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Research article

Environmental impacts of combining pig slurry acidification and separation under different regulatory regimes — A life cycle assessment

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ABSTRACT

Global livestock production is increasing rapidly, leading to larger amounts of manure and environmental impacts. Technologies that can be applied to treat manure in order to decrease certain environmental impacts include separation and acidification. In this study, a life cycle assessment was used to investigate the environmental effects of slurry acidification and separation, and whether there were synergetic environmental benefits to combining these technologies. Furthermore, an analysis was undertaken into the effect of implementing regulations restricting the P application rate to soils on the environmental impacts of the technologies. The impact categories analysed were climate change, terrestrial, marine and freshwater eutrophication, fossil resource depletion and toxicity potential. In-house slurry acidification appeared to be the most beneficial scenario under both N and P regulations. Slurry separation led to a lower freshwater eutrophication potential than the other scenarios in which N regulations alone were in force, while these environmental benefits disappeared after implementation of stricter P regulations. With N regulations alone, there was a synergetic positive effect of combining in-house acidification and separation on marine eutrophication potential compared to these technologies individually. The model was sensitive to the chosen ammonia emission coefficients and to the choice of inclusion of indirect nitrous oxide emissions, since scenarios changed ranking for certain impact categories.

1. Introduction

Global livestock production is rapidly increasing, with total meat production expected to be 455 million tonnes by 2050, compared to 258 million tonnes in 2005/2007 (Alexandratos and Bruinsma, 2012). An increase in meat production will lead to a proportional increase in the amount of manure. This can be perceived as both a positive and a negative development. On the positive side, manure contains nutrients that are crucial for crop growth and it can therefore be seen as a valuable fertiliser. Soil quality can be maintained or improved with the use of manure instead of mineral fertiliser due to the presence of organic matter in manure. On the other hand, natural resources are needed to handle and transport manure, and emissions to the environment occur during manure storage and field application. More than half of the world's pork production originates from intensive systems, which are mainly located in eastern North America, western Europe, and Southeast and East Asia (Steinfeld et al., 2006). These areas are known for their high livestock density and problems with nutrient losses, especially nitrogen (N), and soil accumulation, especially phosphorus (P). Manure treatment technologies are continually being developed in order to decrease the overall environmental impacts of manure. However, it is important to analyse whether these impacts are being decreased or technologies are just leading to burden shifting and having impacts in other life cycle stages or impact categories instead.

Slurry acidification is a technology that is used to decrease ammonia (NH_3) and greenhouse gas (GHG) emissions from the slurry management chain (Hou et al., 2015). Decreasing the pH of slurry decreases the dissociation of NH_4^+, and therefore decreases NH_3 emissions (Fangueiro et al., 2015). The acid-base equilibrium concentration of $NH_3(aq)$ decreases from 1.8% at pH 7.5 to 0.02% at pH 5.5, which in turn decreases the potential for NH_3 volatilisation due to the $NH_3(aq) \leftrightarrow NH_3(g)$ equilibrium. Examples of additives that can be used for effective slurry acidification include H_2SO_4, HCl and HNO_3. Slurry can be acidified during each of the three major

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management steps: in the animal house, during storage and during field application. In-house acidification involves pumping acidified slurry into the storage area beneath slatted floors. The additive is applied on a daily or weekly basis. Acidifying the slurry early in the management chain leads to decreases in NH_3 emissions from both animal housing and slurry storage and after field application. Ammonia emissions from pig housing are decreased $\leq$70% when slurry is acidified in-house, and by an additional 67% during field application by band-spreading (Kai et al., 2008). This implies that a larger share of N ends up in the soil, which in turn results in an increased mineral N fertiliser value compared to untreated slurry (Sørensen and Eriksen, 2009). Another effect of early acidification is that microbial activity in the slurry is greatly decreased, leading to lower CH_4 and N_2O emissions during storage (Berg et al., 2006; Ottosen et al., 2009; Sørensen and Eriksen, 2009). Acidification during storage is typically performed shortly before the slurry is removed from the storage tank. This is a cheaper approach than in-house acidification, but there can be problems with foaming during acid addition (Fangueiro et al., 2015). Acidification during field application of slurry is the final option. The acid is applied in-line on the slurry tanker, shortly before the slurry leaves the tanker. Acidification at the end of storage and at field application decreases NH_3 emissions in the field $\leq$58%, but does not affect emissions from animal housing and slurry storage (Nyord et al., 2013).

