SINGLE-IMPACT FICHE
MANURE STORAGE TECHNIQUES

IMPACT: AIR POLLUTANTS EMISSIONS

Data extracted in July 2021
Fiche created in February 2024

Note to the reader: This fiche summarises the effects of Manure storage techniques on AIR POLLUTANTS EMISSIONS. It is based on 13 synthesis papers[1], including from 38 to 172 primary studies.

1. WEIGHT OF THE EVIDENCE

CONSISTENCY OF THE IMPACT

The literature review shows that improved manure storage techniques decrease overall the ammonia emission, with relevant variations depending on the technique (**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.

- Storage with additives (either chemical or physical): 7 out of 9 synthesis papers reported positive effect (i.e. decrease ammonia emissions). In 1 synthesis paper, non-significant effect resulted for different additives applied to cattle manure stockpiles and another synthesis paper reported non-statistically tested results regarding the addition of biochar to stockpiles of cattle and poultry manure. Differences in the effects mainly depend on the type of additive (e.g. Physical additives: zeolite, biochar, medical stone, grape seeds and physical mixtures. Chemical additives: acidic substances, metal salts, phosphogypsum, Mg-P salts, Ca-superphosphate, nitrification inhibitors, and chemical mixtures) (see Table 2).
- Storage with microbial inocula: 3 out of 3 synthesis papers reported positive effect (i.e. decrease of ammonia emission) for microbial inocula, including nitrite oxidizing bacteria, nitrogen turnover bacteria and compound microbial agents (see Table 2).
- Storage covers: 8 out of 13 synthesis papers reported positive effect (i.e. decrease of ammonia emission) of storage tanks covered, as compared to uncovered ones. 2 synthesis papers reported non-significant effect and 3 reported non-statistically tested results. Differences in the effects mainly depend on the type of cover (e.g. plastic films, floating inert materials, floating biomass, floating oil layers, natural crusts, etc.). Natural crusts and wooden lids, in particular, showed no significant effect on ammonia emission.
- Storage with biofilters: 3 out of 3 synthesis papers reported positive effect (i.e. decrease of NH_3 emission) for treating air emissions from storage tanks or composting heaps using biofilters to treat air emissions.
- Acidification during storage: 4 out of 5 synthesis papers reported positive effect (i.e. decrease of ammonia emission) of manure acidification during storage. 1 synthesis paper reported non-statistically tested results.
- Compaction during storage: the only 1 synthesis paper reported non-significant effects of compaction of (solid) manure heaps.

