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OPPORTUNITIES AND STRATEGIES TO REDUCE EFFLUENT PRODUCTION BY PIGS

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Abstract

There is increasing concern about the impact that agriculture is having on the environment. As far as the pig industry is concerned, a significant proportion of nutrients that are fed to pigs end up in the effluent. There are two basic options for reducing the amount of effluent produced by pigs. The first is to reduce the oversupply of nutrients being fed, and the second is to improve the efficiency with which nutrients are utilized by the animal. In this paper some of the strategies that currently exist for reducing the output of N and P in piggery waste are discussed. Particular emphasis is given to the use of computer modelling techniques to calculate the nutrient requirement of pigs at various stages of growth, and feeding strategies that make greater use of synthetic amino acids and enzymes.

Introduction

Increasing concern about the impact that agriculture is having on the environment has begun to direct attention towards the amount of nutrients produced by piggeries, and the current and potential strategies that might be available for this to be reduced. With an estimated 60% of N and 80% of P that is ingested being subsequently excreted (Lenis and Jongbloed, 1994), there would appear to be ample scope for improvements to be made. Much of the attention has rightly been focused on the growing-finishing pig, since these contribute 60-70% of the total effluent produced from a typical commercial piggery (Lenis and Jongbloed, 1994). While there are other nutrients, such as Cu, Zn and K, which also have the potential to be of concern in piggery effluent, these will not be discussed as part of this paper. However, similar principles and strategies apply to all nutrients.

There are two basic options for reducing the amount of effluent produced by pigs. The first is to reduce any oversupply of nutrients being fed, and the second is to improve the efficiency with which nutrients are utilized by the animal. The cost, and hence impact on profitability, of both options needs to be taken into account, whilst maximising the quality of the end-product. It is also important to account for the economic value of piggery effluent, and this issue is discussed in detail by Rate (1997).

Nitrogen

The pig requires the amino acids in dietary protein mainly for synthesis of body protein. A proportion of dietary protein is indigestible and this is excreted in the faeces, along with some losses from endogenous sources. However, a much higher proportion of the pigs' N excretion appears in the urine, mainly as a result of an oversupply and/or imbalance of amino acids which cannot be used for body protein deposition (Jongbloed and Lenis, 1992). Urinary N is rapidly degraded to ammonia, whereas faecal N is more resistant to degradation. Coppoolse *et al.* (1990) (cited by Jongbloed and Lenis, 1992) have calculated that of the total intake of N, the average slaughter pig excretes about 20% in the faeces and 50% in the urine. Also, protein digested in the hindgut is excreted almost entirely as urinary N (Lenis, 1989).

A major concern about N pollution is the leaching of nitrate into supplies of drinking water, and N pollution also results in emission of ammonia into the air, contributing to bad odour and to acid rain (Lenis, 1989). In this respect, Lenis (1989) considered N pollution to be of greater significance than that of P.

Calculation of N requirements

Dietary allowances for pigs are commonly set according to the requirements of those individuals within a population that have the highest genetic potential, or to the most demanding period within a particular physiological stage (Henry and Dourmad, 1993). The amino acid requirements for one herd are also often extrapolated to other herds, even though there are subtle differences in environment, genotype or management that can influence a pig's requirement for dietary amino acids. In addition, a wide safety margin is often allowed to account for fluctuations in feed quality. The combined effect of these adjustments and assumptions explain why the supply of N to pigs was, and in many cases still is, far in excess of the animal's real needs.

Computer modelling techniques have been used extensively in recent years to calculate the optimum amino acid requirement for animals in commercial piggeries. Simulation models, such as those developed by Whittemore (1983), Black *et al.* (1986) and Moughan *et al.* (1987), can be used to calculate the amino acid requirements of pigs, of different genetic potentials and live weights, under a range of environmental and physiological conditions. Others (Lenis and Jongbloed, 1994; Henry and Dourmad, 1993) have developed models to look specifically at the issue of N production in effluent.

Smits and Mullan (1996) give several examples of how diet specifications for commercial piggeries in Australia have been re-calculated using the AUSPIG computer simulation model (Black *et al.*, 1986). According to this report, it is not uncommon for diets to be over-formulated by 30% or more, and the re-calculation of those requirements has meant a major reduction in feed costs without any adverse effect on animal performance. Many producers have the potential to reduce the N content of effluent from their piggeries, and at the same time possibly increase profitability, by having their diet specifications calculated using this technology.

