Agricultural Systems 138 (2015) 88–99

Contents lists available at ScienceDirect

Agricultural Systems

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

Integrated manure management to reduce environmental impact: II. Environmental impact assessment of strategies

J.W. De Vries [a,*], C.M. Groenestein [b], J.J. Schröder [c], W.B. Hoogmoed [d], W. Sukkel [e], P.W.G. Groot Koerkamp [b,d], I.J.M. De Boer [a]

[a] Animal Production Systems Group, Wageningen University, P.O. Box 338, Wageningen, 6700 AH, The Netherlands
[b] Wageningen UR Livestock Research, Wageningen University and Research Centre, P.O. Box 135, Lelystad, 6700 AC, The Netherlands
[c] Plant Research International, Wageningen University and Research Centre, P.O. Box 616, Wageningen, 6700 AP, The Netherlands
[d] Farm Technology Group, Wageningen University, P.O. Box 317, Wageningen, 6700 AH, The Netherlands
[e] Applied Plant Research, Wageningen University and Research Centre, P.O. Box 430, Lelystad, 8200 AK, The Netherlands

ARTICLE INFO

Article history:
Received 10 December 2013
Received in revised form 21 February 2015
Accepted 13 May 2015
Available online 19 June 2015

Keywords:
Nitrogen use efficiency
Slurry management
Crop production
Ammonia
Greenhouse gases
LCA

ABSTRACT

Manure management contributes to adverse environmental impacts through losses of nitrogen (N), phosphorus, and carbon (C). In this study, we aimed to assess the potential of newly designed strategies for integrated manure management (IS) to reduce environmental impact. An important aspect of the strategies was that they prevented pollution swapping. Life cycle assessment was used to compute climate change (CC), fossil fuel depletion (FFD), terrestrial acidification (TA), marine eutrophication (ME), particulate matter formation (PMF), N use efficiency (NUE), and phosphorus over application rate (POA), relative to the crop demand for N. We applied the IS to North West European practice (Ref) and included the Dutch current situation of progressive manure management (NL) to illustrate the potential of the IS to reduce environmental impact. Manure management in Ref included production and management of liquid and solid dairy cattle manure applied to maize and grass, and liquid pig manure applied to wheat. A Monte Carlo uncertainty simulation was done to assess the effect of variation in N and C losses and N uptake by crops on the comparison with Ref, IS, and NL. Results showed that the IS reduced all environmental impacts in all manure product and crop combinations and more than doubled the NUE (70% compared with maximum 33% in Ref). Main causes were: segregation of pig and dairy cattle urine and feces inside the housing system reduced methane (CH_4) and ammonia (NH_3) emissions; addition of zeolite to solid dairy cattle manure reduced NH_3 emission; sealed storages in all IS reduced volatilization of N and C; bioenergy production from the feces reduced the production of fossil electricity and heat; and finally N emissions in the field were reduced by ammonia emission reducing application techniques and improved application management (tillage, field traffic en synchronization of manure product application with crop demand). Compared with the Ref, NL had lower TA, PMF, POA, and higher NUE, except for solid cattle manure applied to grass. This result indicates that the Dutch regulations to reduce NH_3 emissions were successful, but that CC can be improved. Compared with NW EU practice, IS reduced environmental impact up to 185% for CC, up to >700% for FFD, up to 96% for TA, up to 99% for ME, up to 100% for PMF, up to 110% for POA and more than doubled the NUE. We concluded that the designed IS avoid pollution swapping in the entire manure management system.

1. Introduction

In livestock production, management of animal manure leads to major losses of nitrogen (N), phosphorus (P), and carbon (C). Manure management includes collection inside the housing system, storage (inside and outside), processing, and field application. In the European Union (EU), about 149 Mtons of liquid pig manure, 448 Mtons of liquid cattle manure and 295 Mtons of solid cattle manure are produced (Henning Lyngsø et al., 2011), of which the Netherlands contributes considerably with 7% of the liquid pig manure, 10% of the liquid cattle manure. The production of solid manure is low with 0.04% of the EU production (CBS, 2011). Production of solid cattle manure in the Netherlands is currently increasing, as a result of initiatives to improve animal welfare. In the EU, only about half of the nitrogen (N) and 70% of the P excreted by animals is recycled as crop nutrient (Bouwman et al., 2009; Oenema et al., 2007), the rest is lost to the environment causing adverse environmental impacts, such as climate change, terrestrial acidification, and marine eutrophication. To reduce environmental impacts, European directives, such as the Nitrates Directive (91/676/EEC), the National Emission Ceilings (NEC) Directive

* Corresponding author. Tel.: +31 317 482980; fax: +31 317 483962.
E-mail address: jerkewdevries@gmail.com (J.W. De Vries).

http://dx.doi.org/10.1016/j.agsy.2015.05.006
0308-521X/

(2001/81/EC) and the Water framework Directive (200/60/EC) were implemented in order to reduce emissions from all Member States (EC, 2012; EU, 2013).

