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Research Paper

Low frequency aeration of pig slurry affects slurry characteristics and emissions of greenhouse gases and ammonia

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Low frequency aeration of slurries may reduce ammonia (NH_3) and methane (CH_4) emissions without increasing nitrous oxide (N_2O) emissions. The aim of this study was to quantify this potential reduction and to establish the underlying mechanisms. A batch experiment was designed with 6 tanks with 1 m^3 of pig slurry each. After an initial phase of 7 days when none of the tanks were aerated, a second phase of 4 weeks subjected three of the tanks to aeration (2 min every 6 h, airflow 10 m^3 h^{-1}), whereas the other three tanks remained as a control. A final phase of 9 days was established with no aeration in any tank. Emissions of NH_3, CH_4, carbon dioxide (CO_2) and N_2O were measured. In the initial phase no differences in emissions were detected, but during the second phase aeration increased NH_3 emissions by 20% with respect to the controls (8.48 vs. 7.07 g m^{-3} [slurry] d^{-1}, $P < 0.05$). A higher pH was found in the aerated tanks at the end of this phase (7.7 vs. 7.0 in the aerated and control tanks, respectively, $P < 0.05$). CH_4 emissions were 40% lower in the aerated tanks (2.04 vs. 3.39 g m^{-3} [slurry] d^{-1}, $P < 0.05$). These differences in NH_3 and CH_4 emissions remained after the aeration phase had finished. No effect was detected for CO_2, and no relevant N_2O emissions were detected during the experiment. Our results demonstrate that low frequency aeration of stored pig slurry increases slurry pH and increases NH_3 emissions.

1. Introduction

In recent years, the growth in intensive pig production has lead the increasing global livestock production (FAOSTAT, 2016). However, intensive production of pigs tends to be decoupled from other agricultural production systems, and therefore a proper management of slurry becomes essential to avoid environmental impacts and to enhance nutrient recycling (Brockmann, Hanhoun, Négri, & Hélias, 2014). During their storage, pig slurries emit considerable amounts of ammonia (NH_3) and greenhouse gases to the atmosphere, mainly in the form of methane (CH_4). In intensive pig production, slurry treatment techniques become essential to

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fulfil the environmental regulations (e.g. Industrial Emissions Directive in Europe). These techniques are devised to facilitate slurry management, reduce the environmental impacts or obtain potential benefits such as high value fertilisers or biogas (Burton & Turner, 2003). However, potential side effects of certain treatments, such as nitrous oxide (N_2O) emissions from aerobic treatments, must be accounted for.

Aeration has long been proposed as a treatment technique to reduce the nitrogen and organic matter loads of slurries, and thus reduce the pollution risk (Bicudo & Svoboda, 1995; Bicudo, 1995; Burton, 1992; Cumby, 1987). During the aeration of animal slurries, the anoxic and reductive conditions in which slurries are normally stored (e.g. <1 g L^{-1} dissolved O_2) change to aerobic and oxidising conditions (e.g. >4 g L^{-1} dissolved O_2) (Cheng & Liu, 2001). Also, aeration normally involves stirring the slurries, both avoiding sedimentation and crust formation. This changes the biochemical and microbial reactions in the slurry, depending on the aeration set-up parameters (for example aeration flow rates, frequency and duration in case of intermittent aeration, tank size and air bubble size, among others).

The effect of aeration on the fate of nitrogen has been long demonstrated (Béline & Martinez, 2002; Béline, Martinez, Chadwick, Guiziou, & Coste, 1999; Cheng & Liu, 2001). These studies have revealed that using appropriate aeration flows in the case of continuous reactors or intermittent aeration for batch reactors achieves high nitrogen removals as a consequence of nitrification and denitrification processes, producing nitrogen gases. Therefore, research has recently focused on reducing N_2O emissions by controlling the process variables including intermittent aeration or aeration flow rates (Castro-Barros, Daelman, Mampaey, van Loosdrecht, & Volcke, 2015; Hu et al., 2010; Hu, Zhang, Xie, Li, Wang, et al., 2011; Hu, Zhang, Xie, Li, Zhang, et al., 2011; Lackner et al., 2014; Mampaey, De Kreuk, van Dongen, van Loosdrecht, & Volcke, 2016; Pan, Wen, Wu, Zhang, & Zhan, 2014; Wang, Guan, Pan, & Wu, 2016). According to these authors, changing operation parameters leads to N_2O emission factors mostly between 1% and 10% of the initial N.

