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A life cycle perspective of slurry acidification strategies under different nitrogen regulations

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ABSTRACT

Livestock manure is a major contributor to ammonia and greenhouse gas emissions and treatment technologies such as slurry acidification can be used to reduce both. In this study, life cycle assessment was used to compare impact potentials of slurry acidification at either the pig housing or the field application stage with conventional slurry management. Furthermore, the effects of differences in environmental regulations concerning nitrogen application limits were analysed. The impact categories analysed were terrestrial eutrophication potential, climate change potential, marine eutrophication potential and toxicity potential. Slurry acidification reduced the terrestrial eutrophication potential by 71% for in-house acidification and by 30% for field acidification. Changes in regulatory plant-available nitrogen application limits resulted in changes in climate change potential and marine eutrophication potential, with lower limits favouring in-house acidification. Acidification can substantially reduce the environmental impacts of animal slurry, but the effect depends on the context of the regulatory regime.

1. Introduction

Global livestock production is rapidly growing as the world's population increases and becomes steadily more affluent (Sommer and Christensen, 2013). However, livestock production has a major impact on the environment. Livestock manure is responsible for approximately 40% of global ammonia (NH_3) emissions, 70% of NH_3 emissions in Europe and 80% of NH_3 emissions in Denmark (Bouwman et al., 1997; Dalgaard et al., 2014; European Centre for Ecotoxicology and Toxicology of Chemicals (1994); Van der Hoek, 1998). The largest NH_3 emissions in Denmark come from pig housing, followed by field application of pig slurry (Nielsen et al., 2014). Livestock manure is also responsible for approximately 1.8% of global greenhouse gas (GHG) emissions, 1.7% of GHG emissions in Europe and 2.8% of GHG emissions in Denmark (European Environment Agency, 2012; O'Mara, 2011).

Slurry acidification is a treatment used to reduce NH_3 emissions to allow farms to comply with national or EU legislation (*e.g.* the EU National Emission Ceiling Directive, European Commission (2001)). In 2014, approximately 12% of all animal slurry in Denmark was acidified (Kjeldal, 2015). Ammonia emissions are decreased by the reduction in pH because the proportion of ammoniacal N that is present as NH_3 is reduced (Fangueiro et al., 2015; McCrory and Hobbs, 2001; Petersen et al., 2012). When the pH is decreased from a pH of typically around 7.5 to 5.5, the gaseous acid-base compound concentration of NH_3 decreases from 1.8% to 0.02% (Fangueiro et al., 2015).

Slurry can be acidified at different stages in the manure handling chain. Acidification in the animal house involves pumping acidified slurry into the storage area beneath the slatted floors. Acidifying the slurry at the start of the manure management chain means that emissions are reduced in animal housing, in slurry storage and after field application. Ammonia emissions from pig housing reduced by up to 70% when slurry was acidified from pH 7.5 to pH 6 and by 67% following subsequent field application by band-spreading (Kai et al., 2008). Another approach is to add the acid in the slurry storage tank just before the slurry is applied to fields or the acid can be applied in-line on the slurry tanker during field application. This approach is

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cheaper than in-house acidification as less equipment and sulphuric acid are needed for decreasing the pH of slurry. Ammonia emissions reduced by 58% during field application when the pH was decreased from 7.8 to 6.8 (Nyord et al., 2013). However, field acidification only reduces NH_3 emissions in the field and does not reduce emissions from the animal housing or manure storage.

In-house slurry acidification efficiently reduces GHG emissions, since the lower pH strongly reduces microbial activity (Ottosen et al., 2009; Sørensen and Eriksen, 2009). Slurry acidification reduced methane (CH_4) and nitrous oxide (N_2O) emissions during storage, and carbon dioxide (CO_2) after soil application (Berg et al., 2006; Fangueiro et al., 2010; Ottosen et al., 2009; Petersen et al., 2012). However, the reported decrease in CO_2 emissions after soil application was probably caused by the volatilisation of carbonates during the acidification process which would otherwise have been emitted after field application. Acidified slurry contained about 38% less carbon (C) than non-acidified slurry at the moment of field application (Fangueiro et al., 2010).

Improved fertiliser value of nitrogen (N) is another advantage of slurry acidification (Kai et al., 2008). Lower NH_3 losses following acidification mean more slurry total-N and plant-available N remains in the slurry applied to fields, resulting in an increased mineral N fertiliser equivalent (MFE) value compared to untreated slurry (Sørensen and Eriksen, 2009). However, it should further be considered that N applications to crops are limited in many parts of Europe through legislation (*e.g.* the Nitrates Directive), since the yield response to N decreases with increasing application levels and NO_3^- leaching increases. For this reason, the production and environmental impacts of slurry acidification technologies will be affected by how regulatory limits frame N application levels.