To reduce losses of N, P, and C from manure management and, therefore, improve the efficiency of using N and P from manure, different strategies have been proposed (Burton and Turner, 2003; Sommer and Hutchings, 2001). Most strategies, however, focus on a single aspect of the manure management system, such as reducing ammonia (NH_3) emission from outside manure storage by covering, or reducing NH_3 emission from manure application by injection instead of broadcast spreading. Such single-issue strategies often cause reduction of one type of emission while increasing another type of emission, a phenomenon referred to as 'pollution swapping'. We formulated strategies for integrated manure management of pig and dairy cattle manure to reduce environmental impact throughout the manure management system by using a structured design approach (De Vries et al., 2015). These strategies aim to reduce emissions of N, P and C and the use of fossil energy along the entire manure management system, or in other words, prevent pollution swapping. To validate this approach, we perform a quantitative assessment of the potential of these strategies to reduce the environmental impact. Life cycle assessment is (LCA) is a generally accepted method to quantify the environmental impact along the life cycle of a product (ISO-14040, 2006).

The aim of this study was to assess the potential of the newly designed strategies for integrated pig and dairy cattle manure management, as designed by De Vries et al. (2015), to reduce environmental impact. We quantified the environmental impact, the N use efficiency (NUE), and P over application rate (as phosphorus pentoxide, P_2O_5) along the manure management system and demonstrated the potential to reduce environmental impact for the case of North Western Europe and the Netherlands.

2. Materials and methods

2.1. LCA approach

In this study, we considered the changes in environmental impact of the strategies, or in other words, performed a consequential LCA (Finnveden et al., 2009). We, therefore, included all environmental impacts from processes that were affected by changes in the manure management system (Weidema et al., 2009).

2.2. Manure management and system boundaries

The manure management system included the manure storage in the animal house, outside manure storage, manure processing, transport, and field application of manure, soil tillage and in-field traffic, and crop uptake of N until harvest. External processes included production of mineral fertilizer and production of electricity, heat, and fuel (Fig. 1). Avoided mineral fertilizer production was included, because the nutrients in the manure products (N, P, and potassium (K)) were considered to substitute nutrients from mineral N, P, and K fertilizers. Similarly, electricity and heat production were avoided with production of bio-energy. Animal production, crop management and transport were outside the system boundary, as they were assumed not to be affected by manure management strategies. Furthermore, emission from transport of manure was not considered, as we assumed the same distances to apply for all situations. Emissions associated with the production of capital goods, such as the installations for manure processing, were excluded from the calculations.

2.3. Unit for comparison

The main function of the manure management systems compared was to manage livestock excreta from the moment of excretion until field application as fertilizer. We, therefore, used a common unit of 1 t excreted urine and feces, either mixed in liquid manure, or kept separate. The same chemical composition of excreta ensured that the same amount of nutrients and dry matter entered each management system.

2.4. Definition of the NW EU reference, Dutch situation and strategies

We applied the strategies for integrated manure management (IS) to current North West European (NW EU) practice (Ref) and used the Dutch situation to represent current progressive manure management (NL). NW EU represents intensive livestock and manure production. In Ref and NL, liquid cattle manure was applied to grassland and arable land for production of silage maize, whereas liquid pig manure was used for wheat production. Solid dairy cattle manure was applied to grassland.

In Ref, liquid pig and cattle manure were produced in a housing system with slatted floors. Manure was stored in-house for an average period of 5 months and in an outside storage tank without cover for an average period of 1 month (Table 1) (Burton and Turner, 2003;

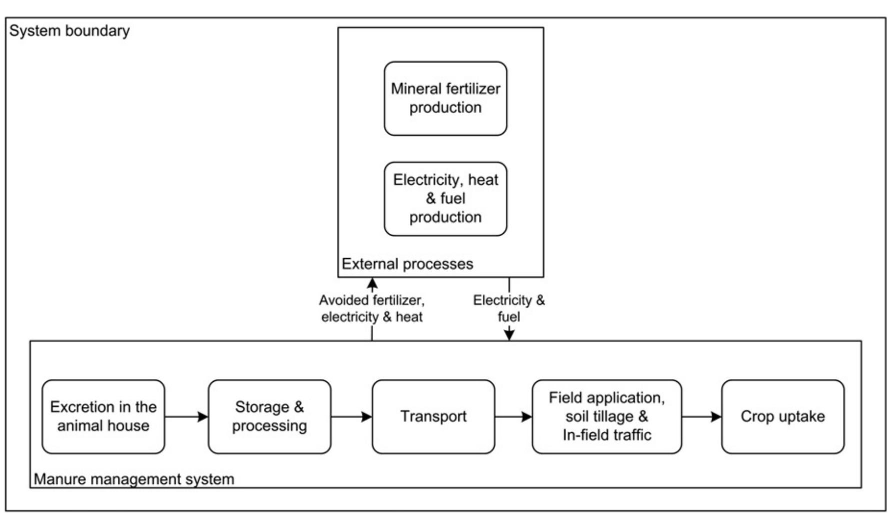

Fig. 1. Manure management system and external production processes that are included in the system boundary: electricity and fuel, and substituted processes: mineral fertilizer, electricity, and heat.