

# Invited Speakers

## S4.3

### **Nutritional Practice and Environmental Impact under Different Production Systems**

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All livestock production systems have the potential to impact the environment either directly through the production of excess nutrients or indirectly through increasing the carbon footprint associated with material movements of feed raw materials or finished products. Excessive nutrient excretion, primarily nitrogen (N) and Phosphorus (P) can be influenced by many factors, however nutritional practice such as diet specification and raw material selection will undoubtedly have the major effect. With the growth of different poultry production systems the potential for an increase in different nutritional strategies has occurred, which may in turn lead to a change in nutrient excretion and environmental impact.

Production systems which impose tight nutritional constraints may indirectly result in nutritionists selecting raw materials which are only available in limited quantities and from specific locations. This will result in an increased carbon footprint associated with their use and an adverse environmental impact.

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#### **Key words:**

Environmental Impact, Nutrient Balance, Production Systems, Organic Poultry, Nutritional Practice

#### **Introduction**

Increases in consumer concerns to animal welfare have resulted in a growing diversification of poultry production systems. Alternative egg production systems have increased to the extent that in the UK they account for 42% of all eggs produced in 2008 (Quarterly UK Egg Packing Station Survey). Organic egg production has grown in the UK to a point where it accounted for 5.8% of all eggs packed during 2007, but this has fallen back slightly during 2008 to 5.5% and is forecast to fall further during 2009 due primarily to economic challenges.

Poultry meat production has seen a similar trend with extensive systems now accounting for 5% of poultry meat being produced within the UK.

Along with concern over animal welfare the perceived environmental benefits of alternative systems have also driven the move to more extensive production. Lampkin (1997) defines organic farming as an approach to agriculture where the aim is to create integrated, humane, environmentally and economically sustainable agricultural production systems. The reference to environmental sustainability is repeated in many other documents and, whilst not consistently defined, is generally regarded as relating to minimising the total energy consumption (carbon footprint) of the enterprise along with optimising the nutrient balance (input = output).

Ongoing advancements in both genetic selection and diet formulation have significantly increased productive capabilities of modern poultry. Havenstein (1994) compared the performance of a 1957 "type" bird fed a 1957 diet, with that of a 1991 bird fed a 1991 diet. The 1991 male had a bodyweight three times that of the 1957 bird with a feed conversion efficiency 30% better. This rate of improvement has continued over the intervening years. The management of the bird and environmental control has also aided this level of improvement. These trends have not only helped improve nutrient balance within many poultry enterprises but have also helped with economic sustainability.

There is therefore a concern that the move to more extensive systems (free range, organic) may result in a reversal of this trend, with a corresponding adverse change in the nutrient balance and potentially an increase in the carbon footprint of such enterprises.

European legislation (EC1804/1999, EC 2092/1991) was formulated to set guidelines for organic production, some of which were specifically designed to provide a framework for minimising energy consumption by promoting closed farm systems (cropping to produce feed ingredients for livestock which produce manure for fertilising the crops) and the concept that the majority of the feed for the livestock will be produced by the farm.

This approach lends itself very well to a grassland/cereal/dairy type of enterprise, however it is more difficult to embrace with poultry enterprises. In order to further control the level of production the legislation places further constraints on....

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- The duration of the growing period
- Stocking density
- Genetic potential of the bird
- Permitted feed ingredients

Free range production, whilst not having the level of legislative control which is applied to organic, will still be regulated with constraints placed on stocking density and dietary raw material inclusions.

## Nutritional Strategies and their Impact on Nutrient Balance

The production of broiler tissue or egg mass is a relatively simple product of nutrient supply and nutrient utilisation. If we consider the conversion of dietary protein into either meat or egg protein then we can propose that the rate of protein utilisation is primarily controlled by the genetic potential of the bird, and the protein supply is set by the nutrient composition of the diet. Secondary factors such as bird health, environment and management will impinge on this process and have either a positive or negative effect.

Invariably nutrient utilisation is never 100% and therefore nutrient excretion will occur irrespective of the level of nutrients supplied. This process of course can be further refined if we consider protein quality or amino acid composition as this will also impact on the efficiency of protein utilisation.

