

**APPENDIX NO. 3**

**ODOUR ASSESSMENT**

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# **Odour Assessment**

**For**

**Integrated Pig Farm Unit**

**At**

**Annistown**

**Killeagh**

**Co. Cork**

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## Introduction

The object of this odour assessment is to identify the potential sources of odour on a pig production unit and to identify the measures that can be taken in order to minimise odours. It has been drawn up for the proposed development of a modernised integrated unit on the site of an existing pig production unit at Annistown, Killeagh, Co. Cork under the management of Mr. Eoin O'Brien. The development will take place in an entirely agricultural hinterland where typical farm odours are to be found and expected.

## Key odour issues

The main odour associated with livestock housing tends to be related to ammonia. It arises primarily from surface areas and the presence of manure and the biological changes that occur as it decomposes and also from the body odour of the livestock. Storage of manure in the open air is a particular source of odour. With respect to the proposed development, the following odour management factors have been identified:

- Building design
- Site location
- Odour in dust emissions
- Animal diet
- Unit management.

These factors are assessed below. The assessment has been facilitated by reference to odour specific guidance prepared by the EPA as listed in the reference list below.

## Building design

The proposed new buildings are of low emission design free of draughts and leaks; they will contain modern computerised ventilation control systems based on Best Available Technique guidelines for the pig industry. The existing old buildings and open air manure storage lagoon will be replaced and upgraded by modern low emission design buildings containing covered manure storage tanks.

Ventilation systems will be run at optimum levels and will be fitted with computer monitors and alarmed back up systems. The ventilation system will prevent room temperatures from rising excessively which would cause an increase in manure decay rates and result in increased odour emissions. The ventilation system will contain multiple roof apex vents that will dispel air high into the atmosphere where it will mix with fresher air and thus minimise odour.

The flooring to be used will be impervious and easily cleaned and disinfected. The floor gradients have been designed in order to avoid settling of wastes within channels. The manure from under floor storage tanks will be regularly removed and will be used by customer farmers for land spreading as an organic fertiliser. Pig manure will be transported in suitably contained leak proof vehicles.

### Site location

The proposed new buildings will be constructed on an existing pig production site located in an agricultural area. It will be surrounded by a high earthen berm at the south, east and west, the earthen berm will be landscaped with trees and shrubs. The berm will be located at the site boundary of the proposed structures and will provide a degree of odour control as they will disturb air flow and thus enhance air mixing and dilution effects over the site. There are no dwellings located to the north of the site or downwind of the site under prevailing wind directions.

### Odour in dust emissions

Dust is an important factor in the release of odour into the atmosphere and may arise from bedding materials or from feed. Dust from bedding materials will not arise from the proposed buildings as bedding materials will not be used, and the animals will instead be kept on slatted floors. Dust from feed will be avoided as a system of wet feeding will be used and all feed will be delivered via pipeline and contained and mixed in sealed containers and then piped around to the feeding stations. As the unit will be run as a high health unit the animals and their pens will be kept clean.

### Animal diet

High protein pig diets can contribute to emissions of ammonia and other odorous compounds. The formulation of diets for pigs at the existing site is carried out by specialist animal nutritionists Devinish Nutrition Ltd with reference to Best Available Technique guidelines. Low protein diets are used on the unit as a result of this odour emissions are minimised (see letter from Devinish Nutrition). This practice will continue and improve into the future in line with improved scientific advancements in the animal feed sector and improved feed utilisation efficiency in the animals themselves due to continued selective breeding for this trait. Improved feed efficiency will result in less waste production per animal.

## Unit management

The existing unit is run as a high hygiene minimal disease unit because of this strict hygiene and cleanliness will be observed around the unit. The proposed new structures will also be managed in this way. This will involve keeping animals and surface areas such as pen floors and walls clean as part of daily routine operational practice in order to minimise disease. Buildings will be power washed and disinfected once vacated before a new batch of animals are moved in. The dirty water from washing will immediately flow into manure storage tanks via channels and slats and will not be allowed to stagnate within buildings as this can cause disease as well as odours. The maintenance of clean facilities will contribute to reduced odour emissions.

