# SINGLE-IMPACT FICHE
# MANURE STORAGE TECHNIQUES

## IMPACT: GHG EMISSIONS

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**Note to the reader**: This fiche summarises the effects of Manure storage techniques on GHG EMISSIONS. It is based on 12 synthesis papers[1], including from 7 to 142 primary studies.

## 1. WEIGHT OF THE EVIDENCE

CONSISTENCY OF THE IMPACT

The literature review shows that improved manure storage techniques have overall positive or no effect on GHG emissions, 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), compared to no substance addition: for $CH_4$ emission, 3 out of 7 synthesis papers reported positive effect (i.e. decrease $CH_4$ emissions), while 2 reported non-significant effect and 2 reported non-statistically tested results. For $N_2O$ emission, results show variable effects, with 3 synthesis papers (out of 7) reporting positive effect and other 3 non-significant effect; 1 additional synthesis paper reported non-statistically tested results. For aggregated GHG emission (accounted as the sum of GHG emissions as $CO_2$-equivalents), the only 1 synthesis paper reported a positive result for storage with additives. Variability in the effects mainly depend on the type of additive, including both physical additives (zeolite, biochar, medical stone, grape seeds and physical mixtures) and chemical additives (acidic substances, metal salts, phosphogypsum, Mg-P salts, Ca-superphosphate, nitrification inhibitors, and chemical mixtures), as detailed in Table 2.
- Storage with microbial inocula, compared to no inoculation: for $CH_4$ emission, the only synthesis papers reported non-significant effect for microbial inocula, such as nitrite oxidizing bacteria, nitrogen turnover bacteria and compound microbial agents (see Table 2). For $N_2O$ emission, results show 2 synthesis paper (out of 3) reporting positive effect and 1 non-significant effect. Variability in the effects mainly depend on the type of additive (nitrite oxidizing bacteria, nitrogen turnover bacteria and compound microbial agents, ammonifiers, nitrobacteria, azotobacter, see Table 2).
- Storage covers, compared to uncovered storage: for $CH_4$ emission, 4 out of 8 synthesis papers reported non-significant effect for storage covered tanks, as compared to uncovered. Other 2 synthesis papers reported negative effect, and 2 reported non-statistically tested results. For $N_2O$ emission, results showed different effects, with 7 out of 13 synthesis papers reporting no significant effects, while 3 reported negative, 1 positive effect and 2 reported non-statistically tested results. Aggregated GHGs emission (accounted as the sum of all GHG emissions as $CO_2$-equivalents): the only synthesis paper reported non-statistically tested results for storage covers. Variability 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.) as indicated in Table 2.
- Acidification during storage, compared to no acidification: for $CH_4$ emission, 2 out of 4 synthesis papers reported positive effect (i.e. decrease of $CH_4$ emission) for manure acidification during storage; another 1 synthesis paper reported non-significant effects and 1 synthesis paper reported non-statistically tested results. For $N_2O$ emission, 1 out of 2 synthesis paper reported positive effect, while 1 synthesis paper of low quality reported non-statistically tested results.
- Compaction during storage, compared to no compaction: for $CH_4$ emission, the only synthesis paper reported non-significant effects for compaction of (solid) manure heaps. For $N_2O$ emission, the only synthesis paper reported non-significant effect.
- Cooling during storage, compared to storage at ambient temperatures: for $CH_4$ emission, results showed variable effects, with 1 out of 2 synthesis papers reporting positive effect and 1 non-significant effects for manure cooling during storage. No results were available for the other metrics.
- Periodical cleaning storage tanks, compared to no cleaning: for aggregated GHGs emission (as sum of all GHG emission, as $CO_2$-equivalents), the only 1 synthesis paper (of low quality) reported non-statistically tested results. No results were available for the other metrics.

Out of the 12 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.

