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Nitrogen-Focused Screening Life Cycle Assessment of Commercial Pig Production from Feed to Slaughterhouse Gate

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Abstract. Pig production is a source of animal protein but generates nitrogen losses that contribute to acidification, eutrophication, and climate change. This study quantifies N flows in a commercial pig production system from feed intake to the slaughterhouse gate, using a functional unit of 1 kg carcass weight. A mass balance model was constructed using literature-based parameters, including N efficiency, carcass yield, and emission factors for manure storage. Feed N intake was estimated at 5.43 kg per pig, with a carcass weight of 66.0 kg. Results show that 30.8% of feed N is retained in the carcass, 18.2% in offal, 11.6% is lost as NH_3, and 0.015% as N_2O, while 39.4% remains in manure after 42 days of storage. Manure storage is identified as the primary N hotspot, holding both the largest residual N pool and the dominant gaseous loss. The NH_3 loss per pig corresponds to an acidification potential of 1.44 kg SO_2 eq per pig and a eutrophication potential of 0.895 kg N eq per pig. Sensitivity analysis shows that NH_3 loss is most responsive to the NH_3 emission factor, followed by feed intake, manure N content, and N efficiency, whereas carcass yield and N_2O emission factor have no effect.

Keywords: Pig Production, Nitrogen Losses, Manure Storage, NH_3 Emission

1. Introduction

Pig production is a major source of animal protein for human consumption. China alone produces about 47% of the world's pork [1]. However, pig farming also causes serious environmental problems. A single commercial pig excretes about 9 kilograms of nitrogen per year through its manure [2]. A portion of excreted N could be released to the environment as NH_3, while the remaining N may stay in manure after storage. Ammonia from the pig feces causes acidification and eutrophication. Nitrous oxide is one of the gases which is known as greenhouse gas; this gas is 298 times stronger than carbon dioxide [3] and causes climate change. In the pig feces, it was found that urine contained 2.3 times more nitrogen than feces [2].

Prior literature has evaluated various elements of N fluxes in pig farming. According to Millet et al. [4], around 49% of the consumed nitrogen is retained in the body by pigs, while the rest is emitted. Gómez-Muñoz et al. [5], discovered that 22.8% of manure nitrogen is converted to

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ammonia and 0.03% of the manure nitrogen to nitrous oxide during manure storage. Another experiment conducted by Niccolucci et al. [6], revealed that 30% of the nitrogen from feed is transferred to the flesh of pork.

Nevertheless, most previous studies focus on only one of the factors that affect the process. In this study, an attempt is made to consider all factors using the data collected by Millet et al. [4], Gómez-Muñoz et al. [5], and Fu et al. [2]. These factors include group housing of barrows, commercial feeding, slaughter weight of 105 kg, and 42 days of manure storage. The aim is to evaluate the amount of feed nitrogen retained in the carcass, lost as ammonia and nitrous oxide, and the most inefficient stage.

2. Method

The goal of this study is to track the nitrogen flow in a pork production system from feed intake to slaughterhouse gate and to identify the main nitrogen loss pathway. The functional unit is 1 kg of carcass weight at slaughterhouse gate. The system boundary includes feed processing, pig housing, 42-day manure storage, transport to slaughterhouse, and slaughtering. Field application of manure is excluded from the system. Key assumptions are made that pigs receive a standard diet without antibiotics or additives, that capital goods such as buildings and machinery are excluded, and that nitrogen distribution between carcass and offal is proportional to their weights. Mass allocation is applied to allocate environmental burdens between carcass and offal.

The data were collected from academic literature and the IPCC guidelines. The specific values used are reported in the Results section. The nitrogen mass balance was calculated as: Manure N = 100% − N efficiency; Manure N after storage = Manure N − NH_3 loss − N_2O loss; NH_3 loss = Manure N × NH_3 emission factor; N_2O loss = Manure N × N_2O emission factor; Carcass N = N efficiency × carcass yield; Offal N = N efficiency − Carcass N. Emission factors used were found in previous literature.

To convert the mass balance percentages into absolute nitrogen flows, the feed nitrogen intake per pig was estimated from the nitrogen excretion data reported in Millet et al. During their experiment 2, barrows with a body weight of 105 kg produced 42 grams of nitrogen per kilogram of body gain [4]. Given the body weight of 66.0 kg, the nitrogen that was excreted in form of manure is determined as follows: N excretion = 42 g N/kg body x 66.0 kg = 2.77 kg N.

