Journal of Cleaner Production xxx (2014) 1–7

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

Greenhouse gas emissions of an on-farm swine manure treatment plant – comparison with conventional storage in anaerobic tanks

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ARTICLE INFO

Article history:
Received 3 December 2013
Received in revised form
21 May 2014
Accepted 6 July 2014
Available online xxx

Keywords:
Swine manure
Greenhouse gases
Anaerobic tanks
Treatment plant
Carbon credits

ABSTRACT

This study aims to estimate greenhouse gas (GHG) emission reduction over a five-month period due to the implementation of a swine manure treatment plant, installed as an alternative to conventional manure storage in anaerobic tanks. The treatment plant, located in Segovia (Spain), was installed in a farrow-to-finish farm with approximately 300 sows, and was based on solid–liquid separation using screw pressing followed by coagulation-flocculation and nitrification-denitrification of the liquid fraction. Information collected during the study of the on-farm treatment plant together with the guidelines proposed by the Intergovernmental Panel on Climate Change (IPCC) was used to quantify GHG emissions for each scenario. Implementing the manure treatment plant led to a total annual GHG emission reduction of 62% (from 1204 t $CO_{2\text{-equiv}}$ to 456 t $CO_{2\text{-equiv}}$). CO_2 and CH_4 emissions fell by 72% and 69%, respectively, whereas N_2O emissions were similar in the two scenarios studied. It should be pointed out that only CO_2 emissions from fossil fuel use were considered in the estimation. In addition, the contribution made by each of the treatment plant units to GHG emission was calculated. Carbon credit exchange might translate to a direct benefit of 0.21 € per m^3 of treated manure. Reducing GHG emissions should thus be considered as a complementary factor in the development of cleaner systems for manure management, yielding both environmental as well as financial advantages.

1. Introduction

In Castilla y León, a region located in Midwest Spain, the intensification of pig production has led to increased livestock wastes in small and localised areas, where the use of manure as an organic fertilizer has sparked a rise in nutrient concentration in soils, groundwater, and surface water. As part of the implementation of the Nitrate Directive of the European Union (91/676/CEE), Castilla y León has classified areas in terms of their vulnerability to water pollution by nitrogen (N) used in agriculture. In these vulnerable areas, N production in the form of animal manure exceeds a threshold of 170 kg ha^{-1} per year over the spreadable area and, as a consequence, a plan for disposing of excess N must be devised.

The most common management practice for liquid manure in Spain is to store it in mostly uncovered anaerobic tanks for between four and six months, prior to exportation for landspreading (Burton and Turner, 2003). Storing swine manure in anaerobic tanks entails a number of significant environmental impact issues, including ammonia and greenhouse gas (GHG) emissions, odours, pathogens, and water quality deterioration (Aneja et al., 2000; Loughrin et al., 2006; Mallin, 2000; Sobsey et al., 2001; Szogi et al., 2006; Vanotti et al., 2008). Moreover, livestock are responsible for 37% of anthropogenic CH_4 and 65% of anthropogenic N_2O, in addition to which some 30% of the GHG released are attributed to manure management (Bernet and Béline, 2009; Steinfeld et al., 2006). Alternative technologies for swine manure treatment must perforce be developed and implemented in order to achieve enhanced environmental protection, including the reduction of GHG emissions.

Capital investment has been identified as the most important challenge facing implementation of cleaner treatment technologies, since these prove very costly compared to conventional manure practices (Vanotti et al., 2008). Fortunately, by adopting the Kyoto protocol, new programmes have been developed aimed at reducing anthropogenic emissions of GHG. Such programmes can help offset the higher installation costs of cleaner technologies and, therefore, stimulate their adoption by pig farmers (Vanotti et al., 2008). However, few comparative studies have thus far explored the GHG emissions of the various manure management systems.

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http://dx.doi.org/10.1016/j.jclepro.2014.07.007
0959-6526/

Please cite this article in press as: Riaño, B., García-González, M.C., Greenhouse gas emissions of an on-farm swine manure treatment plant – comparison with conventional storage in anaerobic tanks, Journal of Cleaner Production (2014), http://dx.doi.org/10.1016/j.jclepro.2014.07.007

Such studies would prove key to improving current knowledge concerning the advantages of adopting manure treatment technologies, not only from an environmental perspective, but also from a financial standpoint, through carbon credit trading.

The present work seeks to estimate GHG emission reduction arising from the installation of a swine manure treatment plant as an alternative to conventional manure storage in anaerobic tanks in N vulnerable area of Castilla y León (Spain). In order to remove surplus nitrogen, the swine manure treatment plant was developed and put into operation at Cuellar (Segovia, Spain) on a farrow-to-finish farm which has approximately 300 sows (14,500 m^3 of manure generated per year). This on-farm system consists of three process units in series: screw pressing, enhanced solid–liquid separation with coagulants and flocculants, and biological nitrification-denitrification (NDN) of the liquid fraction (Riaño and García-González, 2014). Carbon dioxide, CH_4, and N_2O emissions in the storage tank (baseline scenario) and in the treatment plant were quantified using the guidelines proposed by the Intergovernmental Panel on Climate Change (IPCC) together with monitoring information collected during the study of the on-farm treatment plant over a five-month period.

