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Reduction of nitrogen excretion in pigs. Improvement of precision in nutrient requirements

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SUMMARY - Nitrogen excretion in pigs can be reduced by reducing the excess supply of protein in the diets. In order to minimize the protein contents in the diets without affecting the performance of the animals, both the dietary supply and the nutrient requirements of the pigs at different stages should be known with precision. This paper will focus on the current knowledge of amino acid requirements and ways to improve the precision of amino acid supply in farm situations.

Key words: Amino acids, requirements, mathematical models.

RESUME - *"Réduction d l'excrétion d'azote chez le porc. Amélioration de la précision des besoins en nutriments". Il y a la possibilité de réduire les rejets azotés chez le porc en croissance avec l'abaissement du taux de protéines de l'aliment. Pour réduire la teneur en protéine des aliments sans diminution des performances, il est indispensable d'avoir une bonne connaissance de la valeur nutritionnelle des protéines apportées et des besoins quantitatifs en acides aminés pour chaque phase de l'élevage. Cette synthèse concerne les besoins nutritionnels en acides aminés chez le porc en croissance et les conduites possibles pour améliorer la précision de l'apport en acides aminés des aliments, dans les élevages commerciaux.*

Mots-clés : *Acides aminés, besoins nutritionnels, modèle mathématique.*

Introduction

Over the last decade there has been increasing concern about the environmental problems that can be associated with intensive livestock farming. The use of manure to fertilize the arable land around or near the farm is not always possible, specially in some areas with a high density of farm animals. In these areas the utilization/disposal of manure is controlled by government regulations that impose a limitation on the amount of pollutants that can be used per unit of arable land. Among the pollutants identified in manure, the most important ones are nitrogen (N) and phosphorous (P), but other minerals like calcium (Ca), potassium (K), copper (Cu), zinc (Zn), cadmium (Cd) or lead (Pb) are also of concern (Jongbloed and Lenis, 1993).

These elements are excreted in faeces or urine and not retained in the body of the animal for three main reasons: the first one is that part of the nutrients in the feed cannot be absorbed or are not available for the animal, this depends on the characteristics of the feed ingredients; the second reason is that the nutrients that are available for the animal are not used with an efficiency of 100% and inevitable losses exist (often identified as maintenance requirements); and finally, the last and most important reason, is that the nutrients supplied in the diet exceed the requirements of the animals, and therefore, cannot be used and are excreted.

Due to the high variability in the composition (and quality) of the feed ingredients it is difficult to predict with accuracy the nutritive value of the diets. Additionally, it is difficult to predict the exact nutrient requirements of a group of animals due to variability within the group but also due to variation in environmental conditions. As a result, in order to make sure that the requirements are met in all situations, it is common practice that the diets are formulated to provide nutrients in excess as a 'safety' measure. These excess nutrients, however, carry an additional cost from both, the economical and the environmental points of view.

This paper will focus on the improvement in the precision in setting the requirements of protein and amino acids for pigs, in order to reduce the N contents in the diets and the N excretion, without affecting the performance of the animals.

Reduction of the protein content in the diet

The easiest way to reduce the nitrogen excreted by pigs is to reduce the protein content of their diets. This, however, should be done ensuring that the requirements of all the indispensable amino acids and that of total nitrogen are met.

In order to study this, we conducted an experiment with growing pigs at IRTA, in which the crude protein (CP) level of a soybean-barley diet was reduced from 19% to 15%, 14% and 12% by reducing the soybean meal content from 22% to 11%, 5.5% and 0% respectively. Soybean meal was replaced by barley and commercially-available crystalline amino acids (i.e., L-Lysine-HCl, L-Threonine, D,L-Methionine and L-Tryptophan), so the calculated minimum requirements for these amino acids were covered by all the diets.

The results demonstrated that the protein content of the diets can be reduced substantially without affecting the performance of the pigs, confirming previous results from our Department (Esteve-García *et al.*, 1995). The reduction of crude protein level did not affect the performance of the animals, except in the diet containing 12% CP (Table 1). During the first part of the experiment (0-26 days), however, the diet containing 14% CP showed slightly lower growth rates than the diets with higher protein contents. This did not occur during the second period, suggesting that during the first part of the experiment the 14% CP diet did not meet the amino acid requirements, whereas these were covered during the second part of the experiment.