Feed quality

Protein digestibility is highly variable among feedstuffs, or even within samples of the same feedstuff, which leads to significant variations in faecal N excretion (Gatel, 1993). Some of this variability is related to the protein itself (quality and quantity), and some is dependent upon other components of the diet (e.g., occurrence of anti-nutritional factors, fibre content). The measurement of the quality of feed ingredients has been well reviewed by van Barneveld (1997). Developments in this area of research will help to reduce the uncertainty in preparing animal diets to specification, and will complement the above mentioned approach to calculating a pig's requirement for dietary amino acids. All of the above will help lower the N content of piggery effluent. However, if higher quality ingredients are to be used in pig diets in an attempt to reduce the nutrient content in effluent, then will there be a surplus of lower quality feedstuffs and by-products that will create an environmental problem of their own?

Feeding strategies to reduce the N in effluent

In a comparison of some of the options available for reducing the N content in effluent, Edwards (1996) concluded that the approach of improving the balance and supply of amino acids was a more cost-effective approach than was treating the waste material. A number of strategies have been investigated.

Phase feeding

An animal's requirement for amino acids is continually changing because it is a function of body weight. Therefore, as an animal grows, the concentration of dietary amino acids can be progressively lowered. Traditionally, up to three different diets have been fed to pigs from the time of weaning until they are slaughtered at about 100 kg live weight (LW). There is now considerable interest in using an approach called phase feeding, whereby a greater number of diets (e.g., five) are fed to a pig from weaning until sale. Each diet is progressively lower in its content of amino acids and, therefore, more closely matches the requirements of the animal being fed. Dourmad *et al.* (1992) have calculated that the adoption of a phase-feeding strategy during the grower period should result in a 15-20% reduction in the N content of effluent. These findings are supported by calculations made by Lenis and Jongbloed (1994).

A similar approach has been taken with sow diets. According to Lenis (1989), until recently in The Netherlands pregnant and lactating sows were fed the same type of diet which was formulated for lactation. The requirements of the pregnant sow are much lower than those during lactation, and the adoption of a two-feed system was estimated to reduce N excretion from 21 to 16 kg per sow per year, a reduction of about 25%.

Blend feeding

A further advancement of phase feeding is called blend feeding, in which the diet could be changed on a weekly, or even daily, basis by mixing together, in various ratios, diets of different composition. In this way, a large range of diets (e.g., 12 from weaning until slaughter) can be prepared from a smaller number of base feeds. Using two diets, which were blended on a weekly basis, Mullan *et al.* (1997) found significant reductions in N intake (20%) and urinary excretion of N (25%) when pigs were blend fed in comparison to being fed a single diet during the growing period. There was no effect of reducing N intake on performance. The cost of more complex feed delivery systems, and the need to have a small weight range within the group of pigs being fed, obviously needs to be taken into account.

Use of synthetic amino acids

Another approach to reduce ultimately the excretion of N is to reduce the crude protein content of the diet by adding synthetic amino acids, while maintaining a balanced supply of essential amino acids. The increasing range of synthetic amino acids that are available at a cost-effective price, could make this an attractive proposition for piggeries located in environmentally sensitive areas. Kerr (1987) for example, formulated diets to either 16% crude protein or 12% crude protein, with the lower crude protein diet containing a number of synthetic amino acids. Total N intake was reduced from 25-19 g/d when the lower crude protein diet was fed and, although faecal N was unaltered, there was more than a 50% reduction in the output of urinary N. Similarly, Gatel and Grosjean (1992) decreased dietary crude protein from 17.0-15.5% in the growing period, and from 14.5-13.5% during the finishing period, by adding more synthetic amino acids, and reported a 15-20% reduction in N excretion.

In a laboratory study conducted by Turner *et al.* (1996), the ammonia emission from a simulated manure pit was measured. In this study, reducing the crude protein content of the diet for grower-finisher pigs from 16-12%, whilst maintaining the balance of essential amino acids by the use of synthetic amino acids, reduced the level of ammonia emissions from piggery effluent by 80%. In another study, Latimier and Dourmad (1993) concluded that improving the amino-acid balance, and hence lowering the crude protein content of the diet, was an efficient way to decrease both N output in the slurry (by 23%) and gaseous N emission from the building (by 25%). Therefore, the potential to reduce N excretion by increasing the biological value of pig diets has been well proven, but the adoption of this approach will depend on how it can be applied in commercial practice and the impact it has on profitability.

