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Farm technological innovations on swine manure in Southern Europe

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ABSTRACT - Swine production has increased steadily throughout the last decades in the European Union (EU). In Spain, swine census grew 58% between 1990 and 2009, being second-ranked within the EU-27, after Germany. This situation has led to major benefits for the efficiency in the production process but can also have drawbacks, as potential environmental impact of areas with high animal density. Management factors related with animal feeding (chemical composition, number of feeding phases, feeder type), drinker type and length of slurry pit storage affect pig excreta composition. In addition, the mitigation of gas pollutants (ammonia and greenhouse gases as methane and nitrous oxide) derived from pig facilities (animal pens and pits below them) and mainly from outdoor lagoons must be considered in the near future. Some strategies to manage the excreta quality may include dietary manipulation, rainwater reutilization systems, the application of additives to the slurry pit, and some other slurry treatments. This review highlighted the importance of water and feed devices on determining the excreta composition of fattening pigs. Management factors related with animal facilities and length of slurry pit storage affect gaseous emissions from pig slurry.

Key Words: drinker type, facilities, gas emissions, slurry composition, swine

Inovações tecnológicas em dejetos de suínos no Sul da Europa

RESUMO - A produção de suínos tem aumentado ao longo das últimas décadas na União Europeia (UE). Na Espanha, o censo cresceu 58% entre 1990 e 2009, sendo o segundo classificado na UE-27, depois da Alemanha. Esta situação tem gerado grandes benefícios para a eficiência no processo de produção, mas também pode ter desvantagens, como o impacto ambiental de áreas com alta densidade animal. Gestão de fatores relacionados com a alimentação animal (composição química, número de fases de alimentação, tipo de alimentação), o tipo de bebedouro e tempo de armazenamento de chorume a céu aberto afeta a composição de excrementos de suínos. Além disso, a mitigação de gases poluentes (amônia e gases de efeito estufa como o metano e o óxido nitroso) provenientes de instalações de suínos (currais e poços abaixo deles), principalmente entre as lagoas ao ar livre, deve ser considerada no futuro próximo. Algumas estratégias para gerir a qualidade de excretas podem incluir a manipulação da dieta, os sistemas de reaproveitamento da água da chuva, a aplicação de aditivos para o poço de chorume e alguns tratamentos de chorume. Esta revisão destacou a importância dos dispositivos de água e dos alimentos sobre a determinação da composição de dejetos de suínos de engorda. Fatores de gestão relacionados a instalações e período de armazenamento de chorume a céu influem nas emissões gasosas provenientes dos dejetos.

Palavras-chave: composição do chorume, emissão de gases, instalações suínos, tipo de bebedouro

Introduction

Swine production has increased steadily throughout the last decades in the European Union (EU). In Spain, swine census grew 58% between 1990 and 2009 (MARM, 2010a), being second-ranked within the EU-27 (16% out of the total census), after Germany (FAOSTAT, 2010). This situation has led to major benefits for the efficiency in the production process but can also have drawbacks, as potential environmental impact of areas with high animal density. In general, pig excreta in Spain is stored as slurry, a liquid mixture of feces and urine without bedding material, temporarily stored in pits below animal pens. The slurry can also contain some traces of animal feed, wasted water and cleaning and/or cooling water residuals. This excreta collecting system generates a large volume of liquid manure with very variable composition, especially regarding dry matter concentration (Table 1). Some management factors related with animal feeding (chemical composition, number of feeding phases, feed presentation), water trough type and length of slurry pit storage may explain such differences. The knowledge of farming factors affecting the composition

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Table 1 - Chemical composition of slurry from fattening pigs (20-100 kg body-weight) (n=187) (Babot et al., 2008a)

	Average	Standard deviation
Dry matter (DM) (% of fresh matter)	8.01	14.71
pH	8.26	0.70
Organic matter (% DM)	61.84	22.61
Organic nitrogen (N) (% DM)	3.01	1.55
NH_4^+-N (% DM)	5.34	3.26
Phosphorus (P) (% DM)	1.77	0.70
Potassium (K) (% DM)	4.72	3.06

of pig excreta is important to design strategies which minimize the environmental impact before using them as organic fertilizers or for other purposes.

Dietary manipulation to mitigate pollution from slurry

Diet manipulation is effective to reduce the pollutant characteristics of slurry. In a recent study, decreasing crude protein (CP) concentration in feed (from 16 to 14% CP) from fattening pigs did not reduce significantly slurry yield (ranged from 5.6 to 4.5±0.4 kg/pig/day), but this dietary change reduced amoniacal nitrogen (NH_4^+-N) (from 5.20 to 3.90±0.29 mg/ml) and volatile fatty acid (VFA) production from slurry (from 24.1 to 21.9±1.3 mmol/l) whereas increased its pH (from 7.84 to 8.10±0.05) (Hernández et al., 2011).

The pollutant characteristics of slurry are more harmful in finishing pigs than in the rest of swine categories. This was evidenced by Moral et al. (2008), who showed that the former group produced slurries with greater electrical conductivity and organic load (as evidenced by biochemical oxygen demand and chemical oxygen demand) than those of other production stages, such as gestating, farrowing and weaning.

Accordingly, legislation has been enforced to limit the use of animal manure or the number of animals per hectare of cultivated land in certain areas (Jongbloed & Lenis, 1998). The main problems have arised from nitrogen (N), greenhouse gas emissions (GHG), phosphorus and heavy metals (Zn, Cu and Cd). In the case of nitrogen, the environmental impairment includes the increase of nitrate levels in ground waters, the acidification of the soil and the eutrophication (excess of nutrients) of surface water. Ammonia (NH_3) emitted from livestock production contributes to the acidification and eutrophication of the environment (Degré et al., 2001), but also has indirect relation to nitrous oxide emission (N_2O) (IPCC, 2006). Furthermore, ammonia is a toxic gas irritating the animal and human respiratory tract when its concentration rises above 15 ppm (Banhazi et al., 2008). Approximately 50% of global ammonia emission is attributed to livestock production and the use of mineral fertilizers (Bouwman & Van der Hoek, 1997).

Ammonia in pig manure mainly originates from the breakdown of urea in urine (highly volatile N) (Jongbloed & Lenis, 1992; Canh et al., 1997). Faecal N is slowly incorporated into microbial protein, while urinary N is rapidly transformed to ammonia and released. In general, it can be considered that more than half of ingested N is excreted as ammonia in urine and faeces (Canh et al., 1998a; Canh et al., 1998 b; Van der Peet-Schwering et al., 1999).

