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Review

Nitrous Oxide Release from Poultry and Pig Housing

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Abstract

The article investigates the scientific literature regarding N_2O emissions according to housing and manure management in poultry and pig buildings. The majority of the N_2O is emitted from manure storages and housing space, with small amounts emitted from the surface of passages. Many factors must be considered in successful emission evaluation, including season of the year, amount and depth of the bedding, animal density, type and floor space, feeding and watering practices, ventilation, temperature, and relative humidity. The liquid manure from poultry housing systems produces greater emissions of N_2O than natural and force-dried manure. The influencing factors appeared to be manure removal frequency and the dry matter content of the manure. There are more housing types in pig barns, which differ in bedding, floor, and manure deposition. The highest N_2O emissions were found in the sawdust bedding, and N_2O production in slatted floor housing is lowest. This paper reports on technical options for mitigating emissions from poultry and swine contributions. The actual rate of N_2O emission is highly dependent on the management strategies implemented on a farm. Consequently, improvements in management practices will affect future N_2O emissions. Finally, emission factors are listed in a table.

Keywords: environment, emissions, greenhouse gas, housing, bedding, manure

Introduction

Gaseous nitrogen compounds (NO_x, N_2O) are known to cause severe environmental problems. NO_x promotes ozone formation in the troposphere, and nitrous oxide (N_2O) is a greenhouse gas that contributes to the reduction of ozone in the stratosphere through the photochemical decomposition of N_2O to NO [1-5].

This gas is produced during several microbial processes in the nitrogen (N) cycle of terrestrial and aquatic systems [6]. Animal husbandry practices can have a large impact on the emission of N_2O. They potentially contribute up to 50% of total agricultural N_2O emissions [7]. Emissions from farms are particularly due to the intensive nitrogen cycle [8-9]. The non-ruminant sector is a minor N_2O emissions contributor compared with ruminant N_2O emissions. The poultry industry is the largest direct N_2O producer of the non-ruminant livestock industries, contributing 92.8% of the total non-ruminant N_2O emissions [10]. In pig houses, N_2O originates only from manure [11].

Nitrous oxide is primarily produced through nitrification and denitrification processes in nitrogen-containing substances such as agricultural soils and via digestion of organic matter in manure storage, where both aerobic and anaerobic conditions can exist [5, 12-13].

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Nitrification occurs under aerobic conditions and follows two steps where ammonium is first oxidized to nitrite, and nitrite is then converted to nitrate, with N_2O as a by-product [7, 14-16]. Ammonia-oxidizing bacteria are responsible for the production of N_2O in nitrification [17].

Denitrification is a series of microbe-mediated reactions of the natural microbial process and is an essential part of the nitrogen cycle [18-19]. This anaerobic process is the stepwise reduction of nitrate to nitrogen via nitrite, nitric oxide, and N_2O [7, 14-16, 20-21].

The N_2O:N_2 ratio produced during denitrification is affected by the presence of anoxia and facultative heterotrophic bacteria capable of denitrification temperatures. The rate of formation and emission of N_2O varies through time with changes in manure porosity, pH, temperature, moisture, amount of solids, N, and protein content of the manure substrate [1, 22-24]. Manure type may affect N_2O emissions in several ways, such as the type of N which changes N_2O production during nitrification and denitrification. Also, the presence of freely available C, which stimulates denitrification activity and O_2 consumption in the soil following, is important [15, 25].

The conditions necessary for denitrification also include the availability of reductants such as organic carbon, low availability of degradable carbohydrates, N_2O reductase activity, and high concentration of NO_3^-, N_2O, or NO. This process has been observed at temperatures between 2 and 50ºC, but every 10ºC rise in substrate temperature may double the rate of denitrification [15, 19, 26-28].

Microbial production in soils is the dominant nitrous oxide source. N_2O emissions increase with the use of nitrogen fertilizers [29-30], from manure and urine excreta applied and aerobic and anaerobic degradation of livestock waste in the lagoons and dry manure piles [31]. According to [32], the urea contributed the highest proportion of N_2O emissions (74.8%) among the fertilizers. The high N_2O emission rates generally corresponding with soil conditions are necessary to denitrification, and nitrification is often an essential prerequisite for the conversion of N fertilizer inputs into soil NO_3^- [33]. Also, N_2O emissions are high when N fertilizers are used for production of concentrates to feed the animals, as well as from excretal returns [29, 34].

Emissions of N_2O arise both directly and indirectly from more sources on poultry and pig farms [35]. These include the storage deposition of manure and urine and the surface of barn floors. [36] found that maximum concentrations of N_2O per 1 kg of LBW were 30% lower in the pig-fattening building than in broiler housing.

Nitrous oxide generation in agricultural systems is still not completely understood. Therefore, the emissions reviewed in the current study are dedicated to N_2O released from housing and solid or liquid wastes application in poultry and pig farms.

Poultry

The levels of gases in poultry housing have been closely associated with manure management [37]. This process is often characterized by the production and evolution of gases. The decomposition of poultry manure can take place in one of two ways. If oxygen is present then the decay is said to be aerobic, and aerobic disintegration of poultry manure is basically an odourless process that produces stabilized organic matter, some carbon dioxide, and water. On the other hand, most manure practices involve anaerobic decomposition. This is typical of liquid manure handling systems and characteristic of collection pits, holding tanks and storage lagoons [38]. This process is characterized by obnoxious odours and the production of considerable amounts of gases that are hazardous to people and livestock.

Once excreted, poultry manure characteristics change further, depending on various manure management systems of collection, storage, transfer, treatment, and utilization. Most poultry are grown on dirt floors with different bedding materials, which generally need to be very absorbent (to limit the production of ammonia and harmful pathogens) and must have a reasonable drying time [39-41].