[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.

| | | | | Statistically tested | | | Non-statistically tested |
|---|---|---|---|---|---|---|---|
| Impact | Metric | Intervention | Comparator | Significantly positive | Significantly negative | Non-significant | |
| Decrease ghg emissions | $CH_4$ | Compaction during storage | Conventional management | 0 | 0 | 1 | 0 |
| | | Storage covers | Conventional management | 0 | 2 | 5 | 2 (1) |
| | | Storage with acidification | Conventional management | 2 | 0 | 1 | 1 (0) |
| | | Storage with additives | Conventional management | 3 | 0 | 2 | 2 (1) |
| | | Storage with cooling | Conventional management | 1 | 0 | 0 | 0 |
| | | Storage with microbial inocula | Conventional management | 0 | 0 | 1 | 0 |
| Decrease ghg emissions | Global warming potential ($CO_2$-eq) | Cleaning storage tanks | Conventional management | 0 | 0 | 0 | 1 (0) |
| | | Storage covers | Conventional management | 0 | 0 | 0 | 1 (0) |
| | | Storage with additives | Conventional management | 1 | 0 | 0 | 0 |
| Decrease ghg emissions | $N_2O$ | Compaction during storage | Conventional management | 0 | 0 | 1 | 0 |
| | | Storage covers | Conventional management | 1 | 3 | 7 | 2 (1) |
| | | Storage with acidification | Conventional management | 1 | 0 | 0 | 1 (0) |
| | | Storage with additives | Conventional management | 3 | 0 | 4 | 1 (0) |
| | | Storage with microbial inocula | Conventional management | 3 | 0 | 0 | 0 |

QUALITY OF THE SYNTHESIS PAPERS

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 12 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 |
|---|---|---|---|---|---|---|---|---|
| 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 | 1) $CH_4$-C loss; 2) $N_2O$ loss | Overall, the studied technologies can reduce total C and N losses. Applying additives, especially biochar and superphosphate, was found to be an effective method for synergistically mitigating C and N losses. | 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 | 1) $CH_4$ emission; 2) $N_2O$ emission | Adding sawdust or straw could significantly reduce $CH_4$ and $N_2O$ emissions during composting. Covering and compressing manure heaps lead to increased $CH_4$ emissions. | 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 | 1) $CH_4$ emission; 2) $N_2O$ emission | Slurry acidification was effective for the reduction of ammonia emissions, and had no pollution swapping effect with other greenhouse gases, like nitrous oxide and methane. All other management strategies, like different storage covers 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 | 36 | 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 ($Mg(OH)_2$ + $H_3PO_4$, | No mitigation technique | $N_2O$-N loss | C/N RR and CO did not reduce $N_2O$ losses, but all other technologies significantly reduced $N_2O$-N loss (MI 75.2% > PA 58.0% > OAT 54.9% > CA 21.5%). Biochar and magnesium-phosphate salts emerged as the most effective N-conserving strategies. | 69% |

