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Impact of nutrition on nitrogen, phosphorus, Cu and Zn in pig manure, and on emissions of ammonia and odours

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Abstract

In order to reduce N, P and trace elements in pig manure, research toward a better agreement between supply and requirement has been undertaken in recent years, and ways to improve the biological availability of these elements in feedstuffs have been investigated. Substantial reduction in N excreted by pigs can be achieved by phase feeding combined with a better adjustment of the dietary amino acid balance. Feeding pigs with low N diets also allows a reduction of ammonia emission and to some extent the production of malodorous compounds. Phase feeding is also effective in reducing P excretion. However, low digestibility of P in feeds remains the main problem, although it is partly alleviated by the supplementation of pig diets with microbial phytase and the use of highly digestible mineral phosphates. In the same way, lowering Cu and Zn dietary supply is obviously an efficient way to reduce pigs' excretion of Cu and Zn. In a whole-farm perspective, improving the efficiency of nutrient utilisation by the animals is an efficient way to reduce import of nutrients from outside the farm and decrease the environmental risks.

Keywords: Pig; Nutrition; Environment; Nitrogen; Phosphorus; Copper; Zinc

1. Introduction

For a sustainable pork production, emission of pollutants from pig farms and use of non-renewable resources should be decreased as much as possible. Nitrogen and phosphorus from manure may be involved in eutrophication of freshwater or seawater. Besides, the world reserves of mineral phosphates are limited and should be preserved. In the same way, the accumulation of Cu and Zn in soils may impose a medium or long term toxicity risk on plants and micro-organisms. Ammonia emission from manure is involved in acidification and eutrophication, with recognized detrimental effects on soil status, forests and biodiversity.

Over the last decades, ways to reduce the environmental impact of N, P and trace elements used in pig production have been investigated. The nutritional approach has received great attention from researchers and legislative decision makers (Jongbloed et al., 1999b). It relies on improvements in our knowledge of the physiology of pigs in order to achieve a better agreement between supply and requirement. The improvement in nutrient availability of feedstuffs is a second option to be investigated.

The aim of this paper is to give an overview of the nutritional possibilities to reduce N, P, Cu and Zn excretion by pigs, as well as emissions of ammonia and odours, and to describe the means that could be or are already implemented in practice.

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2. Reduction of N excretion in pig manure

The efficiency of protein utilisation by pigs depends on the dietary composition and the physiological status or the growing stage of the animals. In growing–finishing pigs fed a cereal-soybean meal diet, about 32% of the N intake is retained (Dourmad et al., 1999b). Faecal N excretion, which amounted to 17% of the intake, corresponds to the undigested protein fraction and endogenous losses, mainly digestive secretions and desquamation of intestinal cells. Digested proteins are absorbed as amino acids which are used for protein synthesis. Obligatory losses of amino acids relate to protein metabolism (turnover) and renewal of skin and hair. The remaining amino acids, after protein deposition and obligatory losses, are catabolised and excreted mainly as urea. With conventional diets, this last fraction is often the most important. Average efficiency of N retention is lowest in sows (23%), intermediate in growing pigs (34%), and highest in weaners (48%) (Dourmad et al., 1999a).

Two complementary approaches can be used to improve the efficiency of N utilisation in pigs and, consequently, to reduce N excretion. The first approach is to ensure adequate protein/amino acid supply over time according to the growth potential of the animals or their physiological state. This requires a joint fitting of daily supply of energy and protein (amino acids), depending on genetic potential and stage of production, and on production objectives. In reproducing sows, N excretion was reduced by 20 to 25% when different diets were allocated for pregnancy and for lactation instead of a single diet for the whole period. Further improvements could be achieved with the use of multiphase feeding during pregnancy. Indeed, the protein requirement is much lower during the early pregnancy compared with later pregnancy (Dourmad and Étienne, 2002). In fattening pigs, Latimier and Dourmad (1993) measured about 10% reduction in slurry N when different diets were applied during the growing and finishing periods, compared to feeding the same diet during both periods (Fig. 1).

Table 1
Effect of crude protein content of the diet on growth performance and N excretion of fattening pigs (30–102 kg) (Dourmad et al., 1993)

	Crude protein, %		
	17.8	15.5	13.6
Average daily gain (g)	846	867	852
Energy efficiency			
Net energy (MJ/kg gain)	27.5	27.4	27.6
Metabolisable energy (MJ/kg gain)	38.2a	37.4b	37.2b
Meat percentage (%)	51.3	52.3	51.6
N excretion (kg /pig)	3.90a	3.10b	2.50c

Means followed by different letters differ significantly ($P<0.05$).