Table 1. Performance of growing pigs fed on diets with varying content of crude protein over a 47 day period (Torrallardona *et al.* unpublished)

Diet	Initial body weight (kg)	Final body weight (kg)	Average daily intake (g/d)	Average daily growth (g/d)	Feed to gain ratio
0-26 Days					
19% crude protein	20.59	38.83[a]	1375	702[a]	1.955[a]
15% crude protein	20.83	39.08[a]	1393	702[a]	1.980[a]
14% crude protein	20.74	37.90[ab]	1313	660[ab]	1.982[a]
12% crude protein	20.82	37.00[b]	1308	623[b]	2.201[b]
Pooled std. error	0.113	0.456	37.8	16.1	0.0275
26-47 Days					
19% crude protein	38.83[a]	55.73[a]	1953[a]	804[a]	2.424[ab]
15% crude protein	39.08[a]	56.49[a]	1979[a]	829[a]	2.387[ab]
14% crude protein	37.90[ab]	54.78[a]	1847[ab]	804[a]	2.297[a]
12% crude protein	37.00[b]	50.86[b]	1694[b]	660[b]	2.600[b]
Pooled std. error	0.456	0.759	57.3	27.5	0.0716
0-47 Days					
19% crude protein	20.59	55.73[a]	1634[a]	748[a]	2.179[a]
15% crude protein	20.83	56.49[a]	1655[a]	759[a]	2.177[a]
14% crude protein	20.74	54.78[a]	1552[ab]	724[a]	2.135[a]
12% crude protein	20.82	50.86[b]	1480[b]	639[b]	2.314[b]
Pooled std. error	0.113	0.759	41.0	15.8	0.0263

a,b: Within each period, values in the same column with different superscripts are significantly different ($P<0.05$)

At the end of the performance test, the pigs were moved into metabolism cages and their N balance, and the production of faeces and urine was determined. The reduction in the content of dietary nitrogen (up to 14%) reduced substantially the water intake and the volume of manure produced. It also reduced the total amount of nitrogen excreted while maintaining N retention, thus improving substantially the efficiency of nitrogen utilization (Table 2).

Table 2. Water intake, manure production and nitrogen balance (g/day) in growing pigs fed on diets with varying content of crude protein (Torrallardona *et al.* unpublished)

Diet	Feed intake	Water intake	Manure excreted	N intake	N retention	N excreted
19% crude protein	1722	3568[a]	2348[a]	49.2[a]	23.1[a]	26.1[a]
15% crude protein	1733	3056[b]	1915[b]	43.0[b]	24.2[a]	18.8[b]
14% crude protein	1697	2498[c]	1436[c]	38.8[c]	23.5[a]	15.4[c]
12% crude protein	1720	2761[bc]	1767[bc]	34.7[d]	20.1[b]	14.5[c]
Pooled std. error	12.7	168.9	148.7	0.31	0.78	0.88

a,b,c,d: Within each period, values in the same column with different superscripts are significantly different (P<0.05)

In order to minimize total amount of N excreted by growing pigs the protein concentration of the diet should be minimized, but taking care that all the amino acid requirements are met. The failure to meet the amino acid requirements would negatively affect the performance and the efficiency of N utilization, and it would also increase the volume of slurry produced. The use of crystalline amino acids will improve the amino acid balance of the diet, so total protein content in the diet can be reduced without failing to meet the requirements.

The amino acid requirements, however, change during the pigs life (Fig. 1, Table 3), and the composition of the diets should be modified as often as possible in order to match precisely the requirements. This can be accomplished with the use of multiple-phase or multi-phase feeding strategies (Henry and Dourmad, 1993).

Amino acid requirements of pigs

The quantitatively most important function of amino acids is the synthesis of proteins, but they also have a role as precursors of non-protein substances (such as hormones, neurotransmitters and others) and as an energy source. The requirements of a particular pig will be defined by the minimum amount of amino acids which will give an optimal response from the pig. Therefore, before a requirement can be established, it is necessary to specify the characteristics of the animal or group of animals for whom the requirement is for, and the response that we want to achieve from them.