Out of the 13 selected synthesis papers, 10 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 air pollutants emissions	NH_3	Compaction during storage	Conventional management	0	0	1	0
		Storage covers	Conventional management	8	0	2	3 (2)
		Storage with acidification	Conventional management	4	0	0	1 (0)
		Storage with additives	Conventional management	7	0	1	1 (0)
		Storage with biofilters	Conventional management	3	0	0	0
		Storage with microbial inocula	Conventional management	3	0	0	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 13 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 air pollutants 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
Ref1	Pig manure composts	China	68	Technologies: covers, amendments, and using air-dry or hyperthermophilic pretreatment. Physical additives: zeolite, biochar, medical stone, grape seeds and physical mixtures. Chemical additives: acidic substances, metal salts, phosphogypsum, Mg-P salts, Ca-superphosphate and chemical mixtures. Microbial additives: NOB (nitrite oxidizing bacteria), NTB (nitrogen turnover bacteria) and compound microbial agents.	No application of technology	NH_3-N loss	Overall, the studied technologies can reduce total N losses by 32.7%. Applying additives, especially biochar and superphosphate, was found to be an effective method for synergistically mitigating C and N losses. Storage covers significantly reduced ammonia-N loss by 14.6%.	69%
Ref2	Dairy manure composts	Global	41	Six mitigation practices in the dairy manure composting process: "sawdust or straw additive", "microorganism additive", "phosphogypsum additive", "compressed and covered", "vermicomposting" and "compost biofilter".	No mitigation measure	NH_3 emission	Applying biofilters, storage covers and additives as sawdust, straw, microorganisms and phosphogypsum were effective ways to reduce ammonia emissions during manure storage/composting.	69%
Ref3	European agricultural systems with slurry fertilisation	Europe	38	Acidification, Biological treatment, Separation, Cover during storage, Injection, Incorporation, or Band application	No slurry treatment, no storage cover, or band spread application	NH_3 emission	Slurry acidification was effective for the reduction of ammonia emissions, and had no pollution swapping effect with other greenhouse gases, like nitrous oxide, methane, and carbon dioxide. All other management strategies, like different storage types and the concealing of the liquid slurry with different materials were effective to varying degrees for the abatement of ammonia emission, but also resulted in the increased emission of at least one other greenhouse gas.	50%
Ref4	Soild manure and organic waste	Global	52	Mitigation strategies in solid manure storage, i.e. microbial inoculation (MI), physical additives (PA), chemical additives (CA), covering (CO). Physical additives were classified into clay, zeolite and biochar. Chemical additives were classified into six types: acidic substances (apple pomace, citric acid, elemental sulphur, phosphoric acid, bamboo vinegar), metal salts ($FeCl_3$, $CaCl_2$, $MgCl_2$, $MgSO_4$), gypsum, Mg-P salts ($Mg(OH)_2 + H_3PO_4$, $MgSO_4 + H_3PO_4$, $MgO + H_3PO_4$, $MgCl_2 + H_3PO_4$, $MgSO_4 + KH_2PO_4$, $MgCl_2 + KH_2PO_4$, $Ca(H_2PO_4)_2 + MgSO_4$), Ca-superphosphate ($Ca(H_2PO_4)_2$), and nitrification inhibitor DCD.	No mitigation technique	NH_3-N loss	Storage covers did not reduce ammonia losses, but all other technologies significantly reduced ammonia-N loss (CA 46.2% > PA 30.9% > OAT 26.9 > MI 25.3%). Biochar and magnesium-phosphate salts emerged as the most effective N-conserving strategies.	69%
Ref5	Animal waste	Not reported	Not reported	Biochar addition on livestock and poultry waste compost (biochar-compost)	Compost of animal waste without biochar addition	NH_3 emissions	Biochar addition to animal waste composting could reduce ammonia emissions, but these results are uncertain due to the methodology used in this study (systematic review, no quantitative analysis).	38%
Ref6	Livestock manure, food waste, sewage sludge and/or green waste	Global	105	Additives (chemical additives, e.g. phosphate, magnesium salts, superphosphate, gypsum etc.; physical additives, e.g. biochar, zeolite, bentonite, etc.; microbial additives, e.g. nitrite-oxidizing bacteria (NOB), NTB (ammonifiers, nitrobacteria, azotobacter) agent, etc.)	No additive	NH_3 emission in terms of cumulative NH_3-N losses as a proportion of the TN of the initial composting material	This global meta-analysis establishes that the use of additives can significantly reduce ammonia emissions during composting.	62%
Ref7	European agricultural systems with slurry fertilisation	Global (including EU)	172	"covering the manure", "application of acidifiers", "manure additives", "manure aeration", "manure turning"	No measure	NH_3 emission	Techniques such as covering the manure, the application of acidifiers and additives, could significantly reduce ammonia emission.	69%
Ref8	Broiler and layer production (chicken)	Global	96	Mitigation strategies in chicken house or in outdoor manure treatment. Land application mitigation strategies.	A reference litter based or layer manure belt based system (diet: conventional, in house: no treatment, outdoor: composting, land application: spreading)	NH_3 emission factor	Overall, biofilters and application of mineral additives to stockpiles led to reduce ammonia emissions of chicken manure treatment and storage in broiler or layer based systems.	62%
Ref9	Pig and cattle manure	Not reported	89	Abatement options at different stages of the manure management system (feeding strategies, animal housing, manure treatment, storage and land application)	No abatement options	NH_3 emissions	Overall, the different abatements options decrease ammonia emissions from pig and cattle manure management. However, these results are based only on descriptive statistics, and not on a model	44%

Reference number	Population	Scale	Num. papers	Intervention	Comparator	Metric	Conclusion	Quality score
							taking into account between-studies variability.	
Ref10	Cattle manure	Global	104	Additives to stockpiles; Stockpile covers; biofilters	No mitigation strategy	NH_3 emissions	This study shows that compost biofilter and stockpile covering were significantly effective in reducing ammonia emissions, while adding additives to manure was not effective.	62%
Ref11	Swine manure	Global	142	Storage covers, Storage with acidification, Storage with additives	No mitigation strategy	NH_3 emissions	Overall, this study shows that all investigated mitigation strategies, with the exception of stockpile cover for which not enough data was available, were effective in reducing ammonia emissions. This study shows that injecting or incorporating swine manure was effective in mitigating ammonia emissions, compared to surface spreading.	62%
Ref13	Liquid manure of dairy cows and swine stables	Global	126	Manure storage/treatment techniques (acidification, storage cover: lid, crust, straw, granules, plastic films, oil)	Conventional storage technique, surface spreading with broadcast, Raw slurry	NH_3	Slurry acidification significantly decreased emissions of ammonia and CH_4 from slurry storages. Covering slurry storages with straw significantly decreased ammonia emissions and increased N_2O emissions.	88%
Ref14	Solid manure (dairy cows, swine, poultry, green waste)	Global	76	Solid manure storage/treatment techniques (turning, forced aeration, compaction, covering, bulking agents, additives)	Solid manure conventional storage (heaps)	NH_3	Covering or compaction decrease ammonia volatilization. The use of specific additives reduces ammonia losses. Nevertheless, their effectiveness varies depending on the substance, dosage, and operational conditions.	69%

