SINGLE-IMPACT FICHE
MANURE PROCESSING TECHNIQUES

IMPACT: GHG EMISSIONS

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Note to the reader: This fiche summarises the effects of Manure processing techniques on GHG EMISSIONS. It is based on 11 synthesis papers[1], including from 7 to 142 primary studies.

1. WEIGHT OF THE EVIDENCE

CONSISTENCY OF THE IMPACT

Compared to absence of manure treatment, manure processing techniques (composting, anaerobic digestion and solid-liquid separation), showed variable effects on GHG emissions (methane (CH_4), nitrous oxide (N_2O) emissions and on aggregated GHG emissions) (**Table 1**).

The table below shows the number of synthesis papers with statistical tests reporting i) a significant difference between the Intervention and the Comparator, that is to say, a significant statistical effect, which can be positive or negative; or ii) a non-statistically significant difference between the Intervention and the Comparator. In addition, we include, if any, the number of synthesis papers reporting relevant results but without statistical test of the effects. Details on the quality assessment of the synthesis papers can be found in the methodology section of this WIKI.

- Composting of solid manure (compared to untreated): for CH_4 emission, 3 synthesis papers indicated non-significant effect, while 2 synthesis papers of high quality reported a positive effect (i.e. decrease of CH_4 emission). For N_2O emission, positive effect (i.e. decrease of N_2O emission) was reported in 5, while 2 reported non-significant effect. For aggregated GHG emissions, the effect of composting was non-statistically tested in 1 synthesis paper of low quality. The variability in the effects mainly depend on the type of composting process technique (e.g. C/N adjustment, vermicomposting, addition of bulking agents, periodical turning, forced aeration, and/or the use of either chemical or physical or microbial additives to the composting piles).

- Anaerobic digestion of slurries (compared to untreated manure): for CH_4 emission, variable effects were reported, with 1 synthesis paper indicating positive effect, while another synthesis paper of low quality reporting non-statistically tested results. For N_2O emission, non-significant effect was reported in 2 out of 3 synthesis papers, while 1 showed positive effect. For aggregated GHG emissions, 2 out of 4 synthesis papers report positive effect and other 2 report non-statistically tested results. Variability in the effects mainly depend on the configuration of the anaerobic digestion process, e.g. either mono-digestion (only manure) or co-digestion (manure + other substrates) or anaerobic digestion in integration to digestate-treatment technologies, such as filtration, reverse osmosis, microalgae, drying, stripping.

- Solid-liquid separation (compared to untreated manure): for CH_4 emission, 1 synthesis paper indicated a positive effect. For N_2O emission, solid-liquid separation showed variable effects. Among 3 synthesis papers, 2 reported non-significant effect, while 1 indicated positive effect. For aggregated GHG emissions, the effect of solid-liquid separation was non-statistically tested in 1 synthesis paper of low quality.

Out of the 11 selected synthesis papers, 9 included studies conducted in Europe (see **Table 2**).

Table 1: Summary of effects. Number of synthesis papers reporting positive, negative or non-statistically significant effects on environmental and climate impacts. The number of synthesis papers reporting relevant results but without statistical test of the effects are also provided. When not all the synthesis papers reporting an effect are of high quality, the number of synthesis papers with a quality score of at least 50% is indicated in parentheses. The reference numbers of the synthesis papers reporting each of the effects are provided in **Table 3**. Some synthesis papers may report effects for more than one impact or more than one effect for the same impact.

				Statistically tested			Non-statistically tested
Impact	Metric	Intervention	Comparator	Significantly positive	Significantly negative	Non-significant	
Decrease ghg emissions	Aggregated GHGs emission	Anaerobic digestion	Conventional management	1	0	0	0
Decrease ghg emissions	CH_4	Anaerobic digestion	Conventional management	1	0	1	2 (0)
		Composting	Conventional management	2	0	3	1 (0)
		Solid-liquid separation	Conventional management	1	0	0	1 (0)
Decrease ghg emissions	N_2O	Anaerobic digestion	Conventional management	1	0	4	2 (0)
		Composting	Conventional management	5	0	4	1 (0)
		Solid-liquid separation	Conventional management	1	0	2	1 (0)

QUALITY OF THE SYNTHESIS PAPERS

[1] Synthesis research papers include either meta-analysis or systematic reviews with quantitative results. Details can be found in the methodology section of the WIKI.