The characteristics of the animal or group of animals have a very important effect on the requirements. Among the identified factors that affect the amino acid requirements the most important are: (i) sex (the amino acid needs of boars are higher than those of gilts, and these are higher than those of barrows; Rérat and Henry 1970; Henry *et al.*, 1971; Cole *et al.*, 1983; Williams *et al.*, 1984; Batterham *et al.*, 1985; Campbell and Taverner, 1988); (ii) weight or age (the requirements decrease with the age of the animal; Fig. 1); (iii) genetic potential (Campbell and Taverner, 1988), (iv) physiological state (pregnancy or lactation); and (v) environmental conditions such as climate and health status (Williams *et al.*, 1997a,b,c).

There can be differences in the estimates of the requirements depending on which parameter is considered as response. Mitchell *et al.* (1968) found different requirements of isoleucine, leucine and lysine whether the response criteria was plasma amino acid concentration or nitrogen balance. Brown *et al.* (1973a,b) found higher lysine requirements for minimum feed efficiency than for maximum weight gain. Yen *et al.* (1986) found higher lysine requirements for growing pigs using growth rate and feed conversion ratio than using blood urea analysis as response. When the same authors used carcass quality parameters they got even lower values. Fuller *et al.* (1979) also found differences when maximum growth rates, minimum feed conversion rate or maximum carcass leanness were considered.

To study the amino acid requirements, it has always been assumed that in pigs, the only source of indispensable amino acids is the diet. Torrallardona *et al.* (1994, 1995), however, have found that amino acids of microbial origin can also be absorbed in the small intestine and contribute to the needs. Since dietary requirements have been determined without accounting for any microbial supply, these may underestimate the real metabolic needs.

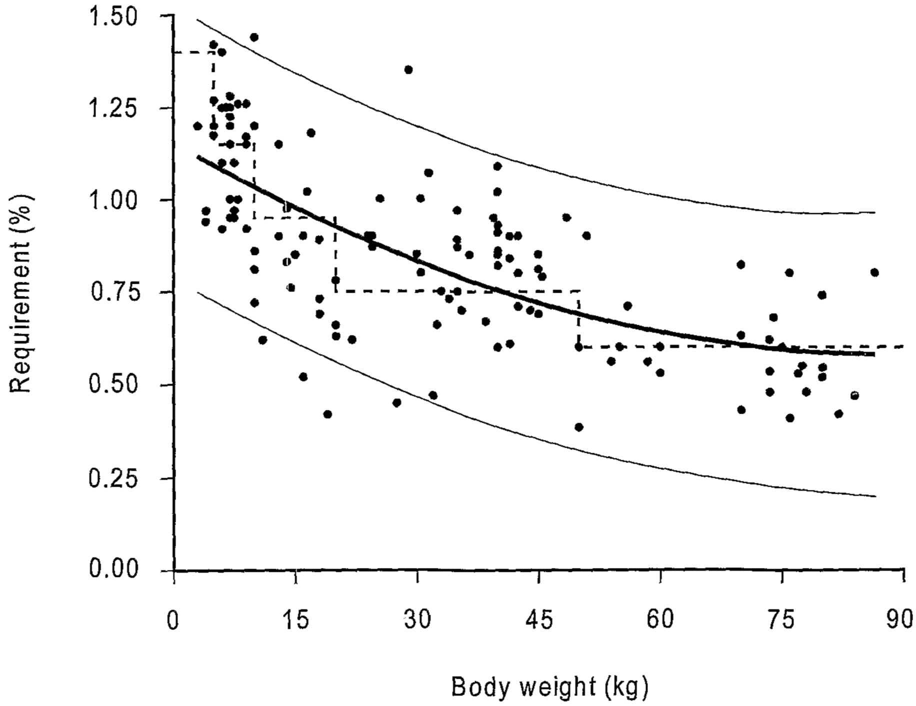

Fig. 1. Lysine requirements (% in diet) for growing pigs. The points represent the requirement determined in each of the 123 experiments reviewed by NRC (1988). Continuous lines represent exponential curve fitting and 95% confidence bands, and the discontinuous line represents NRC (1988) recommendations.