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

				Statistically tested			Non-statistically tested
Impact	Metric	Intervention	Comparator	Significantly positive	Significantly negative	Non-significant	
Decrease air pollutants emissions	NH_3	Compaction during storage	Conventional management			Ref14	
		Storage covers	Conventional management	Ref1, Ref2, Ref3, Ref7, Ref10, Ref11, Ref13 and Ref14		Ref4 and Ref13	Ref8, Ref9 and Ref11
		Storage with acidification	Conventional management	Ref3, Ref7, Ref11 and Ref13			Ref9
		Storage with additives	Conventional management	Ref1, Ref2, Ref4, Ref6, Ref7, Ref8 and Ref14		Ref10	Ref5
		Storage with biofilters	Conventional management	Ref2, Ref8 and Ref10			
		Storage with microbial inocula	Conventional management	Ref1, Ref4 and Ref6			

3. FACTORS INFLUENCING THE EFFECTS ON AIR POLLUTANTS EMISSIONS

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

Factor	Reference number
Additive type	Ref6
Application dosage	Ref6
Bulk density	Ref14
Initial C/N ratio	Ref6
Initial moisture content	Ref6
Initial pH	Ref6
Livestock type	Ref7
Manure characteristics	Ref8
NA	Ref1, Ref1, Ref1, Ref1, Ref1, Ref1, Ref4, Ref4, Ref4, Ref4, Ref4, Ref4, Ref4, Ref4, Ref2, Ref2, Ref2, Ref2, Ref2, Ref2, Ref2, Ref2, Ref3, Ref3, Ref3, Ref3, Ref3, Ref3, Ref3, Ref3, Ref7, Ref7, Ref7, Ref7, Ref7, Ref7, Ref7, Ref8, Ref8, Ref8, Ref8, Ref8, Ref8, Ref8, Ref6, Ref6, Ref6, Ref5, Ref5, Ref5, Ref5, Ref5, Ref5, Ref5, Ref5, Ref9, Ref9, Ref9, Ref9, Ref9, Ref9, Ref9, Ref9, Ref10, Ref10, Ref10, Ref10, Ref10, Ref10, Ref10, Ref10, Ref11, Ref11, Ref11, Ref11, Ref11, Ref11, Ref11, Ref11, Ref13, Ref13, Ref13, Ref13, Ref13, Ref13, Ref13, Ref13, Ref14, Ref14, Ref14, Ref14, Ref14, Ref14
Temperature in the heap	Ref14
Type of additive	Ref1

Factor	Reference number
Type of technology	Ref1

4. KNOWLEDGE GAPS

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

Ref Num	Gap
Ref1	The effects of an air-dry pretreatment on N losses could be further explored because the losses were not considered during the pre-treatment phase.
Ref2	The number of studies quantifying ammonia emission from dairy manure aerobic composting was limited. More attention should be paid to reducing ammonia losses and improving nitrogen retention in composted prod- ucts from dairy manure composting process in the future.
Ref8	Only one observation for comparing LCP diet to conventional diet in layer system;
Ref10	There are only 2 papers that studied the impact of compost additives on gas emissions from beef cattle manure, with one study specified for CH_4 and N_2O and the other for ammonia;
Ref13	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.

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
Ref1	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
Ref2	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
Ref3	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
Ref4	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
Ref5	Akdeniz, N	2019	A systematic review of biochar use in animal waste composting	Waste Management	10.1016/j.wasman.2019.03.054
Ref6	Cao Y, Wang X, Bai Z, Chadwick D, Misselbrook T, Sommer SG, Qin W, Ma L	2019	Mitigation of ammonia, nitrous oxide and methane emissions during solid waste composting with different additives: A meta-analysis	Journal of Cleaner Production	10.1016/j.jclepro.2019.06.288
Ref7	Ti, CP; Xia, LL; Chang, SX; Yan, XY	2019	Potential for mitigating global agricultural ammonia emission: A meta-analysis	Environ. Pollut. 245, 141–148	10.1016/j.envpol.2018.10.124
Ref8	Wang, Y; Xue, W; Zhu, Z; Yang, J; Li, X; Tian, Z;Dong, H; Zou, G;	2019	Mitigating ammonia emissions from typical broiler and layer manure management - A system analysis	Waste Management	10.1016/j.wasman.2019.05.019
Ref9	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
Ref10	Wang, Y; Li, XR; Yang, JF; Tian, Z; Sun, QP; Xue, WT; Dong, HM	2018	Mitigating Greenhouse Gas and Ammonia Emissions from Beef Cattle Feedlot Production: A System Meta-Analysis	Environmental Science & Technology	10.1021/acs.est.8b02475
Ref11	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
Ref13	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
Ref14	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

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