ANIMALCHANGE

SEVENTH FRAMEWORK PROGRAMME

THEME 2: FOOD, AGRICULTURE AND FISHERIES, AND BIOTECHNOLOGIES

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DELIVERABLE **6.2**

Deliverable title: Report on the extent to which manure management might help decrease GHG gas from animal agriculture

Abstract:

Objective

Deliverable D6.2 reviews the greenhouse gas mitigation potential of manure management options in both extensive and intensive ruminant systems and in pig and poultry systems from the project regions (Europe, Latin America and Africa).

Methods

Based on published and unpublished data from the research institutions, the mitigation potential of mitigation options, the potential size of the reduction in GHG emissions for manure management has been quantified by desktop studies. The diversity of livestock production systems, and their associated manure management, is discussed on the basis of three regional cases (Sub-Saharan Africa, Latin America and Europe) with increasing levels of intensification and priorities with respect to nutrient management and environmental regulation. GHG mitigation options for production systems based on solid and liquid manure management are presented, and potentials for positive and negative interactions between pollutants, and between management practices, are discussed.

Results & Implications

Ongoing intensification and specialization of livestock production leads to increasing volumes of manure to be managed, which are a source of the greenhouse gases methane (CH_4) and nitrous oxide (N_2O). Growth in livestock populations are projected to occur mainly in intensive production systems where the largest potentials for manure GHG mitigation may be found. Net emissions of CH_4 and N_2O result from a number of microbial activities in the manure environment. Their relative importance depends not only on manure composition

and local management practices with respect to treatment, storage and field application, but also on ambient climatic conditions.

Integrated crop and livestock production systems are suggested to improve nutrient use efficiency and to reduce GHG emissions in mixed farming systems. In extensive ruminant systems, the priority is to improve nutrient use efficiency both for increasing crop yields (improved livestock manure storage conditions, targeted use of manure nutrients, development of anaerobic storage) and reducing GHG emissions per unit animal product (improved animal breeds, improved animal nutrition through pasture intensification). In intensive ruminant systems and monogastric systems, improving capacity of livestock manure storage and containment is a key issue. Where farm effluents are to some extent ‘wasted’ by direct discharge into water courses, infrastructure is required to enable farmers to store livestock manures. Containment is also an issue in large-scale intensive livestock production, where NH_3 emissions in particular represent a threat to natural environments and human health in addition of being an indirect source of N_2O. With intensive systems, the imbalance between nutrients in livestock manure and need of land available for manure recycling is also a challenge as spreading of manure N in excess of crop requirements increases the potential for environmental losses, including emissions of NH_3, N_2O and other N compounds.

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Authors: Mélanie Blanchard and Philippe Lecomte (CIRAD), Soren Petersen (AU-DJF)

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1. Introduction

AnimalChange will provide scientific guidance on the integration of adaptation and mitigation objectives and design of sustainable development pathways for livestock production in different parts of the world.

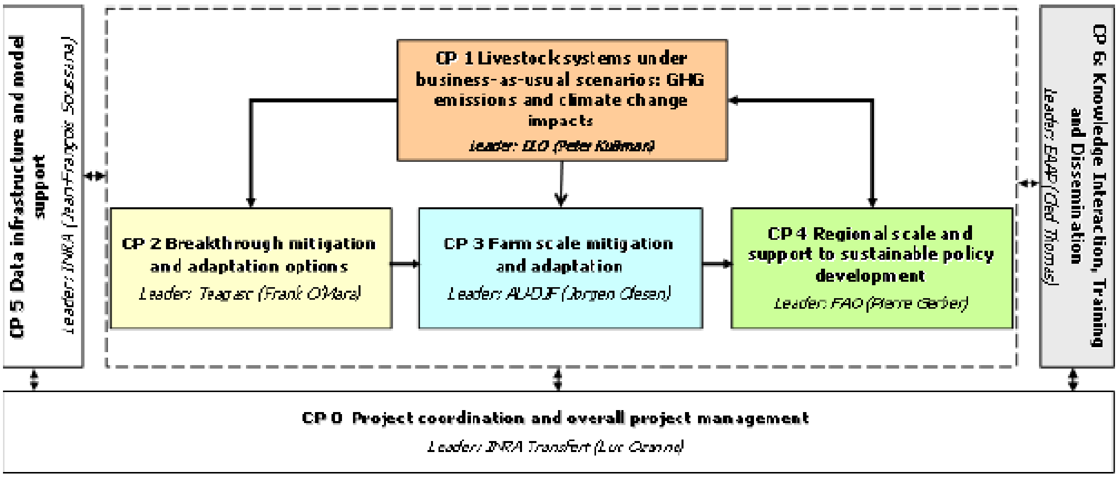
In Component 2, (see fig. 1), an important part of AnimalChange focuses on the options for mitigation and or adaptation. It identifies at the animal and field scales the most promising options available to animal agriculture, and assesses interactions between them. The work will extend to determining and investigating the size of the mitigation potential for the various options, the variation around this mitigation potential, and the causes of this variation with a view to trying to implement more robust and dependable mitigation strategies.