Poultry manure may combine bedding with feathers, spilled water and feed, process-generated wastewater (water for flushing gutters, etc.), and dead birds. As a result, the properties of manure differ not only within one species, but also among different types of poultry birds [42]. The increase in manure organic matter accelerates soil metabolism, reduces oxygen, and raises denitrification and N_2O emissions [43-44]. In contrast, separation of manure solids lowers the organic content of liquid manure, which generally results in lower emissions of N_2O [44-45].

Housing and Manure Management

After poultry manure has been excreted by the animals, it quickly begins to undergo some type of microbial decomposition. The principle behind the decomposition is that the complex molecules in the poultry manure are broken down into simpler compounds [38].

Removing manure from storage in a timely manner is an important aspect of overall manure management on a farm. How fast manure is removed from housing and moved to the point of use depends on the size of equipment, e.g., front-end loaders for handling solid manure, the volume of hauling tanks, pump sizes, and the condition of the equipment. The volume of the hauling equipment and the distance manure is transported will determine the time it takes to empty a manure storage tank [46].

Poultry manure is produced during the normal operation of hatcheries, broiler production, and egg-laying production. It also occurs in turkey and waterfowl production. Since a majority of poultry manure is produced in broiler and layer operations, special attention will be paid to these two specific parts of the poultry industry [38].

Most cage layers are housed in high-rise poultry facilities that are commonly used in egg production [47-48]. Manure is collected and stored beneath the bird cages in a pit under the house [40]. A deep pit is used in the cage layer house to minimize odor and insect problems and eliminate water pollution potential. Manure under the cages is typically stored for 6-18 months. These management objectives can be achieved by keeping the manure as dry as possible [39-40, 49]. Another type of house used in layer production is a single-story stair-step house. The cleaning frequency of both types of systems may be based on several factors: the quality of the manure or manure litter in the pit or in the house, the storage space remaining, or the integrator specified clean-out cycle [40-50]. Concentrations of harmful gases are commonly high in aviaries and floor housing systems in which manure is not regularly removed [51].

Generally, poultry manure has higher total solids content than most other manures. Dilution with water increases the potential for odor, so handling the manure as a solid is usually preferred. Manure – especially from high-rise and belt-scrape houses – may be handled as solid, liquid, or slurry, whereas manure from a shallow-pit layer house is handled as liquid or slurry [42].

Liquid poultry manures (those containing less than 150 g. kg^{-1} dry matter) are generated when manure is scraped or flushed into storage reservoirs, such as tanks, detention basins, aerobic or anaerobic lagoons, and oxidation ditches [52-53]. Liquid manure is generally flushed to a manure treatment anaerobic lagoon or a storage pond before it is land-applied as fertilizer, whereas slurry may be stored in an aboveground tank [42, 54].

Manure storage as slurry, manipulating slurry pH to values lower than 6 and storage as solid manure under anaerobic conditions, help to reduce N_2O emissions during the manure storage stage. Therefore, a combination of decreased storage time in warm weather and extended winter storage is a viable option in many regions [43-44].

Manure is removed also with a scraper or by flushing to a waste treatment lagoon or waste storage pond. A shallow pit usually means a liquid type of flushing is used every few days, while a deep pit means the manure is handled in solid form and need only be cleaned out once or several times a year.

Most broiler operations result in the production of solid poultry manure, which is referred to as poultry litter or broiler litter. Litter is used in confinement buildings for raising turkeys and other birds. Solid poultry manure contains more than 150 g dry matter kg^{-1}, which makes them amenable to solid-waste handling systems [52].

Common bedding materials include wood shavings, sawdust, peanut hulls, husk, straw, and other dry, absorbent, low-cost organic materials [55-57]. Sand is also occasionally used as bedding. The final product is a mixture of poultry excreta, spilled feed, feathers, and material used as bedding in poultry operations [40].

An absorbent litter material is usually laid down on the floor and the choice of absorbent litter depends on the needed absorption and commercial availability. The removal of this litter is handled in solid form and can be done after each brood or yearly, or can be left for longer periods [38]. It is normally removed when the birds are moved out [40]. Treating the poultry litter in a biogas digester can substantially reduce emissions while also providing energy [58]. Nitrous oxide losses from poultry litter were generally low compared with NH_3 emissions, comprising only about 1.3% of the gaseous N losses (0.48 g N per bird for N_2O vs. 30.8 g N per bird for NH_3) [59].

Many factors must be considered in successful emission reduction including the time of year, depth of the litter, floor space per bird, feeding practices, disease, the type of floor, ventilation, watering devices, litter amendments, and even the potential fertilizer value of the litter after it is removed from the house. Other factors can be expected to have an influence, such as litter amount (initial amount or regular inputs), flocking density, mortality, temperature, and moisture of outside air [60-62]. Also, additional authors have highlighted the quality of litter and quality of air related to the intensity of ventilation [41, 63].

Emissions from Hen and Broiler Housing

The production of N_2O from poultry manure depends on faeces composition, the microbes and enzymes involved, and the conditions after excretion [64]. Further, owing to interactions between available C and N sources in the correct oxidation form, semi-permeable manure storage covers can enhance N_2O formation [44, 65-66]. N_2O emissions are sometimes very difficult to quantify, and low N_2O concentrations are close to the detection limit of gas analyzers. No N_2O emission data are available for other types of poultry like turkeys, ducks, geese, etc. The reported N_2O emissions from poultry vary greatly and have to be judged critically, because the measured concentrations were very low (sometimes only slightly above the ambient concentration of N_2O) [67-68].

Over the last two decades, egg production has shifted from deep-pit housing systems (liquid manure management) to manure-belt housing systems (solid manure management). The results of Fournel [69] showed that liquid manure from deep-pit housing systems produces greater emissions of N_2O than natural and forced dried manure from belt housing systems. The influencing factors appear to be manure removal frequency and the dry matter content of the manure [69]. The emissions from manure storage are largely affected by storage conditions, including ventilation rate, air temperature, and stacking profile [47, 54].