Requirements assessed by empirical methods

Traditionally the requirements have been determined by empirical methods in which the response of pigs to increasing amounts of one amino acid in a basal diet was studied. The requirement was then defined as the level of intake up to which there was an increasing response and beyond which there was none (ARC, 1981). With this method it is necessary to ensure that the experimental basal diet is limiting in the amino acid being studied, and that all the other nutrients are supplied in adequate amounts (but not in large excesses as this could cause interactions between amino acids). The collection of results obtained with these methods have been the basis for the recommendations published in tables such as ARC (1981) or NRC (1988).

As discussed above, the amino acid requirements of pigs change with their age (or body weight) and physiological state. Accordingly, the pigs are divided into different categories and the amino acid requirements are defined for each category (Table 3).

A major drawback with basing the requirements on results from empirical trials is that the experiments reviewed to produce these tables were performed during a relatively long period of time prior to their publication; the genetic potential of the pigs used in the experiments selected was very variable, as were the environmental conditions, the feed composition and the criteria for optimum response. Therefore, the values obtained show a high variability (Fig. 1), and average values have been taken as the requirement. The accuracy of the requirements established this way is not very precise.

Over the last two decades the genetic potential of pigs has improved dramatically, with growth and protein deposition rates very different to those of the pigs from the experiments used to create the ARC (1981) and NRC (1988) requirement tables. A new set of experiments should be conducted to study the requirements of today's pigs, but these would require a considerable effort and, by the time enough data was available to formulate new recommendations, the genetic potential of the pigs would have further developed thus outdating the values obtained.

Table 3. Requirements (g/MJ DE) of some indispensable amino acids for pigs of different ages and physiological stages. Data taken from ARC (1981) and NRC (1988)

	Lysine	Threonine	Sulfur AAs	Tryptophan
ARC (1981)				
Piglets 0-3 weeks old	1.12	0.67	0.56	0.16
Piglets 3-8 weeks old	0.98	0.59	0.49	0.14
Pigs 15-50 kg	0.84	0.50	0.42	0.12
Pigs 50-90 kg	0.60	0.36	0.30	0.09
Pregnant sows	0.34	0.29	0.23	0.06
Lactating sows	0.50	0.35	0.27	0.10
NRC (1988)				
Piglets 1-5 kg	0.98	0.56	0.48	0.14
Piglets 5-10 kg	0.81	0.48	0.41	0.12
Pigs 10-20 kg	0.67	0.39	0.34	0.10
Pigs 20-50 kg	0.53	0.34	0.29	0.08
Pigs 50-110 kg	0.42	0.28	0.24	0.07
Bred gilts, sows and boars	0.31	0.21	0.16	0.06
Lactating sows	0.43	0.31	0.26	0.09

Requirements assessed by factorial methods

Another way to calculate the amino acid requirements is to consider them as the sum of the components that require amino acids for the different body functions. For growing pigs there are two major components of the requirements: the most important is for lean tissue growth (or protein accretion) and the other one is for maintenance. Maintenance represents a small fraction of the total requirements in the young fast-growing animals, but becomes more important as the animal approaches maturity. In adult animals (boars and sows) maintenance predominates, but depending on the physiological state of the animal (i.e., gestating sow), protein accretion can become important. Lactating sows have a very important additional component for milk protein secretion.

Maintenance requirements

The maintenance requirement of pigs has been defined as the minimum amount of amino acid required to maintain nitrogen equilibrium. To do so, amino acid supply should equal the obligatory losses. The obligatory losses of amino acids result from the following processes (Fuller, 1994): urinary excretion, irreversible modification of amino acids, synthesis of non-protein substances, minimum rates of amino acid oxidation and losses from the epithelia (skin, hair and gut losses). Quantitatively the most important components of the obligatory losses are those from minimum rates of oxidation and those from protein and amino acids secreted into the gastrointestinal tract (i.e., endogenous losses; Fuller, 1991).