Containers used to store animal tissue are leak proof and are covered by sealed lids in order to prevent the release of odours. The containers are regularly removed for delivery to a rendering plant by a licensed contractor. The unit is being operated in this manner as a condition of its present Integrated Pollution Prevention and Control license and this system will continue in the proposed new buildings.

## Conclusions & mitigation

While it would be practically impossible to separate the potential emissions from the proposed development from the emissions out of the existing development on the site, it is safe to say that there are no odour problems with the existing development as there have not been any complaints regarding odour from the site. As outlined above all known Best Available Technique mitigation measures to combat odour emissions will be employed in the proposed development, odorous emissions from the enlarged modernised site as a whole are not likely to cause nuisance or impair amenity beyond the site boundary. Mitigation measures have been identified and incorporated into the design of the proposed buildings. In addition, measures identified with respect to ongoing unit management and animal feeding will be incorporated into the site environmental management plan.

## References

Odour Impacts and Odour Emission Control Measures for Intensive Agriculture – EPA Publication 2001.

Odour Impact Assessment Guidance for EPA Licensed Sites (AG5)EPA 2010

Integrated Pollution Control Licencing. Batneec Guidance Note For The Pig Production Sector. Environmental Protection Agency 1998.

Integrated Pollution Prevention and Control (IPPC). Reference document on Best Available Techniques for Intensive Rearing of Poultry and Pigs. European Commission July 2003.



Mr Tony Dunlea  
Murphy McCarthy Engineering Ltd  
EastPark House  
Marina Commercial Park  
Centre Park Road  
Cork

2<sup>nd</sup> August 2013

Dear Tony

With reference to on-going discussions I can confirm that Devenish Nutrition Ltd have been engaged by Mr Eoin O'Brien with regard to his proposed extension to his piggery at Mogeely, East Cork.

We have been engaged by Mr Eoin O'Brien to provide complete nutritional services designed to minimise odour and fertiliser emissions from the site as per our DeviCare programme, developed in conjunction with Dr John O'Doherty of University College Dublin, which is proven to reduce emissions from pig production, through targeted precision nutrition.

I attach below summary results contained in the attached scientific paper re DeviCare,

1. Completed and published research work by Aidan Leek et al, (Biosource Technology, 2003), which confirms reductions in dietary protein levels result in reductions in odorous emissions

Table 1; Emission Rates per Animal on Varying Protein Diet

	Dietary Crude Protein Levels			
	13%	16%	19%	22%
Odour Emissions (OuEs/animal)	12.1	13.2	19.6	17.6
Odour Emissions (OuEs/livestock unit)	77.6	80.0	115.8	102.9
Ammonia Emissions (OuEs/Animal)	3.11	3.89	5.89	8.27

As has been discussed, we are currently working on DeviCare Phase III, which further significantly reduces protein usage and emissions, and are very encouraged by initial results.

We are ready to implement our programme at any time, as discussed.

Yours Sincerely

Aidan O'Toole  
Pig Sector Director  
Devenish Nutrition Ltd

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## The influence of diet crude protein level on odour and ammonia emissions from finishing pig houses