In swine production, gaseous emissions may be managed at an enteric and/or manure pit level. In this regard, additives added in feed or in slurry pits could also act at different levels in order to reduce NH_3 emissions. Until now, the assessment of most of these substances has been focused on their effects on animal performance and immunological and health status. Nevertheless, feed additives have the potential to modify the N excretory pattern or the hindgut fermentation patterns involved in methane production and other volatile compounds. Certain potential feed additives groups are prebiotics, organic acids, acidifying salts and plant extracts.

Prebiotics are not digested either in the stomach or the small intestine, because they can not be hydrolized by intestinal enzymes. When these substances (mainly non digestible derived oligosaccharides of 3-10 glucose units) reach the large intestine they are used as a substrate for some bacteria fermentative processes (Williams et al., 2001). There are several studies relating some prebiotics with a reduction in the excretion of ammonia and certain volatile faecal metabolites (phenols and cresols). The inclusion of 15% inulin (a type of fructooligosaccaride) reduced 34% ammonia emission in growing-finishing pigs (60-110 kg) (Hansen et al., 2007). In this sense, prebiotics modify fermentation parameters in vitro by increasing lactic acid, total VFA, acetic and butyric content but reducing propionic acid content (Martín-Pelaez et al., 2008). In a recent experiment about in vitro cecal fermentation of non-starch polysaccharides, a dose-dependent reduction of the ammonia concentration and branched-chain VFA/simple-chain VFA ratio was observed (Bauer et al., 2010). This response seems to indicate an increase of these carbohydrate fermentations to the detriment of protein fermentation in the hindgut.

In addition, prebiotic utilization has been useful to reduce odorous compounds, the inclusion of 5% inulin extract reducing faecal skatole excretion by finishing pigs (Rideout et al., 2004). Accordingly, similar results were recorded in an in vitro fermentation model using fructo-oligosaccharides as a substrate and rectal faeces as inoculum (Li et al., 2009). Also, when utilizing β-glucans as a substrate, predominantly saccharolytic species may sequester greater proportions of available nitrogen for bacterial protein synthesis (Gibson et al., 1995), thus possibly reducing the potential for degradation to proteinaceous metabolites, i.e. valeric acid (O'Shea et al., 2010).

Another potential group of feed additives with environmental action are organic acids. In monogastrics, they have been normally used as feedstuff preservatives due to their antifungal and antibacterial properties as well as feed acidyfiers in post-weaning piglets so that to facilitate protein gastric digestion and improve its digestibility (Gabert & Sauer, 1995; Roth, 2000). Organic acids are easily metabolized substances and most of them enter into the Krebs cycle through different metabolic pathways to be oxidized to carbone dioxide. In other cases, they are final products of different microorganism carbohydrate fermentation and in the case of benzoic acid it is metabolized in the liver through conjugation with glycine to form hippuric acid, which is eliminated in urine (Kristensen et al., 2009).

The inclusion of formic acid in growing pig diets does not influence digesta dry matter content, pH or VFA concentration in the different digestive tract compartments (Roth et al., 1992). However, feed addition of formic acid triggered a significative decrease in ammonia concentration in the stomach and also reduced lactic acid in the small intestine. Such results may indicate decreased digestive microbial activity, which would benefit the host due to the lower metabolite production of ammonia, amines and toxins.

Another potential organic acid to mitigate ammonia production is benzoic acid, which reduced 48% this gas emission when it was supplied as salt form in feed at levels between 2.4% and 4.8% to growing pigs (Canh et al., 1998c), or even a 57% reduction when it was supplied in pure form at a 3% level, although it did not reduce odour from slurry (Hansen et al., 2007). The decrease in ammonia emission by adding benzoic acid in feed may be explained by a reduction in urinary pH, both in growing pigs (Canh et al., 1998c; Buhler et al., 2006) and lactating sows (Kluge et al., 2010). However, in the earlier experiments there was a slight decrease in feed intake with the highest benzoic acid level of inclusion (2%), although nutrient digestibility was increased.

Also, the feed addition of 1% adipic acid reduced 25% ammonia emission from slurry (van Kempen, 2001). The reduction in ammonia emission, though, did not correspond to the reduction in urinary pH but corresponded to the reduction in fecal pH as a result of mixing the urine and feces, in which feces act as a strong buffer.

General agreement seems to indicate that the pH of slurry is the main factor causing the reduction of ammonia emission. Decreasing dietary electrolyte balance (dEB) or including acidifying calcium salts were also useful tools to reduce urinary pH and lowering ammonia emission from slurry (Canh et al., 1998a; Mroz et al., 2000). In fact, practical low-fibre diets contain about 320 meq dEB/kg dry matter (DM) and a calcium level of about 0.7% achieved by supplying $CaCO_3$. Adding 1.1% to 2.4% $CaSO_4 \cdot 2H_2O$ or $CaCl_2 \cdot 2H_2O$ to the diet instead of $CaCO_3$ and reducing dEB to 100 meq/kg DM can lower the urinary pH by nearly 2 units. Ammonia emission from slurry would then be reduced by about 35% (Canh et al., 1998a). However, the use of calcium sulphate in fibrous diets reduced urinary pH but hardly affected the pH of manure (urine and faeces) (Mroz et al., 2000). This implies that the faecal nutrients may have a buffering potential to neutralize the acidogenic effect of supplemental sulphate.

In another experiment, the inclusion of anhydrous calcium chloride in nursery pig diets reduced aerial ammonia without affecting slurry pH (Colina et al., 2001). In this case, the growth performance of piglets was decreased, possibly due to metabolic acidosis produced by amount of calcium chloride (1.95%), which was set to adjust the dietary electrolyte balance to approximately zero.

Also some plant extracts may be useful to reduce gaseous pollutants from livestock. The use of yucca extracts in pig diets (65 to 125 ppm) (Amon et al., 1995; Colina et al., 2001) and in the manure pit (3.2 g/10 litres on a daily basis, Amon et al., 1995) has been especially effective in reducing ammonia emissions from pig buildings (over 25% decreases). The effects of yucca extract may be associated with its glyco-components, which bind ammonia and other noxious gases in the slurry, decreasing emissions from the manure pit. Another factor that has been attributed to the reduction of aerial ammonia by this plant is the inhibition of urease activity due to the yucca sarsaponin content (Preston et al., 1987).