Fuller *et al.* (1989) measured the relationship between increasing levels of all the indispensable amino acids (when first limiting) and N retention. They calculated the maintenance requirements by extrapolating it to zero N retention; their estimates are shown in Table 4.

Table 4. Estimates of the amino acid requirements for maintenance and for body protein accretion of growing pigs, and for milk protein synthesis

	Maintenance† ($mg/kg^{0.75}$ d)	Protein accretion† (g/16 g N)	Milk protein secretion†† (g/16 g N)
Threonine	53	4.69	5.19
Valine	20	5.25	6.75
Met + Cys	49	3.58	4.13
Methionine	9	1.88	-
Isoleucine	16	4.30	5.54
Leucine	23	7.80	9.89
Phe + Tyr	37	8.42	6.47
Phenylalanine	18	4.11	-
Lysine	36	6.81	7.92
Tryptophan	11	1.21	2.03

†Fuller *et al.* (1989)
††Estimated from the amino acid composition of sow's milk (Elliott *et al.*, 1971) and the marginal efficiency of amino acid utilization for protein accretion (Fuller, 1994)

Protein accretion requirements

In growing pigs, protein accretion is the major component of the total amino acid needs. The rate of protein accretion increases from birth to a maximum and then declines gradually to zero as maturity is reached. The peak of maximum protein accretion is reached at variable age and body weight depending on the sex and genetics of the animals. In pregnant sows, protein accretion is required for the growth of fetal tissues and also of other products of conception (placenta, etc.). The amino acid requirements for protein accretion in growing pigs have been estimated by Fuller *et al.* (1989), (Table 4).

Milk protein secretion

Lactating sows can produce up to 7 kg of milk per day (ARC, 1981; NRC 1988), which assuming a protein content in the milk of 5.7%, is equivalent to a rate of secretion of milk proteins in the order of 400 g per day (ARC, 1981). This is about three times higher than the protein deposition rates achieved by growing pigs. There is little information on the specific amino acid requirements for milk protein synthesis. These, however, could be estimated from the amino acid composition of the milk (Elliot *et al.*, 1971), if we knew the efficiency with which amino acids are used for milk protein synthesis. Such values of efficiency are not available in the literature, but presumably should be similar to those calculated for protein accretion in growing pigs (Fuller, 1994). The requirements for milk protein secretion calculated using the efficiencies for protein accretion are shown in Table 4.

Ideal protein for pigs

In growing pigs, the ideal protein concept is based on the assumption that although pigs with very different growing rates require different amounts of protein, the quality (amino acid pattern) of this protein is exactly the same. This is because the amino acid composition of the protein deposited is, in theory, identical. Lysine is the amino acid for which there is more information available, so ideal protein patterns are usually expressed as % of lysine. For a given pig (with a particular genotype, sex and environment), if we know its requirements for a single amino acid (e.g., lysine), it is possible to predict the needs of all the other amino acids, including those for which there is little (or inaccurate) information.

However, amino acids are not only required for protein accretion. They are also required for other body functions like maintenance, gestation or lactation, and it is likely that each of these functions has its own ideal protein pattern. The ideal pattern for growth and for maintenance has been estimated by Fuller *et al.* (1989). The pattern for gestation is taken to be the same as that for growth, whereas that of milk protein production is closely related to the composition of milk protein. The ideal protein patterns for protein accretion, maintenance and milk secretion are shown in Table 5.

The sum of the amino acids required for each of the functions mentioned above, will result in a particular amino acid pattern for each of the different categories of pigs, depending on the relative importance of each of the functions. Baker and Chung (1992), have divided the ideal amino acid pattern for growing pigs in three categories; 5-20, 20-50 and 50-110 kg of body weight. The differences in the pattern between the three categories are due to the increase of the maintenance needs relative to growth needs when the animal gets heavier. For adult animals, the maintenance component places a greater emphasis on the ideal pattern, and for lactating sows the milk protein secretion is very important.

