WHAT IS THE CONTRIBUTION OF PIGLET WASTE IN THE FIRST WEEK AFTER WEANING TO GREENHOUSE GAS EMISSIONS?

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- Emission
- Weight gain
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- Swine

ABSTRACT

This study aims to characterize the waste of weaned piglets and estimate the emissions of N\textsubscript{2}O in kg of CO\textsubscript{2} eq/kg of weight gain in the first week of housing. Primary data were obtained in the first week after weaning of piglets to identify how much waste from this animal category may affect the environment. The life cycle assessment was applied to verify the amount of manure and the emission of nitrous oxide (N\textsubscript{2}O) considering the weight gain (WG) of piglets in the first post-weaning week. Eight waste collections were carried out in two lots representing an average of 8,099 animals with initial and final weight of 5.01 and 5.84 kg, respectively. The production of residues was 0.128 kg of dry matter (DM) for each kilogram of WG produced. The waste production has an emission capacity of approximately 4x10\textsuperscript{-4} kg N\textsubscript{2}O/kg WG in the first post-weaning week. Considering that N\textsubscript{2}O has a global warming potential almost 300 times higher in retaining heat than CO\textsubscript{2}, each 1 kg of piglet produced can emit about 0.129 kg of CO\textsubscript{2} equivalent from the N\textsubscript{2}O produced. According to the number of piglets evaluated in this study, the total emission can reach 1.85 tons of CO\textsubscript{2} equivalent in the first post-weaning week alone.

Palavras-chave:
- Emissão
- Ganho de peso
- Meio ambiente
- Gases do efeito estufa
- Suínos

QUAL A CONTRIBUIÇÃO DOS DEJETOS DE LEITÕES NA PRIMEIRA SEMANA PÓS-DESMAME SOBRE AS EMISSÕES DE GASES DE EFEITO ESTUFA?

RESUMO

Este trabalho teve como objetivo caracterizar os dejetos brutos de leitões desmamados e estimar as emissões de N\textsubscript{2}O em kg de CO\textsubscript{2} eq/kg de ganho de peso na primeira semana de alojamento. Os dados primários foram obtidos na primeira semana pós-desmame dos leitões para identificar o quanto os resíduos dessa categoria animal podem impactar o meio ambiente. A avaliação do ciclo de vida foi aplicada para verificar a quantidade de dejetos e a emissão de óxido nitroso (N\textsubscript{2}O) considerando o ganho de peso (GP) dos leitões na primeira semana pós-desmame. Foram realizadas oito coletas de dejetos considerando dois lotes, que representaram uma média de 8099 animais com peso inicial e final de 5.01 e 5.84 kg, respectivamente. A produção de resíduos foi de 0.128 kg de matéria seca (MS) para cada quilograma de GP produzido. Esta produção de dejetos brutos tem uma capacidade de emissão de aproximadamente 4x10\textsuperscript{-4} kg de N\textsubscript{2}O/kg de GP na primeira semana pós-desmame. Considerando que o N\textsubscript{2}O tem um potencial de aquecimento global quase 300 vezes mais eficaz na retenção de calor do que o CO\textsubscript{2}, cada 1 kg de leitão produzido pode emitir cerca de 0.129 kg de CO\textsubscript{2} equivalente a partir do N\textsubscript{2}O produzido, caso esses dejetos não sejam submetidos a algum processo de tratamento, pois essa produção é em relação ao dejeto bruto. De acordo com o número de leitões avaliados neste estudo, a emissão total pode chegar a 1.85 toneladas de CO\textsubscript{2} equivalente apenas na primeira semana pós-desmame.
INTRODUCTION

Pork is the second most consumed animal protein in the world, representing 40.1% of world per capita consumption. This figure means a large-scale production of pork. Brazil is in fourth position in the world ranking, with a production of 4.436 million tons of pork in 2020 (ABPA, 2021).