Slurry acidification affects a number of environmental indicators during all stages of the slurry management system. A whole-farm assessment of slurry acidification, including all stages of the slurry management system, has been presented in Kai et al. (2008), but only includes NH_3 emissions. The review of slurry acidification by Fangueiro et al. (2015), mentions the need to investigate whether slurry acidification induces any burden shifting, *i.e.* whether a reduction in NH_3 losses leads to other environmental impacts at other life stages. Life cycle assessment (LCA) is a widely used approach in the analysis of environmental impacts related to slurry management (Croxatto Vega et al., 2014; De Vries et al., 2013; Hamelin et al., 2011; ten Hoeve et al., 2014), but has yet to be applied to slurry acidification. The goal of this study was therefore to use an LCA approach to investigate the environmental impacts of slurry acidification, including the potential effects of legislation. The objectives were *i)* to compare the environmental impact potentials of two different slurry acidification techniques with conventional slurry management, and *ii)* to analyse the environmental impact potentials of slurry acidification under varying N application limits.

2. Materials & methods

2.1. LCA approach

This study was performed according to the LCA approach described in ISO 14040 and ISO 14044 standards (ISO 14040, 2006; ISO 14044, 2006). Whenever possible, system expansion was used to avoid allocation. LCA modelling was performed using EASETECH software (Clavreul et al., 2014). The Ecoinvent database 2010 V2.2 was used for background processes (Althaus et al., 2007; Nemecek and Kägi, 2007). The functional unit in this study was the treatment of 1000 kg of slurry excreted by fattening pigs under prevailing Danish conditions.

2.2. Scope

The geographical scope was Denmark for the slurry treatment processes (housing, storage and field application). Processes that occur outside Denmark (*e.g.* mineral fertiliser production) were also included. The technical scope for the assessment was the best available technology in Denmark. Emissions from mineral fertiliser, acidified and non-acidified slurry were analysed from the moment slurry was excreted by the pigs until 100 years after field application, including gaseous emissions, leaching to groundwater and losses to surface water from the soil and C sequestration. During these 100 years the same practice was assumed and this timeframe was chosen in order to include long-term effects of slurry application to agricultural soils. For greenhouse gases the 100-year time horizon was considered for the climate change potential.

2.3. Scenarios and system boundaries

2.3.1. System boundaries

The processes included in this study are shown in Fig. 1. The system excludes the production of the fattening pigs, and the buildings and equipment used for the storage and application of slurry. These processes were assumed to be equal for all scenarios and were assumed not to change as a result of changes in slurry management practice.

2.3.2. Scenarios

In this study, two slurry acidification scenarios were considered and compared with a reference scenario in which slurry was not acidified:

- No acidification scenario: conventional slurry management
- Field acidification scenario: identical to the no acidification scenario, apart from addition of sulphuric acid during application of the slurry to the field (Nyord et al., 2013; VERA, 2012)
- In-house acidification scenario: daily acidification of slurry during in-house storage followed by outdoor storage and land application of the acidified slurry using a trailing hose system (Danish Environmental Protection Agency, 2011; Infarm A/S, 2015)

2.4. Life cycle data inventory and assumptions

2.4.1. Chemical composition of slurry

The chemical composition of the excreted slurry had the following characteristics: dry matter 8.3%, organic matter 6.5%, total-N 0.63%, mineral-N 0.43%, total P 0.16% and total K 0.31% (Poulsen, 2013; Sommer et al., 2015). The composition after outdoor storage and at field application was derived from mass balances based on the initial slurry composition, degradation, inputs to the system and emissions from the system (Table S1, Supporting information (SI)).

2.4.2. In-house storage and acidification of slurry

Livestock management and manure treatment in all scenarios corresponded to Danish requirements and regulations. It was assumed that the fattening pigs consumed a standard Danish pig diet and were kept in pig houses with fully slatted floors. In the in-house acidification scenario, slurry in the pit below the slats was acidified with on average 9.7 kg concentrated sulphuric acid (96% H_2SO_4) per tonne of slurry to reach pH 5.5 on a daily basis (Sørensen and Eriksen, 2009). In the no acidification and field acidification scenarios, the slurry was left untreated during in-house storage. After an in-house storage time of approximately six weeks, slurry was pumped from the channels into an outdoor storage tank.