The second approach is to improve the dietary amino acid balance and, consequently, reduce the required crude protein (CP) content of the diet. This can be obtained through a combination of different protein sources and/or the substitution of protein by inclusions of free amino acids. In fattening pigs, Dourmad et al. (1993) measured a 35% reduction of N excretion after improvements in the dietary amino acid profile (biological protein value) without affecting feed intake, average daily gain, feed efficiency and carcass composition (Table 1).

The ultimate reduction of N excretion can be reached when multiphase feeding is combined with a perfect balance between essential amino acids (close to the ideal protein concept), and with an optimisation of the supply

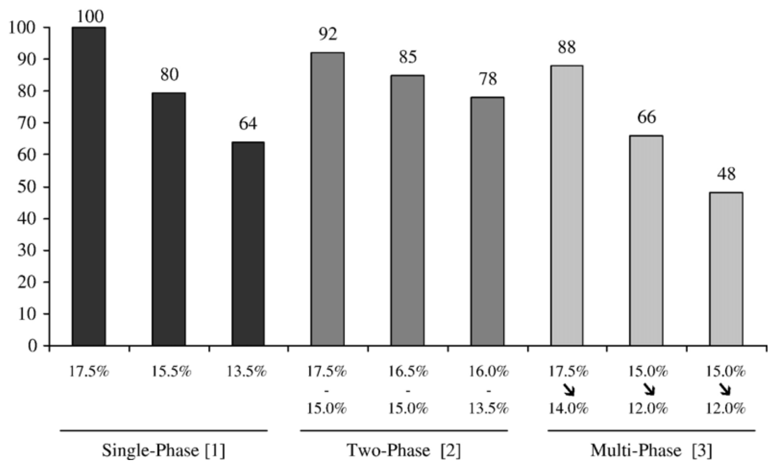

Fig. 1. Effect of dietary protein content and protein feeding strategy on N excretion (100 = excretion with one-phase feeding of a 17.5% CP diet). Adapted from [1] Dourmad et al. (1993), [2] Latimier and Dourmad (1993), and [3] Bourdon et al. (1997).

of non-essential amino acids. Such a feeding strategy has been evaluated experimentally by Bourdon et al. (1997). In that study, the use of a single diet (17.5% CP) over the whole growing–finishing period was compared to a "multiphase" strategy which consisted of the mixing of two diets (13.0 and 10.7% CP, re-equilibrated with free amino acids) in proportions that were optimised each week. Growth performance and carcass quality were similar, and N excretion was reduced by about 50% (1.83 vs. 3.56 kg N per pig) (Fig. 1). With this feeding strategy, N excretion represented only 50% of N intake. This can be considered to be close to the maximal attainable reduction in N excretion.

It must be pointed out that the development of such feeding techniques for reducing N excretion by pigs requires good knowledge of the amino acid availability in feedstuffs, and of the changes in amino acid requirements according to growing stage or physiological state. This is now within reach with the use of modelling techniques for predicting requirements (NRC, 1998; van Milgen et al., in press; Dourmad et al., in press) together with a better knowledge of variations in amino acid availability in feedstuffs (NRC, 1998; CVB, 2000; INRA-AFZ, 2004). This can be achieved in practice by using computerized blend feeding systems which allow adapting the diet composition on a daily or weekly basis (Feddes et al., 2000; Pomar et al., 2007).

The reduction in dietary protein content results in a lower proportion of N excreted in urine relative to faeces, which might affect the utilisation of manure N after field application (Sørensen and Fernandez, 2003). In a study of Portejoie et al. (2004), the ratio ammoniacal N:total N in fresh manure decreased from 0.79 with the 20% CP diet to 0.63 with the 12% CP diet. However, in the studies of Gerdmann et al. (1999) and Sørensen and Fernandez (2003) the plant availability of slurry N was not clearly affected by the dietary protein content.

3. Reduction of ammonia losses

By changing feeding practices it is possible to influence urea concentration in the urine and the pH of slurry, which in turn will affect ammonia release (van de Peet-Schwering et al., 1999). When pigs are fed low CP diets, urinary urea concentration and pH decrease (Canh et al., 1998; Portejoie et al., 2004). When water is available ad libitum, feeding low CP diets also results in lower urine production due to decreased water consumption (Pfeiffer et al., 1995; Portejoie et al., 2004). The changes in slurry characteristics result in lower ammonia losses during housing, storage and following application of slurry (Canh et al., 1998; Hayes et al., 2004; Portejoie et al., 2004). For instance, in the study of Portejoie et al. (2004) ammonia emissions over the whole period, from excretion to field application, were decreased by 63% when dietary CP was decreased from 20 to 12% in finishing pigs (Table 2).

