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Life cycle assessment of pig slurry treatment technologies for nutrient redistribution in Denmark

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ABSTRACT

Animal slurry management is associated with a range of impacts on fossil resource use and the environment. The impacts are greatest when large amounts of nutrient-rich slurry from livestock production cannot be adequately utilised on adjacent land. To facilitate nutrient redistribution, a range of different technologies are available. This study comprised a life cycle assessment of the environmental impacts from handling 1000 kg of pig slurry ex-animal. Application of untreated pig slurry onto adjacent land was compared with using four different treatment technologies to enable nutrient redistribution before land application: *(a)* separation by mechanical screw press, *(b)* screw press separation with composting of the solid fraction, *(c)* separation by decanter centrifuge, and *(d)* decanter centrifuge separation with ammonia stripping of the liquid fraction. Emissions were determined based on a combination of values derived from the literature and simulations with the Farm-N model for Danish agricultural and climatic conditions. The environmental impact categories assessed were climate change, freshwater eutrophication, marine eutrophication, terrestrial acidification, natural resource use, and soil carbon, nitrogen and phosphorus storage. In all separation scenarios, the liquid fraction was applied to land on the pig-producing (donor) farm and the solid fraction transported to a recipient farm and utilised for crop production. Separation, especially by centrifuge, was found to result in a lower environmental impact potential than application of untreated slurry to adjacent land. Composting and ammonia stripping either slightly increased or slightly decreased the environmental impact potential, depending on the impact category considered. The relative ranking of scenarios did not change after a sensitivity analysis in which coefficients for field emissions of nitrous oxide, ammonia and phosphorus were varied within the range cited in the literature. Therefore, the best technology to implement in a given situation depends on the environmental problem in question, local policy, cost and practicality.

1. Introduction

Large amounts of animal slurry are produced in Europe and slurry management is associated with several environmental impacts. The principal impact categories affected by animal slurry management are; *(a)* climate change potential, *(b)* acidification potential, mainly induced by ammonia (NH_3) emissions, *(c)* eutrophication potential, and *(d)* the use of fossil resources (De Vries et al., 2012; Lopez-Ridaura et al., 2009). Potential impacts of livestock production on the surrounding environment that are generally not reported in life cycle studies relate to emissions of odorous compounds, microbes, antibiotics, hormones and heavy metals such as copper and zinc (Berenguer et al., 2008; Blanes-Vidal et al., 2009; Hansen et al., 2012; Igel-Egalon et al., 2012; Klein et al., 2010; Mantovi et al., 2003).

The environmental impacts are greater in areas with high livestock densities, where field nutrient application of slurry may approach or exceed the capacity of the crops. In the EU15, such areas can be found e.g. in The Netherlands, Belgium, western France, the UK, Ireland, northern Italy, north-west Germany and Denmark (Grizzetti et al., 2007). Concern about the consequences of nitrate (NO_3^-) leaching in such areas has led national and EU authorities to limit the application rate of slurry N. Phosphorus surpluses from excess slurry application also create a risk of P losses (MacDonald et al., 2011) and are a concern in relation to

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implementation of the EU Water Framework Directive (Council Directive 2000/60/EC of 23 October 23 2000).

In contrast, in areas with low livestock densities, agricultural fields receive insufficient amounts of nutrients from slurry to maintain good crop yields and farmers need to apply supplementary mineral fertilisers. Non-renewable natural resources, such as phosphate rock, oil and natural gas are used for the production of N and P mineral fertiliser and considerable impacts are related to the extraction, manufacture and use of these fertilisers. A geographical redistribution of animal slurry nutrients would enable a reduction in the consumption of mineral fertiliser in areas with low livestock densities and would lower environmental impacts in areas with high livestock densities. Increasing oil prices will increase the price of N mineral fertiliser, so there will probably be an economic incentive to utilise slurry N more effectively in the future. In addition, in areas where current or future EU or national environmental legislation imposes restrictions on the application of slurry to land, farmers face limitations on their current or future livestock production and there may be economic benefits to be gained from a geographical redistribution of slurry nutrients.