Freshwater eutrophication potential is mainly caused by P losses to the aquatic environment. Intensive livestock production has led to P surpluses on a large proportion of farms in Denmark, as cattle and pig manure contain relatively large amounts of P. In other areas, on many farms, agricultural fields do not receive sufficient P and farmers rely completely on the application of mineral fertilisers to their fields. The over-fertilisation in some areas leads to P leaching and run-off which can pollute surface waterbodies (Christensen et al., 2013). In addition, phosphorus is a non-renewable resource for which there is no substitute (Scherer and Pfister, 2015). Syers et al. (2008) proposed three reasons for increasing efficiency in the use of P fertiliser: phosphate rock is a non-renewable resource with a limited stock, many soils in developing countries need an improvement in P status, and the loss of soil P is a major contributor to freshwater eutrophication. The large amounts of manure particularly increase the heavy metal content of Cu and Zn.

In order to enhance nutrient re-distribution, slurry treatment technologies have been developed that focus on the separation of slurry into solid and liquid fractions. The liquid fraction contains most of the easily available N, but less than half of the P, so is mainly valued as an N fertiliser. The solid fraction is easier to transport, due to its relatively low water content. It has a high concentration of slowly available N and P, so it is mainly valuable as a P fertiliser. Many technologies can be applied for separation, *e.g.* drum filter, screw press, decanter centrifuge, sieving and natural settling (Foged et al., 2011).

The separation of in-house acidified pig slurry has advantages and disadvantages compared with separation alone. On the one hand, the volume of the liquid fraction increases if slurry is acidified before separation, making the solid fraction less voluminous (Cocolo et al., 2013). On the other hand, a larger share of macro- and micro-nutrients ends up in the liquid fraction, resulting in a smaller amount of P to be removed from the farm (Cocolo et al., 2013). Fangueiro et al. (2010) observed a decrease in N_2O emissions from acidified liquid and solid fractions that are not observed for unacidified liquid and solid fractions nor for unseparated acidified slurry. Acidification of the liquid fraction after centrifuge separation has the advantage of reducing NH_3 emissions from this fraction, compared to no acidification. Less strong acid is needed than when unseparated slurry is acidified. However, only emissions from the liquid fraction are decreased, not emissions from the solid fraction.

Currently there is no regulation that limits the amount of P that can be applied from animal manure in most European countries (Amery and Schoumans, 2014). In Denmark there are strict regulations on maximum N application for crops, but no rules for P. This is likely to change in the near future and may significantly increase the motivation for farmers to apply technologies that ensure more efficient distribution of manure P.

The aim of this study was to investigate the environmental effects of slurry acidification and slurry separation, and whether there were synergetic environmental benefits from combining these technologies. Furthermore, an analysis was performed as to whether the implementation of regulations restricting P application rates to soils influenced the environmental impacts of the two technologies.

2. Materials and methods

2.1. LCA approach

A life cycle assessment (LCA) approach was taken in this study to determine the environmental impact potential of combining slurry acidification and separation and to compare them with the environmental profiles of no treatment, and treatment with acidification or separation individually, under both an N regulation regime and a P regulation regime.

The LCA framework and methodology used in this study complied with ISO 14040 and ISO 14044 standards (ISO 14040, 2006; ISO 14044, 2006). Wherever possible, system expansion was used to avoid allocation. The software used for the LCA modelling was EASETECH (Clavreul et al., 2014) and the Ecoinvent database 2010 V2.2 was used for background processes (Althaus et al., 2007; Nemecek and Kägi, 2007). The functional unit that formed the basis for assessment was the management of 1000 kg of slurry excreted by fattening pigs under prevailing Danish conditions. All resources and emissions are expressed per functional unit in order to ensure an equal basis for comparison of the different manure management scenarios.

2.2. Scope

The geographical scope for the slurry management processes (treatment, slurry storage in animal housing, storage in outdoor facilities and field application) was Denmark, and the analysed technologies were contemporary. This means that data on slurry composition, emissions to the environment, slurry treatment conditions, machinery, transportation distances, crops, soil profiles, temperatures and regulations are representative for Denmark. Background processes that occur outside Denmark (*e.g.* mineral fertiliser production) were also included. Emissions and resource consumptions were analysed from the moment slurry was excreted by finishing pigs to 100 years after field application. The effects of emissions that contribute to climate change were considered for a period of 100 years from the moment they reached the atmosphere.

2.3. Scenarios and assumptions

2.3.1. System boundaries

The LCA included resource use and environmental impact potentials associated with indoor and outdoor storage and field application of slurry and its treatment fractions, field processes, transportation between the different life cycle stages, production and use of electricity, sulphuric acid, and agricultural lime, and the production, transportation and application of mineral fertiliser (Fig. 1). Processes not included were the production of fattening pigs and its related impacts, and the physical buildings and