The electrolytic balance (EB), calculated as (Na^+ + $K^+ - Cl^-$), is often used by nutritionists to evaluate the acidogenicity of the diet, a decrease in the EB resulting in a decrease in urinary pH. When dietary CP content is reduced, EB also decreases because of the high K content of most protein sources. This partly explains the effect of CP on urinary pH. However, as shown by Canh et al. (1998), more drastic changes in urinary pH and ammonia volatilisation can be obtained by inclusion of the Ca salts $CaSO_4$ or $CaCl_2$ instead of $CaCO_3$. The addition of Ca-benzoate (Canh et al., 1998) or benzoic acid (Guiziou et al., 2006) was also effective in reducing slurry pH and ammonia volatilisation, because these products are metabolized to hippuric acid which is rapidly excreted in urine. In the study of Guiziou et al. (2006), the addition of 1% benzoic acid to the diet resulted in a reduction of about 40% in ammonia emission. A similar effect (25% reduction in ammonia emission) was observed with adipic acid (van Kempen, 2001), which is partially excreted in urine.

Urea N excretion can also be reduced by including fibrous feedstuffs in the diet. With more fermentable non-starch polysaccharides (NSP) in the diet, some of the N excretion is shifted from urine to bacterial protein in faeces (Canh et al., 1998; Kreuzer et al., 1998, Sørensen and Fernandez, 2003), while total N excretion is not affected. Moreover, slurry pH is decreased with the use of fermentable NSP due to volatile fatty acid (VFA) formation in the hindgut of the pig and in the slurry. Canh et al. (1998) measured a linear relationship between NSP

Table 2
Effect of protein feeding of fattening pigs on slurry characteristics and ammonia volatilisation (Portejoie et al., 2004)

	Dietary crude protein content		
	20%	16%	12%
Slurry composition			
Amount (kg pig^{-1} d^{-1})	5.7	5.1	3.6
DM (%)	4.4	4.6	5.9
Total N (g N/kg)	5.48	4.30	3.05
Total ammoniacal N (g N/kg)	4.32	3.13	1.92
pH	8.92	8.61	7.57
N balance (g pig^{-1} d^{-1})			
Retention	23.2	23.5	21.9
Excretion	40.7	27.6	15.0
Ammonia volatilisation	17.4	13.8	6.4
Available to plants	23.3	13.8	8.6

intake and slurry pH or ammonia volatilisation; for each 100 g increase in NSP intake, the slurry pH decreased by 0.12 units and the ammonia emission from slurry decreased by 5.4%.

The utilisation of manure N after field application may also be affected by the level of NSP in the diet, because a greater proportion of N is excreted in faeces in more complex organic forms. Availability of slurry N was reduced after the inclusion of dietary fibre with low fermentability (Sørensen and Fernandez, 2003), whereas it was not affected when the dietary content of fermentable structural carbohydrates increased (Gerdmann et al., 1998; Sørensen and Fernandez, 2003), although in all cases the proportion of N excreted in urine decreased. Combined with the proportion of urinary N, the fibre content of faeces gives a good prediction of the plant availability of slurry N (Sørensen and Fernandez, 2003).

4. Effect of feeding on odours

Odours are mainly associated with volatile compounds that pigs excrete with manure, or which are released during manure storage (de Lange et al., 1999). These volatile compounds are generated by the microbial conversion of feed in the large intestine of pigs or in manure pits. Based on a literature review, Le et al. (2005) suggested that CP and fermentable carbohydrate (FC) would play a major role in the production of odour nuisance from pig production.