The idea of the "Ideal Protein Concept" was proposed many years ago by several workers, Han & Baker, 1991, 1993, Baker and Han 1994, Mack et al 1999, Morris et al 1999 and Lemme A, 2003. The concept suggests that the rate of protein utilization is determined by the balance of amino acids in the diet and is set by the first limiting amino acid. This is often expressed diagrammatically as "Liebig's Barrel" where the staves of the barrel represent the individual amino acids and the protein accretion is represented by the amount of water in the barrel. The barrel can be filled up to the level of the lowest stave and can only be filled further if the lowest stave is raised, ie additional individual amino acid is added. In order to set a standard for the ideal protein, animal requirements are now often stated as a percentage of the lysine requirement (Table 1).

**Table 1 Suggested ideal protein balance for broiler (expressed as % of Lysine)**

	<b>M &amp; C</b>	<b>Methionine</b>	<b>Threonine</b>	<b>Tryptophan</b>
Evonick	75	43	66	16
CVB	73		63	16

The amino acid balance within the diet can be adjusted through diet reformulation, and the introduction of synthetic amino acids has greatly helped with rectifying individual amino acid shortfalls. In an average broiler diet the sulphur amino acids (methionine plus cystine) are generally first limiting and the use of synthetic methionine is used as standard to redress the balance.

It is also important to remember that a secondary consequence of the first limiting amino acid is that all other amino acids in excess of their ideal percentage cannot be utilised for protein accretion and will therefore be de-aminated and contribute to the nitrogen excretion.

It therefore follows that by optimising the amino acid balance within the diet we can reduce the crude protein level (excess amino acids) and subsequently reduce the nitrogen excretion.

Amino acid utilization will also be affected by amino acid digestibility which will vary considerably between individual raw materials (Table 2).

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**Table 2 Amino Acid Digestibility in various raw materials (%) (source Evonik)**

	<b>Lysine</b>	<b>M + C</b>	<b>Threonine</b>	<b>Tryptophan</b>
Maize	92	90	85	81
Sorghum	90	84	83	87
Wheat	86	91	87	86
Soya	90	86	85	89
Beans	85	68	78	66
Potato Protein	90	93	93	92
Corn Gluten 60	76	83	79	66

In order to take advantage of such differences, diets should be formulated on the basis of digestible amino acids. If diets are formulated on this basis, along with the ideal protein concept, it has been shown that for each 1% reduction in crude protein there is the potential for a reduction of 10% in nitrogen excretions.

Table 1 shows suggested amino acid profiles for overall broiler performance, with the major focus on bodyweight gain and feed conversion efficiency. It has been postulated that the profile should be adjusted depending on the output that is trying to be optimised.

The Arkansas broiler study reported by Coon, C. (2004) involved seven dose response experiments each determining two amino acid requirements relative to lysine for a range of output criteria. The optimum digestible amino acid profiles for weight gain, feed:gain ratio, uric acid excretion and nitrogen/amino acid accretion were then calculated using broken line, polynomial and exponential regression models (Table 3).

**Table 3 Optimum amino acid profiles for weight gain, feed/gain and uric acid excretion using broken line, polynomial and exponential regression models (Coon, C. 2004)**

		<b>Lysine</b>	<b>Melthione</b>	<b>M + C</b>	<b>Threonine</b>	<b>Tryptophan</b>
Broken Line	Weight gain	100	35.5	67.6	75.4	19.1
	Feed/gain	100	36.1	69.9	70.0	19.2
	Uric acid excretion	100	31.8	60.0	64.7	19.4
Polynomial	Weight gain	100	43.6	75.6	76.8	19.5
	Feed/gain	100	44.0	78.7	73.2	19.7
	Uric acid excretion	100	49.1	85.9	71.3	18.6
Exponential	Weight gain	100	35.6	64.5	77.4	19.8
	Feed/gain	100	36.2	65.9	63.6	18.5
	Uric acid excretion	100	35.9	77.4	67.8	20.8

Diets were formulated using the weight gain and feed/gain profiles for each regression model and fed to broiler chicks for a 10 day feeding period, and the various output criteria were measured (Table 4).

**Table 4 Performance of broilers fed diets formulated to different amino acid profiles (Coon, C. 2004)**

		<b>Weight gain/d GMS</b>	<b>Feed/gain</b>	<b>Uric Acid excretion (%)</b>
Broken Line	Weight gain	42.51	1.4015	4.70
	Feed/gain	40.94	1.483	4.94
Polynomial	Weight gain	44.39	1.36	4.46
	Feed/gain	46.87	1.337	3.40
Exponential	Weight gain	39.24	1.375	6.49
	Feed/gain	43.02	1.464	6.53

It can be seen from the data that the diets formulated using the profiles generated from the polynomial model gave the best overall performance, with a numerically improved value for uric acid excretion compared to the two other approaches. The main differences in amino acid value between the different systems is in regard to the sulphur amino acids. As these are generally regarded to be first limiting for broilers, the high levels in the polynomial approach are thought to account for the better performance and reduced uric acid excretion.