The afore-mentioned additives could be added in manure pits below animal pens, which also allow the use of some other acidifying products, as aluminium chloride ($AlCl_3$). Smith et al. (2004) found that 0.25 to 0.75% $AlCl_3$ (based on estimated manure production volumes) reduced the pH of slurry and ammonia emission. However, the effects of $AlCl_3$ addition on manure pH and NH_3 losses were the greatest immediately after treatment and decreased with time. In this sense, it was suggested that a 1 week flush cycle length would optimise the overall effectiveness of reducing ammonia losses.

On the other hand, there is little knowledge about the effects of feed additives on enteric and waste methane (CH_4) emission from swine. *In vitro* models have revealed that the response to several organic acid salts as disodium fumarate is highly dependent on the diet characteristics, fibrous leading to greatest methane reduction than high energy diets (García-Martínez et al., 2005). In addition, yucca extracts have been proved to reduce in vitro methane production without influencing gas production kinetics or total VFA concentrations in a variety of diets (Xu et al., 2010), but, to our knowledge, nothing is known about the effects of many other feed additives. Taking into account that 55% of methane from excreta is produced during manure storage (pigs yielding 3.3 kg CH_4/ year but only 1.5 kg CH_4/ year from enteric fermentation) (Monteny et al., 2001), methane emission reduction strategies should focus on the control of critical processes not only during animal digestion but during on-farm storage (indoor, outside).

Additionally to the demonstrated effects of some feeding strategies on the nitrogen and organic matter fraction of slurry, recently a concern exists on the evidence that the concentration of minerals such as phosphorus (P) and heavy metals such as zinc (Zn) and copper (Cu) in soils could be excessive in some areas with intensive livestock production. These heavy metals are often oversupplied in pig diets because they are used as growth promoters at pharmacological levels, or because large safety margins are applied. Thereby, they represent an important source of environmental pollution not characterised until now.

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. Phase feeding can reduce P excretion, because the required concentration of P per kg of feed decreases with increasing live weight of the pig (Jongbloed & Lenis, 1998). However, main reduction of P excretion can be obtained by increasing P digestibility. In feedstuffs of plant origin two third of total P is present as phytic acid P, which is almost indigestible for pigs (Jongbloed, 1987). According to Jongbloed & Lenis (1998) phytase-supplemented feeds for growing-finishing pigs and pregnant sows need little or no supplementary P. Depending on P sources, pig category and phytase dose, P-digestibility can increase varying from 8 to 30% units (Jongbloed et al., 2004; Van der Peet- Schwering et al., 1999; Walz & Pallauf, 2003). In a survey conducted in Spain (Babot et al., 2008b), all the growing-finishing pig diets were phytase supplemented, whereas 87% of starter diets for weaned pigs, 37.5% of pregnant sow diets and 57% of lactating sow diets included phytase to improve P digestibility. These results indicated that the use of phytase was extended in fattening pig diets but it could increase in adult sow diets.

Main heavy metals of concern in pig manure are copper, zinc, and cadmium. 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, 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. Cadmium is not supplemented to the diet, but gets into the feed by using contaminated feedstuffs.

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. Nevertheless, the practical supply remains higher than the usually published requirements (less than 10 ppm), and average retention efficiency is still less than 1% (Dourmad & Jondreville, 2007).

The maximal allowed Zn incorporation in pig diets was reduced in 2003 to 150 ppm, compared to 250 ppm before (EC, 1334/2003). 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). Even though the situation has been improved by these 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 approached, resulting in a better agreement between spreading and export by plants. However, some factors such as the stimulation of fermentation by dietary non-starch polysaccharides affect net mineral flux in the large intestine that, in turn, can influence mineral excretion in faeces. Additionally, negative effects of low fermentable cellulose on apparent retention may increase the daily requirement for minerals of pigs (Metzler-Zebeli et al., 2010).

Feeder and drinker devices as factors influencing the slurry composition

In a survey conducted in Spain which included data from 364 swine facilities, the most usual drinker type was nipple bowl drinker (68%), followed by constant valve drinker (9%) and drinker located within feeder (9%), and nipple drinker (3%) (Babot et al., 2008b). Drinker type and water flow rate influence significantly water use (Brumm et al., 2000). Nipple bowl drinker needs both tactile and oropharyngeal stimulation (Torrey et al., 2008), which reduces water waste. Accordingly, the MARM (2010) suggested that these drinkers reduced 24% water use and 5 to 14% slurry yield compared to nipple drinkers. In the same study, it was pointed out that the use of drinker located within the feeder may decrease water use by 20% and slurry yield decreased between 4 and 12%.

To evaluate the effect of drinker devices (Figure 1) on water use and slurry production in growing-finishing pigs during the cold period (October-March), a two-year experiment was conducted in the CEP Research Facilities (unpublished data). In this study, water use was affected by the drinker device along the fattening period (P<0.001). Nipple bowl drinker showed the lowest water disappearance, whereas bite drinker showed the greatest values during the growing-finishing period (Figure 2). Nipple square cup showed similar water use to nipple bowl drinker during the early growing-finishing period but the former increased

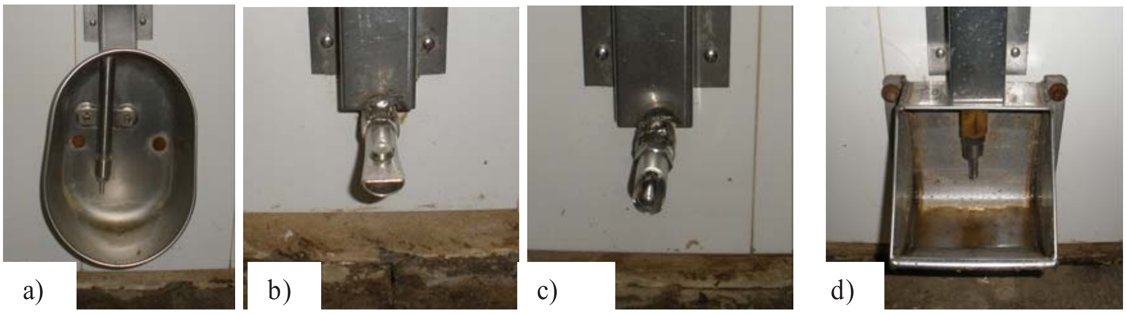

Figure 1 - Drinker devices used: (a) nipple bowl drinker, (b) pig teat drinker, (c) bite drinker, (d) nipple square cup.