Few studies have evaluated the direct effect of diet manipulation on odour production, mainly because it is difficult to assess odours objectively. As mentioned previously, protein nutrition affects ammonia production, but the ammonia production is not well correlated with odour strength (Le, 2006). Using olfactometry, Hayes et al. (2004) showed a significant reduction in both ammonia and odour emissions when CP content was reduced, but this was not observed in all studies. Hobbs et al. (1996) reported that the concentration of nine out of ten odorous compounds in the air was significantly reduced when low CP diets were fed to the pigs. Le (2006) also found a reduction by 80% in the odour emission, as determined by olfactometry, when dietary CP was reduced from 18 to 12%. Moreover, the results from the same author suggested an interaction between effects of CP and FC on odour production, suggesting that odour production depends also on the balance between dietary CP and FC. The manipulation of gut fermentation could also be a way to alter the production of odorous compounds such as skatole (de Lange et al., 1999). Using a different methodology for assessing “pleasantness”, “irritation” and “intensity” scores of odours, Moeser et al. (2003) were able to significantly discriminate between diets differing in composition. The diets that yielded manure with the worst odour were high in sulphur (rich in garlic or feather meal), whereas a purified diet mainly based on starch and casein presented the lowest score (most pleasant). This is in agreement with the >700% increase in odour emission measured by Le (2006) with diets supplemented with a sulphur-containing amino acid (methionine) at high levels.

5. Reduction of P in pig manure

In growing–finishing pigs fed a cereal-soybean meal diet, about 45% of P intake is absorbed, about 30% is retained, and the remaining 15% is excreted via urine (Poulsen et al., 1999). Totally, 70% of P ingested is excreted either via the faeces or via urine. In order to reduce P losses, P supplied to pigs should be adjusted to their requirement, and strategies to improve P availability should be implemented (Poulsen, 2000; Knowlton et al., 2004). This approach relies on an accurate knowledge about feed P availability and P requirement according to the physiological status of pigs.

A first approach to improve P uptake efficiency is to use highly digestible mineral P supplements. For example, monocalcium rather than dicalcium phosphate should be used because of its much higher digestibility (INRA-AFZ, 2004). However, most strategies implemented to reduce P excretion by pigs refer to improvements in phytic P utilisation (Jongbloed et al., 1992).

In many countries, microbial phytase is currently introduced in diets for pigs because of its well-documented positive effect on P digestibility. Total P supply may be decreased, resulting in a 40 to 50% reduction of P excretion (Jongbloed and Lenis, 1992; Latimier et al., 1994, Table 3). However, the response of digestible P to graded levels of microbial phytase is curvilinear, and the maximum P digestibility never exceeds 60–70%, even at

Table 3
Effects of three P feeding strategies on growth performance and P excretion of growing–finishing pigs (30–102 kg body weight) (Latimier et al., 1994)

	Basal	Mineral P	Phytase
Phosphorus content (g/kg)	3.9	5.2	3.7
Phytase activity (FTU/kg)	210	205	735
Average daily gain (g/d)	764a	805b	795b
Feed conversion ratio (kg/kg)	2.73	2.65	2.66
Bone breaking strength (N m)	11.9a	13.7b	14.3b
Volume of slurry (l/pig)	358	337	331
Phosphorus in slurry (kg/pig)	0.36	0.50	0.26

Means followed by different letters differ significantly ($P<0.05$); no statistical analysis for volume or P content in slurry.

high levels of phytase supplementation. Based on literature reviews, equivalency equations of digestible P for microbial phytase were established (Kornegay, 2001; Johansen and Poulsen, 2003) and can be used for diet formulation.

In the same way as for protein and amino acid supply, the second approach to reduce P excretion is to ensure adequate supplies over time according to the growth potential of the animals or their physiological status. This requires a precise evaluation of pigs' P requirements, as well as P availability in feed ingredients. In practice, this can already be achieved by the use of a feeding system relying on, e.g., P apparent digestibility (CVB, 2000; INRA-AFZ, 2004) and the factorial determination of P requirements (Jongbloed et al., 1999a; Jondreville and Dourmad, 2005). Finally, this allows the reduction of safety margins when formulating pig diets, resulting in a decrease in P excretion.

6. Methodologies to reduce Cu and Zn in pig manure

Cu and Zn are involved in many metabolic functions, and their provision in sufficient amount in pig feeding is indispensable to ensure good performance and animal health (Revy et al., 2003, Jondreville et al., 2002). However, because they are used as growth promoters at pharmacological levels, or because large safety margins are applied, Cu and Zn are often oversupplied in pig diets. Consequently, these elements are highly concentrated in pig manure and accumulate in soil, where they may impose a medium or long-term toxicity risk to plants and micro-organisms (Jondreville et al., 2003). Moreover, when a treatment is applied to the slurry, Cu and Zn will follow the solid fraction where their concentration often exceeds the maximal values allowed for the utilisation of these products as organic fertilisers. The only way to decrease the concentration of trace element in manure is to restrict their incorporation in the diet.