In order for the swine to reach the ideal slaughter weight, which is around 90 kg or more of live weight (PIÑEIRO et al., 2019), and to meet the demands of the consumer market, careful handling of the animals is necessary. Therefore, pig farming is divided into phases to ensure better quality in the final product. In this context, nutrition has been formulated and processed according to the needs of each stage of breeding, thus meeting the requirements of animals as for their physiological demands (XIONG et al., 2019). Each stage of swine has different characteristics, both in terms of handling and the residual attributes that constitute animal waste.

Among the phases of pig rearing, nursery has a significant importance in animal performance, since its beginning is marked by one of the most critical periods of pig farming, which is the weaning of piglets (JAYARAMAN & NYACHOTI, 2017). At this phase, the animals recently separated from the mother need a period of adaptation to the new diet and the rearing environment. In general, the swine diet is based on corn and soybean meal as the main ingredients. However, at the nursery phase, milk substitutes are used, especially during adaptation days, to minimize the impacts caused by weaning (PIETRAMALE et al., 2021).

During the adaptation, diarrhea resulting from changes in the conditions of the gastrointestinal tract and housing make animals vulnerable, causing a common drop in weight gain of piglets (ROCHA et al. 2016). Due to histological changes in the gastrointestinal tissue of piglets at the weaning phase, the diet provided in the nursery phase has an altered chemical composition and structure according to the development of the animals’ gastrointestinal tract (WANG et al. 2022). In addition, it is clear that not only physiological factors affect the performance of animals in the adaptation period, but also issues of social behavior of animals. According to Valentim et al. (2021), the mixing of litters of piglets after weaning causes a hierarchical dispute that interferes with food intake, also decreasing the performance of the animals.

Feeding directly affects the production of metabolic heat by the animal and the properties of the waste produced, emitting some forms of greenhouse gas (GHG) at the post-weaning phase (CHERUBINI et al., 2015; ANDRETTA et al., 2018). GHG emissions are present at all stages of animal production, from the extraction of natural resources to the end of the chain, when the product reaches the consumer’s plate (RUVIARO et al., 2020). Among the gases that most cause concern about the volumes emitted are carbon dioxide (CO₂), methane (CH₄), and nitrous oxide (N₂O); this order follows the proportion of emitted gases (OLIVEIRA et al., 2020). However, the global warming potential follows the order N₂O, CH₄, and finally CO₂ (SHAKOOR et al., 2021).

During the nursery phase, emissions must already be taken into account, even if the piglets produce a smaller amount of manure compared to animals at the other phases. With the beginning of the ration-based feeding, the emission of gases with potential impact on the environment is already taken into account. To estimate the amount of greenhouse gases emitted by swine manure, it is common to use some mathematical models that can provide emission values according to the composition of the manure. Rigolot et al. (2010) used mathematical models to evaluate the volume, composition, and emissions of greenhouse gases from swine manure according to the characteristics of the diet and considering the housing effect of the animals.

Based on the above, this study aims to evaluate how much the adaptation process of the first week after piglet weaning may contribute to emissions of N₂O, as one of the greenhouse gases of greatest impact, calculated in CO₂-equivalent.

MATERIAL AND METHODS

Waste collection took place in a post-weaning piglet breeding unit located near the city of Dourados, MS, Brazil. The analyses were carried out at the Agricultural Residue Management...
Soon after collection, the characterization of the waste was carried out through the analysis of total solids (TS), volatile solids (VS), nitrogen (N), neutral detergent fiber (NDF), and acid detergent fiber (ADF). First, the waste was dried in a forced air ventilation oven for 72 hours at 60°C; after drying, it was ground and sent to the laboratory for the analyses described above.

The levels of TS and VS were measured according to the methodology described by Apha (2005). The NDF and ADF contents were determined according to the methodology described by Silva & Queiros (2006). The N concentrations were determined using a VARIO MACRO Elementar analyzer.

The animals received diets to meet the requirements of the phase according to the recommendations of Rostagno et al. (2017). Table 1 shows the chemical composition of both the feed consumed by piglets at the post-weaning phase and the waste produced.

