



Analyzing Carbon and Nitrogen Balances in Swine Production Systems: A Methodology to Evaluate the Global Warming Potential of Swine Production in the Philippines



ABSTRACT

Understanding the carbon and nitrogen balance in a swine body can contribute greatly in quantifying and assessing greenhouse gas emissions in swine production. In this study, the carbon balance and nitrogen balance in swine were assessed using literature data and different case scenarios in the Philippines. GHG emissions from 10 backyard farms and 12 commercial farms in the country were quantified and emission per pig class from their manure management system were estimated. The routes of carbon and nitrogen in the pig's body were presented through material balance. For nitrogen flow in the swine system, the majority of the consumed nitrogen is retained in the pig's body and the rest is excreted in the manure. Similarly, most carbon in the swine system is retained in its body, while the rest goes out of the system by exhalation and enteric fermentation, or is excreted in the manure. The study provides a new framework for assessing the global warming potential through carbon and nitrogen balances. The output of this study could serve as a basis developing strategies for reducing GHG emissions, improving resource efficiency, and promoting sustainable livestock management.

Keywords: *swine production, nitrogen flow, carbon flow, carbon footprint*

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INTRODUCTION

The demand for meat and meat products has continuously increased with pork as the most widely consumed meat in the world (Reckman *et al.* 2013). There is a consistent market demand for livestock products to support the preference of the world's growing population. To address this increasing demand, the animal industry aims to increase production of hogs.

Filipinos have been consuming mostly meat products from swine. In fact, the swine industry is the second largest contributor to the agriculture in the Philippines next to rice. With the growing population in the country, the Philippine swine industry showed an increase in production from 2016 to 2018. The Philippine Statistics Authority reported a 2.01% increase in the volume of hog production for the fourth quarter of 2018 compared to the last quarter of 2017. Moreover, as of January 2019, there is an increase of 0.83% to the number of swine population (12.71 million heads) compared to the previous year's inventory.

As the animal industry grows, there are pressing issues regarding the harmful effects of raising commercial livestock to the environment. In terms of its impact on climate change, livestock, including swine, contributes

to global warming by releasing greenhouse gases mainly from feed production and manure management systems.

In the study conducted by the EU Emission Commission Joint Research Centre, emission from livestock production was almost 18% of the world's anthropogenic greenhouse gases (GHG). Based on the Philippine Greenhouse Gas Inventory Management and Reporting System, the agriculture sector contributed about 27% out of the 204 MT CO₂ emission in 2020. About 30% of which can be accounted for by the livestock sub-sector (Philippine Climate Change Commission 2024).

Two most notable GHGs from animal agriculture are CH₄ and N₂O (Grossi *et al.* 2019). These gases have more potent effects than CO₂ in terms of warming the earth, ultimately affecting global climate patterns. Methane has a global warming potential (GWP) of 28, while N₂O has 265 (IPCC 2013).

Methane is produced from the breakdown of livestock manure under anaerobic conditions. Similarly, nitrous oxide emerges as a result of the nitrogen contained in livestock waste undergoing nitrification and denitrification processes. Another source of methane

emission in livestock is enteric fermentation. During enteric fermentation, methane is released as a by-product of the livestock digestive process where microbes, particularly the methanogens, in the animal's digestive system break down organic matter from the feed consumed by the animal (IPCC 2019).

Methane (CH_4) and nitrous oxide (N_2O) emissions in the context of livestock are closely related to the carbon and nitrogen content of the animals' diets. Understanding the source and fate of carbon and nitrogen is important in predicting the production of GHG. Thus, this study assessed the carbon balance and nitrogen balance of swine. Moreover, GHG emissions from swine production facilities in the country were quantified by analyzing crude protein (CP) and volatile solids (VS) content from feeds and manure, which are potential precursors to N_2O and CH_4 production, respectively.

MATERIALS AND METHODS

Carbon and nitrogen balances were assessed and GHG emissions from swine production systems were estimated (Figure 1).