Authors [21] analyzed the effect of a tunnel ventilation system on N_2O losses in a laying hen's farm and found that emissions tended to be higher in winter than in summer. The nitrous oxide emission rate was negatively affected by the rate of ventilation. This effect should be the reason that explains the lowest emissions in summer. However, not only the temperature but also the amount of air released from poultry buildings and the content of that air should be new variables in an operating ventilation system [63].

N_2O emissions were in two buildings for laying hens (a battery system with aerated open manure storage, vertical tiered cages with manure belts with forced air drying) [70]. No significant emissions were registered for N_2O, which was consistently close to zero for both techniques. This depends also on the air exchange. N_2O concentrations in the enriched cages system with ventilation under the floor of the cages were significantly lower than in the system with the ventilation by the fan placed in the wall [71].

Litter type, management, humidity, and temperature affect gas concentration and emissions from broiler fattening [64, 72]. Results [73] showed that similar indoor thermal environments in all three measured houses were maintained through ventilation management and environmental control. Gaseous and particulate matter concentrations of the enriched colony house were comparable with those of the conventional cage house. In comparison, the aviary house had poorer indoor air quality, especially in wintertime.

Similarly, concentrations of aerial nitrous oxide in broiler, cage, and perchery houses over 24 h during winter and summer were close to ambient levels [74]. Results of [75] demonstrated that N_2O emissions from layer chickens were twice as large as for broiler chickens (direct N_2O emissions of 0.25 vs. 0.17 kg $CO_2 \cdot yr^{-1} \cdot head^{-1}$, indirect N_2O emissions of 1.39 vs. 0.68 kg $CO_2 \cdot yr^{-1} \cdot head^{-1}$). N_2O concentrations in broiler housing ranged from 0.92 to 8.24 $mg.m^{-3}$ daily [36]. The increased litter depth increased N_2O emissions [76]. Authors [77] found very low N_2O emissions in the housing of broilers, which were on the level of the detecting threshold of their measuring device. It is probable that the very dry litter in this house inhibited the microbial processes necessary to produce both gases [63].

Pigs

Housing systems often concentrate animals into relatively small areas, which can result in waste disposal problems. The choice of manure management system has a direct influence on space requirements, air quality, pen hygiene, and overall building design. There are more housing types in pig barns, which differ by bedding (deep litter system, straw flow system), floor system (slats, straw flow), and manure deposition (lagoon, manure heap) [28, 78-80].

Collected pig manure can be solid (farmyard manure, deep litter) or liquid form (slurry with typically 1% to 10% of dry matter) [6]. Additional bedding or drying is required to handle manure as a solid. Solid manure handling is common for shed and open-lot systems used for swine gestation and finishing. Where these systems are used, solid storage for manure is required, along with facilities for controlling runoff [49]. Slurry and liquid manure can be stored below the partial or full-slotted floor under slat pits or outside tanks in belowground or aboveground storage facilities, or treated in an anaerobic lagoon [36, 49, 81]. In other production systems, effluent from barns is transferred into open anaerobic ponds (lagoons), where the effluent is typically stored for many months with the potential to generate large quantities of emissions [28]. It is estimated that 20-30% of this waste is stored in lagoons with the subsequent application of the effluent onto soil [82]. If 100% of digested slurry is utilized as bio-fertilizer, the emissions intensity could be further reduced by 17 times compared to the case without slurry utilization [58].

A primary objective in manure handling is to minimize the accumulation of noxious gases and odors [79, 49]. Pit ventilation and removing manure from the building to outdoor storage can also reduce odor and gas accumulations within the building. Where odor control is important, an anaerobic waste-treatment lagoon is often recommended [49]. In the USA, hog operations produce more than 14 Tg of manure each year. About 30% of this manure is stored in anaerobic lagoons before effluent applications on land [83]. Manure affects the balance between NH_3 and N_2O emissions. This interaction may be positive (e.g., both emissions are reduced by an airtight cover during storage and stimulated by composting), or negative (e.g., direct N_2O emissions from soil will potentially increase if losses of NH_3 are prevented during storage or field application) [34].

Emissions from Housing

As in poultry, N_2O production is also low in the housing of pigs [77], depending on the density and composition of animal manure. Quality of manure is important, but emissions also depend on many other factors. The fattening period accounts for more than 70% of total emissions, while the gestation, lactation, and weaning periods each contribute about 10% of total emissions. Emissions of N_2O contribute to 2% of total emissions from pig buildings [11].

An increase of the available area for group-housed gestating sows kept on straw-based deep litter decreased N_2O emissions, probably due to reduced anaerobic conditions required for their synthesis [84]. The main factors for gas emissions of deep litter pig manure are the initial bulk density of the manure, influencing the free air space and gas exchange, and initial carbon and nitrogen contents [79]. Nitrous oxide emissions per animal unit from deep-litter sheds were negligible in winter and 8.4 $g.LU.d^{-1}$ in summer [85]. With deep litter systems, N_2O emissions increase regularly in the course of time, principally thanks to the accumulation of dejection and compaction [86-87].

The significant effects on N_2O concentrations in the piggery with slatted housing show ventilation system intensity. Nitrous oxide was reduced by increasing the suction rate, and differences between the low and high ventilation intensities were significant (0.78 ppm vs. 0.61 ppm) [88].

The release of gases varies during the day. Those variations may explain why the results presented by other authors differed so much. Emissions of N_2O from partially slatted pig units at the peak hours (13:00-14:00) was twice as high as that observed around 06:00, even though room temperature was kept at around 17ºC. N_2O emissions from during a full fattening period of eight weeks were recorded between 8.4 $g.pig^{-1}$ and 9.1 $g.pig^{-1}$ [89].