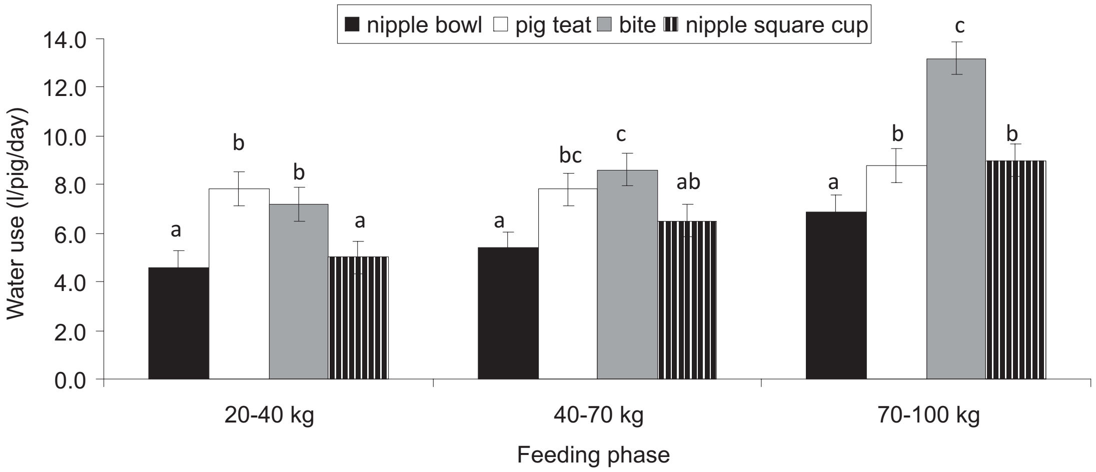

Figure 2 - Water use in growing-finishing pigs (20-100 kg) raised under a 3-phase feeding programme with different drinking devices. Different letters within each feeding phase indicate significant differences among drinker devices (P<0.05).

steadily until the end of the fattening period. This water disappearance led to an average slurry yield of 6.6, 10.5, 9.6 and 6.7±3.0 litres/pig/day in nipple bowl, pig teat, bite and nipple square cup drinkers, respectively, which indicates that the water device exerts an important effect on daily slurry yield.

Water use does not differ between winter and summer seasons if cooling is provided during the hot season (Brumm et al., 2000). By contrast, water disappearance from nipple drinkers plus dry feeder in summer was two fold greater than water use from wet/dry feeders (16 vs. 7.5 litres/pig/day). However, they observed no effect of feeder type on water disappearance in a winter experiment (5.9 vs. 6.2 litres/pig/day) (Miyawaki et al., 1994).

In another study evaluating the effect of different management factors on the composition of slurry from 23 fattening pigs (20-100 kg live-weight) (Álvarez-Rodríguez et al., 2011), the period of the year or the feed presentation type did not affect the slurry yield ($P>0.05$), which was on average 4.1 litres/pig/day, but had large variability (standard deviation 3.0 litres/pig/day). The slurry yield was negatively correlated with its dry matter (DM) concentration ($r=-0.48$, $P<0.01$). The slurry DM did not differ between hot and cold periods of the year or between wet/dry and dry feeders (Table 2, $P>0.10$). However, this parameter was negatively correlated with the ammonium N concentration of slurry ($r=-0.65$, $P<0.001$) and potassium ($r=-0.63$, $P<0.001$).

In the afore-mentioned study, the period of the year affected the organic matter concentration of slurry, with lower values in the hot than in the cold period (Table 2). This result evidences a greater microbial activity throughout the slurry storage in the hot period of the year, which would deplete the easy degradable organic matter to produce organic volatile compounds, CO_2 and CH_4. In this sense, Moller et al. (2004) observed a direct relationship between the emission of these gases and ambient temperature, especially when the storage periods exceeded 30 days. Likewise, the organic matter concentration of slurry was slightly greater in facilities with wet/dry feeders than in those using dry feeders ($P<0.10$). Wet/dry feeders are effective in reducing water spillage and slurry yield (Brumm et al., 2000). Nevertheless, the greater organic matter concentration of slurry from facilities using wet/dry feeders might suggest a greater feed spillage in this feeding system, although this hypothesis has to be confirmed in a larger study including more farms and measures.

Concerning organic nitrogen concentration of slurry, the period of the year and the feeder type did not affect this parameter (Table 2, $P>0.10$). According the regional legislation (DOGC, 2010), the estimated N intake by each pig during the fattening cycle (139 days) was 4.78 ± 0.63 kg N, whereas the individual estimated excretion was 2.65 ± 0.58 kg N (54.1%). The amount of N volatilized accounted for 0.60±0.31 kg N/pig (22.6%). The feeder type affected the ammonium N concentration of slurry ($P<0.10$), with greater values in the wet/dry feeder type than in dry feeders (Table 2). Phosphorus concentration of slurry did not differ between periods of the year or feeder types ($P>0.10$), but it was positively correlated with the feed to gain ratio ($r=0.58$, $P=0.003$). This relationship may involve a greater P excretion in animals with the worst productive performance, and suggests that breeding selection for growth traits could help in reducing as well nutrient excretion.

In the same study, the feeder type had an effect on potassium concentration of slurry (Table 2, $P<0.10$), concomitantly to ammonium N concentration. In fact, the concentration of both nutrients was correlated positively ($r = 0.83$, $P<0.001$). This relation could be explained because both ammonium N and potassium are soluble elements in the liquid fraction of slurry (Yagüe et al., 2008), and there is a direct relationship between protein and potassium concentration in dietary feedstuffs (Meschy, 1998). The above described results are in agreement with Irañeta et al. (2002), who observed that the nutrients concentration of slurry (N-P-K) was greater in wet/dry feeder types than in dry feeders with bowl and nipple drinkers.

Table 2 - Effects of period of the year and feeder type on the composition of slurry from fattening pigs[1]

	Period of the year (P)		Feeder type (F)		*P*-value	
	Hot	Cold	Wet/dry	Dry	P	F
Dry matter (DM) (% of fresh matter)	7.26±0.87	6.31±1.21	6.14±1.26	7.42±0.82	0.57	0.46
Organic matter (% DM)	57.9±4.4a	78.3±7.5b	76.5±6.6b	59.7±4.4a	0.05	0.06
Organic N (% DM)	2.86±0.20	2.95±0.28	2.91±0.29	2.90±0.19	0.82	0.98
NH4$^+$-N (% MS)	7.12±1.34	8.68±1.87	10.38±1.95b	5.41±1.27a	0.55	0.07
P (% DM)	1.74±0.15	1.71±0.22	1.73±0.22	1.73±0.15	0.92	0.99
K (% DM)	6.17±1.06	6.90±1.47	8.61±1.54b	4.46±1.00a	0.72	0.06

[1] Different letters within the same factor indicate significant differences ($P<0.10$).