Component 2 gather three Workpackages:

WP 6 -Breakthrough biophysical mitigation options

WP 7 -Breakthrough biophysical adaptation options

WP 8- Integrating adaptation and mitigation options



The current deliverable (D6.2) is part of WP6. WP 6 objective is to identify new and forthcoming mitigation options and quantify both the potential size of the reduction in GHG emissions obtainable and the uncertainty associated with this reduction. It will provide the data on mitigation options that will power the modeling activities in Components 3 and 4. WP6 focus on mitigation in both extensive and intensive ruminant systems and monogastric systems. In the first task “Manure management” mostly desktop studies, and limited experimental evidence (AU-DJF, CIRAD) is reviewed. Based on published and unpublished data existing in the institutions the mitigation potential of promising technologies is assessed having in scope the framework of farm-scale models to be developed in Component 3 on GHG emissions from manure as influenced by specific manure treatment processes (including anaerobic digestion to produce CH_4 and use it as a source of energy) and management strategies. The uncertainty analysis of Component 1 will be adopted for a critical assessment of mitigation potentials. Specifically, knowledge about biogas and energy generation potentials of manure from intensive farming of pigs, broilers and cattle in Europe will be collected. In Africa and South America, the knowledge about biogas yields is sparse and it has been proposed to carry out a screening examination of the biogas potentials of excretal returns from the different animal categories in these regions.

This deliverable (D6.2) is a step in this process. It reports on the extent to which manure management can decrease emissions of CH_4 and N_2O in animal production systems, in Sub-Saharan Africa, Europe and South America. It describes manure management practices in different livestock systems and GHG mitigation measures by handling and treatment of manure.

Three meetings were held in relation to this deliverable during the annual meetings of AnimalChange Edinburgh, 2012; Dublin, June 2013, Dublin GAAAC 2013 and a collective paper (see annex 1) was published in an international journal (Petersen *et al.*, 2013).

Section 2 focuses on livestock system and manure management system in Sub-Saharan Africa, Western Europe and Latin America. Section 3 describes GHG mitigation potentials via changes in manure management. Section 4 describes measures of GHG mitigation by treatment of the manure and land spreading. Finally, Section 5 provides some concluding remarks.

2. Livestock system and manure management system in Sub-Saharan Africa, Western Europe and Latin America

GHG emissions from manure management vary with manure type, manure management practices, manure management systems and the proportion of manure managed in each systems. In addition, climatic conditions play an important role in GHG emissions from manure.

Manure management can lead to methane (CH_4) and nitrous oxide (N_2O) emissions. **CH_4** is released from all manure environments from the anaerobic decomposition of organic material occurring with manure storage both in liquid systems and compacted manure (Osada *et al.*, 2000; Chadwick *et al.*, 2011). In addition, higher ambient temperature and moisture content also favor CH_4 emission. Frequent removal of manure under cool temperate climates had been proposed to reduce CH_4 emissions (Sommer *et al.*, 2009). CH_4 emission is affected by type of treatment, storage facility, climate and composition of the manure directly related to animal types and diets. Manure CH_4 emissions are lower in regions with dry systems manure handling (drylot, solid storage, Africa, Latin America). In liquid manure systems, the proportion of manure CH_4 emissions in total CH_4 emissions is considerable, particularly in regions where animals are confined (e.g. West- Europe).

During handling, storage and spreading oxidized nitrogen leads to **N_2O** emission and to ammonia (NH_3) volatilization and nitrate leaching (NO_3^-). N_2O emissions are influenced by the amount of N excreted and in dry manure handling systems (drylot, solid systems) by the interfaces between oxic-anoxic states.

2.1. Livestock systems and manure management systems in Sub-Saharan Africa

Sub-Saharan Africa is characterized by extensive subsistence farming. Cropping systems are dominated by corn, sorghum and millet and cotton production, and the area available for grazing is limited. Livestock consists mainly of cattle at 0.08-4.8 TLU ha^{-1}(Anon. 2007), where 1 TLU (tropical livestock unit = 250 kg liveweight; Hoffmann *et al.*,2001). During the dry season, animals are confined and fed crop residues. When the agricultural season begins, shepherds lead their livestock to graze pastures either near the farm or through transhumance.

There is a diversity of animal manure systems across farms (Manlay *et al.*, 2002; Blanchard *et al.*, 2013). The main priority is recycling of organic matter and nutrients for crop production. Garbage piles with domestic waste, daily sweepings and faeces from small ruminants, may be produced in the homestead area. Confining animals helps produce organic fertilizers in significant quantities by facilitating manure collection. Some farmers add bedding material and feed leftovers to the pen or animal shed (Landais and Guérin, 1992, Landais and Lhoste, 1993,Ganry *et al.*, 2001), which further increases the quantity and nutrient content of manure since nutrients in urine are trapped by the litter. Household compost may be produced in pits near the homestead area based on animal faeces, feed and crop residues, and domestic waste (Ganry *et al.*, 2001).