Total emissions of N_2O reached the highest values in winter and were influenced especially by high concentrations of gases in the housing area [90]. Similarly, the highest daily emission rates of N_2O were found in the winter batch, and the lowest emission rates in the summer batch. The calculated emission factors showed 0.17 kg of N_2O per animal and year [91]. Whatever the floor type in pig housing, emissions increased from the beginning to the end of the fattening periods by about four times for N_2O [92].

The effects of slat characteristics on N_2O emissions have been rarely studied. Generally, the N_2O emissions are low in slatted floor housing [93-95]. However, it can be assumed that they are of little importance, considering the formation process of these gases. Emissions are associated with the amount of slurry in deep pits and the size of the polluted floor in the housing area [96]. Most important is the frequency of manure removal. Emissions were reduced when underground manure pits were discharged weekly [89].

Protection of the environment should take into account seasonal influences. In winter cycle the total emissions of N_2O were 1.7 times higher than in summer [97]. For the other work, N_2O emissions during winter were also higher than in summer [98].

Covers on slurry stores are an effective means of reducing ammonia emissions. Minimizing the stirring of stored slurry (depending on the diet of the pigs and the dry matter content of the slurry) and introducing new slurry below the surface will allow the build-up of a natural crust [99].

Floating crusts on manure storage are environments with intense microbial activity, and microbial processes are governed by the extent of use oxen conditions that are governed by the moisture of the crust. The crust provides a substrate that spans anaerobic and aerobic environments where N_2O production can occur [19, 34]. Natural surface crusts may develop into a porous matrix with high O_2 availability that harbors an active population of aerobic microorganisms. The occurrence of NO_2^- and NO_3^- in the crusts also indicates the presence of actively metabolizing NH_3^-oxidizing bacteria [66]. An increase in N_2O emissions in all crusted treatments exposed to anoxia was observed [65]. Authors concluded that covering the stored manure is very efficient for mitigating NH_3 emissions, but manure crusts may increase the emissions of N_2O due to nitrification and subsequent denitrification.

Pig slurry has fewer tendencies to form a natural surface crust than cattle slurry. For this reason it is especially important to cover pig slurry stores in order to avoid NH_3 emissions. However, N_2O emissions release is different. After 200 days of storage under warm conditions, NH_3 emissions from uncovered pig slurry were about 40% higher than emissions from the covered store. Nitrous oxide emissions from uncovered pig slurry reached an N_2O level of 119 $g.m^{-3}$ after 200 days, compared to 114 $g.m^{-3}$ from the covered store under warm conditions. After 50 days, N_2O emissions were 23 and 30 $g.m^{-3}$ from the uncovered and covered stores, respectively. Under cold conditions, the uncovered store emitted 36 $g.m^{-3}$ and the covered store 18 $g.m^{-3}$ [100].

Bedding and Floor Comparison

Several bedding materials were tested in regards to emissions. The most frequent substrates are straw and sawdust. Compared to straw litters, sawdust litters produce more N_2O [101-103]. It was recorded 3.9 times more higher N_2O emissions in fattening pigs kept on sawdust litter bedding than straw litter bedding (1.39 $g.d^{-1}$ vs. 0.36 $g.d^{-1}$ per pig) [101]. These results were confirmed by the same authors the next year. Nicks [102] found significantly higher N_2O emissions in fattening pigs kept on sawdust litter bedding than straw litter bedding (2.09 $g.d^{-1}$ vs. 0.03 $g.d^{-1}$ per pig). With the sawdust-based litter, the N_2O emission was highest during the fattening of the first batch, up to 7 g per pig per day in the third series of measurements. Over the three fattening periods altogether, the sawdust-based litter produced significantly more N_2O (+ 2.06 $g.pig.d^{-1}$) [102].

The straw flow systems have been developed combining regular straw supply, sloped floor, and frequent manure scraping. This kind of manure management is efficient for reducing N_2O emissions, but increases NH_3 emissions [86, 92, 104-105]. With fattening pigs kept in a straw flow pen, gaseous emissions were significantly lower for N_2O (-55%) compared to pigs housed on straw-based deep litter [87]. N_2O emissions were negligible from straw-based litter; they were reduced gradually from one batch to the other, from an average of 3.98 $g.d^{-1}$ for batch 1 to an average of 0.70 $g.d^{-1}$ for batch 3 [102].

Emissions from the deep litter system were significantly higher than from the slatted floor system for nitrous oxide (+106%) [92]. Also, authors [106] confirmed that N_2O emissions were higher in a deep litter piggery than in building with fully-slatted floor (by 74%, 0.047 $g{\cdot}day^{-1}{\cdot}kg^{-1}$ vs. 0.027 $g{\cdot}\ day^{-1}{\cdot}kg^{-1}$). The influence of the type of floor on N_2O emissions was evaluated in the raising of weaned pigs. Emissions from rearing the weaned pig seem lower with a fully slatted plastic floor system than with deep litter systems. A similar trend was found with sawdust [103].

N_2O emissions observed during the fattening of pigs kept on the slatted floor were significantly lower than on

Table 1. N$_2$O emission factors from poultry and pig facilities.