The quality of each synthesis paper was assessed based on 16 criteria regarding three main aspects: 1) the literature search strategy and primary studies selection; 2) the statistical analysis conducted; and 3) the evaluation of potential bias. We assessed whether authors addressed and reported these criteria. Then, a quality score was calculated as the percentage of these 16 criteria properly addressed and reported in each synthesis paper. Details on quality criteria can be found in the methodology section of this WIKI.

2. IMPACTS

The main characteristics and results of the 11 synthesis papers are reported in **Table 2** with the terminology used in those papers, while **Table 3** shows the reference numbers of the synthesis papers reporting for each of the results shown in **Table 1**. Comprehensive information about the results reported in each synthesis paper, in particular about the modulation of effects by factors related to soil, climate and management practices, are provided in the **summaries of the synthesis papers** available in this WIKI.

Table 2: Main characteristics of the synthesis papers reporting effects on ghg emissions. The references are ordered chronologically with the most recent publication date first.

Reference number	Population	Scale	Num. papers	Intervention	Comparator	Metric	Conclusion	Quality score
Ref2	Pig manure composts	China	68	Optimized composting techniques. Optimal C/N ratios, optimal moisture, turning once weekly, intermittent aeration or optimized aeration rates, and using air-dry or hyperthermophilic pretreatment.	No application of technology	Total C loss, CH_4-C loss, CO_2-C loss, N_2O-N loss	Overall, the studied technologies can reduce total C and N losses, including N_2O, CH_4 and CO_2 emissions.	69%
Ref3	Dairy manure composts	Global	41	"vermicomposting"	No mitigation measure	Gaseous emission (CH_4, N_2O, CO_2, NH_3)	Vermicomposting had no effect on both N_2O and CH_4 emissions from manure.	69%
Ref4	European agricultural systems with slurry fertilisation	Europe	38	Biological treatment (anaerobic digestion); Solid-liquid separation	No slurry treatment	GHG emission (CH_4, N_2O)	Anaerobic digestion was effective to varying degrees for the abatement of CH_4 and CO_2 emissions, but also resulted in the (non-significant) increased emission of N_2O emissions. Solid-liquid separation showed no effect on CO_2 and N_2O emissions, while being effective for CH_4 emission abatement.	50%
Ref8	Arable land and grassland	Global	44	Fertilisation with pre-treated manure (either composted or digested farmyard manure (FYM), pig, cattle or poultry.	Fertilisation with raw manure (farmyard manure (FYM), pig, cattle or poultry)	N_2O emissions	Raw manure resulted in significantly higher N_2O emission than pre-treated (either composted or digested) manure.	69%
Ref9	Soild manure and organic waste	Global	36	Mitigation strategies in solid manure composting, i.e. C/N ratio regulation (C/N RR), optimized aeration rate or turning frequency (OAT).	No mitigation technique	N_2O-N loss	Carbon/nitrogen regulation in composting did not reduce NO_2 losses, but optimized aeration rate or turning frequency significantly reduced N_2O-N loss (by 54.9%).	69%
Ref12	Pig and cattle manure	Not reported	89	Anaerobic digestion	No abatement options	CH_4, NO_2 emissions	This study shows that anaerobic digestion can reduce CH_4 emissions from from pig and cattle manure management. However, several options are associated with tradeoffs on N_2O emissions from storage of digestate. These results are uncertain, because based only on descriptive statistics, and not on a model taking into account between-studies variability.	44%
Ref13	Swine manure	Global	142	Anaerobic digestion; Composting with additives	No mitigation strategy	NO_2 emissions	Land application of digestate, as compared to raw manure, was not effective in reducing N_2O emissions ($p>0.05$). For mitigation of emissions during active composting, additives have proven to be effective in reducing N_2O (32%, $p < 0.01$) emissions. The impact was not significant for CH_4 emission (-9%, $p=0.650$).	62%
Ref14	Dairy cattle	Cold climatic countries	7	Composting of solid manure, Solid-liquid separation, Anaerobic digestion of slurry	No mitigation strategy	CH_4 and N_2O emissions	This review identify several promising strategies for mitigating GHG emissions from dairy manure, including AD, solid–liquid separation, composting, manure storage covers, and complete emptying of liquid manure storage at spring application. These results are uncertain due to the methodology used in this study (systematic review, no quantitative analysis).	19%
Ref15	Liquid manure of dairy cows and swine stables	Global	126	Field application of Solid-liquid separated fractions and digested slurry	Field application of raw slurry	CH_4 and N_2O emission	The overall effect of liquid fractions on N_2O emissions did not differ from that of raw slurry. Field-applied digestates and solid fractions showed on average 25% ($P > 0.05$) and 46% ($P < 0.01$) lower N_2O emissions than field-applied untreated manure, respectively.	88%
Ref16	Dairy farms slurry manures	Global	30	Anaerobic digestion of manure only.	Raw slurry	CH_4 emission during land application; CH_4 emission during storage; Aggregated GHGs emission during storage		56%
Ref17	Solid manure (dairy cows, swine, poultry, green waste)	Global	76	Solid manure Solid manure improved composting techniques (turning, forced aeration, compaction, covering, bulking agents, additives)	Solid manure conventional storage (heaps)	CH_4, N_2O emissions	Turning have shown potential for reducing GHGs emissions, whereas no clear effects were detected for forced aerated system.	69%