Estimates of nutrient cycling and losses associated with manure management in South Mali indicate that 46 % of the N in crop residues and faeces is returned to the soil of common pastures or areas of transhumance, while 13% is lost in gaseous forms at the time of excretion. Organic manure produced on the farm represents 24% of the N and17% is lost through leaching or in gaseous form during handling and storage of manure and compost

(Blanchard *et al.*, 2013). The N cycling efficiencies were close to those reported by Rufino *et al.* (2007) of 13-28%. With the rising price of mineral fertilisers, reduction in fertiliser subsidies, and programs promoting organic manure quality, there is an increasing focus on efficient use of nutrients in livestock manure.

Manure management systems for dairy and beef production according to the definitions by IPPC 2006 is burned for fuel (6.9% and 6.2 % respective), or managed in drylots (34.5 and 34.3 respective), pastures or ranges (39.7% and 46.6 % respective) or as solid storage (18.5 % and 13 % respective; FAO, 2013) (Tables 1 and 2).

Mitigation options proposed are to cover the pit and compost on floors (Rufino *et al.* 2006), limit the storage time (Tittonell *et al.*, 2010) and confine the animals by improving forage availability and quality (Landais and Lhoste, 1993).

2.2. Livestock systems and manure management systems in Western Europe

European livestock production is increasingly intensive, with specialization and mechanization leading to larger farms (Burton and Turner, 2003). Intensive systems are dominated by cattle, pigs and poultry, with less than 10% of animal feed produced on the farm (Kruska *et al.*, 2003). The geographic uncoupling of feed production leads to the concentration of nutrients in livestock-intensive areas

Large proportions of the total nutrient intake are excreted: 60-70% of ingested N for fattening pigs and laying hens, and 70-90% for cattle depending on physiological stage (Peyraud *et al.*, 2012). Manure is commonly used as a fertilizer on the farm, but transfer between farms is also seen in regions with high livestock densities. Regulations allow to prevent discharge to rivers and streams. The EU Nitrates Directive stipulates a maximum annual application of 170 kg ha^{-1} of manure N (EC, 1991). Derogations exist that allow higher rates for crops with a high N uptake potential. Nutrient recycling is a challenge for large livestock farms with little or no land.

In Western Europe, 26.6 -47.6 % of livestock excreta (respectively for dairy or beef production) are deposited during grazing and thus not handled. The remaining is collected in housing systems, a percentage that tends to increase (FAO, 2013). Manure management systems producing solid manure represent 29.5 and 25.9 % of excreta for dairy and beef production, respectively. The remainder is handled as slurry that is either stored in pits beneath animal confinements or in outside tanks (Oenema *et al.*, 2007; 41.6 and 22.1 %, respectively, for dairy and beef production, FAO, 2013). However, the proportion of manure in liquid form varies considerably between countries. It is generally higher (>65%) in central and northern Europe, even reaching more than 95% in the Netherlands, and lower (<50%) in UK, France and some parts of Eastern Europe where housing systems are often associated with bedding materials (Tables 1 and 2).

Farmers adopt liquid manure management systems for easier handling, higher percentage of plant-available N (higher mineral N-to-organic N ratio), reduced straw requirements since the availability and the price of straw is a constraint. There also several options for treatment with a potential to improve manure quality and reduce losses towards the environment (mechanical separation, aeration of slurry, biogas production).

2.3. Livestock systems and manure management systems in Latin America

In central and south America, a small proportion of the dairy manure is burned for fuel (0.4 %). The majority of dairy production manures is deposited on pasture or range (53.5 %) or managed in drylot (41.5 %) and a small portion is handled in solid form (4.7 %). There is no management of liquid manures (slurry or uncovered anaerobic lagoon; FAO, 2013) (Tables 1 and 2).

With beef production, without animal containment systems, manure for the most part is directly deposited on pastures or range (91.8 %). A small proportion is managed in drylot (4.8 %) or solid form (3.2 %).

In the more intensive livestock systems, pigs, poultry and even cattle, the farms that are focused on the production of milk or meat are becoming better monitored. There is a growing interest for conventional measures to mitigate the impacts (e.g. composting, biogas, etc.) and for crop fertilization by manure. On the other hand, these mitigation measures have a high cost and are unevenly distributed across farms.

For grazing livestock systems, GHG mitigation can be obtained through increases in production efficiency through changes in animal breeds and improved breeding and through pasture intensification that can lead to a lower production of manure per unit of meat and milk produced.

Another measure is the use of additives that may improve feed efficiency. For instance, the supply of mineral salts to grazing livestock is an important practice for farmers.

3. GHG mitigation potentials by manure management

3.1. Housing

3.1.1. Diet manipulation and nutrient balance

Diet has a direct effect on CH_4 emissions from enteric fermentation and an indirect effect on CH_4 emissions during storage, by affecting manure composition (Hindrichsen *et al.*, 2005). Decreased digestibility of dietary nutrients is expected to increase organic matter concentration in manure, which may increase manure CH_4 emission.

The effect of diets on denitrification and N_2O emission is related to the animal protein balance. An excess dietary protein will increase N excreted in manure and N_2O emission following land application. A reduction in manure N concentration will also reduce manure N_2O emissions (Misselbrook *et al.*, 1998). Inclusion of some natural compounds (such as tannins from pasture legumes, *e.g.* from birdsfoot trefoil) in the diet can increase the proportion of N excreted as organic N by faeces and reduce the excretion of urea-N in urine, thereby reducing the potential for NH_3 and N_2O emissions (Misselbrook *et al.*, 2005). However, such dietary changes may also affect the animal protein supply.