360 hens, Lohmann LSL-Lite, 19-27 wks of age; solid manure on the belt, dried manure on the belt, SLR in deep-pit; during 8 wks, 15 min, sampling air, GC; 2.60 g yr^{-1} hen^{-1}, 2.48 g yr^{-1} hen^{-1}, 2.78 g N$_2$O yr^{-1} hen^{-1} [69].
Laying hens, floor with straw, 0.017 kg place^{-1}yr^{-1} [115].
Laying hens, floor with wood shaving, 0.043-0.079 kg place^{-1}yr^{-1} [115].
Laying hens, floor with 3/4 straw and 1/4 wood shaving, 0.155 kg place^{-1}yr^{-1} [115].
Battery CC, 0.95 g.LU^{-1} h^{-1} [115].
Battery CC, 0.02-0.15 g.LU^{-1} h^{-1} [69].
Floor system, 0.05-0.35 g.LU^{-1} h^{-1} [69].
10,000 broilers, from 1.9 ds; force ventilated, wood shavings DL; GC, sampling, 35 measured ds; 0.0 g. LU^{-1} day^{-1} [77].
Hens, Lohmann white, 18 to 78 wks; 3 systems on the same farm, manure storage, 2 cycle flocks; CC (196,120 hens, 516 cm^2. hen^{-1}, EC (49,754 hens, 752 cm^2.hen^{-1}, AV (46,762 hens, 1253 to 1257 cm^2.hen^{-1}), PIGM, monitored continually; CC (housing 0.00 g. hen^{-1}d^{-1}, manure storage 0.03 g. hen^{-1}d^{-1}), EC (housing 0.00 g. hen^{-1}d^{-1}, manure storage 0.03 g. hen^{-1}d^{-1}), AV (housing 0.00 g.d^{-1}, manure storage 0.01 g. hen^{-1} d^{-1}) [67].
Hens; manure stockpiles, surface area 68 m^2, 19 m^3; uncovered (27820 kg, N 25.2 kg.t^{-1}) vs. covered (25120 kg, N 25.8 kg.t^{-1}); FTIR, 32 ds; N$_2$O emissions below detection [68].
Hens, 52,000 Lohmann-Brown, LBW 2.0 kg; EC, building 17 m x 66 m, EC in 6 rows; AT 18.0 C to 25.4 C (mean 22.4 C), light:dark 17:7; PIGM; yr average 4.5 ± 0.28 mg.d^{-1}.hen^{-1}, summer 3.5 ± 1.2 mg.d^{-1}.hen^{-1}, winter 5.2 ± 1.7 mg.d^{-1}.hen^{-1} [21].
10 hens, enriched cage, with vs. without exhausting device, head level, 6 consecutive ds (summer, winter), INNOVA; summer 1.005 ± 0.094 mg.m^{-3} vs. 1.033 ± 0.116 mg.m^{-3} , winter 1.055 ± 0.063 mg.m^{-3} vs. 1.076 ± 0.061 mg.m^{-3} (71)
Broilers, mechanically ventilated barn (130 × 14 m, 16 lateral exhaust fans), summer (20,100 birds) vs. winter cycle (24,000 birds), PIGM, mean 1.74 mg.h^{-1}.bird^{-1} vs. 2.13 mg.h^{-1}.bird^{-1}; 1.73 g.bird^{-1} vs. 2.07 g.bird^{-1} for cycle [116].
25,000 broilers, concrete floor, chopped straw, ventilated by tunnel and cross two-sided ventilation, PIGM, higher in winter and autumn (from 3.57 mg.m^{-3} to 8.24 mg.m^{-3}) than in spring and summer (0.92 mg.m^{-3} to 1.48 mg.m^{-3}) [36].
21,000 broilers, tunnel ventilated barn (100 x 11 m), air inlets (height 0.38 m) along the sidewalls, exhaust fans (ventilation 2178 m^3 h^{-1} at 0.0 Pa, -365,5 m^3 h^{-1} at 50.0 Pa), bedding rice hulls; 42 ds, PIGM, winter, measured 1, 4, 10, 12, 18, 23, 26, 28, 32, 35 and 40 d; 0.041 ± 0.002 g d^{-1} bird^{-1}, 6.7 ± 0.3 g d^{-1} LU^{-1} [61].
52,000 broilers, 2 tunnel-ventilated houses (120 x 14.75 m, 1700 m^2 floor area, 10 fans, clay floor, wood shavings); FTIR, 42 d age, litter depth 47 mm vs. 67 mm; 0.30 g.bird^{-1} vs. 0.69 g.bird^{-1} [76].
54,000 broilers, 2 tunnel-ventilated houses (120 x 14.75 m, 1700 m^2 floor area, 10 fans, clay floor, wood shavings, depth of 40-50 mm); CP 19.8 % vs. standard diet (CP 21.3 %); FTIR, 42 d age; 0.39 g.bird^{-1} vs. 0.42 g.bird^{-1} [76].
57,000 broilers (Cobb), barn (93 m x 29 m, height 4.5 m, sawdust 0.9 kg.m^2), control vs. water additive Biopolym (3 g per 100 kg LBW.d^{-1}); PIGM, growing cycle, October-November; 0.44 vs. 0.34 g.bird^{-1}, 0.15 vs. 0.12 g.h^{-1} per 500 kg bedding material [117].
160 fattening pigs; 16 pens, SFS without DMR vs. SFS with DMR; liquid feed (54 % maize, 22 % grain, and 22 % soy bean); FTIR, June to March; 39.9 g.place^{-1}.yr^{1} vs. 24.5 g.place^{-1}.yr^{1} [100].
Fattening pigs, FSF, 0.02-0.04 kg.place^{-1}.yr^{1} [115].
Fattening pigs, FSF, 0.15 kg.place^{-1}.yr^{1} [115].
300 fattening pigs, 25 kg LBW; partly SF, force ventilated; GC, 17 ds; 0.4 g.LU^{-1}d^{-1} [77].
Fattening pigs; 6 housing systems, FSF, DL (wood chips), DL + additives to bedding: Ecozyme, Envirozyme, Bioactive powder, UMS-A-Ferm; PIGM; from 0,8 to 4,95 ppm, no measured emission in FSF, DL average 1.7 g.d^{-1} - 10.0 g.d^{-1}, 0.59 - 3.44 kg.place^{-1}.yr^{-1} [80].
240 fattening pigs, 2 pens; FSF (0.7 m^2.pig^{-1}, 796 g LBWG) vs. DL (wood chips, 1.0 m^2.pig^{-1}, 806 g LBWG); additives Envirozyme, Ecozyme, Bioactive powder; PIGM, no measured emission in FSF, DL from 0.59 to 3.46 kg.place^{-1}.yr^{-1} [93].
Fattening pigs; without straw; 0.31 kg.place^{-1}.yr^{-1} [115].
Fattening pigs; DL; 1.9-2.4 kg.place^{-1}.yr^{-1} [115].
108 fattening pigs; LBW from 31 to 110 kg, N 6.16 kg.pig^{-1}; sawdust DL 40-50 cm, additive Envistim; NOxA, GC, 112 ds; 0.3 g. h^{-1} [104].
288 fattening pigs, LBW from 26 to 107 kg, N 6.28 kg.pig^{-1}; sawdust DL 70 cm, additive Bactostim; NOxA, GC, 121 ds; 0.2 g.h^{-1} [104].
36 fattening pigs; N 6.7 kg.pig^{-1}; FSF, 0.7 m^2.pig^{-1}; NOxA, GC; 0.0 g.h^{-1} [104].
Fattening pigs; DL; 1.55-3.07 kg.place^{-1}.yr^{-1} [115].