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### Abstract

Feed trials were carried out to assess the influence of crude protein content in finishing pig diets on odour and ammonia emissions. Eight pigs (4 boars and 4 gilts), average initial weight 70.8 kg (s.e. 3.167) were housed in two pens that were isolated from the rest of a pig house at University College Dublin Research Farm, Newcastle, Dublin, Ireland. Four diets containing 130, 160, 190 and 220 g kg<sup>-1</sup> crude protein were fed during six four-week feeding periods (one treatment per room). The first week of the feeding periods served to allow odour build up in the pens and as a dietary adjustment period. The pens had partially slatted floors that were cleaned and had all the manure removed after each four-week period. Odour and ammonia concentrations were measured on days 9, 14, 16, 21 and 23 of each trial period. Odour samples were collected in Nalophan bags and analysed for odour concentration using an ECOMA Yes/No olfactometer. The odour threshold concentration was calculated according to the response of the olfactometry panel members and was displayed in O<sub>u</sub> m<sup>-3</sup>, which referred to the physiological response from the panel equivalent to that elicited by 40 ppb v<sup>-1</sup> *n*-butanol evaporated in 1 m<sup>3</sup> of neutral gas. Ammonia concentrations in the ventilation air were measured using Dräger tubes. The odour emission rates per animal for the 130, 160, 190 and 220 g kg<sup>-1</sup> crude protein diets were 12.1, 13.2, 19.6 and 17.6 O<sub>u</sub> s<sup>-1</sup> animal<sup>-1</sup>, respectively ( $P < 0.01$ ). The odour emission rate per livestock unit (500 kg) for the 130, 160, 190 and 220 g kg<sup>-1</sup> crude protein diets were 77.6, 80.0, 115.8 and 102.9 O<sub>u</sub> s<sup>-1</sup> LU<sup>-1</sup>, respectively ( $P < 0.01$ ). The ammonia emission rates per animal for the 130, 160, 190 and 220 g kg<sup>-1</sup> crude protein diets were 3.11, 3.89, 5.89 and 8.27 g d<sup>-1</sup> animal<sup>-1</sup>, respectively ( $P \leq 0.001$ ). There was no significant difference in the average daily intake and the average daily gain for the four diets ( $P > 0.05$ ). Manipulation of dietary crude protein levels would appear to offer a low cost alternative, in relation to end-of-pipe treatments, for the abatement of odour and ammonia emissions from finishing pig houses.

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**Keywords:** Pig; Diet; Crude protein; Odour; Ammonia; Olfactometry; Abatement

### 1. Introduction

Pig production has changed in Ireland from a small scale enterprise carried out by a large number of farmers as an addition to the main farming enterprises, to a small number of specialist producers operating large scale units using high quality breeding stock and up to date techniques (Lara et al., 2002). Similar to other intensive farm operations, pig production generates substantial quantities of manure (faeces and urine) and mortalities, which lend themselves to a mixture of va-

pours, gases and dust combinations; odour and ammonia emissions are of particular environmental concern.

Odour emissions from pig production units can cause nuisance in the surrounding areas. Several guidelines and recommendations exist for protecting a neighbourhood from odour nuisance and are concerned on the one hand with the determination of set-back distances and, on the other hand, with the implementation of odour reducing techniques (Gallmann et al., 2001). The main sources of odour include building ventilation, manure storage and land spreading. Often these odorous mixtures are a consequence of animal manure decomposing anaerobically to form unstable intermediate by-products resulting in a complex mixture of over 168 volatile

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compounds of which 30 are odorous (O'Neill and Phillips, 1992). These compounds created from natural biological reactions include organic acids, aldehydes, alcohols, fixed gases, carbonyls, esters, amines, sulphides, mercaptans, aromatics and nitrogen heterocycles.

The monitoring and reduction of ammonia emissions from livestock farming is a critical requirement of the European Commission Acidification Strategy and the EU Directive 2001/81/CE on National Emission Ceilings (Commission of the European Communities, 1997) which have called for a limitation of ammonia emissions from all EU countries. There are a number of on-farm sources of ammonia: animal housing, manure storage, field-applied manure and excreta deposited on the land by animals. Ammonia loss from the animal building is stimulated by the area of flooring covered by excreta, the chemical composition of the excreta, the temperature in the house and the ventilation rate of the house (Hutchings and Sommer, 2001). Of the total nitrogen ingested into the finishing animal approximately 50% is returned in the urine and 20% in the faeces (Jongbloed and Lenis, 1992). Ammonia is the product of the degradation of nitrogenous compounds. Bacteria in the faeces produce a urease enzyme, which converts the urea in the urine into ammonia. Atmospheric ammonia contributes to the acidification and eutrophication of soil and surface waters (Sutton et al., 1993; van der Eerden et al., 1998). Ammonia emissions in Europe originate mainly from agriculture, in particular from livestock farming. It is estimated that agricultural enterprises contribute 80–95% of ammonia emissions across Europe. Approximately 50% of ammonia emissions from pig production arises from pig buildings and the storage of manure (van der Peet-Schwering et al., 1999).