The generated waste mass was estimated from the mathematical model based on the work of Rigolot et al. (2010a), as described in Equation 1.

\[ X_{\text{feces}} = X_{\text{feed}} \times (1 - CD_x) \]  

Where,
- \( X_{\text{feces}} \) = Mass of manure produced (kg);
- \( X_{\text{feed}} \) = Amount of feed consumed (kg);
- \( CD_x \) = Coefficient of digestibility of ingredients’ dry matter (Rostagno et al., 2017)

From the bromatological analysis of diets and the waste generated by piglets, in addition to the

| Table 1. Bromatological profile of ingested feed and feces produced at the post-weaning phase |
|---------------------------------------------|-----------------|-----------------|-----------------|-----------------|-----------------|
|                                      | TS (%) | VS (%) | NDF (%) | ADF (%) | N (%) |
|___________|_________|_________|_________|_________|_______|
| Lot 1     | 8.28   | 77.46   | 25.62   | 21.68   | 3.71   |
| Lot 2     | 6.69   | 80.07   | 27.00   | 22.66   | 3.64   |
| Mean      | 7.48   | 78.77   | 26.31   | 22.17   | 3.68   |

|                                      | TS (%) | VS (%) | NDF (%) | ADF (%) | N (%) |
|___________|_________|_________|_________|_________|_______|
| Lot 1     | 9.01   | 82.37   | 28.58   | 26.02   | 3.36   |
| Lot 2     | 6.44   | 77.55   | 25.25   | 20.44   | 3.81   |
| Mean      | 7.72   | 79.96   | 26.92   | 23.23   | 3.59   |

TS – Total solids; VS – Volatile solids; NDF – Neutral detergent fiber; ADF – Acid detergent fiber; N - Nitrogen
mass of waste produced, it was possible to estimate the nitrous oxide ($N_2O$) emissions for each kilogram of piglet weight gain in the first week after weaning, as described in Equation 2. For this estimate, the mathematical model proposed by Rigolot et al. (2010b) was adapted to the results found through laboratory analyses.

\[ N_{2O\text{ emitted}}(Kg) = \frac{44}{28} \times 0.06 \times \text{Initial } N \times \text{Final } N \]  

(2)

Where,
- $N_{2O}$ = Nitrous Oxide;
- $44 = N_{2}$ waste emission factor
- $28 = \text{Temperature factor (estimated average for installations destined for the phase studied)}$
- $0.06 = N_{2O}$ waste emission factor
- $N_{\text{initial}} = \text{Estimated nitrogen from the diet of animals.}$
- $N_{\text{final}} = \text{Nitrogen determined in laboratory analysis of animal waste.}$

According to Oliveira et al. (2020), the concentration of $N_{2O}$ in the atmosphere is much lower than that of $CO_2$ and methane ($CH_4$). However, the heating potential of $N_{2O}$ is about 300 times more potent than that of carbon dioxide ($CO_2$) (Almeida et al., 2015). In this way, the estimated values of $N_{2O}$ were multiplied by 300 to estimate the $CO_2$ eq. per kilogram of piglet weight gain at the end of the first week after weaning.

RESULTS AND DISCUSSION

Weight gain is a key variable to assess the performance of pigs, especially at the post-weaning phase, as the animal’s developmental capacity at this first phase will determine its productive potential (Zhai et al., 2020). During post-weaning, it is extremely important that pigs receive a balanced diet capable of meeting all their requirements. Thus, weight loss may be avoided during this period, and a correct diet provides a better modulation of the intestinal microbiota of these animals, with a good development of intestinal functions and of the immune system (Chen et al., 2018).

The performance of pigs is also related to birth weight, as some piglets have a low birth weight, causing a disadvantage in weight gain in relation to heavier pigs (Lo Verso et al., 2020). In addition, weaning weight and age are also major influences on animal performance during subsequent phases (Valentim et al., 2021). The average weaning weight of piglets was 5.01 kg, with a variation between 4.91 and 5.12 kg, between the first and second lots (Table 2). The average weight gain during the first post-weaning week was 0.83 kg, with variations between the first and second lots of 0.67 and 0.99 kg, respectively. Pig weights were similar as those reported by Valentim et al. (2021) in a meta-analytic study in which the lowest value was 4.51 kg/animal at 18 days of lactation. It was not possible to identify the age of animals in these studies due to the miscegenation of animals in each lot.