The reason for this is that the efficiency of nitrogen use by the pigs is 49% [4]. This means that 51% of the ingested nitrogen will be excreted. Hence, the feed nitrogen intake by each pig was computed as follows: Feed N intake = N excretion ÷ (1 − N efficiency) = 2.77 ÷ (1 − 0.49) = 5.43 kg N.

Impact mapping is done using the N-based approach. The three impact categories considered in this case include eutrophication, acidification, and the climate impact of N_2O. NH_3 emissions can be associated with acidification and eutrophication, and N_2O emissions can be associated with the climate change or the Greenhouse effect. All these impacts have been considered for the reason that they are directly connected with nitrogen emissions from pigs.

Sensitivity analysis is conducted in order to examine the influence of varying the values of input parameters on NH_3 emissions in nitrogen expressed in %. Six parameters were varied: N use efficiency, NH_3 emissions factor, carcass yield, feed intake, manure N content, and N_2O emission factor from manure. In each of them ±20% was changed.

The factors used for acidification, eutrophication, and climate change were obtained from the TRACI 2.1 approach [7]. The factors for acidification and eutrophication resulting from emissions to air of NH_3 are 1.88 kg SO_2 eq / kg NH_3 and 1.17 kg N eq / kg NH_3, respectively. The emission

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factor of NH_3 from manure storage is stated in terms of NH_3-N; hence, NH_3-N was first converted to NH_3 by a ratio of molecular weights 17/14. For N_2O emissions, the emission factor from manure storage is expressed as N_2O-N. Therefore, N_2O-N was converted to N_2O using the molecular weight ratio 44/28 before applying the global warming potential of 298 kg CO_2 eq / kg N_2O [3].

3. Result

Based on the literature data used in this study, the nitrogen mass balance for the pork production system is summarized in Table 1. Of the feed nitrogen input (100%), 30.8% is retained in the carcass, 18.2% is distributed to offal, 11.6% is lost as NH_3 during manure storage, 0.015% is lost as N_2O, and 39.4% remains in manure after storage.

Table 1. Distribution of feed nitrogen in the pork production system

Input	Percent of feed N	Output	Percent of feed N
N in diet	100	N in carcass	30.8
		N in offal	18.2
		NH_3 loss	11.6
		N_2O loss	0.015
		N in manure after storage	39.385
		Total	100

Based on a feed nitrogen intake of 5.43 kg N per pig and a carcass weight of 66.0 kg, the NH_3 loss of 11.6% corresponds to 0.630 kg NH_3-N per pig. This is equivalent to 0.765 kg NH_3 per pig after conversion using the molecular weight ratio of NH_3-N to NH_3 (17/14). This translates to an acidification potential of 1.44 kg SO_2 eq per pig and a eutrophication potential of 0.895 kg N eq per pig. Expressed per 1 kg carcass weight, the acidification potential is 0.0218 kg SO_2 eq per 1 kg carcass weight and the eutrophication potential is 0.0136 kg N eq per 1 kg carcass weight. The N_2O loss of 0.015% corresponds to 0.000815 kg N_2O-N per pig. After conversion to N_2O using the molecular weight ratio 44/28, this is equivalent to 0.00128 kg N_2O per pig, translating to a climate change potential of 0.381 kg CO_2 eq per pig, or 0.00577 kg CO_2 eq per 1 kg carcass weight.

The nitrogen efficiency (49%) and carcass yield (62.9%) used in this mass balance were obtained from Millet et al. [4]. The ammonia and nitrous oxide emission factors for manure storage (22.8% and 0.03% of manure nitrogen, respectively) were obtained from Gómez-Muñoz et al. [5]. The N_2O emission factor for crop cultivation was obtained from the IPCC [3].