3.1.2. Manipulation of storage temperature

Higher ambient temperature and higher manure moisture content favor CH_4 emissions (

Table 3). Cooling of slurry below slatted floors to 10°C has been found to reduce CH_4 emissions by 30-46% compared to the situation without cooling (Sommer *et al.*, 2004; Groenestein *et al.*, 2012). Efficacy will depend on the methanogenic potential of the slurry. Studies find significant (50-86%) reductions in GHG emissions (CH_4+N_2O) from pig housing with frequent manure removal (Groenestein *et al.*, 2012).

3.2. Solid manure

3.2.1. Composting

During composting, microorganisms under exothermic and aerobic conditions, transform degradable organic matter into CO_2 and water. This process has several benefits to manure handling, odor control, manure moisture and pathogen control, organic matter stabilization, etc. Composting of solid manure is used as bedding in dairy production systems to reduce cost of production and provide cow comfort (Husfeldt *et al.*, 2012). Aeration may reduce CH_4 emissions, but increase N_2O and NH_3 emissions (Pattey *et al.*, 2005; Webb *et al.*, 2012). Manure can either be left undisturbed during the composting process, mechanically turned, or actively aerated. Combined CH_4 and N_2O emissions are generally lower after forced aeration and turning compared to passive composting (Table 4)

3.2.2. Cover of solid manure during storage

Covering solid manure during storage with straw or a plastic sheet reduces N_2O and CH_4 emissions (Table 4). Yamulki (2006) reports reductions of -42 to -11% for N_2O emission with straw cover on farmyard manure, and -45 to -50% for CH_4 emission (comparison with uncovered manure in CO2 equivalents).

However, different studies report both a reduction (-17 to -98%) and an increase (+111%) in CH_4 and N_2O emissions after covering poultry and cattle solid manure with a plastic sheet (Chadwick, 2005, Hansen *et al.*, 2006, Thorman *et al.*, 2006). Covering heap manure may also reduce ammonia emissions (Chadwick, 2005; Webb *et al.*, 2012).

3.3. Liquid manure

3.3.1. Cover of slurry during storage

Covers on slurry during storage are mainly adopted to reduce NH_3 emissions. N_2O emissions from liquid manure are negligible during storage without surface crust (VanderZaag *et al.*, 2009). Potentials for nitrification and denitrification can develop and lead to N_2O emissions if crust dries and oxygen enters the crust (Sommer *et al.*, 2000; Petersen *et al.*, 2013).

Reported values (Table 5) show that covering slurry (from cattle or pigs) with either a solid cover or a straw cover often results in lower CH_4 emissions (to -28 to +37% with straw cover and -70 to -14% with solid cover), higher N_2O emissions (+57 to +100% with straw cover and -50 to +30% with solid cover), and in general a reduction of overall GHG emissions in CO_2 equivalents when compared to uncovered slurry (VanderZaag *et al.*, 2009; Guarinon *et al.*, 2006; Berg *et al.*, 2006; Amon *et al.*, 2007; Clemens *et al.*, 2006).

4. GHG mitigation potentials by treatment manure and land spreading

4.1. Treatment technologies

4.1.1. Manure separation

Manure separation is a process where a fraction of slurry particles is isolated by one of several mechanical separation processes (Burton, 2007). Storage of the liquid fraction may result in lower N_2O emissions than untreated slurry if crust formation is prevented. However, N_2O emissions from the solid fraction during storage can be high (Fangueiro *et al.*, 2008), and thus overall N_2O emissions during storage may increase significantly after separation without additional measures. Separate storage of the liquid and solid fractions after manure separation have in most cases, resulted in lower CH_4 emissions (Table 6).

Likewise, combined CH_4 and N_2O emissions from storage of both separation products have usually, but not always, been lower than from untreated manure (Dinuccio *et al.* 2008; Mosquera *et al.*, 2011). Slurry separation requires additional measures to achieve GHG mitigation during subsequent storage: cover solid and liquid fractions or anaerobic digestion of solid fraction (Sutaryo *et al.*, 2012).

4.1.2. Anaerobic digestion

Anaerobic digestion optimises the methanogenesis from manure. Degradable organic matter in manure and other organic substrates is transformed into biogas (mainly CO_2 and CH_4).

The process provides energy substituting fossil fuel. It reduces the potential for CH_4 emissions during subsequent storage. But an enriched methanogenic microflora in digested slurry will continue to produce CH_4 at high rates during the cooling phase (Sommer *et al.*, 2000). CH_4 emission must be collected to retain potential GHG mitigation. Studies show a reduction in CH_4 (-32 to -68%), and in GHG emission in CO_2 equivalents (-14 to -59%) from storage of digested manure compared to untreated cattle slurry (Table 6).

4.1.3. Aeration

Studies reported a reduction in CH_4 emission (-35 to -99%) with aeration of cattle and pig slurry (Amon *et al.*, 2006; Martinez *et al.*, 2003). Amon *et al.* (2006) reported, however, an increase in N_2O emission (by 144%) with aeration of cattle slurry (Table 6).

