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Ammonia abatement by slurry acidification: A pilot-scale study of three finishing pig production periods

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ABSTRACT

Livestock production systems can be major sources of trace gases including ammonia (NH_3), the greenhouse gases methane (CH_4) and nitrous oxide (N_2O), and odorous compounds such as hydrogen sulphide (H_2S). Short-term campaigns have indicated that acidification of livestock slurry during in-house storage can reduce NH_3 emissions, and also may influence other emissions. In this study, emissions of NH_3 were quantified by measuring continuously during three complete finishing pig production periods of about 10 weeks each, and emissions of CH_4 and H_2S less frequently. Emissions were determined from sections with 30–32 pigs with or without daily adjustment of slurry pH to below 6. Ammonia losses from reference sections with untreated slurry were between 9.5 and 12.4% of N excreted, and from sections with acidified slurry between 3.1 and 6.2%. Acidification reduced total emissions of NH_3 by 66 and 71% in spring and autumn experiments, and by 44% in the summer experiment. Regression models were used to investigate sources and controls of NH_3 emissions. There was a strong relationship between NH_3 emissions and ventilation rate during spring and autumn, but less so during summer where ventilation rates were generally high. It was concluded that the contribution from floors to NH_3 emissions was <50%. There was some evidence for reduced CH_4 emissions from acidified slurry, but CH_4 emissions were generally low and apparently dominated by enteric fermentation. No effect on N_2O emissions was observed. The effect of acidification on emissions of H_2S differed between experiments. Implications of slurry acidification for subsequent field application, including N and S availability, and soil pH, are discussed.

1. Introduction

Deposition of ammonia (NH_3) from livestock production is a major threat to terrestrial and aquatic ecosystems and air quality (Dise et al., 2011; Moldanová et al., 2011; Peel et al., 2013). A European assessment identified health issues related to NH_3 as a major socio-economic cost of livestock production (Sutton et al., 2011). Intensive pig operations are important point sources of atmospheric NH_3 (Oenema et al., 2007) as a result of high N excretion rates, liquid manure management and, in temperate regions, forced ventilation of housing facilities (Sommer et al., 2006; Feilberg and Sommer, 2013).

A large proportion of NH_3 emitted from animal houses is deposited locally (Sommer et al., 2009; Vogt et al., 2013). As a consequence, Danish regulations (Ministry of the Environment, 2013) require that new or modified pig production facilities in locations near sensitive ecosystems adopt NH_3 abatement measures to prevent an increase in N deposition, such as scrubbing of NH_3 from ventilation air (Melse et al., 2009) or acidification of slurry in the pit below slatted floors (Kai et al., 2008) which may also improve in-house air quality for livestock and workers (Zhang et al., 1998; Jensen, 2002). Slurry acidification has been proven efficient for NH_3 abatement in several countries across Europe (*e.g.* Stevens et al., 1989; Bussink et al., 1994; Pain et al., 1994). Commercial equipment for in-house acidification of slurry now exists which removes a volume of slurry for pH adjustment with concentrated sulphuric acid (H_2SO_4) each day. Part of the acidified slurry is returned to the pit while the remainder, corresponding to the daily production, is transferred to an outside storage tank. The

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pH reduction persists during slurry storage (Petersen et al., 2014a) and after field application (Kai et al., 2008), hence NH_3 emissions from these sources are also reduced.

Although it is known that slurry acidification will reduce NH_3 emissions, some interactions complicate the response. Firstly, the effectiveness of acidification will depend on the relative importance of emissions from the slurry pit as opposed to emissions from soiled surfaces (Sommer et al., 2006). Secondly, model predictions (Hafner et al., 2013; Petersen et al., 2014b) and micro-sensor measurements on defined solutions (Petersen et al., 2014b) and pig slurry (unpublished data) show that surface pH of slurry undergoing NH_3 emission may be more than 1 unit higher than bulk pH (Petersen et al., 2014b). Furthermore, effectiveness of acidification may vary over time due to changes in N excretion rate, slurry composition, temperature, and ventilation rate (Kavolelis, 2003). It is thus important to assess the effectiveness of acidification under conditions that represent full-scale production and complete production cycles, ideally at different times of the year. The study reported here is the first to meet all these requirements.

