especially in Asia, use lower amino acid : AME ratio recommendations than those used elsewhere. It can be argued that because growth rate and feed efficiency tend to be reduced in response to low AME feed programmes, then percentage amino acid requirements are also proportionately reduced. The justification for this may have more to do with physical quality of feed effects (mash or poor pellets) on growth and feed intake than AME concentration per se, as shown in Figure 9. In contrast, most commercial recommendations by commercial organizations are based on constant amino acid : AME ratios per age across all AME concentrations.

Many reports for modern broiler genotypes (for example, Saleh *et al.*, 2004) show, despite increased body weight with increased AME concentration, breast meat weigh remains relatively constant. By corollary, lean body mass must remain relatively unchanged. Therefore, optimum amino acid intakes, if directly determined by lean tissue growth rate, will be relatively constant across all AME concentrations. The data of Saleh *et al.*, (2004) also show ME intake per kg bodyweight increased as AME concentration increased implying broilers were over consuming AME as AME concentration increases. If predicted optimum amino acid and AME intakes are combined to express amino acid requirements as amino acid: AME ratios then these ratios will not be constant but highest with low AME diets. Extending these arguments to the turkey performance data in Table 5 leads to the prediction that amino acid: AME ratio requirements will decrease with AME concentration. Needless to say, because of the effects on breast growth, this is an area where more research is required for modern genotypes to define these responses more accurately.

Other effects

The arguments above are primarily based on pen trial data. As discussed earlier, extrapolating pen trial data to commercial conditions with variable disease status and high stocking density is not straightforward and can be misleading. This applies particularly to low AME diets where broilers have to significantly increase feed intake to achieve good growth performance or where physical quality of the feed is variable. Testing proposed changes in nutrient density under commercial conditions is essential before company wide changes are implemented in order to guarantee

Conclusion

In many countries, low nutrient density feed programmes based on either lower energy cereal alternatives to corn or low fat diets are used profitably; often using the same genotypes as used in the USA. These feeding programmes have evolved to suit local ingredient economics and availability and reinforce the argument that there are no fixed requirements for nutrients only economic optima. Producers traditionally using high nutrient density diets as in the USA are coming under increasing price competition for corn and fats or oils for non livestock markets. For these producers, predicting the economic consequences of changing either ingredients or nutrient density is more relevant today than ever before. There is some evidence that broilers and turkeys may differ in the scope of their response to nutrient density but for both species, there is strong evidence that feed cost per kg breast is minimized at lower AME concentrations than is the case for feed cost per kg live. Predicting the effects of nutrient density on feed intake in practice is a major challenge as these may differ between pen trials and commercial farms. For broilers, this is also a time of rapid genetic change in the potential of new commercial genotypes for feed efficiency and breast growth which

may alter the response to changing nutrient density. Decreasing nutrient density also poses practical problems such as risks of poor litter quality, increased litter quantity and costs in feed manufacturing which must not be overlooked.

It must be remembered that nutrient density has an impact on the efficiency of the whole production system from feed mill to farm to litter disposal to processing economics. To obtain the economic optimum requires analysis of the whole system rather than looking at one area in isolation.

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