Table 5. Ideal protein pattern (% of lysine) of amino acids required for maintenance, body protein accretion and milk protein synthesis (calculated from Table 4)

	Maintenance ($mg/kg^{0.75}$ d)	Protein accretion (g/16 g N)	Milk protein secretion (g/16 g N)
Threonine	147	69	66
Valine	56	77	85
Met + Cys	136	53	52
Methionine	25	28	-
Isoleucine	44	63	70
Leucine	64	115	125
Phe + Tyr	103	124	82
Phenylalanine	50	60	-
Lysine	100	100	100
Tryptophan	31	18	26

Prediction of amino acid requirements using mathematical models

When the amino acid requirements are estimated experimentally, a particular genotype of pigs and environmental conditions are used. Since the conditions in the farm can be different to those of the experiments, the performance of the animals can be also different. Tibau *et al.* (1995) observed that pigs of identical genotype performed differently whether they were housed under experimental or farm conditions. Therefore, the validity of values obtained experimentally can be questioned. In order to overcome this problem, the amino acid requirements in each individual situation should be estimated, and without doubt the use of animal growth models will be very useful in the near future.

In a mathematical model for growing pigs, at least the following information is needed (Black and de Lange, 1995):

(i) *Body composition*. The fat, protein, ash and water contents in the body and its weight at the end of the simulated growth period should be predicted. This will allow the calculation of the amounts of protein, fat, ash and water that the pig will retain. This is highly influenced by the genetics and sex of the animal, which will determine the maximal protein deposition rate (Pd_{max}), and the minimum body lipid to body protein ratio. The Pd_{max} of a particular group of pigs can be estimated by controlling the performance of a representative group of animals between 50 and 80 kg (Moughan, 1995).

(ii) *Nutrient intake*. It is the major driving force of animal growth models. It depends on feed intake and on nutritive composition of the feed. Feed intake has been predicted with simple equations that relate it empirically with body weight (ARC, 1981; NRC, 1988), but important factors other than liveweight, like genotype, physiological state, composition of the diet, climate and stocking arrangements are considered in more complex models (Black *et al.*, 1986). The feed intake of growing-finishing pigs in a particular farm can be measured by controling the intake of a few pens in three different 14d periods (de Lange and Schreurs, 1995).

(iii) *Availability of the dietary nutrients*. Availability is defined as the proportion of the nutrient in the diet which is digested and absorbed in a form suitable for utilization. The availability of the dietary amino acids is estimated by their disappearance up to the terminal ileum (apparent and true ileal digestibility measurements). The amino acids that disappear in the hindgut are catabolized by the microflora and are not available for the pig (Zebrowska, 1973). Some amino acids that are digested and absorbed, may do so in a form which is unsuitable for their utilization by the animal (early Maillard compounds or some D-isomers of amino acids). This is the case of some feedstuffs undergoing heat processes, and amongst the amino acids lysine appears to be particularly sensitive followed by threonine, methionine, tryptophan and phenylalanine, on the other hand the branched chain amino acids (isoleucine, leucine and valine), appear to be less susceptible to heat damage (Batterham, 1992, 1994).

(iv) *Maintenance requirements*. Apart from energy, amino acids are also needed for maintenance. As discussed above they include the amino acids that are inevitably catabolized, those lost in the gut and those lost in sloughed skin and in hair growth. Estimates of amino acid maintenance requirements (as a function of body weight) are given in Table 4.

(v) *Growth requirements*. Growth is determined by the deposition of protein, fat, ash and water, which will be driven by the changes in body composition discussed above. The amino acid requirements for growth can be calculated from the requirements for protein accretion (Table 4) and the maximum protein deposition rate (Pd max). In order to achieve the Pd max, not only all of the amino acids, but also the energy, must be supplied in the required amounts (Dunkin *et al.*, 1986). The optimal protein:energy ratio will be related to the relative rates of protein and fat deposition (described above). Both Pd max and the protein:energy ratio required will be determined primarily by the age, genotype and sex of the animal (Campbell *et al.*, 1985, Campbell and Taverner, 1985).

With the information described above, mathematical models can predict the amino acid requirements of pigs with very particular characterizes. In the near future, the application of mathematical models will allow the precise formulation of diets. This, together with management practices like homogenization of groups of animals (e.g., by weight and sex), and multi-phase feeding strategies, will improve the precision of the nutrient suplly in the diet and therefore minimize the excretion of nutrients.

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