GHGs are present in all industrial and non-industrial processes as factors of high environmental impact (Tullberg et al., 2018). However, food production has been wrongly accused of increasing GHG emissions and their impacts on the environment; after all, many production factors are no longer inventoried (ElDessouky et al., 2018). Claiming that the potential environmental impacts of swine production do not exist is negligent if evaluating the industrial production system, since it depends on large-scale grain production for animal feed. However, ways to reduce impacts have been studied both in terms of production efficiency and manure treatment technologies.

Table 2. Piglet performance during the first post-weaning week

| Productive profile | WE | WO | TWG | FIR | FC |
|--------------------|----|----|-----|-----|----|
| Lot 1              | 5.12 | 5.79 | 0.67  | 1.43 | 2.13 |
| Lot 2              | 4.91 | 5.90 | 0.99  | 1.66 | 1.67 |
| Mean               | 5.01 | 5.84 | 0.83  | 1.54 | 1.90 |

WE – Average entry weight (kg); WO – Average output weight (kg); TWG – Average total weight gain (kg); FIR – Average feed intake (kg); FC - Feed conversion
applied to swine systems (PIETRAMALE et al., 2021; CHERUBINI et al., 2015).

Actions related to means of mitigating environmental impacts in the swine production activity may be applied to the management of animals, improving their housing and breeding conditions at each physiological phase. Thus, making productive efficiency a decision-making point on the mitigation of GHG emissions must be precisely calculated; after all, the more one produces with the same resource, the better it is for the environment. Martinelli et al. (2020) calculated the eco-efficiency of poultry activity and identified that greater animal weight gains dilute greenhouse gas emissions regarding CO$_2$, CH$_4$, and N$_2$O.

The manure dry mass was 0.128 kg/kg of WG during the studied phase, or in natural matter of waste, it resulted in 0.245 kg of manure/kg of WG. The recommendation is that the waste mass be directed to biodigesters, so that GHG emissions can be captured and used as renewable energy sources. The productive potential of N$_2$O was estimated at 0.0004 kg/kg of WG, transformed into kg of CO$_2$ eq. to assess the phase’s global warming potential. In this study, even the N$_2$O representing a smaller portion of the gas emissions still presents a considerable amount of CO$_2$ eq./kg mass on the piglet weight gain (Table 3). Although the volume emitted is low in a numerical context, when considering total weight gain, the volume of CO$_2$ eq. is estimated at 820.71 kg/lot during the week of adaptation of the animals only from the N$_2$O emitted by the manure.

In a study by Gudiño et al. (2020) on Iberian swine production systems of the “Pata Negra” type in Southwest Spain with animals of breeds adapted to the system, the same more extensive and organic breeding models have similar environmental impacts as those of conventional models. In this study, the manure emitted was about 0.283 kg of N$_2$O/animal at the beginning of the growth phase.

In another study carried out by Reckmann et al. (2013), the post-weaning phase represented about 13% of CO$_2$ eq. of the production chain of finished swine, with an average of 94 kg of live weight. The N$_2$O/animal unit at the end of the chain was 1.07 kg, of which 30% refer to rearing stages, of which the nursery stage represents 13%, totaling 0.042 kg of N$_2$O/piglet at the post-weaning phase.

A volume similar as that reported in the study by Reckmann et al. (2013) on the emission of N$_2$O/piglet was found by Gutierrez et al. (2018), but at the phase that corresponds to that proposed here, i.e., the first days after weaning. However, the animals studied by Gutierrez et al. (2018) weaned at heavier weights, around 12.29 kg/piglet, different from the piglets housed in this study, which had 5.01 kg/animal. This weight difference may be related to age at weaning; this is an indicator to which we did not have access, by which older animals at weaning tend to weigh more and suffer less from the impacts of the first post-weaning week. This factor makes the comparison of emissions unfair, but it also expresses how weight and age at weaning may directly affect production efficiency and emissions of gases impacting the environment.