Computer modelling to reduce N excretion

It is difficult to measure the N excretion from a commercial piggery, and in this respect simulation models can be used to predict the effect on performance, profitability and N excretion before or following a change in feeding strategy. Black (personal communication) has used AUSPIG (Black *et al.*, 1986) to calculate the amino acid requirements of pigs between 50-100 kg LW. Compared to the existing commercial diet (Control), feeding a diet (AUSPIG) that was formulated to supply 103% of the requirement for amino acids of the pig at 55 kg LW reduced feed costs by $8 per tonne, reduced total N excretion by 17%, and increased profit by $0.60 per pig (Table 1). When another four diets were formulated (Phase-1) to reflect a phase-feeding system, diet costs were progressively reduced and profit per pig increased by $2.00 as compared to the existing commercial diet. It was possible to reduce the dietary crude protein content of the diets further by the addition of synthetic amino acids (Phase-2) without any effect on animal performance. However, the further reduction in the N content of the effluent would need to be balanced against the extra cost of these particular diets.

Table 1. Predicted profitability and N excretion of male pigs grown from 50-100 kg LW when offered a range of diets differing in crude protein content.

	Control	AUSPIG	Phase-1	Phase-2
Dietary protein %				
diet 1	21.8	18.6	18.5	15.3
diet 2			18.2	15.0
diet 3			17.8	14.5
diet 4			17.2	13.5
diet 5			16.6	11.8
Feed cost ($/pig)	35.23	35.62	34.40	37.91
Change in profit ($/pig)	0	+$0.60	+$2.02	-$2.70
Total N intake (g/d)	73.7	64.1	60.4	45.2
Total N excretion (g/d)	51.4	41.7	38.1	22.8
N excretion as % of Control	100	83	75	44

Phosphorus

Phosphorus is an essential element in animal diets, being vital for the development and maintenance of skeletal tissue, and has an important role in many biochemical and metabolic functions. The amounts of P available to the pig from feedstuffs of plant origin are insufficient to satisfy the pigs' requirement for P for adequate growth and skeletal development, so it is necessary to add inorganic P to most pig diets. This is because 60-90% of the total P in plant feedstuffs is in the form of phytic acid or phytate-P.

Phytic acid (phytate) is an anti-nutritional factor present in all feedstuffs of plant origin as a variety of poorly-soluble, predominately Ca and Mg salts. Phytates are poorly digested because pigs lack the phosphatase enzyme required to cleave the phosphate groups from the phytin molecule (Cromwell *et al.*, 1993). Phytate is the name given to the phosphoric acid ester of the cyclic alcohol inositol (myo-inositol hexakisphosphate). The structure and chemistry of phytic acid is described comprehensively in a review by Reddy *et al.* (1982). In plant seeds, phytic acid is a reservoir for P, as P constitutes 28% of the molecular weight of phytic acid. Phytic acid carries up to 12 negative charges and has a tremendous chelating potential to combine with positively-charged nutrients, including Ca and trace minerals. Phytate-mineral complexes such as these are unavailable for absorption. Similarly, phytic acid can combine with amino acids such as lysine and arginine to form protein-phytate complexes which reduces the digestibility of bound protein, together with possible binding to endogenous digestive enzymes (e.g., Honig and Wolf, 1991; Caldwell, 1992).

The concentration of P in plant material in the form of phytic acid varies considerably, ranging from 0.5-1.9% in cereals (except polished rice), 0.4-2.1% in legumes, 2.0-5.2% in oilseeds (except soya bean meal), and 0.4-7.5% in protein products (e.g., wheat gluten, soya protein concentrate) (Reddy *et al.*, 1982). Although feedstuffs of vegetable origin contain adequate amounts of P, only 20-50% is digestible by pigs. To counteract the low availability of phytate-P, animal by-products (e.g., meat and bone meal) and mineral (inorganic) P compounds (e.g., dicalcium phosphate), both of which have a high concentration of P and a high availability (70-90%), are commonly added to pig diets (Jongbloed and Kemme, 1990). However, the continued supplementation of pig diets with inorganic P, together with indigestible phytate, ultimately means that there is an increase in the amount of P excreted and hence present in piggery effluent.