The overall potential for loss of N as NH_3 or denitrification products will be high during aeration, and N_2O emissions as high as 19% of total N in pig slurry have been reported (Chadwick *et al.*, 2011). Hence, measures to conserve N during aeration would be needed to ensure GHG mitigation via this treatment.

4.1.4. Additives and acidification

Chemical additives change the chemical environment of slurry and may alter the formation of CH_4 and N_2O (Table 6). Martinez *et al.* (2003) reported reductions in CH_4 emission of 47-64% by different chemical additives in pig slurry (NX13, Staloson or Biosuper). In 2012, around 10% of the total slurry volume in Denmark was acidified to a pH around 6 by one of several technologies. Acidification by sulphuric acid reduce CH_4 emissions from cattle slurry by 67-87% (Petersen *et al.*, 2012), and from pig slurry by 94-99%, (Petersen; unpublished results) during 3-month storage periods.

4.2. Land spreading

4.2.1. Application method, rate and timing

Emissions of CH_4 after land spreading of manures are insignificant (Collins *et al.*, 2011) relative to the large losses from manure storage and enteric fermentation. Measures to reduce N_2O emissions after land spreading include choice of application method, and optimising rate and timing of application to match crop requirements, and a complex interaction with soil type and soil moisture (Thomsen *et al.*, 2010).

Choice of manure application technique appears to have little impact on direct N_2O emissions and indirect emissions due to NH_3 emissions and nitrate leaching (Velthof et al, 2010). There is an increase of N_2O emissions curvi-linearily when N application rates exceed crop N requirements (Van Groenigen *et al.*, 2004; Cardenas *et al.*, 2010). Proper timing of application has been shown to influence both direct and indirect N_2O emissions after land spreading of manures (Weslien *et al.*, 1998; Chambers *et al.*, 2000; Thorman *et al.*, 2007).

4.2.2. Use of nitrification inhibitors

Synthetic nitrification inhibitors have been developed to promote plant N uptake by reducing losses via NH_3 leaching or denitrification. Research has re-focussed to mainly consider effects of nitrification inhibitors on both direct and indirect N_2O emissions from N amendments to soil (Di and Cameron, 2012).

Laboratory studies (Hatch *et al.*, 2005) report greater inhibition of N_2O than field studies. Dittert *et al.*, (2001) suggests that soil conditions, variations in temperature or leaching/runoff after excessive rainfall, reduces the effect of nitrification inhibitors. Efficiency of nitrification inhibitors declines linearly with soil temperature above 10°C (higher nitrification rates and rapid nitrification inhibitors degradation; Subbarao *et al.*, 2006).

Table 1 . Relative importance (%) of manure management systems for dairy production in world regions (FAO 2013)

Manure management system	North America	Russian Federation	Western Europe	Eastern Europe	Near East and North Africa	East and South east Asia	Oceania	South Asia	Central South America	Sub-Saharan Africa
Burned for fuel	0,0	0,0	0,0	0,0	3,6	1,5	0,0	20,0	0,4	6,9
Daily spread	9,5	0,0	2,3	1,4	0,0	0,0	1,2	0,0	0,0	0,0
Drylot	0,0	0,0	0,0	0,0	39,4	29,1	0,0	54,4	41,5	34,5
Uncovered anaerobic lagoon	27,2	0,0	0,1	0,0	0,0	0,0	4,6	0,0	0,0	0,0
Liquid / Slurry	26,3	0,0	41,6	10,2	0,0	3,1	0,1	0,0	0,0	0,0
Pasture/range	11,8	22,5	26,6	17,0	46,1	30,7	94,2	23,5	53,5	39,7
Solid storage	25,2	77,5	29,5	71,3	10,9	35,7	0,0	2,0	4,7	18,5

Table 2 . Relative importance (%) of manure management systems for beef production in world regions (FAO 2013)

Manure Management system	North America	Russian Federation	Western Europe	Eastern Europe	Near East and North Africa	East and South east Asia	Oceania	South Asia	Central south America	Sub-Saharan Africa
Burned for fuel	0,0	0,0	0,0	0,0	9,3	0,6	0,0	20,0	0,2	6,2
Daily spread	0,0	0,0	4,2	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Drylot	12,8	0,0	0,1	0,0	34,5	33,9	0,0	58,2	4,8	34,3
Uncovered anaerobic lagoon	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Liquid / Slurry	0,7	0,0	22,1	65,0	0,0	0,0	0,0	0,0	0,0	0,0
Pasture/range	43,4	0,0	47,6	33,0	42,8	27,7	100,0	20,3	91,8	46,5
Solid storage	43,2	0,0	25,9	2,0	12,9	37,8	0,0	1,4	3,2	13,0

Table 3. Effect of different mitigation options during housing on CH_4, N_2O and GHG emissions in CO_2 equivalents as a percentage change compared to the untreated manure.