To facilitate nutrient redistribution, a range of different technologies have been or are currently being developed. The technology most widely applied at present is slurry separation, where the slurry is separated into a solid and a liquid fraction (Hjorth et al., 2010; Møller et al., 2007). Concentrating a proportion of the nutrients into a less bulky solid fraction reduces the cost of transporting these nutrients to areas where they can be utilised more effectively. Several separation methods are available. Screw press separation is a relatively cheap method that produces a liquid fraction containing most of the water and easily available N and potassium (K), but less than half of the P (Hjorth et al., 2010). Centrifuge separation is more expensive but partitions most P to the solid fraction (Hjorth et al., 2010). The solid fraction contains a high concentration of organic N and organic and mineral P. Agricultural land near livestock production units has often received animal slurry for many years, which means that P concentrations in the soil are already sufficiently high to satisfy crop demand (Grizzetti et al., 2007). Other technologies that have been developed to facilitate the redistribution of nutrients include NH_3 stripping from the liquid fraction (Alitalo et al., 2012), which allows a redistribution of inorganic N and at the same time reduces NH_3 emissions. Finally, composting of the solid fraction (Park et al., 2011; Bustamante et al., 2012), stabilises this fraction and reduces its volume, making it easier and less odorous to store and transport.

The advantages of redistributing nutrients have to be weighed against the environmental impacts associated with the technology. In this study, a life cycle assessment (LCA) approach was used to determine the environmental impact potential of different slurry treatment technologies and compare them with conventional slurry management.

2. Materials & methods

2.1. LCA approach

Life cycle assessment (LCA) is a methodology which can be used to compare resource consumption and environmental impacts of products or services providing the same function (JRC-IEA, 2010). The LCA framework and methodology used here comply with the ISO 14040 and ISO 14044 standards (ISO 14040, 2006; ISO 14044, 2006). A consequential approach was used, i.e. with substitution of by-products, use of marginal data for electricity and mineral fertiliser, and examination of life cycle processes that were expected to be different for the systems studied. The LCA was based on information from the literature and a systems analysis of the treatment technologies (Hutchings et al., 2013), including simulations with the Farm-N model (Hutchings, 2010). The LCA itself was conducted using GaBi software (www.pe-international.com). The functional unit that formed the basis for assessment was management of 1000 kg of slurry excreted by pigs.

2.2. Scope

The geographical scope for the assessment was Denmark. This means that technologies most often used in Denmark were modelled. The technologies for slurry treatment analysed are currently used in Denmark or have high potential applicability. Emissions from slurry, liquid and solid fractions were analysed from the moment the slurry was excreted by pigs until 20 years after field application, as modelled by the Farm-N model (Hutchings, 2010). The effects of all emissions were considered for a period of 100 years from the moment they reached water bodies or the atmosphere.

There are differing views in the literature on whether and how to include biogenic CO_2 emissions in LCA. In most studies on slurry treatment, biogenic CO_2 is excluded (e.g. De Vries et al., 2012; Lopez-Ridaura et al., 2009). The positions taken by the relevant standards are not entirely consistent. The ISO 14044 standard does not provide guidance on the issue of biogenic emissions (ISO 14044, 2006). US EPA (2011) states that there should not be categorical rules about inclusion or exclusion of biogenic carbon (C). PAS2050 suggests that biogenic CO_2 emissions should be inventoried, but that characterisation is optional. ILCD and the draft PEF (JRC-IEA, 2010, 2012) state that both biogenic emissions and biogenic uptake should be reported separately from non-biogenic flows and that characterisation factors should be applied. In order to assess the impact of inclusion of biogenic CO_2 on results and to analyse soil C changes, biogenic CO_2 was included in the inventory analysis in the present study. Furthermore, the life cycle impact assessment was performed twice; including and excluding biogenic CO_2.

2.3. Slurry management system and scenarios

This study considered four technologies for redistributing slurry nutrients from a pig-producing ('donor') farm to fields on a 'recipient' farm and compared them with a reference scenario:

- Reference scenario: Conventional slurry management, including in-house storage, external storage and application on the donor farm.
- Screw press scenario: Slurry separation with a mechanical screw press, with donor farm application of the liquid fraction, and transportation and application on a recipient farm of the solid fraction.
- Screw press with composting scenario: As for the screw press scenario, but with composting of the solid fraction (with the addition of a bulking agent), then transportation to a recipient farm.
- Decanter centrifuge scenario: Slurry separation with a decanter centrifuge, with donor farm application of the liquid fraction, and transportation and application on a recipient farm of the solid fraction.
- Decanter centrifuge with NH_3 stripping scenario: As for the decanter centrifuge scenario, but with NH_3 stripping of the liquid fraction resulting in a compact N fertiliser (ammonium sulphate), and a rejectate with very low N content.

2.3.1. Assumptions

The reference scenario was based on conventional slurry management in Denmark, with in-house storage for 6 weeks, covered outdoor storage for 6 months and field application with a slurry tanker. It was assumed that the pigs consumed an average Danish