Calculation of P requirements

The most logical way to reduce the amount of P excreted by the pig is to supply P in better agreement with the pig's requirement. As a result of anti-pollution legislation and codes of recommended practice in various parts of Europe, feed manufacturers and pig producers have considered the mineral content of pig diets. In The Netherlands, for example, pig diets have had their P content reduced to about one-half of the previously recommended levels. In order to comply with output quotas for P, diets containing as little as 3 g/kg digestible P for growing pigs, and 2 g/kg for finishing pigs, have been proposed. In contrast, the conventional requirement in the UK is about 8 g P/kg diet dry matter, with an assumed digestibility of 80% for inorganic and 50% for organic P (Whittemore and Manson, 1995).

While reductions in dietary mineral supply are clearly beneficial from a pollution perspective, research needs to be conducted to ensure that any recommended reductions in requirements do not compromise the health, well-being and performance of the pig. This requires a better knowledge of the supply of P in the feedstuffs used routinely in pig production, especially in regard to the digestibility and availability of P to the pig rather than just using the level of "total" P in a diet. Furthermore, a better knowledge of the animal's requirement at its different stages of growth needs to be known, and the factorial method of calculating the requirements for P has been used to do this (see Jongbloed *et al.*, 1991). Similarly, split-sex feeding (i.e., where female and male pigs receive different diets to account for genetic differences in nutrient requirements) is a strategy which can also be used effectively to reduce P excretion.

Feeding strategies to reduce the P in effluent

As with N, there needs to be better agreement between supply and requirement of P to the pig, and one strategy to ensure this is phase feeding. Phase feeding is a strategy used by a number of pig producers at present, and should be encouraged as a cost-effective means of reducing P excretion from pig herds. In the simplest instance, the use of a grower diet from 45-70 kg LW and a finisher diet from 70-106 kg LW instead of a single diet over the same weight range reduced P excretion by 6% (Coppoolse *et al.*, 1990; cited by Jongbloed and Lenis, 1992). Although Mullan *et al.* (1997) did not measure P intake and excretion in their blend-feeding experiments, it can be assumed that P intake was also reduced with a concomitant reduction in P excretion. In a similar vein, a slightly bigger reduction in P excretion by growing pigs has been reported by mixing a feed rich in minerals and vitamins with a feed having a low concentration of protein and minerals in a changing ratio (multi-phase feeding). This results in the supply of P being brought closer to the pig's actual requirements (Jongbloed and Lenis, 1992).

Use of liquid feeding systems to increase P availability

The use of liquid-feeding systems in conjunction with added phytase offers a means of improving P digestibility due to an increase in contact time between the enzyme and the substrate. Most naturally occurring phytases have a pH optimum between 5.0 and 5.6 (Reddy *et al.*, 1982), and Séguier *et al.* (cited by Brooks *et al.*, 1996) found that maintaining a mixture of feed, water and exogenous phytase at pH 5.4 improved phytate hydrolysis. More recently, Geary (unpublished, cited by Brooks *et al.*, 1996) soaked wheat and soya bean meal in water alone, or water plus phytase, at a temperature of 50°C, and followed the release of inorganic P at 24 h and 48 h after steeping commenced. Geary (unpublished, cited by Brooks *et al.*, 1996) reported significant increases in the concentration of soluble P from raw materials such as soya bean meal which possess little or no endogenous phytase. Even in materials such as wheat, which possess relatively high levels of endogenous phytase, there is considerable release of inorganic P when the grain is soaked in water (Figure 1).