Sample Collection, Preparation and Analysis

A matrix for sampling swine feeds and manures from backyard and commercial swine farms with

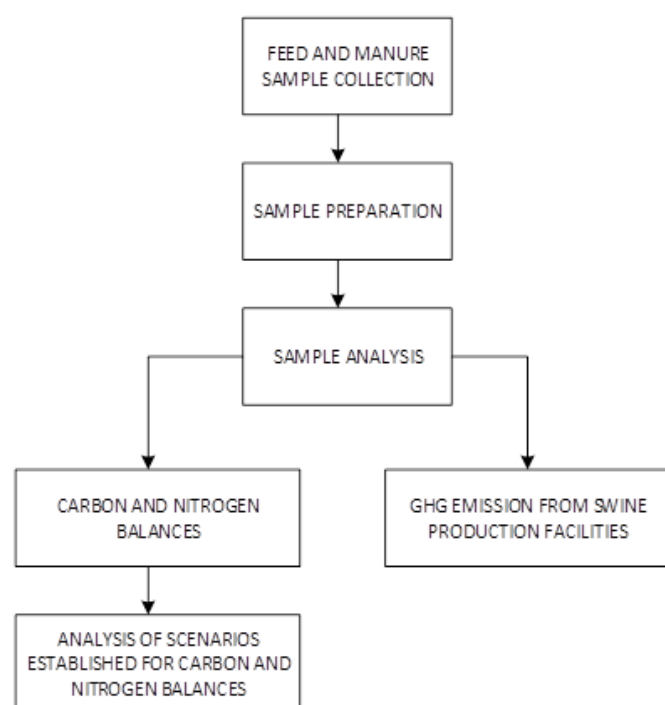


Figure 1. Flowchart for analyzing carbon and nitrogen balances and GHG emission estimation.

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different farm operations were followed (Table 1). Two pig breeds were typically observed in the swine farms, the large white and the landrace. For each pig class, three pens were randomly selected for sampling. Manure samples were collected and stored in an ice box to control the temperature. Lower temperature decreases microbial activity such as methanogenic fermentation and volatilization of organic matter that results in methane emission. The samples were kept cold until they reached the laboratory for analysis.

Sample Preparation and Analysis

Approximately 50g of feed samples were collected for every pig class in each farm. The feed samples were sealed in a plastic bag and labeled. Feed samples were air dried to avoid clumps during grinding, while 25-50 g of manure samples were oven-dried at 103-105°C for 2-3 hr until samples were moisture-free. Crude Protein of feeds and manures were determined using the Kjeldahl Method while Volatile Solids were determined using Method 1684 by the U.S. Environmental Protection Agency.

Carbon Balance in Swine

According to IPCC's Special Report on Global Warming of 1.5°C, carbon neutrality or net zero CO_2 emission is achieved when anthropogenic CO_2 emission is balanced with CO_2 removal over a specified period of time. This means that the total output of an activity or production is neutral or equal to zero if emissions are counterbalanced or are absorbed from the atmosphere by carbon sinks.

For the case of swine production, carbon neutrality applies as feeds are commonly derived from biomass sources. Not all of the carbon from feeds is absorbed by the swine body and some are released as CO_2 exhaled by pigs, while CO_2 and CH_4 are released from manure management systems (Philippe and Nicks 2015), and CH_4 can also be released through enteric fermentation. The CO_2 released in swine systems is assumed to be net zero since swine feeds, which are mainly composed of plant-based ingredients (biomass) sequesters or absorbs the CO_2 released in the atmosphere through photosynthesis. However, carbon being converted to methane is treated differently and is included as emission since it is a more potent GHG compared to CO_2 which could have a more substantial impact on global warming.

Carbon in Feeds. The total carbon present in feeds was calculated from the individual components of the composite feed mix. Every pig class had a varying feed

formulation. The major feed ingredients used in the country, such as corn and soybean, were identified, along with the percentage composition of these feed ingredients for each pig class. FeedPrint NL, a carbon footprint tool used for animal nutrition, was used to determine the percent carbon per feed ingredient. The tool provides a database of common feed ingredients and its corresponding percent carbon.

Carbon during Exhalation. One source of emission in a swine farm is the CO₂ production during pig's respiration. Various methods to estimate its production involve relating it to the respiratory quotient (ratio between volume of CO₂ production and volume of oxygen consumption) and deriving it from animal heat production (energy used for maintenance, production, and thermoregulation). Various models have also been made to estimate its production in different pig classes. A model was created to simplify the determination of CO₂ production by relating it to the pig's body weight (BW). It was used to estimate CO₂ exhalation (E-CO₂, pig, in kg CO₂ day⁻¹) for pigs of 20-120 BW (*Aubrey et al. 2004 as cited by Philippe and Nicks 2015*) (Equation 1).

$$\text{E-CO}_{2, \text{ pig}} = 0.136 \text{ BW}^{0.573} \quad (1)$$

Carbon Retained in the Pig's Body. One of the routes of carbon to the pig's body is through retention in the pig's body mass. An assumption was made to simplify the estimation of the carbon retained in the animal's body. For every kilogram of animal body mass, 200 g is carbon (*Desutter and Ham 2005*). Average values for daily gain of pig in the Philippines were taken *PHILSAN (2010)* Feed Reference Standards 4th Edition. The value for daily gain was used to determine the daily amount of carbon retained in the pig's body.