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Several workers have looked to measure the overall amino acid utilization in broiler production. Patterson 1998 carried out measurements of litter nitrogen and phosphorus and carcass accretion of nitrogen and phosphorus and by difference calculated the residual loss (Table 5).

**Table 5 Partitioning of feed Nitrogen and Phosphorus in commercial broilers of weighted mean age of 49.4 days expressed as % of Feed (Patterson 1998)**

	Feed	Litter	Carcass	Residual Loss (atmosphere)
Nitrogen	100	30.56	51.08	18.36
Phosphorus	100	57.40	34.97	7.63

Coon (2004) calculated the theoretical tissue, nitrogen accretion, along with the theoretical feather nitrogen accretion, and by difference to the calculated nitrogen intake, calculated the % utilization of each individual amino acid (Table 6).

**Table 6 Utilization of digestible amino acid for broilers of different ages (Coon 2004)**

	% Utilization (Accretion/Intake %)	
	0 – 21 days	32 – 43 days
Lysine	59.00	58.29
Methionine	41.40	44.62
M + C	68.47	52.68
Threonine	69.58	54.02
Tryptophan	72.20	48.96
Average of all amino acids	71.16	61.70

The combined data for the two calculations shows that the utilization of amino acid nitrogen reduces significantly as the bird ages.

Along with nitrogen, one of the other major nutrients considered important in the area of environmental pollution is phosphorus. As early as the 1930's (Buckner et al 1930) recommendations were being published for the phosphorus requirement of poultry. However, it was also recognised that not all of the phosphorus present in the feed was biologically available and as much as 85% of the total phosphorus may be bound as phytate (Ravindran et al 1994). The use of exogenous enzymes, primarily phytase, are known to release the bound phosphorus and workers as early as Nelson in 1968 (Nelson et al 1968) advocated their use to increase the bioavailability of dietary phosphorus.

Phosphorus excretion is therefore influenced by the level of phosphorus supplied in the diet and the nutrient uptake by the bird. The level of uptake will in turn be influenced by the bird's biological requirement and the availability of the nutrient to the bird. We have already discussed the fact that a portion of the phosphorus in vegetable material may be bound as phytate which can be released by phytase, however we should also consider the availability of phosphorus from other dietary sources. Well over 50% of the dietary non phytate phosphorus in an average poultry diet will be supplied as mineral phosphorus or from animal proteins. Phosphorus availability will also vary considerably between these sources and therefore careful ingredient selection should be carried out when trying to reduce phosphorus excretion through dietary means.

Another route that has been considered, to try and reduce the level of non available phytate phosphorus in feed raw materials is through selective breeding, utilizing genetic modification to produce high available phosphorus (HAP) corn. Through the use of this material and appropriate adjustments in the feed formulation, up to a 40% reduction in excreted phosphorus can be achieved (Iragavarapu & Doerge, 1999).

One of the concerns that has recently been expressed with the use of phytase, to control the excretion of phosphorus, is that the breakdown of the phytate phosphorus will increase the water solubility of the excreted phosphorus and hence increase the soil runoff of phosphorus and thus increase the potential to pollute water courses (De Laune et al 2001). This is a very contentious area and some workers (Moore et al 1998) have shown that the use of phytase will numerically reduce the level of soluble phosphorus excreted (Table 7).

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**Table 7 The effect of exogenous phytase on the excretion of total phosphorus and soluble phosphorus in broilers (Moore et al 1998)**

Dietary Regime	Level in broiler litter (mg/kg)	
	Total Phosphorus	Soluble Phosphorus
Normal Corn	7868 (a)	1127 (a)
Normal Corn + Phytase	8068 (a)	944 (a)

Other workers (Maguire et al 2004) found no consistent relationship between dietary modification effecting phosphorus output and phosphorus solubility.

It would therefore appear that the use of phytase to reduce excreted phosphorus is unlikely to have an impact on the form of the excreted phosphorus and hence its fate.

## Implications within different production systems

There is great diversity between poultry production systems throughout Europe, each with their own particular aspect of breed, management, feed, etc. Many are controlled by industry codes of practice and in many cases European or national legislation.