Table 1. Continued.

Fattening pigs; DL; 1.43-1.89 kg.place^{-1}.yr^{-1} [115].
Fattening pigs; DL; 1.09 kg.place^{-1}.yr^{-1} [115].
Fattening pigs; DL (straw); 0.05 kg.place^{-1}.yr^{-1} [115].
Fattening pigs; SFS; 1.6-2.4 kg.place^{-1}.yr^{-1} [115].
40 fattening pigs, Danish Landrace, LBW from 32.4 kg to 85.5 kg; partially SF, SLR removed weekly, SLR production 0.309 m^3.pig^{-1}, AT 16.4 °C, RH 62.9%, AVR 2080 m^3.h^{-1}; feed consumption 119.8 kg.pig^{-1}, AT of SLR 17.0 °C, DM of SLR 5.88%; PIGM, 8 wks; 8.4 g.d^{-1} , 0.55 kg.LU^{-1}.yr^{-1} [89].
40 fattening pigs, Danish Landrace, LBW from 31.9 kg to 87.1 kg; partially SF, SLR left in the pit, SLR production 0.289 m^3.pig^{-1}, AT 16.6 °C, RH 60.6%, AVR 2138 m^3.h^{-1}; feed consumption 124.5 kg.pig^{-1}, AT of SLR 16.5 °C, DM of SLR 4.95%, PIGM, 8 wks; 9.1 g.d^{-1}, 0.59 kg.LU^{-1}.yr^{-1} [89].
80 fattening pigs, Piétrain×Belgian Landrace, 5 batches, LBW from 23.8 kg to 112 kg and 110 kg; FSF (floor space 12.2 m^2, 0.75 m^2.pig^{-1}) vs. DL (straw, 30 cm depth, floor space 19.3 m^2, 1.20 m^2.pig^{-1}); PIGM, 4 M, once a M, 6 consecutive ds; 0.54 g.d^{-1} vs. 1.11 g.d^{-1} [92].
96 fattening pigs, Piétrain×Belgian Landrace; FSF (floor space 12.2 m^2, 0.75 m^2.pig^{-1}, No 16, LBW from 23.4 kg to 110.2 kg , growing and finishing meal, intake 2.17 kg.d^{-1}) vs. SFS (slope 6 %, straw 34.4 kg.pig^{-1}, 0.79 m^2.pig^{-1}, LBW from 23.3 kg to 113 kg LBW, growing and finishing meal, intake 2.24 kg.d^{-1}); PIGM, 3 batches, 4 M, once a M, 6 consecutive days; 0.67 g.d^{-1} vs. 0.68 g.d^{-1} [86].
96 fattening pigs, Landrace, LBW from 23.3 kg to 113 kg; DL (46.9 kg straw.pig^{-1}, 1.2 m^2, No 16) vs. SFS (34.4 kg straw.pig^{-1}, 0.75 m^2, No 16), room 103 m^3, 30.2 m^2, 3 batches, growing and finishing meal; PIGM, 4 M, once a M, 6 consecutive ds, 1.50 g.d^{-1} vs. 0.68 g.d^{-1}, 10.96 g.LU^{-1} vs. 4.98 g.d^{-1}.LU^{-1} [87].
108 fattening pigs, 3 batches; sawdust DL (81 kg.pig^{-1}), No 54, 1.2 m^2.pig^{-1}, LBW from 22.5 kg to 114.7 kg vs. straw DL (39.6 kg.pig^{-1}), No 54, 1.2 m^2.pig^{-1}, LBW from 22.4 kg to 111.5 kg; PIGM, M intervals, 6 ds; 2.09 g.d^{-1} vs. 0.03 g.d^{-1} [102].
Fattening pigs, 6 farms; FSF, channel or side wall ventilation; PIGM, summer, winter; indoor concentration 0.817 ppm, 154 g.place^{-1}.yr^{1} [118].
Fattening pigs, 1 farm, low emission stable; partially SF, sloped pit walls, water channel (reduced emitting surface system), side wall ventilation, air scrubber; PIGM, summer, winter; indoor concentration 0.731 ppm, 136 g.place^{-1}.yr^{1} [118].
Fattening pigs, LBW from 30 to 80 kg; 2 housing systems, side walls ventilation, FSF (0.77 m^2·pig^{-1}, liquid fodder,) vs. DL (0.77 m^2·pig^{-1}, dry fodder AL); PIGM; 0.027 g.d^{-1}.kg^{-1} vs. 0.047 g.d^{-1}.kg^{-1} [106].
64 fattening pigs, Danish Landrace x Yorkshire x Duroc; summer, AT 20.5 °C, batch 79 d, LBW 29.9 to 111.0 kg; winter, AT 19.4 °C, batch 93 d, LBW 29.6 to 119.5 kg; 2 identical rooms (5.7 x 4.9 m, 2/3 FSF and 1/3 SF (smaller slot openings), partial pit and ceiling-top exhausts; ventilation 1 (diffusion ceiling and ceiling-jet air inlets) vs. ventilation 2 (wall-jet air inlets); PIGM, N_2O concentrations low (0.32-0.5 ppm) in all locations (room exhaust, slurry-pit exhaust, air inlet) [94].
Fattening pigs; partially SF, naturally ventilated, adjustable side walls, anaerobic effluent pond, short hydraulic retention-time tank, housing; winter (No 483, LBW 80.5 kg, LBWG 0.74 kg.d^{-1}, feed conversion ratio 3.0) vs. summer (No 438, LBW 70.7 kg, LBWG 0.75 kg.d^{-1}, feed conversion ratio 2.4); FTIR, 30 ds, N_2O concentrations from the pond and housing close to, or below, the detection limits, retention-time tank 0.001 mg.LU^{-1}.d^{-1} vs. 5.9 mg.LU^{-1}.d^{-1} N_2O-N [28].
360 fattening pigs, insulated barn, FSF, 3 vacuum fans in the ceiling, max. ventilation rate 21,000 m^3.h^{-1}; PIGM, N_2O daily ranged from 1.08 to 6.39 mg.m^{-3}, increased concentrations in autumn and winter (3.62 mg.m^{-3} to 6.39 mg.m^{-3}) [36].
Fattening pigs, SFS, ventilation 3 exhaust ceiling fans, inlet flaps along the sidewalls; summer (348, LBW 25 kg to 110 kg, 105 ds) vs. winter (352, LBW 25 kg to 110 kg, 121 ds); PIGM, 12 min intervals; 0.1 kg.pig^{-1}yr^{1} vs. 0.2 kg.pig^{-1}yr^{1} [90].
Fattening pigs, SFS, SLR in deep pits, 16 pens, ventilation 3 exhaust ceiling fans, inlet flaps along the sidewalls; summer (356, LBW 30 kg to 110 kg, 96 ds) vs. winter (352, LBW 30 kg to 110 kg, 120 ds); PIGM, 12 min intervals; 0.17 kg.pig^{-1}yr^{1} [91].
40 gestating sows, Belgian Landrace, parity 4.4 vs. 4.6; straw DL, 2.5 m^2.sow^{-1}, vs. 3.0 m^2.sow^{-1}, LBW from 202.9 kg to 255.4 kg vs. 206.2 kg to 263.2 kg; restricted cereals diet; 4 batches; PIGM, 6 ds (in gestation wks 6, 9, 12); 2.48 g.d^{-1} vs. 1.78 g.d^{-1} [84].
200 weaned pigs, 5 batches, without changing the litter in between batches; sawdust DL (30 cm, 5 kg.pig^{-1}), 0.54 m^2.pig^{-1}, LBW from 7.65 kg to 24.8 kg vs. straw DL (30 cm, 5 kg.pig^{-1}) 0.54 m^2.pig^{-1}, LBW from 7.65 kg to 24.6 kg, transition and post weaning feeds; PIGM, M intervals, 6 ds; 1.39 vs. 0.36 g. d^{-1} [101].
Weaned pigs, from 3.5 to 11 wks, DL, winter (No 958, LBWG 0.53 kg.d^{-1}, feed conversion ratio 2.1) vs. summer (No 948, LBWG 0.50 kg.d^{-1}, feed conversion ratio 2.1), N2O negligible in winter, 8.4 g. LU^{-1}.d^{-1} [85].
20 weaned pigs; FSF vs. DL (straw, 30 cm, 8 kg.pig^{-1}); LBW from 7.14 kg to 23.0 kg, LBWG 382.17 g.d^{-1}; post-weaning feed AL, feed conversion ratio 1.66 kg feed.kg LBWG^{-1}; PIGM, 3 wks, 6 ds; 0.00 g.d^{-1} vs. 0.03 g.d^{-1} [103].
20 weaned pigs, FSF vs. DL (sawdust, 20 cm, 26.7 kg.pig^{-1}), LBW from 7.14 kg to 23.0 kg, LBWG 382.17 g.d^{-1}; post-weaning feed AL, feed conversion ratio 1.66 kg feed.kg LBWG^{-1}, PIGM; 3 wks, 6 ds, 0.01 g.d^{-1} vs. 0.32 g.d^{-1} [103].