Design and management of slurry pits to mitigate air pollution from the slurry

Some management recomendations to reduce environmental load may involve the use of straw combined with partial slatted floor, the reduction of slurry pit area, the use of independent water and excreta collectors in sow crates, sloping manure pits to facilitate urine slipping to a central collector, and shortening the slurry storage time within the pits below animal pens (Marm, 2010b). Most of these best available practices involve an extra cost which may be considered (Table 3).

Gaseous emissions from pigs raised on the slatted floor and on the deep litter were, respectively, 6.2 and 13.1 g per pig per day for NH_3, 0.54 and 1.11 g per pig per day for N_2O, 16.3 and 16.0 g per pig per day for CH_4, 1.74 and 1.97 kg per pig per day for CO_2 and 2.48 and 3.70 kg per pig per day for H_2O. Except for the CH_4 emissions, all the differences were significant ($P<0.001$). On average, the emissions associated with the deep litter system were significantly higher than from the slatted floor system for ammonia (+110%), nitrous oxide (+106%), carbon dioxide (+14%) and water vapour (+49%). Only methane emissions did not differ with regard to floor type, with about 16 g emitted per pig and per day. The warming potential of greenhouse gases released from the deep litter system was significantly greater (+18%) than from the slatted floor system (Philippe et al., 2007).

Gaseous emissions from sows kept on slatted floor compared to sows housed on straw-based deep litter were significantly greater for NH_3 (12.77 vs. 9.05 g/day/sow; $P<0.001$) and CH_4 (10.12 vs. 9.20 g/day/sow; $P<0.01$), and significantly lower for N_2O (0.47 vs. 2.27 g/day/sow; $P<0.001$), CO_2 equivalents (0.44 vs. 0.94 kg/day/sow; $P<0.001$) and CO_2 (2.41 vs. 2.83 kg/day/sow; $P<0.001$). There was no significant difference for water vapour emissions (3.25 vs. 3.21 kg/day/sow; $P>0.05$). The main environmental disadvantage of the deep litter system pointed in that study was the greater N_2O-emissions and thus greater CO_2eq-emissions compared to slatted floor. However, the use of deep litter was related to reduced NH_3- and CH_4-emissions in gestating sows (Philippe et al., 2011). In the former experiment conducted with fattening pigs, greater NH_3-emissions were obtained with the deep litter system compared to the slatted floor system. The amounts of supplied straw could explain the different results. Indeed, while the excreted nitrogen was quite similar (around 40 g N/day per animal) in the two experiments, the straw supply was greater with the sows than with the fattening pigs (900 g/day/sow vs. 400 g/day/pig). More straw increased the C/N ratio of the litter which favours bacterial growth and promotes the N assimilation into stable microbial protein with lower NH_3- emissions as a consequence (Dewes, 1996). This explanation was also supported by Gilhespy et al. (2009), who observed a reduction of NH_3-emissions with a greater straw supply (8 kg vs. 4 kg straw/pig/week).

In organically raised pigs, There were clear differences in ammonia emission between farms ($P<0.001$), varying between 0.0 and 7.7 g/day/m^2 from the buildings and between 3.6 and 17.6 g/day/m^2 from the outside yards. Location (inside/outside) and degree of fouling of the floor area also had significant effects on ammonia emission ($P<0.001$). Differences in ammonia emissions between farms were mainly related to the manure removal system, design of the building and frequency of cleaning of outside yard. The farm with daily scraper cleaning and the farm with the slatted floor system had significantly lower emissions than the farm with bi-weekly manual removal of manure from a solid floor. Regular cleaning of the outside yard seems very important to reduce ammonia emission (Ivanova-Peneva et al., 2008).

The reduction of the amount of NH_3 emissions produced on the fouled floor surfaces of growing-finishing pig houses has been also approached by searching a slat design which

Table 3 - Best available practices for slurry management to reduce its ammonia emissions with respect to the reference housing system (adapted from Piñeiro et al., 2009)

Pig category	Practice	NH_3	Extra cost (euros/head/year)
Growing period	Pits with slope to facilitate faeces and urine separation	↓ 30-35%	1.27-2.67
	Partial slatted floor	↓ 25-35%	0.88
	Frequent emptying	↓ 25%	0
Finishing period	Partial slatted floor	↓ 30-35%	3.61-4.33
	V-shaped pits	↓ 10-30%	6.45-7.74
	Well managed straw bed pens	↓ 20-30%	36.51-42.07
	Frequent emptying	↓ 30-60%	0

minimises the contact between excreta and concrete (Hamelin et al., 2010). Compared with the control design that is typically used in pig houses, the presence of a notch resulted in average reductions between 23 and 42% of the NH_3 emissions from the fouled slat surfaces. Modifying the slat cross-section shape, however, did not have any significant effect on NH_3 emissions from the fouled floor surfaces. Similarly, the application of an epoxy coating on the slats did not have any significant effect on NH_3 emissions from the fouled floor surfaces.

The combination of ceiling and pit ventilation (10% of maximum ventilation capacity) resulted in significantly lower NH_3 concentrations in the room air (42.6%) and in the slurry-pit headspace (22.3%) compared with only ceiling ventilation by removing the highly concentrated gases and odours from the headspace above the liquid manure surface (Saha et al., 2010).

Key factors driving ammonia emissions from a pig house slurry pit were evaluated in a recent study (Ye et al., 2011). Out of the nine factors evaluated (ventilation flow, floor system, headspace height in pit, slurry pit curtain, slurry temperature, pit temperature, room temperature, outdoor temperature, and room relative humidity), the five parameters that explained most of the variability of the NH_3 emissions from the pig room were ventilation rate, floor system, slurry temperature, headspace height in pit, and slurry pit curtain. Ammonia emission rate increased as room ventilation rate increased with diffuse ceiling inlet. However, according to this study, the lower slurry temperature could reduce NH_3 emission or compensate the effects of higher ventilation rate.

Concluding remarks and future prospects

Pig production is now challenged with maintaining the environmental quality, which limits the indiscriminate use of slurry as organic fertilizer. In addition, the mitigation of gas pollutants (ammonia and greenhouse gases as methane and nitrous oxide) derived from pig facilities (animal pens and pits below them) and mainly from outdoor lagoons must be considered in the near future. Some strategies to manage the excreta quality may include dietary manipulation, rainwater reutilization systems, the application of additives to the slurry pit, slurry aeration and some other slurry treatments, i.e. solid-liquid separation, anaerobic codigestion or nitrification-denitrification processes (Table 4). This review also highlighted the importance of water and feed devices on determining the excreta composition of fattening pigs. Management factors related with animal feeding facilities and length of slurry pit storage affect pig excreta composition and gas emissions.