Mitigation options	Animal category	Manure management system	N_2O	CH_4	CH_4 and N_2O	Reference
Frequent manure removal	Pigs		-39	-56	-51	Amon *et al.*, 2007
	Pigs			-40		Haeusserman *et al.*, 2006
	Weaned pigs		0	-50	-50	Groenestein *et al.*, 2011
	Fatteners		0	-86	-86	Groenestein *et al.*, 2011
Cooling	Pigs	Slurry		-31		Sommer *et al.*, 2004
	Fatteners	Slurry		-43		Groenestein *et al.*, 2011
	Nursing sows	Slurry		-46		Groenestein *et al.*, 2011
	Gestating sows	Slurry		-33		Groenestein *et al.*, 2011
	Weaned pigs	Slurry		-30		Groenestein *et al.*, 2011

Table 4. Effect of different mitigation options during housing on CH_4, N_2O and GHG emissions in CO_2 equivalents as a percentage change compared to the untreated manure.

Mitigation options	Animal	Manure management system	N_2O	CH_4	CH_4 and N_2O	Reference
Forced composting	Cattle	Farmyard manure	-35	-90	-78	Amon *et al.*, 2001 (Summer)
	Cattle	Farmyard manure	-41	+32	-7	Amon *et al.*, 2001 (winter)
	Cattle	Farmyard manure	+44	-81	-34	Pattey *et al.*, 2005
	Cattle	Farmyard manure		-28		Hao *et al.*, 2001
Straw cover	Cattle	Farmyard manure (conventional farm)	-42	-45	-42	Yamulki, 2006
	Cattle	Farmyard manure (organic farm)	-11	-50	-14	Yamulki, 2006
Plastic sheet cover	Cattle	Solid manure	-70	-6	-36	Chadwick, 2005
	Cattle	Solid manure	+2000	-81	-17	Chadwick, 2005
	Cattle	Solid manure	-54	+120	+111	Chadwick, 2005
	Pigs	Solid fraction of digested manure	-99	-87	-98	Hansen *et al.*, 2006
	Poultry	Poultry manure	-32			Thorman *et al.*, 2006
	Poultry	Poultry manure	+304			Thorman *et al.*, 2006

Table 5. Effect of different mitigation options during housing on CH_4, N_2O and GHG emissions in CO_2 equivalents as a percentage change compared to the untreated manure.

Mitigation options	Animal category	Manure management system	N_2O	CH_4	CH_4 and N_2O	Reference
Straw cover	Cattle	Slurry (straw layer 15 cm)	+57	-25	-23	VanderZaag *et al.*, 2009
	Cattle	Slurry (straw layer 30 cm)	+100	-27	-24	VanderZaag *et al.*, 2009
	Cattle	Slurry (straw layer 7 cm)		+37		Guarino *et al.*, 2006
	Cattle	Slurry (straw layer 14 cm)		+3		Guarino *et al.*, 2006
	Pigs	Slurry (straw layer 7 cm)		+7		Guarino *et al.*, 2006
	Pigs	Slurry (straw layer 14 cm)		-28		Guarino *et al.*, 2006
	Pigs	Slurry (straw layer 6-8 cm)		+22	+238	Berg *et al.*, 2006
Solid cover	Pigs	Slurry (warm period, 50 days)	+30	-32	+1	Amon *et al.*, 2007
	Pigs	Slurry (warm period, 200 days)	-4	-70	-52	Amon *et al.*, 2007
	Pigs	Slurry (cold period, 50 days)	-50	-37	-48	Amon *et al.*, 2007
	Cattle	Slurry (winter)	-13	-14	-13	Clemens *et al.*, 2006
	Cattle	Slurry (summer)	+20	-16	-11	Clemens *et al.*, 2006
	Cattle	Digested slurry (winter)	+2	-29	-4	Clemens *et al.*, 2006
	Cattle	Digested slurry (summer)	-19	-14	-16	Clemens *et al.*, 2006

Table 6. Effect of different mitigation options during housing on CH_4, N_2O and GHG emissions in CO_2 equivalents as a percentage change compared to the untreated manure.

Mitigation options	Animal	Manure management system	N_2O	CH_4	CH_4 and N_2O	Reference
Manure separation	Pigs	Slurry (5°C)	0	-8	-8	Dinuccio *et al.*, 2008
	Pigs	Slurry (25°C)		+3	+41	Dinuccio *et al.*, 2008
	Cattle	Slurry (5°C)	0	+4	+4	Dinuccio *et al.*, 2008
	Cattle	Slurry (25°C)	0	-9	-9	Dinuccio *et al.*, 2008
	Cattle	Slurry	+1133	-34	-23	Fangueiro *et al.*, 2008
	Cattle	Slurry + wooden lid	+10	-42	-39	Amon *et al.*, 2006
	Pigs	Slurry		-93	-29	Mosquera *et al.*, 2011
	Cattle	Slurry		-42	+25	Mosquera *et al.*, 2011
	Pigs	Slurry		-18		Martinez *et al.*, 2003
	Cattle	Slurry		-40		Martinez *et al.*, 2003
Anaerobic digestion	Cattle	Slurry	-9	-32	-14	Clemens *et al.*, 2006
	Cattle	Slurry	+49	-68	-48	Clemens *et al.*, 2006
	Cattle	Slurry + wooden lid	+41	-67	-59	Amon *et al.*, 2006
Aeration	Cattle	Slurry	+144	-57	-43	Amon *et al.*, 2006
	Pigs	Slurry (periode 1)		-99		Martinez *et al.*, 2003
	Pigs	Slurry (periode 2)		-70		Martinez *et al.*, 2003
Dilution	Pigs	Slurry		-35		Martinez *et al.*, 2003
	Cattle	Slurry		-57		Martinez *et al.*, 2003
Additives	Pigs	Slurry + NX $_{23}$		-47		Martinez *et al.*, 2003