Just as productive efficiency generates an impact on GHG emissions, the type of animal waste and its respective management (storage and destination) are critical factors in these emissions. Shakoor et al. (2021) highlight the importance of obtaining detailed information on the emissions of different types of waste to assess the possibilities of applying the final waste in agricultural crops in order to mitigate GHG emissions.

Table 3. Impact profile of post-weaning swine manure

| Lot   | TWG       | AFI/kg of WG | Cddm  | DM$_{feces}$/kg of WG | WV/kg of WG | N/WG    | N$_2$O/WG | CO$_2$ eq./WG |
|-------|-----------|--------------|-------|-----------------------|-------------|---------|-----------|--------------|
| Lot 1 | 0.6700    | 2.1343       | 0.9018| 0.1405                | 0.2677      | 0.0048  | 0.0004    | 0.1346       |
| Lot 2 | 0.9900    | 1.6768       | 0.9298| 0.1165                | 0.2237      | 0.0044  | 0.0004    | 0.1246       |
| Mean  | 0.8300    | 1.9055       | 0.9158| 0.1285                | 0.2457      | 0.0046  | 0.0004    | 0.1296       |

TWG - Average total weight gain (kg); AFI/kg of WG - Average feed intake/kg of average weight gain; Cddm - Coefficient of digestibility of dry matter; DM$_{feces}$/kg of WG - Dry matter volume of manure per kilogram of weight gain; WV/kg of WG - Waste volume (manure + water)/kg of average weight gain; N/WG - Nitrogen (%)/kg average weight gain; N$_2$O/WG - kg of nitrous oxide/kg average weight gain; CO$_2$ eq/WG - kg of carbon dioxide equivalent/kg average weight gain
In this sense, recently Xia et al. (2020) performed a meta-analysis to identify how the application of different animal manure sources (barnyard, swine, cattle, and poultry manure) to agricultural soils affects soil $\text{N}_2\text{O}$ and emission factors considering only tests in fieldwork carried out on a global scale. Tests carried out with manure from barnyard, swine, cattle, and poultry manure, both raw (composted) and pre-treated (digested), were analyzed. The authors stated that, regardless of the type of manure, the application increases the emission of $\text{N}_2\text{O}$ from the soil, and such emissions are also affected by climatic conditions, agricultural practices, and initial properties of the soil. Raw manure emission was significantly higher than digested manure, indicating that pre-treatment is essential in mitigating emissions.

Shakoor et al. (2021) performed a meta-analysis similar as that of Xia et al. (2020), but also including $\text{CO}_2$ and $\text{CH}_4$ emissions, and corroborate the evidence that the effects of animal manure on GHG emissions depend on soil attributes (pH, texture, and porosity), type of crop, environmental conditions, and climatic zone. Although Shakoor et al. (2021) have observed a lack of studies in areas with a tropical climate, Xia et al. (2020) obtained indications of higher emissions of $\text{N}_2\text{O}$ in warm temperate climates compared to tropical climates.

Aita et al. (2014; 2019) developed some strategies, in experimental research, seeking to mitigate $\text{N}_2\text{O}$ resulting from the application of liquid manure from dairy cattle and swine in a no-tillage system in Argisols and Latosols in the southern region of Brazil. The residues were applied on the surface of crop residues and also by means of subsurface injection into the soil. These experiments showed that the emissions of $\text{N}_2\text{O}$ from liquid swine manure applied to the surface of Latosol were on average 73.9% than in the Argisols, obtaining average emission factors of 1.23% for Argisol and 0.43% for Latosol. The average emission factors of $\text{N}_2\text{O}$ from the manure injected into the soil were higher than when applied on the surface for both types of soil. Although there was a decrease in ammonia volatilization ($\text{NH}_3$) and a greater retention of N in the soil, its concentration in the injection grooves together with carbon and moisture favored the production of $\text{N}_2\text{O}$.