Table 4 - Management ools to mitigate the environmental impacts of swine excreta (adapted from Campos et al., 2004)

Animal production phase	Storage (individual or collective)
Water use reduction	Enough capacity
Diet manipulation	Avoid rainwater enter
Feed additives inclusion	Lagoon covering
	Lagoon additives use
	Storage after solid/ liquid separation
Farm treatment	Waste plants
Biogas production	Nitrogen reduction
Solid/liquid separation	Organic matter reduction
Nitrogen reduction from liquid part	Biogas production
Composting solid part	Volume reduction
Concentration of nutrients	Concentration of nutrients

References

ÁLVAREZ-RODRÍGUEZ, J.; HERMIDA, B.; TEIRA, M.R. et al. Factores de explotación que afectan a la composición de purín en cerdos de engorde. In: JORNADAS SOBRE PRODUCCIÓN ANIMAL DE LA ASOCIACIÓN INTERPROFESIONAL PARA EL DESARROLLO AGRARIO, 14., 2011, Zaragoza, España. **Proceedings...** Zaragoza: 2011. 3p.

AMON, M.; DOBEIC, M.; MISSELBROOK, T.H. et al. A farm scale study on the use of De-odorase for reducing odour and ammonia emissions from intensive fattening piggeries. **Bioresource Technology**, v.51, p.163-169, 1995.

BABOT, D.; TEIRA, M.R.; GARCÍA, P. et al. **Aproximació a la producción i composición de les dejeccions porcines**. Generalitat de Catalunya: Departament d'Agricultura, Alimentació i Acció Rural, 2008a. 80p.

BABOT, D.; TEIRA, M.R.; GALLART, R. et al. Evaluación de factores condicionantes de la producción de purines de porcino en condiciones de campo. In: MAGRÍ, A.; PRENAFETA-BOLDÚ, F.X.; FLOTATS, X. (Eds.). **Libro de Actas del I Congreso Español de Gestión Integral de Deyecciones Ganaderas**. Barcelona: Service-Point, 2008b. p.123-130.

BANHAZI, T.M.; SEEDORF, J.; RUTLEY, D.L. et al. Identification of risk factors for sub-optimal housing conditions in Australian piggeries: Part 1 Study justification and design. **Journal of Agricultural Safety and Health**, n.14, p.5-20, 2008.

BAUER, E.; WILLIAMS, B.A.; VOIGT, C. et al. *In vitro* fermentation of various carbohydrate-rich feed ingredients combined with chyme from pigs. **Archives of Animal Nutrition** v. 64, n.5, p.394-411, 2010.

BOUWMAN, A.; VAN DER HOEK, K. Scenarios of animal waste production and fertilizer use and associated ammonia emission for the developing countries. **Atmospheric Environment**, n.31, p.4095-4102, 1997.

BRAUDE, R. Twenty five years of widespread use of copper as an additive to diets of growing pigs. In: L'HERMITE, P.; DEHANDTSCHUTTER, J. (Eds.) **Copper in animal wastes and sewage sludge**. Dordrecht, The Netherlands: D. Reidel Publishing Co., 1980. p.3-15.

BRUMM, M.C.; DAHLQUIST, J.M.; HEEMSTRA, J.M. Impact of feeders and drinker devices on pig performance, water use and manure volume. **Journal of Swine Health and Production**, v.8, n.2, p.51-57, 2000.

BÜHLER, K.; WENK, C.; BROZ, J.; GEBERT, S. Influence of benzoic acid and dietary protein level on performance, nitrogen metabolism and urinary pH in growing–finishing pigs. **Archives of Animal Nutrition**, v.60, p.382-389, 2006.

CAMPOS E.; ILLA J.; MAGRÍ A.; PALATSI J. et al. **Guía de los tratamientos de las deyecciones ganaderas**. Generalitat Catalunya: ARC, 2004. 70p.

CANH, T.T.; VERSTEGEN, M.W.A.; AARNINK, A.J.A. et al. Influence of dietary factors on nitrogen partitioning and composition of urine and feces of fattening pigs. **Journal of Animal Science**, v.75, p.700-706, 1997.

CANH, T.T.; AARNINK, A.J.A.; VERTEGEN, M.W.A. et al. Influence of dietary factors on the pH and ammonia emission of slurry from growing-finishing pigs. **Journal of Animal Science**, v.76, p.1123-1130, 1998a.

CANH, T.T.; AARNINK, A.J.A.; SCHUTTE, J.B. et al. Dietary protein affects nitrogen excretion and ammonia emission from slurry of growing-finishing pigs. **Livestock Production Science**, v.56, p.181-191, 1998b.

CANH, T.T.; AARNINK, A.J.A.; MROZ, Z. et al. Influence of electrolyte balance and acidifying calcium salts in the diet of growing–finishing pigs on urinary pH, slurry pH and ammonia volatilisation from slurry. **Livestock Production Science**, n.56, p.1-13, 1998c.

COLINA, J.J.; LEWIS, A.J.; MILLER, P.S. et al. Dietary manipulation to reduce aerial ammonia concentrations in nursery pig facilities **Journal of Animal Science**, v.79, p.3096-3103, 2001.

DEGRÉ, A.; VERHÈVE, D.; DEBOUCHE, C. Emissions gazeuses en élevage porcin et modes de réduction: revue bibliographique. **Biotechnology, Agronomy, Society and Environment**, v.5, p.135-143, 2001.

DEWES, T. Effect of pH, temperature, amount of litter and storage density on ammonia emissions from stable manure. **Journal of Agricultural Science**, v.127, p.501-509, 1996.

DIARIO OFICIAL DE LA GENERALITAT DE CATALUÑA (DOGC). ORDEN AAR/506/2010, de 2 de noviembre, por la que se establecen los criterios para la aplicación de los niveles de reducción en la excreción de nitrógeno del ganado porcino mediante la mejora de la alimentación, de acuerdo con el anexo 2 del Decreto 136/2009, de 1 de septiembre, de aprobación del programa de actuación aplicable a las zonas vulnerables en relación con la contaminación de nitratos que proceden de fuentes agrarias y de gestión de las deyecciones ganaderas. Generalitat de Catalunya: Departamento de Agricultura, Alimentación y Acción Rural, 2010.