For the purposes of this comparison I intend to focus on three particular systems – intensive, where birds are confined to an enclosed house for the duration of their lives, free range, where birds have access to range, have restrictions on stocking density, slaughter age and feed composition; and organic where specific legislation further controls many aspects of production. In addition I will use poultry meat production as the main example, however it is considered that egg production will be affected in much the same way.

**Table 8 Key constraints for different chicken meat production systems**

Standard Used	Intensive ACP Standards	Free Range Council Regs 1906/90	Organic OF and G
Stocking Density	≤ 38kg/m <sup>2</sup>	House: 13 birds or ≤ 27.5kg/m <sup>2</sup> Range: 1m <sup>2</sup> /bird	House: 10 birds or ≤ 21kg/m <sup>2</sup> (fixed housing) Range: 4m <sup>2</sup> /bird
Slaughter Age	No limit	≥ 56 days	≥ 81 days (for conventional genetics)
Access to range	Not required	Continuous daytime access required for at least half the bird's life	Access required for at least one third of the bird's life
Feed Constraints	Generally no feed constraints	Minimum of 70% cereal	<ul style="list-style-type: none"> <li>No GM derived ingredients</li> <li>No solvent extracted ingredients</li> <li>No synthetic amino acids</li> <li>≥ 90% of ingredients, of agricultural origin, to be organic (≥ 95% from 1.1.10 to 31.12.11) (100% thereafter)</li> <li>Only approved conventional materials to be used</li> </ul>

Commercial nutritionists therefore must work with the constraints imposed and try to produce a diet which achieves the aim of the stated production system. It must be remembered that the basic nutritional principles of growth or egg production are the same irrespective of the production system being used, if diets thereafter differ as a consequence of legislative control, then the biological output of the system is likely to be affected.

Raw material constraints as shown in Table 8, will impact on the ability of the nutritionist to produce a suitable diet. Applying the constraints as shown, three suitable poultry finisher diets have been formulated.

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**Table 9**      **Theoretical diet formulations based on commercial practice (BOCM PAULS own data 2009)**

	<b>Intensive</b>	<b>Free Range</b>	<b>Organic</b>
Cereal Content	62	70	78
Animal Protein	2	6	4
Vegetable Protein	27	16	15
Mineral/Others	3	3	3
Fats & Oils	6	5	0
Crude Protein	19	19	18.5
Energy	13.5	13.1	12.3
Dig Lysine	1.1	1.1	0.82
Dig Methionine	0.49	0.5	0.33
Dig Threonine	0.75	0.68	0.59
Gms Protein/MJ	14.1	14.5	15.0
mg dig lysine/gm Protein	57.9	57.9	44.3
GM dig meth:gm dig lysine	0.44	0.45	0.40
GM dig threo:gm dig lysine	0.68	0.62	0.72
Total Phosphorus	0.46	0.46	0.60
Digestible Phosphorus	0.34	0.34	0.34
Phosphorus digestibility	74%*	74%*	57%

\* indicates the use of Phytase enzyme

We can therefore see that in general the organic diet provides an excess of protein in relation to the energy content when compared to the intensive diet, with the free range diet intermediate. The quality of that protein, as shown by the level of lysine in relation to the total crude protein, and the ratio of methionine to lysine, is inferior in the organic diet. This scenario is driven primarily by the lack of synthetic amino acids, but is also accentuated by the unavailability of well balanced alternative protein sources and the difficulty in using liquid oils and fats.

Whilst the use of enzymes is permitted within the organic legislation, only those that are guaranteed non GM (or produced using organisms of non GM origin) are permitted. The availability of such sources is limited and therefore may not be available for use. Certain individual accreditation bodies may also choose to exclude enzymes as a further way of differentiating organic production.

In the above scenario the use of enzymes has been excluded from the organic diet and consequently the level of total phosphorus required to achieve the desired level of digestible phosphorus has increased. This has been highlighted by a significant reduction in the calculated phosphorus digestibility.

Given the difference between the diets it would be postulated that the organic scenario would result in a higher nitrogen and phosphorus excretion per kg of body weight gain when compared to both the free range and intensive systems.

Kratz S et al (2004) reviewed the nutrient balances of fifteen broiler production units in Germany, five units from each of three different production systems, intensive indoor, free range and organic.

Nutrient input (feed, water supplement and bedding) were measured and compared to outputs (bird carcass calculated using standard data). Nutrient gain per unit of nutrient intake was calculated. Using standard guidelines for nutrient excretion, the quantity of nitrogen and phosphorus excreted per farm unit was also calculated.