straw-based deep litter (0.54 vs. 1.11 g per pig per day for N_2O) [92]. Mean daily emissions per pig fattened on the slatted floor or on the sloped floor were, respectively, 0.67 and 0.68 g [86]. Practically no N_2O emissions were observed from rooms with a slatted floor while the N_2O emissions were 0.03 and 0.32 g N_2O-N.d^{-1} for the straw and sawdust deep litter, respectively [103]. Frequent manure removal seems to be an efficient means for reducing N_2O emissions from pig buildings for both slatted and bedded floor systems. Manure removal operations may be associated with specific storage conditions and efficient treatment in order to further reduce emissions [11].

Emission from Manure Application

N_2O emissions from soil application of animal wastes are a major contributor to total GHG emissions from agriculture [27]. Field application is considered the main source of agricultural N_2O since all manure types significantly increase microbial production of N_2O from soils [107]. Soils contribute about 65% of the total N_2O produced by terrestrial ecosystems [1, 31]. Microbial N_2O production and consumption processes depend on several interacting environmental controls such as N supply, soil temperature, soil moisture, oxidatione reduction potential, the availability of labile organic compounds, soil type, soil pH, and climate [30, 108]. Sources of N_2O emissions are associated with volatilization of land-applied manures [25]. If 100% digested slurry is utilized as bio-fertilizer, the emissions intensity could be further reduced by 17 times compared to the case without slurry utilization. Treating the poultry litter in a biogas digester can substantially reduce GHG emissions while also providing energy [58].

The variation in the extent of emissions from different types of manure demonstrates the effects of manure properties such as moisture content, total N, and available N content on emissions generation [109]. N_2O fluxes were enhanced by the fresh dung but not by urine [110]. Nitrous oxide emission varies with the nature of the effluent applied.