DOURMAD, J-Y.; JONDREVILLE, C. Impact of nutrition on nitrogen, phosphorus, Cu and Zn in pig manure, and on emissions of ammonia and odours. **Livestock Science**, v.112, p.192-198, 2007.

FAOSTAT. [2010]. **Statistics**. Available in: http://faostat.fao.org/ Accessed on: 10/12/2010.

GABERT, V.M.; SAUER, W.C. The effect of fumaric acid and sodium fumarate supplementation to diets for weanling pigs on aminoacid digestibility and volatile fatty acid concentrations in ileal digesta. **Animal Feed Science Technology**, v.53, p.243-254, 1995.

GARCÍA-MARTÍNEZ, R.; RANILLA, M.J.; TEJIDO, M.L. et al. Effects of disodium fumarate on in vitro rumen microbial growth, methane production and fermentation of diets differing in their forage:concentrate ratio. **British Journal of Nutrition**, v.94, p.71-77, 2005.

GIBSON, G.R.; BEATTY, E.R.; WANG, X. et al. Selective stimulation of bifidobacteria in the human colon by oligofructose and inulin. **Gastroenterology**, v.108, p.975-982, 1995.

GILHESPY, S.L.; WEBB, J.; CHADWICK, D.R. et al. Will additional straw bedding in buildings housing cattle and pigs reduce ammonia emissions? **Biosystems Engineering**, v.102, p.180-189, 2009.

HAMELIN, L.; GODBOUT, S.; THÉRIAULT, R. et al. Evaluating ammonia emission potential from concrete slat designs for pig housing **Biosystems Engineering**, v.105, p.455-465, 2010.

HANSEN, C.F.; SØRENSEN, G.; LYNGBYE, M. Reduced diet crude protein level, benzoic acid and inulin reduced ammonia, but failed to influence odour emission from finishing pigs. **Livestock Science**, v.109, p.228-231, 2007.

HERNÁNDEZ, F.; MARTÍNEZ, S.; LÓPEZ, C. et al. Effect of dietary crude protein levels in a commercial range, on the nitrogen balance, ammonia emission and pollutant characteristics of slurry in fattening pigs. **Animal** (*in press*), doi:10.1017/S1751731111000115, 2011.

INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE - IPCC. Guidelines for national greenhouse gas inventories. In: EGGLESTON, H.S.; BUENDIA, L.; MIWA, K. et al. (Eds.). **General guidance and reporting**. Hayama, Japan: National Greenhouse Gas Inventories Programme. Institute for Global Environmental Strategies, 2006. v.1.

IRAÑETA, I.; SANTOS, A.; ABAIGAR, A. Purín de porcino ¿Fertilizante o contaminante?. **Navarra Agraria**, v.132, p.10-24, 2002.

IVANOVA-PENEVA, S.G.; AARNINK A.J.A.; VERSTEGEN, M.W.A. Ammonia emissions from organic housing systems with fattening pigs. **Biosystems Engineering**, v.99, p.412-422, 2008.

JONDREVILLE, C.; HAYLER, R.; FEUERSTEIN, D. Replacement of zinc sulphate by microbial phytase for piglets fed a maize-soybean meal diet. **Animal Science**, v.81, p.77-83, 2005.

JONDREVILLE, C.; REVY, P.S.; DOURMAD, J.Y. Dietary means to better control the environmental impact of copper and zinc by pigs from weaning to slaughter. **Livestock Production Science**, v.84, p.147-156, 2003.

JONDREVILLE, C.; REVY, P.S.; JAFFREZIC, A. et al. Le cuivre dans l'alimentation du porc : oligoélément essential, facteur de croissance et risque potentiel pour l'homme et l'environnement. **INRA Productions Animales**, v.15, p.247-265, 2002.

JONGBLOED, A.W. **Phosphorus in the feeding of pigs**. 1987. 343f. PhD Thesis, Agricultural University Wageningen.

JONGBLOED, A.W.; LENIS, N.P. Alteration of nutrition as a means to reduce environmental pollution by pigs. **Livestock Production Science**, v.31, p.75-94, 1992.

JONGBLOED, A.W.; LENIS, N.P. Environmental concerns about animal manure. **Journal of Animal Science**, v.76, p.2641-2648, 1998.

JONGBLOED, A.W.; VAN DIEPEN, J.T.M.; KEMME, P.A. et al. Efficacy of microbial phytase on mineral digestibility in diets for gestating and lactating sows. **Livestock Production Science**, v.91, p.143-155, 2004.

KLUGE, H.; BROZ, J.; EDER, K. Effects of dietary benzoic acid on urinary pH and nutrient digestibility in lactating sows. **Livestock Science**, v.134, p.119-121, 2010.

KRISTENSEN, N.B.; NØRGAARD, J.V.; WAMBERG, S. et al. Absorption and metabolism of benzoic acid in growing pigs. **Journal of Animal Science**, v.87, p.2815-2822, 2009.

LI, C.Y.; LIU, J.X.; WANG, Y.Z. et al. Influence of differing carbohydrate sources on L-tryptophan metabolism by porcine fecal microbiota studied in vitro. **Livestock Science**, v.120, p.43-50, 2009.

MARM. **Anuario de Estadística 2009**. Ministerio de Medio Ambiente, Rural y Marino, Gobierno de España, 2010a. 1190p.

MARM. **Guía de mejoras técnicas disponibles del sector porcino**. Ministerio de Medio Ambiente, Rural y Marino, Gobierno de España, 2010b. 136p.

MARTÍN-PELÁEZ, S.; GIBSON, G.R.; MARTÍN-ORUÉ, S.M. et al. In vitro fermentation of carbohydrates by porcine faecal inocula and their influence on *Salmonella Typhimurium* growth in batch culture systems. **FEMS Microbiology Ecology**, v.66, p.608-619, 2008.

MESCHY, F. **Balance electrolítico y productividad en animales monogástricos**. XIV Curso de Especialización FEDNA, 1998, 13p.

METZLER-ZEBELI, B.U.; HOODA, S.; MOSENTHIN, R. et al. Bacterial fermentation affects net mineral flux in the large intestine of pigs fed diets with viscous and fermentable nonstarch **Journal of Animal Science**, v.88, p.3351-3362, 2010.

MIYAWAKI, K.; ITOH, S.; HOSHINA, K. Water requirement and water-saving effect in finishing pigs fed with wet/dry feeders. **Japanese Journal of Swine Science**, v.31, p.35-42, 1994.