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**Table 10 Comparison of farm performance, nutrient utilization and total nutrient excretion for three different production systems (Kratz et al 2004)**

	<b>Intensive</b>	<b>Free Range</b>	<b>Organic</b>
Stocking Density at arrival (birds/m <sup>2</sup> )	21 – 25	13 – 20	5 – 12
Stocking Density on range (m <sup>2</sup> /bird)	Not applicable	1	2 – 10
Duration of growth (days)	40	61	97
Feed Conversion (kg feed/kg usable wt)	1.8	2.36	2.83
Protein Conversion (kg CP/kg usable wt)	0.35	0.42	0.57
ME Conversion (MJ ME/kg usable wt)	22.1	26.9	33.6
Nutrient gain/Nutrient intake			
Nitrogen	0.58	0.49	0.38
Phosphorus	0.50	0.37	0.32
Nutrient Surplus/Nutrient Gain			
Nitrogen	0.73	1.06	1.81
Phosphorus	1.02	1.72	2.26
Nutrient Excretion (kg/ha farmland/year)			
Nitrogen	246	129	61.2
Phosphorus	68.8	33	12.5

The above data therefore quite clearly demonstrates, that with regard to nitrogen and phosphorus, the nutrient utilization efficiency was lower for organic compared to free range, which in turn was lower than intensive. However, due to lower stocking densities and lower bird throughput per year, the total nitrogen and phosphorus excretion per hectare of land was lower for organic compared to free range, which in turn was lower than intensive.

Dietary regime alone will not be the sole driver of these changes in nutrient utilization efficiency. Age of bird, genetics and environmental condition will also play a significant part.

Another factor which may also influence differences between organic systems and conventional systems relate to the nutritional quality of organically produced feed ingredients.

There is a shortage of published data showing comparisons between organically and conventionally grown materials, however BOCM PAULS' own in-house data indicates a higher nutrient variability from organic sources when compared to their conventionally produced equivalents.

**Table 11 Comparison of the nutrient values of organically and conventionally grown materials (BOCM PAULS)**

	<b>Mean Protein</b>		<b>Coefficient of Variation of Protein (%)</b>	
	<b>Organic</b>	<b>Conventional</b>	<b>Organic</b>	<b>Conventional</b>
Wheat	11.2	10.8	12.6	9.2
	n = 41	n = 110		
Barley	10.1	10.0	10.6	9.5
	n = 16	n = 54		
Full Fat Soya Meal	35.4	34.8	3.5	2.4
	n = 30	n = 65		

## Summary

Different production system for both eggs and poultry meat have evolved to meet the demand for product produced to different standards of animal welfare, nutrient content, environmental impact and sustainability.

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At the extremes of the production system we have, at one end, intensively housed, conventional systems and, at the other, extensive organic systems. Neither is better or worse than the other, it is just that they have evolved to meet different aims. Both aim to produce a safe, quality product fit for its purpose, whilst maintaining set standards of bird welfare. However the intensive conventional systems will have cost per kg of product produced, as one of its main drivers, whilst the extensive organic systems will pay greater attention to the holistic approach of production.

Nutrient balance defined as the relationship between nutrient supply, nutrient retention and nutrient excretion in known to be significantly effected by diet design and feed programme. Specifically energy:protein ratio, protein content, amino acid balance and mineral digestibility will impact on the level of nitrogen and phosphorus excreted by an individual animal. Constraints placed on the different production systems by legislation will result in significant variations in nutritional practice and consequently the efficiency of nutrient utilization.

At the individual bird level the efficiency of nutrient utilization is poorer, with organic based systems compared to conventional systems. However one of the fundamental principles of organic farming is the use of a land based system with livestock as part of the farm ecosystem and nutrient cycle. Crop and livestock rotation should be used to manage nutrient recycling and the avoidance of pollution.

For this reason organic systems are generally evaluated as a whole farm unit, and therefore due to lower livestock numbers and slower growth rates the nutrient output/hectare of land is generally lower than conventional systems.

Having said that, it would be sensible to evaluate nutritional practices that can be employed within extensive systems to improve the nutrient utilization at the individual bird level. This is likely to include improvements to the balance of digestible amino acids, and the level of mineral digestibility, particularly phosphorus.

Consideration must also be given to the wider environmental impact that the lack of suitable organic ingredients at a local level may have. The importation of organic ingredients from distant sources can have a significant effect on the carbon footprint.

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