Aerobic treatment systems are not considered best available techniques because they involve a loss of a valuable nutrient and the side effects on N_2O emissions are still considerable (European Commission, 2015). However, the short time aeration (less than 1% of time) of slurries could have the potential to reduce ammonia emissions without these side effects, although to the authors' knowledge, very limited research has been conducted in this area. In this process, two effects are expected to occur: slurry mixing and partial oxygenation. The mixing effect is the main hypothesis for reduced NH_3 emissions. As first suggested by Ni, Hendriks, Vinckier, and Coenegrachts (2000) and reviewed by Hafner, Montes, and Alan Rotz (2013), CO_2 emission from slurry increases surface pH, thus enhancing NH_3 emissions. As a consequence, NH_3 emissions during and immediately after aeration may be lower than untreated slurries. However, it has also been reported that the aerobic treatment of manure increases slurry pH on average, as a consequence of the removal of volatile fatty acids (Fangueiro, Hjorth, & Gioelli, 2015; Sørensen & Eriksen, 2009; Zhang & Zhu, 2005). Therefore, potential effects of short aeration times on pH and NH_3 emissions must be evaluated by research.

The partial oxygenation caused by low frequency aeration may have potential effects on CH_4 and N_2O emissions. Research on aerobic treatment of slurries normally considers a longer duration of the aerobic phase in comparison to the anaerobic phase, and results indicate that nitrification and denitrification is enhanced, whereas methanogenesis is inhibited (Castro-Barros et al., 2015; Cheng & Liu, 2001; Hu et al., 2010; Hu, Zhang, Xie, Li, Wang, et al., 2011; Hu, Zhang, Xie, Li, Zhang, et al., 2011; Lackner et al., 2014; Wang et al., 2016). However, no information is available on how these emissions are affected by low aeration frequency.

The objectives of this study are: first, to determine whether a low frequency aeration (2 min each 6 h) of pig slurry affects its composition and the related emissions of NH_3, CH_4, N_2O and CO_2; and second, to analyse and describe the mechanisms underlying these changes.

2. Methodology

2.1. Experimental design

The experiment was conducted at the Rothamsted Research North Wyke site from 8th June to 22nd July 2016. A slurry storage system similar to that described by Misselbrook, Hunt, Perazzolo, and Provolo (2016) was used, comprising six 1.25 m^3 tanks (1.20 m diameter and 1.12 m height) located in a covered area to exclude rainfall. Slurry was obtained from a local commercial finishing pig farm. Slurry stored for about 8 weeks was collected from the below slat storage and transported to the experimental site using a 6 m^3 slurry tank. Slurry was mixed and then representatively divided among the experimental tanks, and thus each tank was filled with 1 m^3 of slurry (88 cm depth). Three of the tanks were subjected to the aeration treatment, whereas the other three tanks were not treated and served as control tanks. Slurry composition and gaseous emissions were monitored during the experiment.

The experiment consisted of three phases. The first phase lasted for the first 7 days of storage and all tanks were subjected to the same management, that is, none of the tanks was aerated. During this phase, potential differences among tanks were evaluated. The second phase lasted for 4 weeks during which aeration was conducted in the aeration treatment tanks. The aeration system consisted of a low frequency injection of air. Each slurry tank under the aeration treatment had 170 L min^{-1} of ambient air injected over 2 min every 6 h. Injection was programmed to occur at 03:00 h, 09:00 h, 15:00 h and 21:00 h. An automatic controller was designed specifically to control operation times, and air was injected using a pump (Becker VT 4.10, Wuppertal, Germany). Air was injected at the bottom of each tank through a 32 mm diameter PVC pipe. Details of the aerated and non-aerated tanks can be seen in Fig. 1. Finally, in a third phase over the last 9 days of the experiment, no aeration was conducted in any of the tanks, aiming to evaluate potential permanent changes in slurry composition and gaseous emissions after the aeration treatment had finished. From each tank, representative slurry