Manipulating the diet of finishing pigs by reducing the crude protein can reduce the total nitrogen excretion, reduce the ammonia emissions and alter the components of volatile fatty acids and other odorous compounds while not influencing the animal growth (Sutton et al., 1996). Phillips et al. (1999) identified dietary manipulation as the "best bet" for reducing ammonia emissions based on a ranking and weighting exercise. The aim of the present research was to study the influence of a range of crude protein levels on the generation of both odour and ammonia emissions from finishing pigs on partially slatted floors under controlled environmental conditions.

## 2. Methods

### 2.1. Animals

The finisher pigs used in this study were selected from a commercial herd, progeny of a Landrace X Large White Sow and a meat line sire. In total, 24 pigs, 12

boars and 12 gilts, were assigned one of four dietary treatments. Each dietary treatment was replicated 3 times with 8 pigs, 4 boars and 4 gilts, per treatment. Pigs were individually weighed at the start of the experimental period and each treatment was balanced for initial liveweight. Pigs were weighed after collection of the last odour and ammonia measurements and the average daily gain (ADG,  $\text{g d}^{-1}$ ) over the experimental period was calculated.

Two experimental pens were used at any one time and the diets were analysed in pairs. To minimise any seasonal effect, each dietary replicate was paired with a different diet.

### 2.2. Animal facilities

Two partially slatted floor pens in the pig finishing house on the University College Dublin Research Farm were individually sealed off from the rest of the building. Each pen was fitted with a variable speed centrifugal fan and thermostatically controlled electrical radiant heater. The pens had separate air inlets and outlets and could be heated and ventilated independently. The ventilation rate was calculated by measuring the airflow from the pens using a Testo 400™ handheld monitoring device fitted with a vane anemometer. The ventilation rate in both pens was kept constant during the trials at approximately  $48.3 \text{ m}^3 \text{ h}^{-1} \text{ animal}^{-1}$  (s.e. 1.3). The internal temperature in the house was kept constant at approximately  $21.0 \text{ }^\circ\text{C}$  (s.e. 0.32).

### 2.3. Feed and feeding

Pigs were provided with ad libitum access to un-pelleted meal through a single space hopper located on the solid floor of each pen. Feed intake was noted as the hopper was filled. Remaining feed at the end of the trial was recorded and the average daily feed intake (ADFI,  $\text{g d}^{-1}$ ) was calculated. Feed conversion ratio (FCR) was determined for each group. Water nipples were located over the slatted part of the pen.

Four diets (Table 1) were formulated using standard feeding values for the ingredients (O'Grady, 1996) to give diet crude protein contents of 220, 190, 160 and 130  $\text{g kg}^{-1}$  fresh weight. Formulated levels of digestible energy (DE;  $13.5 \text{ MJ kg}^{-1}$ ) and 'ideal protein' (lysine 11  $\text{g kg}^{-1}$ ) were maintained across all the diets.

The diets were fed during six four-week feeding periods. Week 1 allowed the pigs to acclimatise to the experimental diets and excreta levels to build up under the slatted area.