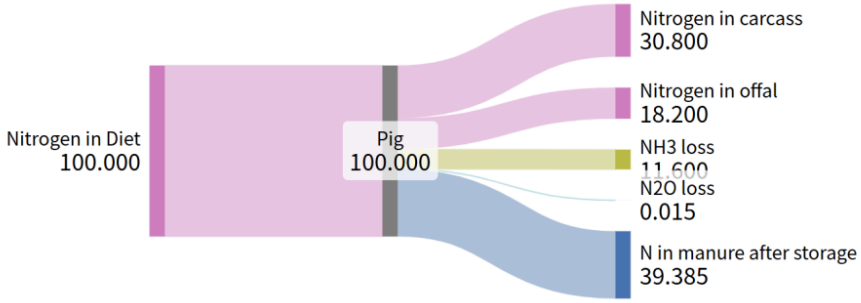


Figure 1. Nitrogen flow diagram from feed to slaughterhouse gate

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The results of the hotspot identification are shown in Figure 1. The largest nitrogen output is manure remaining after storage (39.4% of feed N). This represents a potential pollution source if not properly managed. The largest actual gaseous loss is NH_3 (11.6%), which contributes to acidification and eutrophication. Therefore, manure storage is identified as the main nitrogen hotspot in this pork production system.

The results of the sensitivity analysis are shown in Figure 2. Among the six parameters tested, NH_3 loss in nitrogen, expressed as a percentage of feed nitrogen, was most sensitive to changes in the NH_3 emission factor: a 20% increase in this factor led to a 2.4 percentage-point increase in NH_3-N loss as a percentage of feed N. Changes in feed intake and manure nitrogen content each produced a similar effect, with a 20% increase in either parameter raising NH_3-N loss as a percentage of feed N by 2.3 percentage points. In contrast, a 20% increase in nitrogen efficiency reduced NH_3-N loss as a percentage of feed N by 2.2 percentage points, because more nitrogen is retained in the animal and less is available in the manure for volatilization. Carcass yield and the N_2O emission factor from manure had no effect on NH_3-N loss as a percentage of feed N, as the former only redistributes nitrogen between carcass and offal without altering manure nitrogen, and the latter represents a separate loss pathway that does not interfere with ammonia emissions.

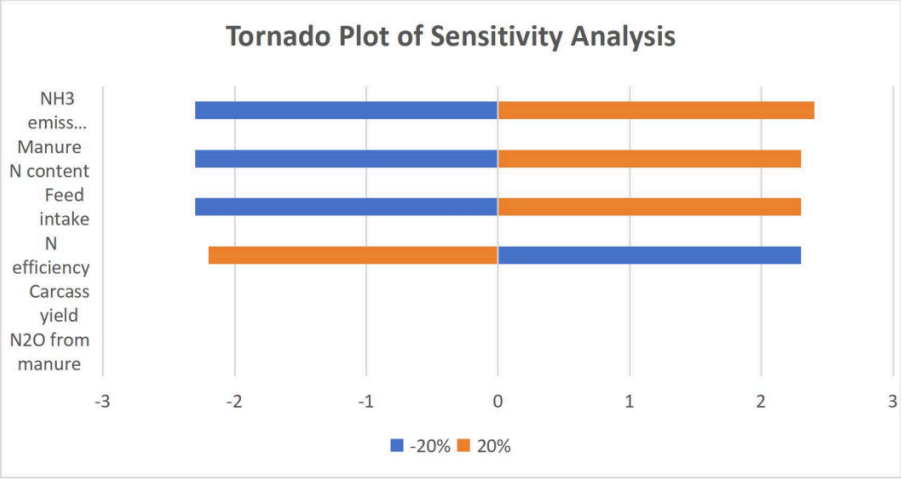


Figure 2. Sensitivity analysis of NH_3 loss to ±20% changes in key parameters

4. Discussion and conclusion

The mass balance results show how feed nitrogen is distributed in this pork production system. The largest amount of nitrogen stays in the manure after storage (39.4%), followed by carcass (30.8%) and offal (18.2%). Gaseous losses are much smaller: ammonia accounts for 11.6%, while nitrous oxide is only 0.015%. This distribution happens for two main reasons. First, pigs only retain 49% of the nitrogen they eat [4], meaning the other 51% is excreted. Second, during 42 days of storage, only 22.8% of the nitrogen in manure is lost as ammonia [5]. This means most of the excreted nitrogen stays in the manure instead of being released into the air. As a result, a large amount of nitrogen remains in the stored manure after the farm gate. The hotspot analysis therefore identifies manure storage as the main nitrogen loss hotspot, since both the largest remaining nitrogen in manure and the largest gaseous loss occur at this stage.