Carbon Emission due to Enteric Fermentation. Enteric fermentation which happens in the animal's digestive system produces gaseous waste products such as methane and CO₂. Swine have a monogastric digestive tract, which produces much less CH₄ emission than that of ruminants due to enteric fermentation. As suggested by IPCC, Tier 1 Approach should be used since no country-specific database and methodology are available for the country. Enhanced livestock characterization is also not available, and enteric fermentation is not considered a key category for swine according to IPCC. A value of 1.0 kg CH₄ per head per year was used in the Philippines, regardless of the pig's physiological stage.

Carbon Emission in Manure. The remaining carbon unaccounted in the animal body is excreted through

manure (feces and urine). The carbon content in manure can be estimated by relating it to the percentage of nitrogen in manure and determining the C/N ratio of swine manure (Equation 2). According to the Philippine Agricultural Engineering Standard (PAES 414-2:2001), C/N ratio for swine manure is 7.

$$\text{C in Manure} = \text{Nex} * \text{C/N ratio} \quad (2)$$

Nitrogen Balance in Swine

Nitrogen in the swine's diet results in emission from the excretion of manure since not all of the nitrogen is absorbed by the pig but also excreted in manure. Emissions from nitrogen are in the form of ammonia (NH₃), nitrogen oxides (N₂O, NO_x), and organic nitrogen (*Hassouna et al. 2016*). Nitrous oxide is produced from the manure of the animals that are broken down by microbes in the soil under certain conditions. This process involves both nitrification and denitrification. Nitrification is the conversion of ammonium and other nitrogen compounds in the manure into nitrate and nitrite forms. Denitrification is the subsequent conversion of nitrate and nitrite back into nitrogen gases, including nitrous oxide.

Nitrogen in Feeds. The nitrogen present in the feeds was determined from the crude protein content of the composite feed mix for every pig class. Organic nitrogen content was estimated by dividing the crude protein content by 6.25 according to *AOAC (2000)*.

Nitrogen Retention. Nitrogen is present in dietary crude protein as part of the swine's nutrition. However, it is only converted to body protein with efficiencies ranging from 15 to 33% (*Pomar et al. 2021*). For every pig class, the amount of nitrogen retained in the animal body varies. The percent nitrogen retained in pigs was adapted from *Kornegay et al. (1997)*.

Nitrogen in Manure. The remaining nitrogen from the feeds, which is not retained in the pig is excreted through manure (feces and urine). A large fraction of nitrogen ingested by the swine is excreted via manure leading to potential losses of N to the environment (*Millet et al. 2018*).

A nitrogen balance was used to estimate the excreted nitrogen by subtracting the amount of nitrogen retained in the pig's body from the amount of nitrogen intake of the swine. Another method was analyzing the swine manure collected from different swine farms and determining its crude protein. The amount of nitrogen

theoretically determined in manure was compared to the actual nitrogen excreted in the manure.

GHG Emission Estimation due to Manure Management System

Methane (CH_4) emissions from waste management were estimated using the Tier 1 methodology outlined in *IPCC (2006)*. Meanwhile, the Tier 2 approach from *IPCC (2006)* was employed in estimating N_2O emissions, taking into account emissions due to manure management system (MMS) and due to leaching. The percentage of volatile solids and nitrogen from the laboratory analysis were used to estimate GHG emissions from manure management systems per pig class of swine farms in the Philippines.

RESULTS AND DISCUSSION

Nitrogen Balance

The nitrogen comes from swine feeds. When feed is ingested, part of this is retained in the swine's body and the rest is excreted in the swine manure (**Figure 2**). The nitrogen in the manure is used to estimate N_2O which is a potent GHG with a global warming potential of 265.

Nitrogen in Feeds

Based on experimental data, the crude protein in feed samples resulted to 14.30%. This value is comparable to 16% crude protein in feeds according to *AOAC (2000)*. Using the formula by *AOAC (2000)*, the total N intake was 57.20 g day^{-1} out of the total $2,500 \text{ g day}^{-1}$ of feed intake.

Crude protein is one of the important components of feed given to each pig class. Some criteria are used on the composition of crude protein depending on the amino acids provided in the feed to maximize animal body growth. Among these are the requirements for the first five limiting amino acids namely, lysine, threonine,

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sulfur-containing amino acids, tryptophan, and valine (*Wang et al. 2018*). In their review for feeding low protein diets to swine, *Wang et al. (2018)* further stated that for growing-finishing pigs fed with low protein diets, they require higher amounts of the limiting amino acids than pigs fed with traditional diets, because these limiting amino acids are needed to provide the nitrogen for endogenous synthesis of non-essential amino acids to support protein synthesis. Reducing the protein level by 3% and adding five essential amino acids did not result in any adverse impact on animal performance or nitrogen retention.