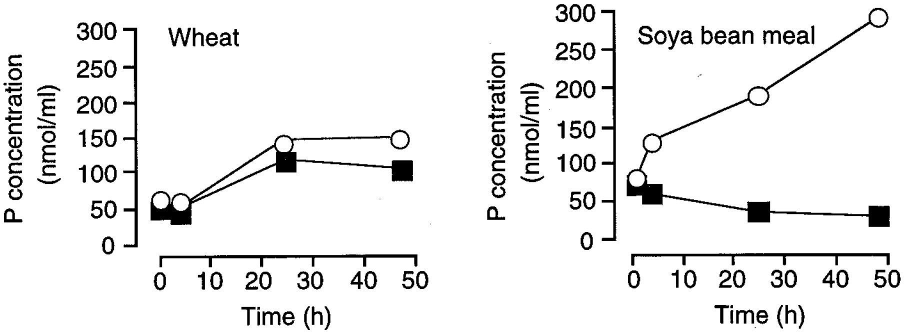

Figure 1. *The effect of steeping wheat and soya bean meal in water (■) or water plus phytase (○) on the concentration of soluble phosphorus in the liquid medium kept at 50°C (Geary unpublished; cited by Brooks et al., 1996).*

These data demonstrate that in a liquid medium where microbial fermentation is present, the heat produced by fermentation is capable of stimulating the catalytic reactions of enzymes. This may reduce the costs associated with having to heat the liquid feed to the optimum temperature for enzyme activity. A system such as this may be even more advantageous if the diet could be maintained in the liquid medium in contact with phytase over a considerable length of time, say 12-24 h before feeding.

Improving the utilisation of nutrients by pigs

Besides ensuring that the supply of nutrients to the animal closely matches their requirement, the other approach can be to improve the efficiency with which the pig can utilise those nutrients. Much attention has been given to the use of feed enzymes, but alternatively others have promoted the idea that improving the potential of the animal to deposit body protein would have beneficial effects on reducing the N content of effluent.

Enzymes

Digestive enzymes hydrolyse components of feedstuffs, however, in many circumstances the pig's natural enzyme levels are too low or the requisite enzymes are missing (Easter *et al.*, 1993). This, therefore, makes it possible that the use of exogenous dietary enzymes could improve digestibility, particularly of N-rich proteins. To date the use of feed enzymes has not given consistently positive results, but further developments are likely to give improvements in N digestibility. Most research and development has concentrated on using enzymes to increase P digestibility.

The use of phytase

Undoubtedly, the major advance in recent years to increase P digestibility and reduce P excretion is the use of microbially-derived phytase. A large number of studies conducted in a variety of countries have shown that the addition of microbial phytase to diets causes an increase in the digestibility of P and a decrease in P excretion. For example, in an experiment conducted in Australia involving 640 weaner pigs, Campbell *et al.* (1995) investigated the interrelationship between the concentration of available P (0.15, 0.25, 0.35 and 0.45%) and phytase supplementation (0 or 100 g/tonne) on pig performance from 19 d (when pigs weighed 11.1 kg) to 40 d after weaning (Table 2). The diets contained wheat, lupin kernels, rice pollard, canola meal and soya bean meal, and had an estimated phytate-P content of 0.35% or 1.25% phytic acid. Pigs offered the diets supplemented with phytase showed superior performance to pigs offered the corresponding diets without phytase. Pigs offered diets with phytase also had equal or better performance when offered the diets containing 0.25% available P than their counterparts offered the unsupplemented diets containing higher levels of available P. These data suggest that phytase improves pig performance independent of its effect on the availability of P in the diet, which may in part be explained by improvements in the availability of other minerals such as Zn and Mg (Adeola, 1995; Adeola *et al.*, 1995).

Table 2. Effects of dietary available P and phytase supplementation on the performance of pigs from 19-40 d after weaning (from Campbell *et al.*, 1995).

Phytase (g/tonne)	Available P (%)	Daily gain (g)	Feed intake (g/day)	Feed:gain (g feed:g gain)
0	0.15	403	640	1.58
	0.25	481	720	1.48
	0.35	530	800	1.51
	0.45	540	820	1.55
100	0.15	472	740	1.56
	0.25	540	770	1.42
	0.35	629	850	1.40
	0.45	595	820	1.38
Significance (*P*):				
Phytase		0.004	0.175	0.093
Available P		0.001	0.133	0.307
Phytase x Av. P		0.939	0.790	0.739