The pens were cleaned after each four-week period and all manure was removed from the underground storage tanks. The diets were mixed on site as required and each batch was sampled. Proximate analysis of diets for dry matter, ash and crude fibre was carried out ac-

Table 1  
Composition and analysed chemical composition of experimental diets

Diets				
Crude protein (g kg <sup>-1</sup> )	220	190	160	130
<i>Ingredient inclusion (kg ton<sup>-1</sup>)</i>				
Wheat	637.5	722.5	810.0	887.7
Soya bean meal	309.2	224.2	136.7	60.0
Soya oil				13.3
DeviCare <sup>®</sup> Supplement <sup>a</sup>	25.0	25.0	25.0	25.0
Amino acid pack <sup>b</sup>	15.0	15.0	15.0	15.0
<i>Analysed composition (g kg<sup>-1</sup>)</i>				
Dry matter	873.2	875.1	873.0	877.1
Crude protein	209.0	184.6	157.4	131.7
Crude oil (ether extract)	29.4	26.9	27.3	33.0
Crude fibre	38.4	39.1	36.4	29.3
Ash	53.2	48.9	46.4	38.2
Gross energy (MJ kg <sup>-1</sup> )	15.98	15.82	15.52	15.81
Relative cost index <sup>c</sup>	1.00	1.05	1.15	1.30

<sup>a</sup> The supplement (DeviCare, Devenish Nutrition, Belfast, N. Ireland) provided minerals and vitamins (per kg diet) as follows 14,000 i.u. Vitamin A (4.2 mg retinol), 2800 i.u. Vitamin D (0.07 mg cholecalciferol), 80 i.u. Vitamin E (80 mg DL-alpha tocopherol), 120 mg copper as copper sulphate and 0.4 g selenium as sodium selenite.

<sup>b</sup> The amino acid pack contained supplementary synthetic lysine to maintain a dietary lysine content of 11 g kg<sup>-1</sup>, and synthetic methionine, threonine and tryptophan on calcium carbonate carrier maintaining minimum dietary levels of 60%, 65% and 20% methionine + cysteine, threonine and tryptophan, respectively, and relative to lysine in the finished diet.

<sup>c</sup> The relative cost of each diet was estimated according to raw material prices at time of publishing and is largely influenced by the additional cost of synthetic amino acid use in low protein diets. The costs of both soybean meal and synthetic amino acids are influenced by market conditions, which will impact the accuracy of this index.

according to the Association of Official Analytical Chemists (1984). Ether extract was determined according to the Soxhlet method, using a Soxtec System (Model 1043, Tecator, Sweden). Gross energy was determined in an adiabatic bomb calorimeter (Parr Instruments, Moline, IL, USA). The nitrogen content (crude protein × 6.25) of the diets was determined using a Leco Autoanalyser (Leco Corporation, St. Joseph, MI, USA).

## 2.4. Olfactometry

### 2.4.1. Collection of odour samples

Air samples were collected in 8 l Nalophan bags using a battery-powered vacuum pump and a rigid container. The samples were collected using the lung principle whereby the air was removed from the rigid container using a battery-powered vacuum pump at a rate of 2 l/min. A critical orifice controlled the air evacuation rate from the sampling container. This created a vacuum in the rigid container and caused the Nalophan bag to fill through stainless steel tubing with odorous air extracted from the exhaust vents. The air samples were sealed and stored in appropriate conditions. All the samples were analysed within 24 h. The odour measurements were carried out according to the European Standard prEN13725 (CEN, 2001) in the olfactometry laboratory in the Department of Agricultural and Food Engineering, University College Dublin. The odour and ammonia concentrations were measured on days 9, 14, 16, 21

and 23 of each four-week feeding regime. Ventilation rate and internal temperature measurements were carried out on the same days.