However, varying protein levels in the diet might influence the composition of intestinal microbiota. The same study has proved that it is feasible to provide swine with low-protein diets while ensuring adequate amino acid supplementation, without compromising pig growth performance or nitrogen retention.

Nitrogen Retention in Pigs

Monogastric animals, such as pigs, have a simple digestive system, like humans. In 1970, Skitsko and Bowland studied the nitrogen digestibility and retention by pigs as influenced by diet, sex, and breeding group. Nitrogen retention was not significantly influenced by diet, weight or age of animal. Even sex and breeding group showed no significant effect on N digestibility and N retention. They explained that higher energy diet increased N digestibility. From the total N feed intake of 57.20 g day^{-1} , the total N retained amounted to 22.88 g day^{-1} , which is about 40%. This is comparable to the range of 35.2 to 42.5% N retention as reported by *Skitsko and Bowland (1970)*.

Nitrogen in Manure

There are several possible sources of nitrogen in manure- undigested or unabsorbed protein and amino acids and products of the urea cycle and microbial protein digestion. In a study of *Shi et al. (2016)*, the effects of

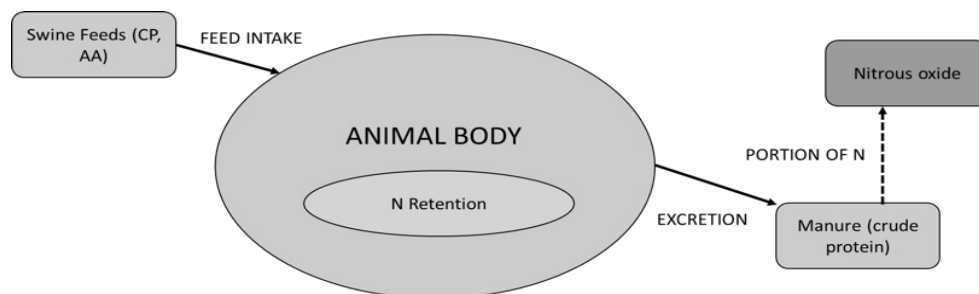


Figure 2. Nitrogen flow in pigs with potential GHG production.

a dietary crude protein level in fecal crude protein were assessed and they concluded that feeding corn-soybean meal-based diet with reduced protein concentration resulted in lower fecal nitrogen flow. Thus, lowered nitrogen flow means lower nitrogen out in manure. However, in order to lower nitrogen flow, there have to be some changes in the diet formulation. As *Shi et al. (2016)* cited *Portejoie et al. (2004)* who stated that dietary manipulations, such as lowering crude protein concentration and/or reducing amino acid inclusion, reduce ammonia (NH_3) emission and is an efficient way to reduce NH_3 emission.

Two case scenarios were used in computing the nitrogen flow (**Table 1**). In Case 1, the amount of nitrogen excreted was the difference between the amount of nitrogen intake and the amount of nitrogen retained in the pig's body. Case 2 on the other hand determined the amount of nitrogen excreted using the percent nitrogen in manure obtained in laboratory analysis and the amount of manure generated for finishing pigs obtained from Philippine Agricultural Engineering Standards.

For Case 1, the amount of nitrogen excreted daily for a finisher pig theoretically amounted to 34.32 g day⁻¹. According to *IPCC (n.d.)*, the nitrogen lost due to volatilization and the nitrogen leached in manure management is 40% and 30%, respectively (*IPCC n.d.*). With that, the amount of nitrogen available for soil application was estimated to be 10.30 g day⁻¹. This results in the reduction in the nitrogen in manure available for plant uptake. For Case 2, the amount of nitrogen excreted obtained experimentally amounted to 34.78 g day⁻¹. The difference between the nitrogen inputs and nitrogen outputs (retention and excreted in manure) was -0.46 g day⁻¹ for a finisher pig which led to -0.80% of N unaccounted.

Overall, the theoretical amount of nitrogen excreted determined through material balance was comparable to the amount of excreted nitrogen determined experimentally.