Table 3: Reference numbers of the synthesis papers reporting for each of the results shown in **Table 1**.

Impact	Metric	Intervention	Comparator	Statistically tested: Significantly positive	Statistically tested: Significantly negative	Statistically tested: Non-significant	Non-statistically tested
Decrease ghg emissions	Aggregated GHGs emission	Anaerobic digestion	Conventional management	Ref16			
Decrease ghg emissions	CH_4	Anaerobic digestion	Conventional management	Ref4		Ref16	Ref12 and Ref14
		Composting	Conventional management	Ref2 and Ref17		Ref3, Ref13 and Ref17	Ref14
		Solid-liquid separation	Conventional management	Ref4			Ref14
Decrease ghg emissions	N_2O	Anaerobic digestion	Conventional management	Ref16		Ref4, Ref13, Ref15 and Ref16	Ref12 and Ref14
		Composting	Conventional management	Ref2, Ref8, Ref9, Ref13 and Ref17		Ref2, Ref3, Ref9 and Ref17	Ref14
		Solid-liquid separation	Conventional management	Ref15		Ref4 and Ref15	Ref14

3. FACTORS INFLUENCING THE EFFECTS ON GHG EMISSIONS

Table 4: List of factors reported to significantly affect the size and/or direction of the effects on ghg emissions, according to the synthesis papers reviewed.

Factor	Reference number
Bulk density	Ref17
Climate	Ref8
Crop type	Ref8
Duration of treatment	Ref8
Moisture content	Ref17
NA	Ref2, Ref2, Ref2, Ref2, Ref2, Ref2, Ref2, Ref8, Ref8, Ref8, Ref9, Ref9, Ref9, Ref9, Ref9, Ref9, Ref9, Ref9, Ref3, Ref3, Ref3, Ref3, Ref3, Ref3, Ref3, Ref3, Ref4, Ref4, Ref4, Ref4, Ref4, Ref4, Ref4, Ref4, Ref12, Ref12, Ref12, Ref12, Ref12, Ref12, Ref12, Ref12, Ref13, Ref13, Ref13, Ref13, Ref13, Ref13, Ref13, Ref13, Ref14, Ref14, Ref14, Ref14, Ref14, Ref14, Ref14, Ref14, Ref15, Ref15, Ref15, Ref15, Ref15, Ref15, Ref15, Ref15, Ref17, Ref17, Ref17, Ref17, Ref17, Ref17, Ref16, Ref16, Ref16, Ref16, Ref16, Ref16, Ref16
Soil organic carbon	Ref8
Type of technology	Ref2
Water filled pore space	Ref8

4. KNOWLEDGE GAPS

Table 5: Knowledge gap(s) reported by the authors of the synthesis papers included in this review.