The incorporation of 150 to 250 ppm Cu in pig diets has been employed for a long time because of its growth promoting effect (Braude, 1980). This practice is currently authorized in EU allowing diets containing a maximum of 170 ppm Cu for pigs up to 12 weeks. After 12 weeks of age, the use of Cu as a growth factor is no more allowed within EU, and the maximal level of incorporation is 25 ppm. Compared to the former allowed inclusion (175 ppm up to 16 weeks of age and 100 ppm thereafter (scenario A, Table 4), this results in a drastic reduction of Cu in manure by almost 60% (scenario B, Table 4). Nevertheless, the practical supply remains higher than the usually published requirements (less than 10 ppm), and average retention efficiency is still less than 1%.

Table 4
Estimates of Zn and Cu balance[1] according to different scenarios of supply in pig feeding

	Cu			Zn			
	A	B	C	D	E	F	G
Concentration in diets (ppm)							
Piglets 1	175	170	10	2500	250	150	70
Piglets 2	175	170	10	250	250	150	50
Fattening pigs	120	25	10	250	250	150	30
Sows	35	25	10	250	250	150	70
Balance (0–110 kg body weight)							
Intake (g/pig)	38.7	13.5	3.3	84.1	68.3	41.7	9.0
Excreted (g/pig)	38.6	13.4	3.2	81.7	65.9	39.3	6.7
Slurry composition (mg/kg DM)	1119	351	84	2542	2128	1269	284
Years to reach 50 mg Cu or 150 mg Zn/kg soil DM	47	160	941	79	95	167	1160

[1]Calculated according to Jondreville et al. (2003).
Scenarios A, D and E correspond to former EU regulation. Scenarios B and F correspond to the current EU regulation. Scenarios C and G are calculated for supplies of Cu and Zn corresponding to the requirements.

Supplementing weaned piglets diets with 1500 to 3000 ppm Zn as ZnO has also been reported to stimulate their growth (Poulsen, 1995). In fact, in 2003 the maximal allowed Zn incorporation in pig diets was reduced to 150 ppm, compared to 250 ppm before (EC, 1334/2003). These levels are much closer to the published requirement, which varies between 100 and 50 ppm depending on growing stage and authors (Revy et al., 2006). Compared to a situation in which weaning pigs are fed a diet with 2500 ppm Zn from 8 to 15 kg BW and 250 ppm thereafter (scenario D, Table 4), the present EU regulation (150 ppm Zn) results in 53% reduction of excretion (scenario F, Table 4).

As for P, the main way to reduce Cu and Zn in pig manure is to adjust the supplies to the requirement, and to improve the availability to the pigs. Zinc requirement of weaned piglets was recently evaluated to be about 90 mg/kg diet (Revy et al., 2006) which is consistent with the former recommendations and below the usual level in practice. When microbial phytase is incorporated in the diet, the Zn supply may be reduced because of increased availability. In weaned piglets, incorporation of 500 phytase units/kg diet was evaluated to be equivalent to the supply of 30 ppm of Zn as Zn sulphate (Jondreville et al., 2005).

With the present EU regulation, Cu and Zn contents in manure DM (about 350 and 1250 mg/kg DM, respectively) are below the maximal concentration allowed in sewage sludge in France (1000 and 3000 mg/kg DM, respectively), but they exceed the concentration allowed for organic fertilizers (300 and 600 mg/kg DM, respectively). Assuming that 170 kg N/ha are spread each year, it will take 160–170 years for the soil to reach 50 mg Cu or 150 mg Zn /kg soil DM (Table 4). This is much longer than with the previous regulation (50 to 100 years).

But although the situation has been drastically improved by these new regulations, Cu and Zn inputs to soil with a manure application rate of 170 kg N/ha still greatly exceed the export by crops. In the future, further reductions in Cu and Zn excretion should be possible (scenarios C and G, Table 4), resulting in a better agreement between spreading and export by plants. However, this will require a better understanding of the factors that affect Cu and Zn availability and a more precise evaluation of the requirements.

7. Conclusion

Improving the efficiency of nutrient utilisation by livestock is an efficient way to reduce the excretion in slurry. In a whole-farm perspective this is an efficient way to reduce the import of nutrients, especially N, P and trace elements, from outside the farm. Moreover, ammonia emissions from livestock housing and during storage and spreading of manure are also affected whenever livestock nutrition is changed, due to changes in chemical composition of the effluents.

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