Nitrogen as Precursors to N_2O Production

Nitrous oxide has a global warming potential (GWP) 265 times that of CO_2 , thus it poses a big impact to the environment. This gas is a by-product of a process called nitrification. As *Philippe and Nicks (2015)* cited *Kebreab et al. (2006)* in their review of GHG emissions from pig houses: nitrification is the process carried out by autotrophic bacteria which converts ammonia (NH_3) into nitrate (NO_3^-), requiring an aerobic environment with a pH value of 5 or higher (**Figure 2**). Along the nitrification

Table 1. Nitrogen balance for swine in the Philippines.

General Information	
Pig Class	Finisher
Body Weight (kg)	89.29
Nitrogen Input	
Feed Intake (g day ⁻¹)	2500.00
Crude Protein in Feeds	14.30%
N Intake (g)	57.20
Nitrogen Retained	
% Nitrogen Retained	40%
N Retained (g)	22.88
Case 1 N Excreted	
N Excreted (g)	34.32
Volatilization in MMS	
% N loss due to Volatilization	40%
N Lost due to Volatilization (g)	13.73
Leaching in MMS	
% N loss due to Leaching	30%
N Loss due to Leaching (g)	10.296
Soil Application	
N available for Application (g)	10.30
Inputs (+) or Outputs (-)	
Feeds N (+)	57.20
Retention in Animal N (-)	22.88
N loss due to Volatilization (-)	13.73
N loss due to Leaching (-)	10.30
N available for Application in Soil (-)	10.30
Inputs - Outputs (g)	0.00
Case 2 N Excreted	
Manure Generation (g)	5800
% Dry Matter in Manure	30.91%
% Nitrogen in Dry Matter	1.94%
N Excreted (g)	34.78
Inputs (+) or Outputs (-)	
Feeds N (+)	57.20
Retention in Animal N (-)	22.88
N loss due to Volatilization (-)	13.91
N loss due to Leaching (-)	10.43
N available for Application in Soil (-)	10.43
Inputs - Outputs (g)	-0.46
% N Unaccounted	-0.80%

process, nitrous oxide (N_2O) is synthesized as a by-product of nitrifying bacteria activity when there is a low-oxygen condition and/or accumulation of nitrites.

The N_2O emission of common swine feeds was estimated, assuming that the amount of feeds wasted per pig class goes to the manure management system (MMS) of the swine farm together with swine manure (**Table 2**). Percent of feed wastage as a percentage of feed ingested per pig class were taken from industry average data. The percent of nitrogen present in feeds per pig class ranges from 2.06 to 3.11%.

Based on Table 84 of the Feed Reference Standards 4th

Edition by PHILSAN where nutrient standards for swine feeds for every pig class are presented, diets for piglets have higher crude protein than adult pigs. For instance,

according to the standards, Hog Booster feeds should not have less than 20.0% CP while Hog Finisher feeds should not have less than 13.50% CP (*PHILSAN 2010*).

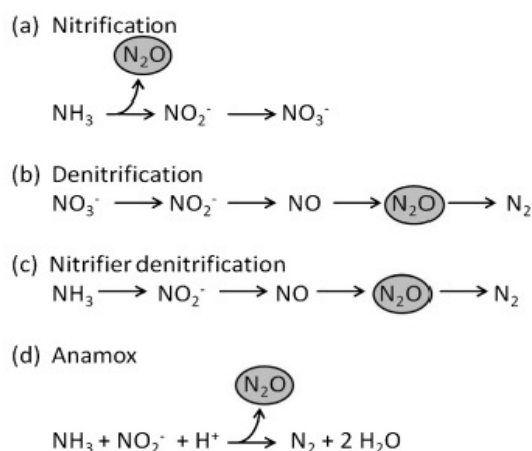


Figure 3. Microbial pathways involved in N_2O synthesis in manure. (Source: *Philippe and Nicks 2014*).

In the total N_2O emission of swine manure per pig class (**Table 3**), an assumption was made that the farm utilizes an anaerobic digester as the type of manure management system, thus no direct N_2O emissions. Total N_2O emissions per pig class is the sum of indirect N_2O emissions due to manure management system (MMS) and indirect N_2O emission due to leaching. Values were converted in terms of $\text{gCO}_2\text{e day}^{-1}$ since it is the common unit in reporting global warming potential. Percentage of nitrogen in manure decreases from booster to finisher. This could be associated with the decrease in the percent composition of nitrogen in feeds per pig class.

For pig classes' booster to finisher, the finisher yields

Table 2. Total nitrous oxide carbon equivalent of common swine feed in the Philippines using IPCC methods (per pig).