### 2.4.2. Measurement of odour threshold concentration

An ECOMA TO7 dynamic olfactometer (ECOMA, Honigsee, Germany) was used throughout the experimental period to measure the odour threshold concentration of the ventilated air from the fattening pens. The odour threshold concentration is defined as the dilution factor at which 50% of the panellist can just detect an odour. The panellists were previously selected by screening using the certified reference gas *n*-butanol (CAS 71-36-3) and only panellists that adhered to the code of behaviour for olfactometry were selected for odour measurements. The odour threshold concentration was calculated according to the response of the panel members and was displayed in O<sub>u</sub> m<sup>-3</sup>, which referred to the physiological response from the panel equivalent to that elicited by 40 ppb v<sup>-1</sup> *n*-butanol evaporated in 1 m<sup>3</sup> of neutral gas (CEN, 2001). Odour units were considered a dimensionless unit, but pseudo-dimensions of O<sub>u</sub> m<sup>-3</sup> have been commonly used for odour dispersion modelling in place of g m<sup>-3</sup> (McGinley et al., 2000).

### 2.5. Measurement of ammonia concentration

Ammonia measurements were taken using Dräger tubes. The Dräger tubes have a measurement range of

0–30 ppm. The tubes were stored in the original packaging at room temperature in a shaded area until use. A hand operated bellows pump draws 100 ml of air through the tube with one stroke, during which the air contained in the pump chamber escapes through the exhaust valve. If ammonia is present, the reagent reacts resulting in a colour change of yellow to blue. The Dräger tubes provide a simple and easy way of measuring ammonia. They are designed for on-the-spot measurement and are expected to show a coefficient of variation of 10–15% (Dräger, 1998).

### 2.6. Statistical analysis

Data were analysed using the PROC MIXED function in SAS 6.14 for Windows (SAS 1996, SAS Institute Inc., Cary, NC, USA). Dietary influence on odour and ammonia was evaluated using a model that included diet as the fixed effect. The main influences of variation between sampling were removed by including internal room temperature and ventilation rate as random variables. Data were checked for outliers prior to analysis by the RSTUDENT option of SAS PROC GLM. No data points were identified as outliers and all observations were included for analysis ( $n = 60$ ). Data is presented as the least-squared means of the three replicates with the standard error of the mean (s.e.).

## 3. Results and discussion

### 3.1. Dietary analysis and pig performance

Results of the dietary analysis are presented in Table 1. The analysed crude protein content of the diets was 209.0, 184.6, 157.4 and 131.7 g kg<sup>-1</sup>. The initial live weight of the pigs was 70.8 kg (s.d. 3.16 kg). The ADG was similar ( $P > 0.05$ ) between the dietary treatments (721.5, 859.6, 800.7 and 768.8 g d<sup>-1</sup>, s.e. 0.09 in diets 130, 160, 190 and 220 g kg<sup>-1</sup> crude protein, respectively). The ADI was similar ( $P > 0.05$ ) between the dietary treatments (1.90, 2.15, 2.11 and 2.06 g d<sup>-1</sup>, s.e. 0.204 in diets 130, 160, 190 and 220 g kg<sup>-1</sup> crude protein, respectively). Consequentially, FCR was similar ( $P > 0.05$ ) between the diets (2.71, 2.49, 2.65 and 2.70, s.e.

0.147 in diets 130, 160, 190 and 220 g kg<sup>-1</sup> crude protein, respectively).

### 3.2. Odour

The odour emission rates are reported per animal and per livestock unit (LU). One livestock unit is equivalent to 500 kg body weight. Table 2 shows that the odour emission rates were highest for the 190 g kg<sup>-1</sup> crude protein diet. The odour emission rates (Ou<sub>E</sub> s<sup>-1</sup> LU<sup>-1</sup>) were significantly reduced by 33% and 31% for the 160 and 130 g kg<sup>-1</sup> crude protein diets, respectively, in comparison to the 190 g kg<sup>-1</sup> crude protein diet. Odour emission rate levels were similar ( $P > 0.05$ ) between the 190 and 220 g kg<sup>-1</sup> crude protein diets.