Environmental conditions during waste application may be a critical moment for the loss of N by volatilization of $\text{NH}_3$ (BELL et al., 2016). Thus, soil temperature, followed by humidity, and the ammonia content in the soil are $\text{N}_2\text{O}$ emission control mechanisms, as Cardoso et al. (2020) and Aita et al (2014) reported. Cardoso et al (2020) measured emission factors for various types of animal waste and found no significant differences between them, obtaining an average of 0.39% of $\text{N}_2\text{O}$ emitted by manure applied to pastures in a tropical climate in Brazil.

The global average results found by Shakoor et al. (2020) indicate that, compared to synthetic nitrogen fertilizers (1.25%), the net emission factor of $\text{N}_2\text{O}$ from animal waste was lower (1.11%) and similar as that recommended by the IPCC (1%). Considering these results, for the authors above, the use of animal waste may be an alternative to the application of synthetic fertilizers since it may help in soil correction, carbon sequestration, and improvement of crop fertility, with benefits for waste disposal, thus justifying a moderate additional contribution to GHG emissions.

Considering the works above, it appears that the values of emission factors of $\text{N}_2\text{O}$ obtained in Brazil differ considerably from works carried out in warm temperate climates (CARDOSO et al., 2020; AITA et al., 2014; 2019). Shakoor et al. (2021) found that research in this area is still incipient and that statistical data are lacking for better inferences about the mechanisms of $\text{N}_2\text{O}$ emission from biofertilized soils.

CONCLUSION

- From the discussions exposed in this study on GHG emissions from swine farming, animal manure is an aggravating factor in terms of environmental impacts, especially in relation to the emission of $\text{N}_2\text{O}$. The mitigation of potential $\text{N}_2\text{O}$ emitters from manure is an action that could lead to benefits in terms of reducing the environmental impacts of swine farming.
- The mass of $\text{CO}_2$ eq./kg over piglets’ weight gain is 0.135 and 0.125 for lots 1 and 2, respectively. This figure is considerably high for gas emissions at this stage.
- The forwarding of waste to recycling methods, such as anaerobic biodigestion, will certainly
mitigate their emission potential, leading to environmental benefits and also the recovery of waste due to the production of clean energy and biofertilizers.

AUTHORSHIP CONTRIBUTION STATEMENT

OLIVEIRA, J.D.: Formal Analysis, Investigation, Resources, Visualization, Writing – original draft; ORRICO, A.C.A.: Project administration, Resources, Supervision, Visualization, Writing – review & editing; PIETRAMALE, R.T.R.: Conceptualization, Investigation, Software, Visualization, Writing – original draft; ROSA, C.O.: Conceptualization, Data curation, Investigation, Validation, Writing – original draft; RUVIARO, C.F.: Funding acquisition, Project administration, Supervision, Writing – original draft, Writing – review & editing; LEITE, B.K.V.: Formal Analysis, Investigation; MACHADO, J.F.: Formal Analysis.

DECLARATION OF INTERESTS

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

REFERENCES

ABPA. Associação Brasileira de Proteína Animal – Anuário. 2021. Available<https://abpa-br.org/wp-content/uploads/2021/04/ABPA_Relatorio_anual_2021_web.pdf>. Acessado em: 12 de Jan. de 2022.

APHA. American Public Health Association. Standard methods for examination of water and wastewater. 21th ed. Washington: American Water Works Association.1.368, 2005.

BELL, M. J.; HINTON, N. J.; CLOY, J. M.; TOPP, C. F. E.; REES, R. M.; WILLIAMS, J. R.; MISSSELBROOK, T.H.; CHADWICK, D.R. How do emission rates and emission factors for nitrous oxide and ammonia vary with manure type and time of application in a Scottish farmland? Geoderma, v. 264, p. 81-93, 2016.