Feeds	Dry Matter	N	Average Daily Feed Intake	Wastage	Indirect N_2O Emission due to MMS*	Indirect N_2O Emission due to Leaching	Total N_2O Emission	Total N_2O Emission
	%	%	kg day ⁻¹	%	gCO ₂ e day ⁻¹	gCO ₂ e day ⁻¹	g CO ₂ e day ⁻¹	g CO ₂ e day ⁻¹
Booster	93.15	3.11	0.11	20	0.54	0.60	0.0043	1.14
Prestarter	91.03	2.91	0.83	15	2.78	3.13	0.0220	5.91
Starter	90.58	2.61	1.5	10	2.99	3.36	0.0203	6.35
Grower	91.10	2.49	2.2	10	4.20	4.73	0.0333	8.94
Gilt	91.89	2.93	2.5	10	5.68	6.39	0.0450	12.07
Jr. Boar	92.08	2.91	2.5	5	2.82	3.17	0.0223	5.99
Finisher	91.79	2.63	2.5	10	5.09	5.73	0.0404	10.82
Gestating	90.93	2.53	2.75	5	2.67	3.00	0.0211	5.67
Lactating	89.73	2.39	5.25	10	9.50	10.69	0.0753	20.19
Dry	91.95	3.03	2.5	10	5.87	6.61	0.0466	12.48
Breeder/Boar	89.16	2.06	2.8	5	2.18	2.45	0.0173	4.62

*Manure Management System

Table 3. Total nitrous oxide carbon equivalent of common swine manure in the Philippines using IPCC methods (per pig).

Feeds	Dry Matter	N	Daily manure production	Indirect N_2O Emission due to MMS*	Indirect N_2O Emission due to Leaching	Total N_2O Emission	Total N_2O Emission
	%	%	kg day ⁻¹	gCO ₂ e day ⁻¹	gCO ₂ e day ⁻¹	gCO ₂ e day ⁻¹	gCO ₂ e day ⁻¹
Booster	23.63	4.60	-	-	-	-	-
Prestarter	23.64	4.00	1.03	8.27	8.94	0.0690	18.50
Starter	24.18	3.24	1.88	0.01	13.68	0.0562	15.05
Grower	25.78	2.70	1.88	0.01	11.75	0.0492	13.18
Gilt	26.76	2.44	5.8	0.03	35.43	0.1323	35.46
Jr. Boar	34.32	3.18	4.91	0.05	50.79	0.1897	50.84
Finisher	29.13	2.56	3.97	0.04	39.46	0.1474	39.50
Gestating	30.91	1.94	14.73	0.02	22.37	0.0958	25.67
Lactating	27.22	2.45	5.8	0.08	83.30	0.3520	98.62
Dry	28.99	2.05	5.8	0.03	32.14	0.1395	37.39
Breeder/Boar	26.23	2.06	4.91	0.02	24.29	0.1082	28.99

*Manure Management System

the greatest N_2O which is $25.66 \text{ g CO}_2 \text{ e day}^{-1} \text{ pig}$. Although a reduction in the amount of nitrogen present in manure was noted, greater N_2O emission in the finisher class may be because of an increase in feed intake and manure generated in this pig class. N_2O emission in the pre-starter stage was greater compared to the starter and grower stages because the percentage of nitrogen present in manure in the pre-starter stage was greater compared to starter and grower stages in pigs. This is due to the denser feeds offered to younger pigs such as boosters and pre-starters.

Carbon Balance

For the carbon balance in a pig (**Figure 4**), the carbon source for the swine's body comes from swine feeds. The carbon from the feeds is stored in the swine's body and the rest of the carbon is emitted through exhalation, enteric fermentation, and excretion.

Feeds are composed of different feed ingredients that are basically sources of energy, carbohydrates, protein, fats, and other nutrients. These ingredients have carbons in their structures. For instance, proteins are composed of a nitrogen attached to a carboxylic group that is made up of carbon, hydrogen, and oxygen. *Patience et al. (2015)* stated in their review of feed efficiency in swine that these carbon-containing compounds are fats, carbohydrates and proteins, which yield energy when they are oxidized. The carbon intake per day amounted to 965.16 g (**Table 4**).

The carbon retention amounted to 158 g , while the carbon emission due to exhalation and enteric fermentation were 486.49 g and 2.05 g , respectively. Parallel to Case 1 and Case 2 of Nitrogen Balance, the carbon excreted in manure was derived from the theoretical nitrogen excreted and the nitrogen excreted determined experimentally using the C/N ratio for swine manure of 7. For Case 1, the carbon excreted in manure

resulted to 240.24 g , while 243.46 g for Case 2 (**Table 4**).