Peirson and Nicholson (1995) reported a reduction in odour emissions per kg liveweight from 0.540 to 0.317 Ou<sub>E</sub> s<sup>-1</sup> kg<sup>-1</sup> (41% reduction) for a control and low nitrogen diet, respectively; the protein levels of the diets were not stated in the published data. Research reported by Hobbs et al. (1996) used gas chromatography–mass spectrometry to analyse the headspace gas for ten individual compounds commonly found in pig odour. Manure samples from two reduced crude protein diets, 131 g kg<sup>-1</sup> crude protein and 139.3 g kg<sup>-1</sup> crude protein and one commercial diet, 189.2 g kg<sup>-1</sup> crude protein were analysed. Nine out of ten odorous compounds were significantly reduced using low crude protein diets ( $P < 0.05$ ). The odour emission rates in this study, even from the low crude protein diets, were higher than some published emission rates from commercial pig units (Holste, 1998; Martinec et al., 1998). This might have been due to the orientation of the fans in relation to the manure surface in the experimental unit. High air velocity near the slurry surface caused by the location of the fans in the pens would increase the air movement above the manure surface, thus increasing the potential for the volatilisation of gases.

### 3.3. Ammonia

Table 3 indicates that ammonia emissions per animal per day were reduced by 62.4% when dietary crude protein was decreased from 220 to 130 g kg<sup>-1</sup>. This equates to a reduction of 8.1% for every 10 g kg<sup>-1</sup> reduction in dietary crude protein.

Table 2  
Mean odour emission rates

Crude protein	130 g kg <sup>-1</sup>	160 g kg <sup>-1</sup>	190 g kg <sup>-1</sup>	220 g kg <sup>-1</sup>	s.e. ( $n = 60$ )	<i>P</i> value
Odour						
Ou <sub>E</sub> s <sup>-1</sup> animal <sup>-1</sup>	12.11 <sup>a</sup>	13.24 <sup>a</sup>	19.57 <sup>b</sup>	17.59 <sup>b</sup>	1.5	0.005
Ou <sub>E</sub> s <sup>-1</sup> LU <sup>-1</sup>	77.64 <sup>a</sup>	80.03 <sup>a</sup>	115.80 <sup>b</sup>	102.88 <sup>b</sup>	8.1	0.009

<sup>a,b</sup>Means with the same superscript within rows are not significantly different ( $P > 0.05$ ).

Table 3  
Mean ammonia emission rates and percentage reduction

Diets	130 g kg <sup>-1</sup>	160 g kg <sup>-1</sup>	190 g kg <sup>-1</sup>	220 g kg <sup>-1</sup>	s.e. (n = 60)	P value
Ammonia g d <sup>-1</sup> animal <sup>-1</sup>	3.11 <sup>a</sup>	3.89 <sup>b</sup>	5.89 <sup>bc</sup>	8.27 <sup>c</sup>	0.509	0.001
Crude protein (analysed)	Total % reduction in NH <sub>3</sub> emissions		Total % reduction in NH <sub>3</sub> emissions for every 10 g kg <sup>-1</sup> reduction in CP (as analysed)			
209.0–184.6	28.78		12.0			
184.6–157.4	33.96		12.5			
157.4–131.7	0.05		7.8			
209.0–131.7	62.39		8.1			

<sup>a,b,c</sup>Means with the same superscript within rows are not significantly different ( $P > 0.05$ ).

Similar results were obtained by Kay and Lee (1997) and Canh et al. (1998) between dietary levels of 187 and 130 g kg<sup>-1</sup> and between 16.5% and 12.5% crude protein, respectively. Reductions in ammonia emission equivalent to 9.8% per 10 g kg<sup>-1</sup> reduction in dietary crude protein are reported by Kay and Lee (1997). Comparing in vivo and in vitro measurements of ammonia release, Canh et al. (1998) report that emissions were reduced by 10% and 12.5%, respectively, per 10 g kg<sup>-1</sup> decrease in dietary crude protein. Kendall et al. (2000) reported a reduction in ammonia concentration from 29.6 to 12.9 ppm (approximately a 56% reduction) in the exhaust air from 12.6% and 9.35% crude protein diets, respectively, supplemented with synthetic lysine. The diets were fed to castrates and gilts over a six-week experimental period and ammonia measurements were measured with Dräger diffusion tubes over 4 h.