	Pigs	Slurry + Staloson		-54		Martinez *et al.*, 2003
	Pigs	Slurry + Biosuper		-64		Martinez *et al.*, 2003
	Cattle	Slurry (Sulphuric acid, pH 5.5)		-87		Petersen *et al.*, 2012
	Pigs	Slurry (Sulphuric acid, in House pH 5.6)		-99		Petersen *et al.* (subm)
	Pigs	Slurry (Sulphuric acid, in store, pH 6.6)		-94		Petersen *et al.* (subm)

5. Concluding remarks

The key of GHG mitigation is containment of nutrients by limiting leakage and atmospheric losses, as the closing of nutrient cycles also serves to prevent direct and indirect GHG emissions. Develop mixed farm with integrated crop and livestock production has been suggested to improve nutrient use efficiency in American (Russelle *et al.*, 2007), European (Ryschawy *et al.*, 2012) and tropical conditions (Ogburn and White, 2012). Priority is, in subsistence farming to improve nutrient use efficiency for increasing crop yields (improved livestock manure storage conditions, targeted use of manure nutrients, development of anaerobic storage). In intensive livestock production, improving capacity of livestock manure storage and containment is an issue. But NH_3 emissions represent a threat to natural environments and human health (Sutton *et al.*, 2011). Containment of nutrients and closing of nutrient cycles is a key to GHG mitigation by constraining inputs for food and feed production. The imbalance between nutrients in livestock manure and need of land available for manure recycling is a challenge, in developing countries, as well as in regions where livestock production is already highly intensified. Changes in livestock numbers projected by 2050 (Bouwman *et al.,* 2012) include dramatic increases in South and Central America (cattle), Africa (cattle, sheep/goats) and South Asia (cattle, pigs, sheep/goats). Will they allow making investments in facilities and processing technologies for better management of manure?

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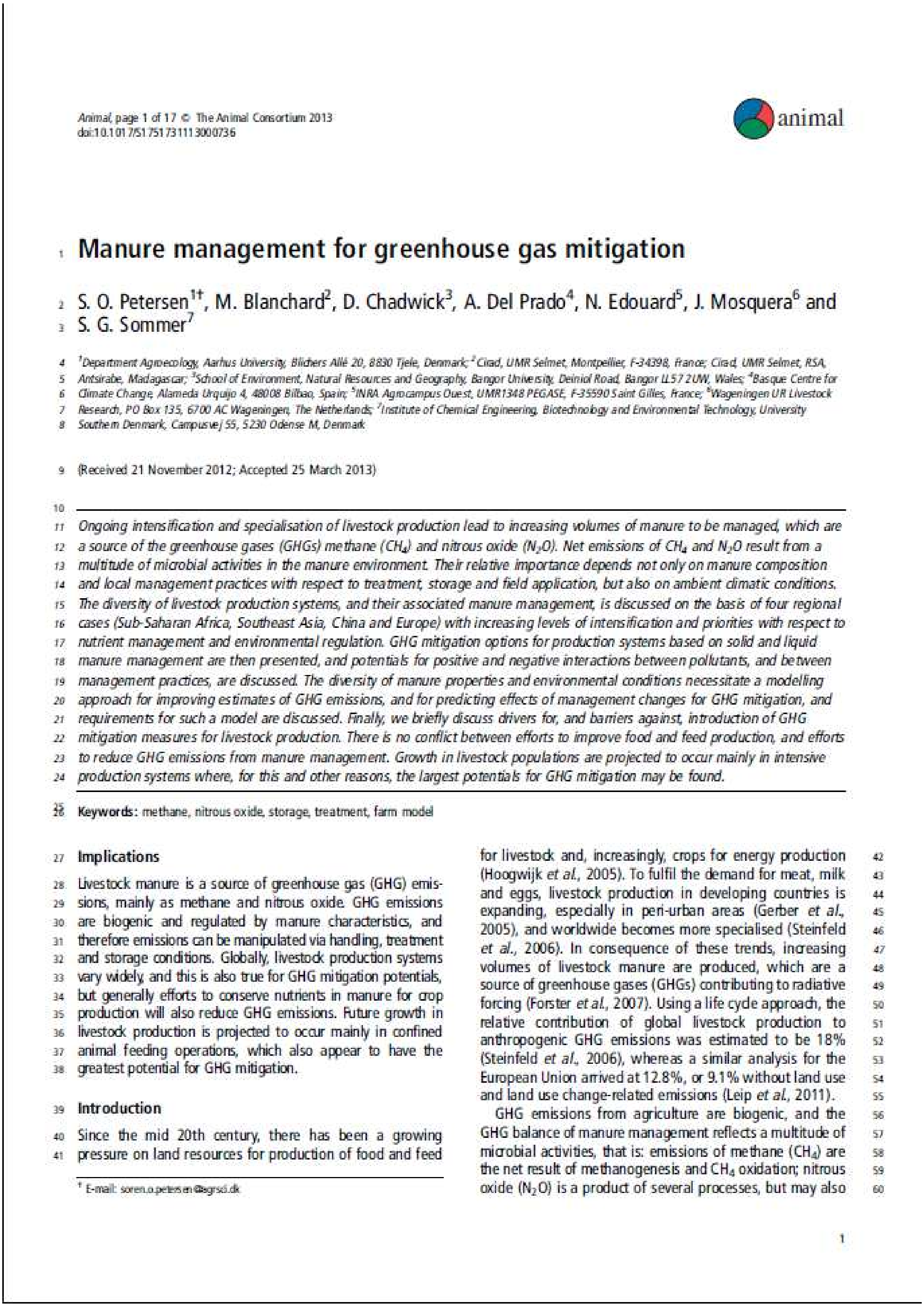
7. Annex 1