The difference between the carbon inputs and the carbon outputs (retention, exhalation, enteric fermentation, and excretion) was 78.37 g day^{-1} and 75.15 g day^{-1} for Case 1 and Case 2, respectively. The difference was comparable to both cases since the value of N excreted for Case 1 and Case 2 was also close to each other. A positive result in the difference between the carbon inputs and outputs means that other carbon sources were unaccounted in the carbon balance in swine. One of the possible sources of this result was the estimation of carbon outputs used for swine.

A value of 1.0 kg CH_4 per head per year was used to estimate the amount of carbon due to enteric fermentation. This value is fixed regardless of the pig's physiological stage. The enteric fermentation has a small percentage in the carbon outputs in swine compared to exhalation, retention, and excretion (**Table 4**). This would mean that a change in the value of the emission of carbon due to enteric fermentation for every pig class would be insignificant.

Other sources of positive result in the difference of carbon inputs and outputs were the assumption that for every kg of mass, there contains 200 grams in the swine's body, and the C/N ratio of 7 provided by PAES.

Volatile Solids as Precursors of Methane Production

Volatile solids (VS) are the part of the manure that produces methane. Production of methane from volatile solids is dependent on the type of manure management system employed in the farm and the methane-producing potential (B_0) of the volatile solids which is region-specific. In Asia, a B_0 of $0.29 \text{ m}^3 \text{ CH}_4 \text{ kg}^{-1} \text{ VS}$ is used. North America has the greatest B_0 value, which according to IPCC is $0.45 \text{ m}^3 \text{ kg}^{-1} \text{ VS}$, which means that it yields greater methane per kg VS excreted per pig. MCF or

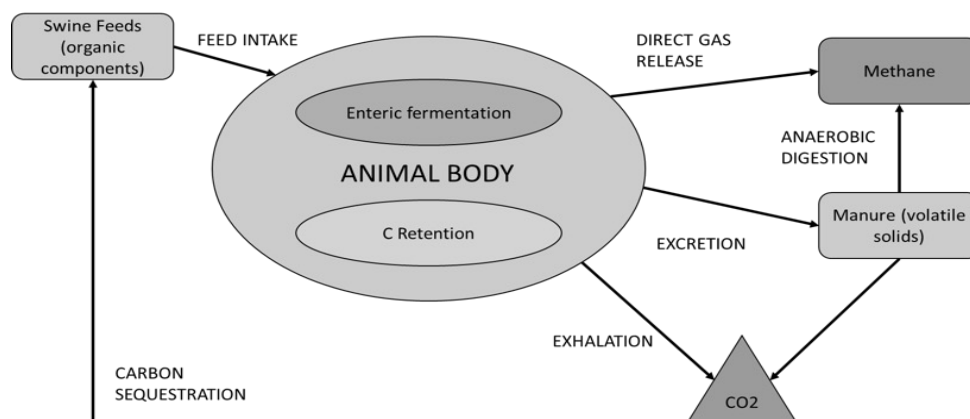


Figure 4. Carbon balance in a swine body.

Table 4. Carbon balance for swine (grams C per animal per day).

Carbon Inputs			
Feed Intake (g)	2500		
	Composition (%)	C (%)	C (g)
Yellow corn (ground)	64.20	39.70	637.19
Soybean meal, US 46%	12.50	37.90	118.44
Wheat pollard hard	13.99	39.50	138.15
Rice bran, D1	2.00	36.90	18.45
Coconut Oil	1.10	74.60	20.52
MDCP	1.58	0.00	0.00
Limestone, Fine	0.90	11.99	2.70
Copra Meal, expeller	3.01	39.50	29.72
Carbon Intake (g day⁻¹)			965.16
Carbon Retention			
Animal contain (g C kg ⁻¹ mass)		200	
Average Daily Gain (kg day ⁻¹)		0.79	
Carbon Retained in the Body (g)			158.00
Carbon Emission due to Exhalation			
E-CO ₂ (g day ⁻¹)		1783.81	
Carbon Emitted in the Body			486.49
Carbon Emission due to Enteric Fermentation			
CH ₄ Emission (g day ⁻¹)		2.74	
C Emitted (g day ⁻¹)			2.05
Case 1. C Present in Manure			
N Excreted			34.32
C Excreted			240.24
Inputs (+) or Outputs (-) (g)			
Feed (+)			965.16
Animals (-)			158.00
Exhalation (-)			486.49
Enteric Fermentation (-)			2.05
Manure (-)			240.24
Inputs - Outputs (g)			78.37
% C Unaccounted			8.12%
Case 2. C Present in Manure			
N Excreted			34.78
C Excreted			243.46
Inputs (+) or Outputs (-) (g)			
Feed (+)			965.16
Animals (-)			158.00
Exhalation (-)			486.49
Enteric Fermentation (-)			2.05
Manure (-)			243.46
Inputs - Outputs (g)			75.15
% C Unaccounted			7.79%

methane conversion factor defines the portion of B₀ that is achieved. In the Philippines, since it is considered a tropical country with an average annual temperature of 26.6°C, it is categorized by IPCC as warm climate. This means that it has a higher MCF value, yielding more methane emissions compared to cool and temperate areas in other regions.