MOLLER H.B.; SOMMER, S.G.; AHRING B.K. Biological Degradation and greenhouse gas emissions during pre-storage of liquid animal manure. **Journal of Environmental Quality**, v.33, p.27-36, 2004.

MONTENY, G.J.; GROENESTEIN, C.M.; HILHORST, M.A. Interactions and coupling between emissions of methane and nitrous oxide from animal husbandry. **Nutrient Cycling in Agroecosystems**, v.60, p.123-132, 2001.

MORAL, R.; PEREZ-MURCIA, M.D.; PEREZ-ESPINOSA, A. et al. Salinity, organic content, micronutrients and heavy metals in pig slurries from South-eastern Spain. **Waste Management**, n.28, p.367-371, 2008.

MROZ, Z.; MOESER A.J.; VREMAN, K. et al. Effects of dietary carbohydrates and buffering capacity on nutrient digestibility and manure characteristics in finishing pigs. **Journal of Animal Science**, v.78, p.3096-3106, 2000.

O'SHEA, C.J.; SWEENEY, T.; LYNCH, M.B. et al. Effect of β-glucans contained in barley- and oat-based diets and exogenous enzyme supplementation on gastrointestinal fermentation of finisher pigs and subsequent manure odor and ammonia emissions. **Journal of Animal Science**, v.88, p.1411-1420, 2010.

PHILIPPE, F.X.; LAITAT, M.; CANART, B. et al. Comparison of ammonia and greenhouse gas emissions during the fattening of pigs, kept either on fully slatted floor or on deep litter. **Livestock Science**, v.111, p.144-152, 2007.

PHILIPPE, F.X.; LAITAT, M.; WAVREILLE, J. et al. Ammonia and greenhouse gas emission from group-housed gestating sows depends on floor type. **Agriculture, Ecosystems and Environment**, v.140, p.498-505, 2011.

PIÑEIRO, C.; MONTALVO, G.; GARCÍA, M.A. et al. Spanish Ministry of the Environment and Rural and Marine Affairs project for the IPPC Directive implementation in Spain: results of 2003-2008 and future work. In: BOOK OF ABSTRACTS OF THE 60TH ANNUAL MEETING OF THE EUROPEAN ASSOCIATION FOR ANIMAL PRODUCTION, 2009. Wageningen Academic Publishers, p.327.

POULSEN, H.D.; JONGBLOED, A.W.; LATIMIER, P. et al. Phosphorus consumption, utilisation and losses in pig production in France, The Netherlands and Denmark. **Livestock Production Science**, v.58, p.251-259, 1999.

PRESTON, R.L.; BARTLE, S.J.; MAY, T. et al. Influence of sarsaponin on growth, feed and nitrogen utilization in growing male rats fed diets with added urea or protein. **Journal of Animal Science**, v.65, p.481-487, 1987.

REVY, P.S.; JONDREVILLE, C.; DOURMAD, J.Y. et al. Assessment of dietary zinc requirement of weaned piglets fed diets with or without microbial phytase. **Journal of Animal Physiology and Animal Nutrition**, v.90, p.50-59, 2006.

REVY, P.S.; JONDREVILLE, C.; DOURMAD, J.Y. et al. Le zinc dans l'alimentation du porc: oligoélément essentiel et risque potential pour l'environnement. **INRA Productions Animales**, v.16, p.3-18, 2003.

RIDEOUT, T.C.; FAN, M.Z.; CANT, J.P. et al. Excretion of major odor-causing and acidifying compounds in response to dietary supplementation of chicory inulin in growing pigs. **Journal of Animal Science**, v.82, p.1678-1684, 2004.

ROTH, F.X.; ECKEL, B.; KIRCHGEßNER, M.Y. et al. Influence of formic acid on pH value, dry matter content, concentration of volatile fatty acids and lactic acid in gastrointestinal tract. 3. Investigations about the nutritive efficacy of organic acids in the rearing of piglets. **Journal of Animal Physiology and Animal Nutrition**, v.67, p.148-156, 1992.

ROTH, F.X. Ácidos orgánicos en nutrición porcina. Eficacia y modo de acción. In: XVI CURSO DE ESPECIALIZACIÓN FEDNA, 2000, Madrid. **Anais...** Madrid, Fundación Española para el Desarrollo de la Nutrición Animal, 2000. 11p.

SAHA C.K.; ZHANG, G.; KAI, P. et al. Effects of a partial pit ventilation system on indoor air quality and ammonia emission from a fattening pig room. **Biosystems Engineering**, v.105, p.279-287, 2010.

SMITH, D.R.; MOORE JUNIOR, P.A.; HAGGARD, B.E. et al. Effect of aluminum chloride and dietary phytase on relative ammonia losses from swine manure. **Journal of Animal Science**, v.82, p.605-611, 2004.

TORREY, S.; TOTH TAMMINGA, E.L.M.; WIDOWSKI, T. M. Effect of drinker type on water intake and waste in newly weaned piglets. **Journal of Animal Science**, v.86, p.1439-1445, 2008.

VAN DER PEET-SCHWERING, C.M.C.; AARNICK, A.J.A.; ROM, H.B. et al. Ammonia emissions from pig houses in the Netherlands, Denmark and France. **Livestock Production Science**, v.58, p.265-269, 1999.

VAN KEMPEN, T.A. Dietary adipic acid reduces ammonia emission from swine excreta. **Journal of Animal Science**, v.79, p.2412-2417, 2001.

WALZ, O.P.; PALLAUF, J. The effect of the combination of microbial phytase and amino acid supplementation of diets for finishing pigs on P and N excretion and carcass quality. **Archives of Animal Nutrition**, v.57, p.413-428, 2003.

WILLIAMS, B.A.; VERSTEGEN, M.W.A.; TAMMINGA, S. Fermentation in the large intestine of single-stomached animals and its relationship to animal health. **Nutrition Research Reviews**, v.14, p.207-227, 2001.

XU, M.; RINKER, M.; MCLEOD, K.R. et al. *Yucca schidigera* extract decreases in vitro methane production in a variety of forages and diets. **Animal Feed Science and Technology**, v.159, p.18-26, 2010.

YAGÜE, M.R.; QUÍLEZ, D.; IGUÁCEL, F. et al. **Métodos rápidos de anàlisis como herramienta de gestión en la fertilización con purín porcino**: conductimetría. Informaciones Técnicas Diputación General de Aragón n.195, 2008. 16p.

YE, Z.; ZHU, S.; KAI, P. et al. Key factors driving ammonia emissions from a pig house slurry pit. **Biosystems Engineering**, v.108, p.195-203, 2011.