2. Methods

2.1. Management scenarios and manure characteristics

Schematic diagrams of the two scenarios studied are shown in Fig. 1 and Fig. 2. The baseline scenario includes: (1) on-farm manure storage in anaerobic tanks over a six-month period, (2) transport to the spreading area and (3) injection into cropland (Fig. 1).

Greenhouse gas emissions from the baseline scenario were compared to those calculated for the treatment plant scenario (Fig. 2). The treatment plant scenario includes: (1) on-farm treatment using screw pressing followed by a coagulation-flocculation process, and nitrification-denitrification (NDN) of the liquid fraction, (2) transport and intermediate storage of the solid fractions produced during screw pressing and coagulation-flocculation steps at a distance of 1 km from the treatment plant, (3) further transport to an average distance of 12 km for land application and (4) spreading of solid fractions over cropland. Transport from the treatment plant to the intermediate storage area was by tractor, and transport from that intermediate storage for landspreading was by 16,000 kg truck. Biologically treated liquid fraction was stored in two ponds. The on-farm system removed approximately 71% of total solids (TS) and 97% of the total chemical oxygen demand (TCOD) from raw manure. It removed 97% of total Kjeldahl nitrogen (TKN), 98% of ammonium (NH_4^+-N), and 89% of the total phosphorous (TP) contained in the manure. In addition, the treatment plant allowed most of the microbes (*Escherichia coli* and *Salmonella*) and heavy metals (cooper and zinc) contained in raw manure to be removed (Riaño and García-González, 2014).

Data used to estimate GHG in both scenarios was obtained by monitoring the treatment plant over a five-month period. The characteristics of the raw manure, liquid manure before and after each treatment unit of the system, and separated solid fractions are shown in Table 1. Characterization of the treatment plant raw manure was also used to determine GHG emission for the baseline scenario. Manure was generated continuously throughout the year (approximately 14,500 m^3). During the monitoring period, the screw pressing unit produced an average of 407 kg d^{-1} of separated solids (on dry matter basis), whereas the coagulation-flocculation unit separated an average of 520 kg $d^{-1}$of solids (on dry matter basis) (Riaño and García-González, 2014). The scope of the present study is limited to manure management as manure production is considered to be identical in the two scenarios. This approach is common in other manure management researches (López-Ridaura et al., 2009), who compared the environmental performance of two scenarios of collective swine slurry management (namely, the transfer of slurry and its injection into cropland and the treatment of the slurry in a collective biological treatment station), developed in the Southeast of Bretagne (France).

2.2. GHG emission calculation

The most important GHG emissions during manure storage, treatment, and landspreading are (1) methane (CH_4) emissions produced during manure digestion under anaerobic conditions, and (2) nitrous oxide (N_2O) emissions during storage and manure handling. Carbon dioxide (CO_2) emissions from manure storage or treatment are not taken into account in the present study, since this is considered part of the so-called short-term carbon cycle, i.e. resulting from recent CO_2 uptake by crops (López-Ridaura et al., 2009). However, CO_2 emissions from fossil energy use are taken into account. Greenhouse gas emissions included in the boundary are calculated separately for both scenarios, following the same methodological approach. Annual GHG emissions were estimated by extrapolating GHG emissions calculated on the basis of the data obtained during the five-month monitoring period. Emissions of CH_4 and N_2O were expressed in terms of CO_2 equivalents using approved Global Warming Potentials (23 for CH_4 and 296 for N_2O) (IPCC, 2001).

2.2.1. Emissions derived from transportation

In the baseline scenario, the distance travelled from the farm to the receiving areas for nutrient disposal was calculated considering an average distance of 12 km using a semi-trailer truck equipped

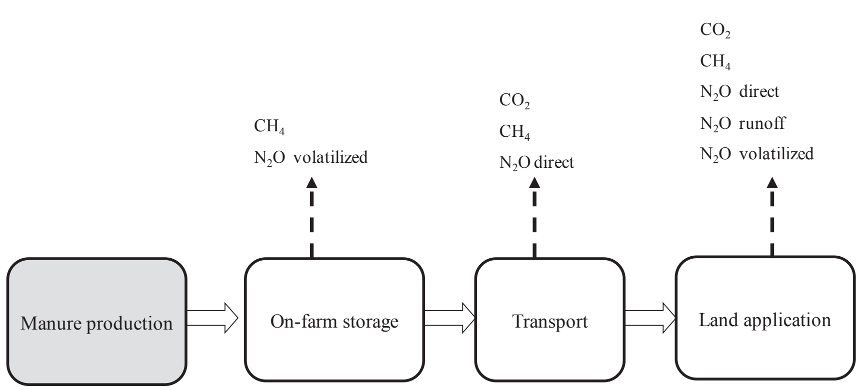

Fig. 1. Schematic diagram of the baseline scenario.