The CH₄ emission of common swine feeds was estimated assuming that the amount of feeds wasted per

pig class goes to the waste management system of the farm together with swine manure (**Table 5**). Percent of feed wastage as a percentage of feed ingested per pig class were taken from industry average data.

The amount of CH₄ emission per pig class in the Philippines is presented (**Table 6**). Dry matter in swine manure was comprised mostly of volatile solids, which are precursors for formulation of CH₄ in the farm's manure management system and is a source of GHG

Table 5. Methane emission carbon equivalent of common swine feeds in the Philippines per pig per day.

Feeds	Dry Matter	Volatile Solid	Average Daily Feed Intake	Wastage	Estimated Methane Emission	Methane Emission CO ₂ eq
	%	%	kg day ⁻¹	%	gCH ₄ day ⁻¹	gCO ₂ e day ⁻¹
Booster	93.15	87.44	0.11	20	0.35	9.75
Prestarter	91.03	85.07	0.83	15	1.87	52.47
Starter	90.58	83.97	1.5	10	2.22	53.25
Grower	91.10	84.11	2.2	10	3.28	91.75
Gilt	91.89	85.54	2.5	10	3.82	106.91
Jr. Boar	92.08	86.05	2.5	5	1.92	53.88
Finisher	91.79	84.83	2.5	10	3.78	105.91
Gestating	90.93	81.41	2.75	5	1.98	55.36
Lactating	89.73	82.34	5.25	10	7.54	211.10
Dry	91.95	85.99	2.5	10	3.84	107.54
Breeder/Boar	89.16	79.96	2.8	5	1.94	54.34

Table 6. Methane emission carbon equivalent of common swine manure in the Philippines per pig per day.

Feeds	Dry Matter	Volatile Solid	Daily manure production	Estimated Methane Emission	Methane Emission CO ₂ eq
	%	%	kg day ⁻¹	gCH ₄ day ⁻¹	gCO ₂ e day ⁻¹
Booster	23.63	79.58	-	-	-
Prestarter	23.64	76.03	1.03	3.60	100.89
Starter	24.18	77.25	1.88	6.85	191.68
Grower	25.78	73.57	1.88	6.90	193.27
Gilt	26.76	72.16	5.8	21.74	608.62
Jr. Boar	34.32	72.76	4.91	23.82	667.04
Gestating	30.91	73.44	3.97	17.47	489.24
Lactating	27.22	74.07	14.73	57.70	1615.71
Dry	28.99	73.45	5.8	23.97	671.27
Finisher	29.13	72.68	5.8	23.98	671.57
Breeder/Boar	26.23	74.69	4.91	18.69	523.25

emission from a swine farm. Methane emission from booster to finishing phase increases, which is the result of an increase in the mass of volatile solids excreted per pig class. An increase in feed intake results in an increase in manure excretion, which ultimately leads to an increase in volatile solids generated in manure.

CONCLUSIONS AND RECOMMENDATIONS

The variability in GHG emissions across pig classes was found to be linked to the quantities of volatile solids and nitrogen present in the manure, which served as predictive factors for CH₄ and N₂O emissions arising from manure management systems.

Furthermore, the study contributed valuable insights into the carbon and nitrogen dynamics within the swine production system. Concerning nitrogen, it highlighted that the nitrogen acquired by the pig is either retained within the pig's body or released through excretion in manure. In the case of carbon, the study identified three

primary pathways: carbon is either retained in the pig's body, expelled from the system via exhalation and enteric fermentation, or excreted in manure. The carbon and nitrogen not included in the material balance can be addressed by developing an enhanced material balance model that integrates additional factors beyond the study's current scope.

The findings of this research hold significance beyond the immediate scope of the study. They can serve as a foundational resource for estimating the overall carbon footprint associated with swine production facilities. Additionally, the study's insights into the carbon and nitrogen flows within the swine industry in the Philippines provide essential information for sustainable management practices and informed decision-making in this sector. Ultimately, this research contributes to a more comprehensive understanding of the environmental impact of swine production and can guide efforts toward reducing its carbon footprint and enhancing sustainability.

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