Peirson and Nicholson (1995) reported an approximate reduction of 33% in ammonia emissions per livestock unit between a control and a low nitrogen diet; the protein levels in the diets however were not stated.

Lower ammonia concentration in pig houses may also have useful benefits to the health of fattening pigs, resulting in associated improvements in pig performance and safety for stockmen. The Control of Substances Hazardous to Health (Health and Safety Executive, 1999) regulation specifies an eight hour time weighted average exposure of <25 ppm, 10 min exposure limit at 25–35 ppm and 0 min at >35 ppm. Animals in an integrated system are constantly exposed, so a maximum level of 20 ppm should be adhered to (Feddes and DeShazer, 1988). Smith et al. (1996) reported that weanling pigs, when given an option of fresh air or ammoniated air, showed a significant decrease in the amount of time spent in the area supplied with ammoniated air.

The use of Dräger tubes in this study gave an on-the-spot grab sample of the ammonia concentration in the air stream; a handheld electrochemical cell will be used for future experiments in order to measure the ammonia concentration and the concentration of other gases continuously.

### 3.4. Comparison of odour and ammonia emissions

In general as crude protein decreased, odour and ammonia emission rates decreased. However, odour emission rates were lower for the 220 than 190 g kg<sup>-1</sup> crude protein diets (Table 2). This might have been due to excess protein in the diet that could result in an imbalance in the feed C:N ratios or in insufficient carbohydrates to promote enhanced microbial decomposition resulting in reduced volatile fatty acids (VFA) (Sutton et al., 1996). Williams (1984) stated that pig odour offensiveness is largely related to the volatile fatty acids in the manure.

Ogink and Groot Koerkamp (2001) stated that reducing the emitting surface of the manure could reduce the emissions of odorous compounds. The implementation of dietary manipulation in combination with other abatement techniques such as reducing the emitting manure surface area, frequent manure removal and improved ventilation systems could lead to a significant reduction in odour and ammonia emission rates (EPA, 2002).

### 3.5. Cost

As seen in Table 1, the relative cost of each diet was estimated. It was largely influenced by the cost of the synthetic amino acids added to the diets low in crude protein. The estimated cost index of the 130, 160, 190 and 220 g kg<sup>-1</sup> crude protein diets was 1.30, 1.15, 1.05 and 1.0, respectively. Synthetic amino acids may be utilised to reduce the excretion of nitrogen in the manure and reduce the ammonia emissions but the cost of adding them to the diets must be taken into consideration relative to the cost of conventional protein sources. The formulation of a synthetic amino acid balance in the diets of finishing pigs as a replacement for protein is more expensive than conventional finishing diets. Fluctuations in the market price of soya bean meal and synthetic amino acids will affect the cost implications of this strategy. Low dietary crude protein levels would appear to offer a low cost alternative, in relation to end

of pipe treatments, of reducing odour and ammonia emissions from finishing pig houses.

#### 4. Conclusions

Dietary crude protein levels of 130, 160, 190 and 220 g kg<sup>-1</sup> were fed to finishing pigs during six four-week feeding periods.

- The odour emission rates were highest for the 190 g kg<sup>-1</sup> crude protein diet. A reduction in the odour emission rates of greater than 30% is achievable.
- The ammonia emission rates were highest for the 220 g kg<sup>-1</sup> crude protein diet. The ammonia emissions per animal per day were reduced by 62.4% when dietary crude protein decreased from 220 to 130 g kg<sup>-1</sup>. This equates to a reduction of 8.1% for every 10 g kg<sup>-1</sup> reduction in crude protein between 209.0 and 131.7 g kg<sup>-1</sup> of total dietary content.
- Future work on ammonia and odour emission rates from pig and poultry units will utilise a handheld electrochemical cell in order to continuously monitor ammonia and other odorous gases.

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