In another experiment conducted in Western Australia to measure apparent P retention, Mullan *et al.* (1994) fed female pigs (45 kg LW) either a standard grower diet containing 0.40% total P (Control) or a diet formulated to contain the same energy and amino acids level but only 0.32% total P (Low-P). A third group (Low-P + Phytase) received the low-P diet plus the phytase enzyme Natuphos® added at 200 g/tonne (3850 U/g). Pigs were fed at 3 x maintenance and digestibility of phosphorus was determined over a 7-day collection period following 12 d of acclimatization. The digestibility of P was increased when pigs were fed the low-P diets and this was further enhanced by the use of phytase (Table 3). Similar improvements in the digestibility of P using low-P diets were reported in an earlier study conducted in Western Australia by Godfrey *et al.* (1993), although these authors reported higher rates of P retention. It appears that differences between the two studies may be accounted for by differences in the Ca:P ratio used, as there is some suggestion that the Ca:P ratio is important in determining the response to added phytase (Qian *et al.*, 1996). Based on the data of Mullan *et al.* (1994), the addition of phytase to a diet containing a low concentration of P would cause a reduction in total P excretion of 56% from the grower/finisher herd. For the piggery where this study was conducted (approximately 41,000 pigs sold/year), this represented a reduction in P excretion from 21.8 t/year to 14.0 t/year.

Table 3. Effects of feeding diets differing in P concentration and addition of phytase on P digestibility (from Mullan *et al.*, 1994).

	Treatment			
Item	Control	Low-P	Low-P + Phytase	SED
No. of pigs	6	7	6	
P intake (g/d)	7.9^{a}	6.3^{b}	6.7^{b}	0.48
P output (g/d)	5.0^{x}	3.2^{y}	3.1^{y}	0.33
P retention (g/d)	2.9	3.2	3.6	0.40
P digestibility (%)	38.1^{a}	48.1^{b}	53.3^{c}	3.81

Values in the same row with different superscripts differ significantly ($^{a,b,c}P<0.01$; $^{x,y}P<0.001$).

Improved animal efficiency

A number of technologies (e.g. β-agonists, porcine somatotrophin (pST)) are available that will increase the potential of the animal to deposit body protein. Some researchers have suggested this as an approach to reduce the nutrient load in piggery effluent. For example, Quiniou *et al.* (1993) reported that when pigs between 51-101 kg LW were treated with pST, there was a significant improvement in growth rate, muscle growth and N retention without apparently increasing the daily protein requirements. As a consequence, N output in urine was reduced by 25% while faecal N remained unchanged. Other research would indicate that the daily protein requirements are increased when pigs receive pST (Dunshea and Walton, 1995), and it would seem likely that there would be a concomitant decrease in N excretion. Anything that reduces the difference between supply and demand for dietary amino acids, has the potential to reduce N output.

Apart from their efficacy as a growth promotant, β-adrenergic agonists may contribute to an important reduction in N excretion in piggery effluent. In reviewing the results of several experiments, Easter *et al.* (1993) reported that their use with pigs from 60-100 kg LW resulted in a 19% increase in N deposition and a 9% increase in N retention. This was estimated to be equivalent to a reduction in annual waste N production of about 760 kg for a commercial unit producing 5,000 pigs (100 kg LW) per year. The same author has made calculations on the potential benefits to reducing N excretion by the use of probiotics or antibiotics. For example, as a result of improvements in feed conversion efficiency, it may be possible to reduce protein consumption without influencing performance. Similarly, it has been suggested that an effect of dietary antibiotics is to increase the digestibility of N and amino acids in the small intestine, but it is unlikely for this to be accepted as an environmentally friendly approach to reduce N output.

There are no accurate figures available on the extent of feed wastage in commercial piggeries, although estimates range between 5-30%. This could therefore be a major contributor to total effluent production, and one that in many instances could be improved through better management. Increasing the number of pigs reared per sow per year will also help lower effluent production from a piggery, although the magnitude of change is likely to be small. Finally, anything that will help a pig grow more efficiently, such as improvements in the animal's environment and/or its health status, will reduce N output to some extent.

Conclusion

A high proportion of nutrients that are fed to pigs end up in effluent. The development of computer models has played a major role in improving our understanding of the animal's requirement for nutrients, especially N. As a consequence, the N content in the diet, and subsequently in effluent, is being reduced without any change in animal performance. With P, the use of the phytase enzyme to improve the availability of P in ingredients has meant that the P content of diets can be reduced, again without a decrease in growth rate. Improving efficiency, especially by reducing feed wastage, will also help reduce effluent production. Such strategies will become commonplace as the pressure to reduce effluent production from piggeries increases.

Symposium continued on next page