Nitrous oxide emissions from land-applied effluent are highly dynamic and affected by application time, application method, and rainfall or irrigation. However, the dominant environmental factors influencing N_2O losses include wind speed and temperature [23]. Following field application, infiltration of liquid is influenced by manure organic matter [34].

According to Bell [109], the timing of the application can be critical if significant losses of N from the soil are to be avoided. Conversely, loss of N via N_2O emissions is higher when manure is applied in wet conditions as N_2O production via denitrification will occur before the crop is able to utilize available N. A proportion of N that volatilizes as NH_3 is considered to be re-emitted as N_2O upon wet or dry deposition to soils from N excretion by animals [107].

A number of studies have shown that N_2O emission rates are highly variable throughout the season, with high rates being associated with grazing and fertilizer application in grazed pastures [1]. The highest losses by denitrification occurred in winter, when soil moisture was at or above field capacity for extended periods.

Season manure application timing (fall vs. spring) had no effect on N_2O emissions for the annual system. The spring application has been recommended as a means to mitigate N_2O because it avoids the high N_2O fluxes related to spring thaw, and N is supplied to a growing crop that may reduce soil mineral N availability for nitrifiers and denitrifiers [111].

N_2O fluxes associated with freeze-thaw events were reduced when manure was applied in spring [112]. However, applying manure in spring also implies higher N availability when soil temperature is rising and rainfall events are frequent, enhancing soil microbial activity. As a consequence, the highest N_2O peaks of the experimental period were measured for the spring treatment after significant rainfall events. When broiler litter and layer manure were applied to winter wheat, mean annual N_2O was greater for autumn (2 kg N_2O–N.ha^{-1}) than spring (0.35 kg N_2O–N.ha^{-1}) applications [109].

Differentiation of N_2O emission factors, which takes specific factors into account such as N type and rate and application technique, can improve the quantification of N_2O emissions from agricultural soils, and is needed to derive most efficient options for mitigation [45]. The emission factors for pig slurry applied to maize land were higher than for cattle slurry; 3.6% for injected pig slurry and 0.9% for surface-applied pig slurry [45].

N_2O emissions are strongly dependent on the method and timing of fertilizer application. Manure incorporation increased N_2O emissions and yield for the perennial system, but both effects were dependent on interannual weather variability and crop growth [113].

The direct nitrous oxide (N_2O) emissions from manure management and from manure applied to soils as an amendment or fertilizer were 2.1% and 1.3%. Direct N_2O emissions from manure deposited on soils by grazing livestock were 23.8% of total GHG emissions [114].

Conclusions

This review discusses the current knowledge about factors controlling N_2O emissions in poultry and pig facilities. Substantial variability shows that more data are needed to better quantify emissions from housing and manure management in some measurements. Also, very low concentrations of N_2O emissions were found (on the level of the detecting thresholds of measuring equipment).

Animal husbandry is a major contributor to global greenhouse gas emissions, in particular nitrous oxide. Therefore, appropriate strategies must be developed for reducing or minimizing emissions. There are various options to reduce N_2O emissions, but the key option is to improve overall N efficiency. Therefore, improving animal feed conversion efficiency becomes a major strategy for mitigating N_2O emissions from these farm species. Although several feeding strategies have been tested to decrease GHG emissions, they seem to be ineffective in reducing emissions both significantly and durably.

In general, floor systems for laying hens seem to emit more N_2O than battery cage or aviary systems. In the broiler housing, very dry litter inhibited the microbial processes needed to produce N_2O. The liquid manure from deep-pit poultry housing systems produces greater emissions of N_2O than natural and forced dried manure from belt-housing systems. The influencing factors appeared to be the manure removal frequency and the dry matter content of the manure. Emissions are reduced when underground manure pits are discharged weekly.

Slurry and liquid manure handling are more common in larger swine-production facilities. Liquid handling requires less time and labor to collect, transfer, and store manure. The efficient manner to reduce N_2O emissions from pig buildings for slatted floor systems seems to be a frequent manure removal. It has been concluded that N_2O emissions from straw and sawdust litter systems of hogs compared with housing on fully slatted floors tend to be higher due to the formation of N_2O. These systems are therefore not recommended. However, welfare on slatted floors is lowered.

The actual rate of N_2O emissions is highly dependent on the management strategies implemented on a farm. Consequently, improvements in management practices will affect future N_2O emissions. However, the choice for a housing system is also guided by other factors, such as animal health, performance, and welfare.

From this review of the literature we can see a clear need for the development and use of standard methods for measuring emission rates from hogs and poultry facilities. Accurate emissions data and emission factors are needed for engineering, planning, and regulatory agencies. These data are used for system design and evaluation of the effect of animal densities on surface and ground waters, and atmospheric environments.

Further research must be carried out to check the validity of emission factors and modelling parameters on a national scale. Precise experimental research studies that will measure emissions from housing are needed to establish emission factors for turkey and waterfowl farms, and the effect of management factors on these values.

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Abbreviations

AL = ad libitum
AT = average temperature
AV = aviary housing
AVR = average ventilation rate
CC = conventional cages
CP = crude protein
d = day
DL = deep litter
DMR = daily manure removal
ds = days
EC = enriched cages
FSF = fully statted floor
FTIR = open path Fourier transform infrared spectroscopy
GC = gas chromatography
GHG = greenhouse gas
h = hour
LBW = live body weight
LBWG = gain of live body weight
LU = live unit (500 kg of LBW)
M = month
MS = manure system
N = nitrogen
NH_3 = ammonium
NOxA = NOx analyser (principle of chemiluminescence)
PIGM = Photoacoustic infrared gas monitor INNOVA
RH = relative humidity
SF = slatted floor
SFS = straw flow system
SLR = slurry
yr = year
yrs = years
vs. = versus
wk = week
wks = weeks

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