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animal

Manure management for greenhouse gas mitigation

S. O. Petersen[1†], M. Blanchard[2], D. Chadwick[3], A. Del Prado[4], N. Edouard[5], J. Mosquera[6] and S. G. Sommer[7]

[1]Department Agroecology, Aarhus University, Blichers Allé 20, 8830 Tjele, Denmark; [2]Cirad, UMR Selmet, Montpellier, F-34398, France; Cirad, UMR Selmet, RSA, Antsirabe, Madagascar; [3]School of Environment, Natural Resources and Geography, Bangor University, Deiniol Road, Bangor LL57 2UW, Wales; [4]Basque Centre for Climate Change, Alameda Urquijo 4, 48008 Bilbao, Spain; [5]INRA Agrocampus Ouest, UMR1348 PEGASE, F-35590 Saint Gilles, France; [6]Wageningen UR Livestock Research, PO Box 135, 6700 AC Wageningen, The Netherlands; [7]Institute of Chemical Engineering, Biotechnology and Environmental Technology, University Southern Denmark, Campusvej 55, 5230 Odense M, Denmark

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Ongoing intensification and specialisation of livestock production lead to increasing volumes of manure to be managed, which are a source of the greenhouse gases (GHGs) methane (CH_4) and nitrous oxide (N_2O). Net emissions of CH_4 and N_2O result from a multitude of microbial activities in the manure environment. Their relative importance depends not only on manure composition and local management practices with respect to treatment, storage and field application, but also on ambient climatic conditions. The diversity of livestock production systems, and their associated manure management, is discussed on the basis of four regional cases (Sub-Saharan Africa, Southeast Asia, China and Europe) with increasing levels of intensification and priorities with respect to nutrient management and environmental regulation. GHG mitigation options for production systems based on solid and liquid manure management are then presented, and potentials for positive and negative interactions between pollutants, and between management practices, are discussed. The diversity of manure properties and environmental conditions necessitate a modelling approach for improving estimates of GHG emissions, and for predicting effects of management changes for GHG mitigation, and requirements for such a model are discussed. Finally, we briefly discuss drivers for, and barriers against, introduction of GHG mitigation measures for livestock production. There is no conflict between efforts to improve food and feed production, and efforts to reduce GHG emissions from manure management. Growth in livestock populations are projected to occur mainly in intensive production systems where, for this and other reasons, the largest potentials for GHG mitigation may be found.

Keywords: methane, nitrous oxide, storage, treatment, farm model

Implications

Livestock manure is a source of greenhouse gas (GHG) emissions, mainly as methane and nitrous oxide. GHG emissions are biogenic and regulated by manure characteristics, and therefore emissions can be manipulated via handling, treatment and storage conditions. Globally, livestock production systems vary widely, and this is also true for GHG mitigation potentials, but generally efforts to conserve nutrients in manure for crop production will also reduce GHG emissions. Future growth in livestock production is projected to occur mainly in confined animal feeding operations, which also appear to have the greatest potential for GHG mitigation.

Introduction

Since the mid 20th century, there has been a growing pressure on land resources for production of food and feed for livestock and, increasingly, crops for energy production (Hoogwijk *et al.*, 2005). To fulfil the demand for meat, milk and eggs, livestock production in developing countries is expanding, especially in peri-urban areas (Gerber *et al.*, 2005), and worldwide becomes more specialised (Steinfeld *et al.*, 2006). In consequence of these trends, increasing volumes of livestock manure are produced, which are a source of greenhouse gases (GHGs) contributing to radiative forcing (Forster *et al.*, 2007). Using a life cycle approach, the relative contribution of global livestock production to anthropogenic GHG emissions was estimated to be 18% (Steinfeld *et al.*, 2006), whereas a similar analysis for the European Union arrived at 12.8%, or 9.1% without land use and land use change-related emissions (Leip *et al.*, 2011).

GHG emissions from agriculture are biogenic, and the GHG balance of manure management reflects a multitude of microbial activities, that is: emissions of methane (CH_4) are the net result of methanogenesis and CH_4 oxidation; nitrous oxide (N_2O) is a product of several processes, but may also

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[†] E-mail: soren.o.petersen@agrsci.dk