In addition to the abatement of NH_3 emissions, Petersen et al. (2014a) found that slurry acidification dramatically reduced emissions of methane (CH_4) during long-term storage. The effect of acidification will depend on the CH_4 production potential in the pit, which in turn depends on the presence of adapted methanogens (Zeeman, 1994; Sommer et al., 2007). Acidification may also change degradation pathways for slurry organic matter and thereby influence the emission of odorants (Eriksen et al., 2012; Hjorth et al., 2015).

In this report, we document emissions of NH_3 with and without slurry acidification during three complete finishing pig production periods. In the first period, emissions of CH_4, and of total reduced sulphur (mainly H_2S) as a proxy for odour emissions (Blanes-Vidal et al., 2009), were also quantified. We hypothesised that NH_3 emissions would increase with increasing N excretion rate and ventilation, and that slurry acidification would reduce NH_3 emissions independent of season. We further expected CH_4 emissions from acidified slurry to remain low throughout the production period.

2. Materials and methods

Three experiments were undertaken between February 2012 and September 2013, representing three complete growth periods, to determine emissions as influenced by slurry acidification. Summary information about the three experiments, referred to as spring, summer and autumn experiment, is presented in Table 1.

2.1. Experimental production facility

Experiments were carried out at the Danish Pig Research Centre's experimental station Grønhøj in Western Denmark (Fig. 1). The facility consisted of six identical and separated climate chambers (sections), four of which were used for each experiment. Sections 1 and 2 were linked to an acidification unit, as were 3 and 4, whereas sections 5 and 6 served as reference. Each section contained two pens, one for female and one for castrated male pigs.

The climate chambers were constructed with separate air intakes and exhausts, and separate slurry pits. In order to control air temperature, the chambers were mechanically ventilated, with a minimum ventilation rate of $300\,m^3\,h^{-1}$ and a maximum capacity of $3200\,m^3\,h^{-1}$. The pens had fully slatted floors and a 60 cm deep slurry pit underneath. Two thirds of the pen floor had 9 cm beams (concrete slats) and one third 18 cm beams (drained floor). Each pen was equipped with a dry feeder and a drinking bowl. A sprinkler system with one nozzle was installed above the fouling area to cool the pigs when outside temperatures exceeded 15 °C.

2.2. Experimental treatments

During each production period (experiment), emissions from sections with untreated and acidified slurry were compared. In each experiment, two sections were untreated and two were acidified. Each section contained 30 or 32 finishing pigs, *i.e.* 15 or 16 animals per pen. The numbers at the end of the growth period were often not the same since it was sometimes necessary to remove one or more animals during the course of the experiment. The animal mass was 31–33 kg at introduction, and 105–119 kg when exported (Table 1); except for a small difference between starting weights of the autumn experiment, there were no differences between live weights in acidified and reference sections. Except for the summer growth period, these conditions compared well with the Danish norms which are based on starting and finishing weights of 32 and 107 kg, respectively (Poulsen, 2013). The pigs had *ad-libitum* access to a heat-treated (81 °C) pelleted feed based on wheat, barley and soybean meal. The feed contained 11.9% water, 4.9% ash, 15.6% protein, 3.4% lipids and 0.19% sulphur, all on dry wt. basis, and 15.1 MJ kg^{-1} fresh wt. The feed boxes were filled two or three times per day and the weight recorded.

Table 1
Overview of three finishing pig production periods referred to as spring, summer and autumn. Treatment differences ($P < 0.05$) with respect to initial and final weights are indicated by lower-case and upper-case letters, respectively.

	Spring		Summer		Autumn	
Duration (day)	77		76		69	
No. pigs section^{-1}	32		30		32	
Ventilation rate, daily mean [min; max]						
Acidified ($m^3\,h^{-1}$)	928 [253; 1876]		2645 [624;3323]		1019 [385; 2064]	
Reference ($m^3\,h^{-1}$)	1048 [283; 2023]		2704 [507; 3307]		995 [373; 1996]	
Acid used (kg pig^{-1})	5.1		5.6		5.6	
Date	Start 2/13/2012	End 4/30/2012	Start 6/24/2013	End 9/8/2013	Start 10/1/2012	End 12/9/2012
Average weight						
Acidified (kg)	31.4c	110.3B	33.2b	117.5A	33.1b	105.5B
Reference (kg)	30.9c	106.4B	33.7ab	118.7A	34.2a	105.4B