This remaining nitrogen matters for the environment. Unlike ammonia, which causes local problems like acidification and eutrophication right away, the remaining manure N represents a potential source of future environmental losses if manure is later applied to land without proper

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management. When farmers spread this manure on fields, it can turn into new ammonia and nitrous oxide emissions, or leach into water as nitrate. The actual environmental impact of pig production is therefore larger than what this study shows because the system boundary stops at storage and does not include field application.

The sensitivity analysis shows that NH_3 loss in nitrogen, expressed as a percentage of feed nitrogen, responds most strongly to changes in the NH_3 emission factor, followed by feed intake, manure nitrogen content, and nitrogen efficiency. Carcass yield and manure N_2O emission factor do not exert any effect. The NH_3 emission factor has the most pronounced effect since it represents the factor that regulates the portion of the manure nitrogen lost as ammonia. An increase of 20% in the NH_3 emission factor results in a 2.4 percentage point increase in the NH_3-N loss as a portion of the feed N from 11.6% to 14.0%. The feed intake and manure nitrogen content demonstrate similar effects since both factors define the quantity of the nitrogen entering the manure. The increased feed intake causes increased nitrogen entry, while the increased manure nitrogen content results in a higher portion of the excreted nitrogen entering the manure.

The case of nitrogen efficiency is exactly opposite to that of feed intake and manure nitrogen concentration. If nitrogen efficiency goes up by 20%, then NH_3 loss goes down to 9.4% of feed N. This happens due to the retention of more nitrogen in the body of the pig and its lesser excretion, which leads to the presence of lesser amount of nitrogen in the manure and less ammonia formation. Such decrease in NH_3 loss can be compared in its value to the increase in NH_3 loss as a result of feed intake or manure nitrogen content change. There is no effect of carcass yield on NH_3 loss, as it simply affects the distribution of the amount of nitrogen between carcass and offal, but does not influence nitrogen excretion and manure nitrogen content. N_2O is not included in the list of response variables for the sensitivity analysis, as it is formed through the processes other from those forming NH_3.

The results from the research have practical applications in the mitigation process. In view of the role played by the NH_3 emission factor, the measures involving its direct reduction will have a significant effect on the level of emissions from livestock. The similar impacts of the three factors, namely feed intake, manure N-content, and nitrogen efficiency, imply that changes made to the diet of the animals through the reduction of protein content in their feed will be beneficial in the mitigation process. Nevertheless, the use of these practices alone will not solve the issue of excess nitrogen. There is a substantial amount of nitrogen in the manure which is needed to be dealt with after the storage process. This can be achieved by applying the manure to crops in a more efficient manner.

For instance, a cradle-to-farm gate LCA of Alpine dairy systems showed an acidification potential of 17.3 g SO_2 eq and eutrophication potential of 6.04 g PO_4 eq per kg fat- and protein-corrected milk [8]. This particular dairy system was chosen since it falls within the same category of livestock production systems and its functional unit, system boundary, and impact categories are similar to those used in this LCA study. The two LCAs present environmental burdens in terms of grams per kg of animal-based product (at farm/slaughterhouse gate level) and the assessments of acidification and eutrophication potentials due to nitrogen losses. Though dairy and pig farming involve different livestock and different feeds for animals, they are both characterized by the same nitrogen loss pathways, which include partial retention of feed N in products, as well as excretion and loss of manure N in the form of NH_3, which causes acidification and eutrophication. It should be noted that in the dairy farm case study, there is management of the manure and its application as fertilizers, while in this case study, we stop at the gates of the slaughterhouse and have only the manure storage for 42 days; thus, the comparison has been made at the livestock production system

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level but not at the same system boundary. It can be seen that the acidification potential of this case study is similar to that of the milk production process, while the eutrophication potential is higher.

Despite these findings, there are three major weaknesses associated with this study. For starters, it relies on literature-based data from various sources instead of conducting measurements on one particular farm. In addition, it simplifies things by assuming uniform nitrogen partitioning between carcass and offal. Lastly, the boundaries of the system include manure storage only, and thus it cannot be considered at a whole farm level because manure will be spread across fields, resulting in other nitrogen losses. Despite all that, this research can provide useful knowledge concerning nitrogen management within the process of pig production.

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