Ref Num	Gap
Ref2	The effects of an air-dry pretreatment on C losses could be further explored because the losses were not considered during the pre-treatment phase.
Ref3	The number of studies quantifying NH_3 emission from dairy manure aerobic composting was limited. More attention should be paid to reducing NH_3 losses and improving nitrogen retention in composted products from dairy manure composting process in the future.
Ref8	The number of studies included in this study is low and more field experiments are needed to measure N_2O emission after manure application, including various agricultural practices (tillage and irrigation) and soil properties (soil temperature and microbial community). With increasing data availability in recent and future studies, it is important to critically identify the influence and integrated mechanisms involved in N_2O emissions to achieve optimal manure management and agricultural practices for field manure application.
Ref15	The results collected did not allow comparing management options across animal species (e.g. pigs vs. cattle). Data from both field-and laboratory-scale studies were included in our database as data solely from field-scale studies were insufficient.
Ref17	The number of studies reporting CH_4 losses from solid waste management applying additives is limited. Our results are based on 9 experiments from only two studies examining the effect of phosphogypsum addition on gaseous emissions. Average values suggest that this strategy tends to reduce CH_4 emissions (mean: -59%). However, more data are still required to confirm this trend. Although the number of experiments investigating the influence of management practices on GHG emissions has grown during the last decade, an important restriction of our dataset is that there is still a limited knowledge basis with respect to gaseous losses from solid waste management, particularly for CH_4 and N_2O emissions at commercial scale. In addition to this, the collected results showed large variability, which emphasizes the need to produce additional data through precise and accurate research methods to obtain robust EF estimates that can help reduce current uncertainties.

5. SYNTHESIS PAPERS INCLUDED IN THE REVIEW

Table 6: List of synthesis papers included in this review. More details can be found in the summaries of the meta-analyses.

Ref Num	Author(s)	Year	Title	Journal	DOI
Ref2	Zhang Z., Liu D., Qiao Y., Li S., Chen Y., Hu C.	2021	Mitigation of carbon and nitrogen losses during pig manure composting: A meta-analysis	Science of the Total Environment 783 147103	10.1016/j.scitotenv.2021.147103
Ref3	Ba, SD; Qu, QB; Zhang, KQ; Groot, JCJ	2020	Meta-analysis of greenhouse gas and ammonia emissions from dairy manure composting	Biosystems engineering	10.1016/j.biosystemseng.2020.02.015
Ref4	Emmerling, C; Krein, A; Junk, J	2020	Meta-Analysis of Strategies to Reduce NH_3 Emissions from Slurries in European Agriculture and Consequences for Greenhouse Gas Emissions	Agronomy 10, 1633	10.3390/agronomy10111633
Ref8	Xia, F; Mei, K; Xu, Y; Zhang, C; Dahlgren, RA; Zhang, MH	2020	Response of N_2O emission to manure application in field trials of agricultural soils across the globe	SCIENCE OF THE TOTAL ENVIRONMENT, 733, 139390.	10.1016/j.scitotenv.2020.139390
Ref9	Zhao, SX; Schmidt, S; Qin, W; Li, J; Li, GX; Zhang, WF	2020	Towards the circular nitrogen economy - A global meta-analysis of composting technologies reveals much potential for mitigating nitrogen losses	Sci. Total Environ. 704, 135401	10.1016/j.scitotenv.2019.135401
Ref12	Sajeev, EPM; Winiwarter, W; Amon, B	2018	Greenhouse Gas and Ammonia Emissions from Different Stages of Liquid Manure Management Chains: Abatement Options and Emission Interactions	Journal of environmental quality	10.2134/jeq2017.05.0199
Ref13	Wang, Y; Dong, HM; Zhu, ZP; Gerber, PJ; Xin, HW; Smith, P; Opio, C; Steinfeld, H; Chadwick, D	2017	Mitigating Greenhouse Gas and Ammonia Emissions from Swine Manure Management: A System Analysis	ENVIRONMENTAL SCIENCE & TECHNOLOGY	10.1021/acs.est.6b06430
Ref14	Jayasundara, S; Appuhamy, JADRN; Kebreab, E; Wagner-Riddle, C	2016	Methane and nitrous oxide emissions from Canadian dairy farms and mitigation options: An updated review	CANADIAN JOURNAL OF ANIMAL SCIENCE	10.1139/cjas-2015-0111
Ref15	Hou, Y; Velthof, GL; Oenema, O	2015	Mitigation of ammonia, nitrous oxide and methane emissions from manure management chains: a meta-analysis and integrated assessment	Glob. Chang. Biol. 21, 1293–1312	10.1111/gcb.12767
Ref16	Miranda, ND; Tuomisto, HL; McCulloch, MD	2015	Meta-Analysis of Greenhouse Gas Emissions from Anaerobic Digestion Processes in Dairy Farms	Environ. Sci. Technol. 49, 5211–5219	10.1021/acs.est.5b00018
Ref17	Pardo, G; Moral, R; Aguilera, E; del Prado, A	2015	Gaseous emissions from management of solid waste: a systematic review	Glob. Chang. Biol. 21, 1313–1327	10.1111/gcb.12806