| Reference number | Population | Scale | Num. papers | Intervention | Comparator | Metric | Conclusion | Quality score |
|---|---|---|---|---|---|---|---|---|
| | | | | $MgSO_4 + H_3PO_4$, $MgO + H_3PO_4$, $MgCl_2 + H_3PO_4$, $MgSO_4 + KH_2PO_4$, $MgCl_2 + KH_2PO_4$, $Ca(H_2PO_4)_2 + MgSO_4$), Ca-superphosphate ($Ca(H_2PO_4)_2$), and nitrification inhibitor DCD. | | | | |
| Ref5 | Animal waste | Not reported | Not reported | Biochar addition on livestock and poultry waste compost (biochar-compost) | Compost of animal waste without biochar addition | 1) $CH_4$ emission; 2) $N_2O$ emission | Biochar addition to animal waste composting could reduce $CH_4$ and $N_2O$ 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 | 1) $N_2O$ emission; 2) $CH_4$ emission; 3) Total $CO_2eq$ | This global meta-analysis establishes that the use of additives can significantly reduce $N_2O$ and $CH_4$ emissions, and total GHG emissions expressed as GWP during composting. | 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 | 1) $CH_4$ emission; 2) $N_2O$ emission | This study shows that several abattement options can reduce GHG emissions from from pig and cattle manure management. However, several options are associated with tradeoffs between the different GHG considered. These results are based on descriptive statistics, but not on a model taking into account between-studies variability. | 44% |
| Ref10 | Cattle manure | Global | 104 | Additives to stockpiles; Stockpile covers | No mitigation strategy | 1) $CH_4$ emission; 2) $N_2O$ emission | This study shows that the different tested mitigation strategies were not significantly effective in reducing GHG emissions. Stockpile covers had negative effect on $CH_4$ emissions. | 62% |
| Ref11 | Swine manure | Global | 142 | Storage covers, Storage with acidification, Storage with additives | No mitigation strategy | 1) $CH_4$ emission; 2) $N_2O$ emission | Overall, this study shows that among investigated mitigation strategies, cooling and compost cover were effective in reducing $CH_4$ and $N_2O$ emissions, respectively. This study shows that avoiding to spread swine manure in rice paddies and adding nitrification inhibitors in the manure before spreading in upland were effective in mitigating $CH_4$ and $N_2O$ emissions, while slurry injection increased $N_2O$ emissions. | 62% |
| Ref12 | Dairy cattle | Cold climatic countries | 7 | Complete emptying or cleaning of manure storage; Manure storage cover. | No mitigation strategy | 1) $CH_4$ emission; 2) $N_2O$ emission | 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 (only systematic review, no quantitative analysis). | 19% |
| 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 | 1) $CH_4$ emission; 2) $N_2O$ emission | Slurry acidification significantly decreased emissions of $NH_3$ and $CH_4$ from slurry storages. Covering slurry storages with straw significantly increased $N_2O$ emissions, covers with plastic films significantly reduced $N_2O$. Covers had no effects on $CH_4$ 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) | 1) $CH_4$ emission; 2) $N_2O$ emission | Covering or compaction did not show significant effects on reducing either $CH_4$ or $N_2O$ emissions. The use of specific additives has no effect on $N_2O$, while few data where available for $CH_4$. 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 ghg emissions | $CH_4$ | Compaction during storage | Conventional management | | | Ref14 | |
| | | Storage covers | Conventional management | | Ref2 and Ref10 | Ref1, Ref3, Ref11, Ref13 and Ref14 | Ref9 and Ref11 |
| | | Storage with acidification | Conventional management | Ref3 and Ref13 | | Ref11 | Ref9 |
| | | Storage with additives | Conventional management | Ref1, Ref2 and Ref6 | | Ref1 and Ref10 | Ref5 and Ref14 |
| | | Storage with cooling | Conventional management | Ref11 | | | |
| | | Storage with microbial inocula | Conventional management | | | Ref1 | |
| Decrease ghg emissions | Global warming potential ($CO_2$-eq) | Cleaning storage tanks | Conventional management | | | | Ref12 |
| | | Storage covers | Conventional management | | | | Ref12 |

| | | | | Statistically tested | | | Non-statistically tested |
|---|---|---|---|---|---|---|---|
| Impact | Metric | Intervention | Comparator | Significantly positive | Significantly negative | Non-significant | |
| | | Storage with additives | Conventional management | Ref6 | | | |
| Decrease ghg emissions | $N_2O$ | Compaction during storage | Conventional management | | | Ref14 | |
| | | Storage covers | Conventional management | Ref13 | Ref3, Ref11 and Ref13 | Ref1, Ref2, Ref4, Ref10, Ref11, Ref13 and Ref14 | Ref9 and Ref11 |
| | | Storage with acidification | Conventional management | Ref3 | | | Ref9 |
| | | Storage with additives | Conventional management | Ref1, Ref4 and Ref6 | | Ref2, Ref6, Ref10 and Ref14 | Ref5 |
| | | Storage with microbial inocula | Conventional management | Ref1, Ref4 and Ref6 | | | |

## 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 |
|---|---|
| Additive properties | Ref6 |
| Additive type | Ref6 |
| Bulk density | Ref14 |
| Initial moisture content | Ref6 |
| Moisture content | Ref14 |
| 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, Ref6, Ref6, 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, Ref12, Ref12, Ref12, Ref12, Ref12, Ref12, Ref12, Ref12, Ref13, Ref13, Ref13, Ref13, Ref13, Ref13, Ref13, Ref13, Ref14, Ref14, Ref14, Ref14, Ref14, Ref14 |
| Type of additive | Ref1 |
| 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 C losses could be further explored because the losses were not considered during the pre-treatment phase. |
| Ref2 | 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. |
| 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 $NH_3$; No research is available for the effect of biofilter on compost $CH_4$ and $N_2O$ emissions specifically for beef cattle manure; |
| Ref12 | No quantitative statistical analysis is reported in this synthesis study. |
| 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. |
| Ref14 | 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 |
|---|---|---|---|---|---|
| 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 |
| 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 |
| Ref12 | 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 |
| 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 |