AITA, C.; GONZATTO, R.; MIOLA, E. C. C.; SANTOS, D. B.; ROCHETTE, P.; ANGERS, D. A.; CHANTIGNY, M. H.; PUJOL, S. B.; GIACOMINI, D.A. GIACOMINI, S. J. Injection of dicyandiamide treated pig slurry reduced ammonia volatilization without enhancing soil nitrous oxide emissions from no till corn in Southern Brazil. Journal of Environmental Quality, v. 43, n. 3, p. 789-800, 2014.

ANDRETTA, I.; HAUSCHILD, L.; KIPPER, M.; Pires, P. G. S.; POMAR, C. Environmental impacts of precision feeding programs applied in pig production. Animal, v. 12, n. 9, p. 1990-1998, 2018.

CARDOSO, A. S.; JUNQUEIRA, J. B.; REIS, R. A.; RUGGIERI, A. C. How do greenhouse gas emissions vary with biofertilizer type and soil temperature and moisture in a tropical grassland? Pedosphere, v. 30, n. 5, p. 607-617, 2020.

CHERUBINI, E.; ZANGHELINI, G. M.; TAVARES, J. M. R.; BELETTINI, F.; SOARES, S. R. The finishing stage in swine production: influences of feed composition on carbon footprint. Environment, Development and Sustainability, v. 17, n. 6, p. 1313-1328, 2015.

CHEN, X.; XU, J.; REN, E.; SU, Y.; ZHU, W. Co-occurrence of early gut colonization in neonatal piglets with microbiota in the maternal and surrounding delivery environments. Anaerobe, v. 49, p. 30-40, 2018.

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DE ALMEIDA, R. F.; NAVES, E. R.; SILVEIRA, C. H.; WENDLING, B. Emissão de óxido nitroso em solos com diferentes usos e manejos: Uma revisão. *Revista em Agronegócio e Meio Ambiente*, v. 8, n. 2, p. 441-461, 2015.

GARCÍA-GUDIÑO, J.; NTR MONTEIRO, A.; ESPAGNOL, S.; BLANCO-PENEDO, I.; GARCIA-LAUNAY, F. Life cycle assessment of Iberian traditional pig production system in Spain. *Sustainability*, v. 12, n. 2, p. 627, 2020.

GUTIERREZ, M. D. R. V.; DA SILVA, A. L.; FLORES, M. P.; CASTANEDA, F. E. M.; CAMPOS, A. R. M.; GARDEA, J. M.; TENORIO, G. G. Life cycle assessment of pig production-a case study in mexican farm. *Economic and Social Development: Book of Proceedings*, p. 734-741, 2018.

JAYARAMAN, BALACHANDAR.; NYACHOTI, CHARLES M. Husbandry practices and gut health outcomes in weaned piglets: A review. *Animal Nutrition*, v. 3, n. 3, p. 205-211, 2017.

LO VERSO, L.; TALBOT, G.; MORISSETTE, B.; GUAY, F.; MATTE, J JACQUES.; FAZENDEIRO, C.; GONG, J.; WANG, Q.; BISSONNETTE, N.; BEAULIEU, M. L. The combination of nutraceuticals and functional feeds as additives modulates gut microbiota and blood markers associated with immune response and health in weanling piglets. *Journal of Animal Science*, v. 98, n. 8, 2020.

OLIVEIRA, P.; AZENHA, M.; RODRIGUES, P.; ALVES, T.; LEMES, A.; PEDROSO, A. D. F. Emissão de óxido nitroso em pastagens tropicais de sistemas de produção de bovinos de corte. Embrapa Pecuária Sudeste-Capítulo em livro técnico (INFOTECA-E), 2020. Available <https://www.infoteca.cnptia.embrapa.br/infoteca/handle/doc/1131450>. Acessado em: 20 de Jan. de 2022.

PIETRAMALE, R. T. R.; CALDARA, F. R.; BARBOSA, D. K.; DA ROSA, C. O.; VANZELA, M.; PÁDUA, A. B.; RUVIARO, C. F. How much the reproductive losses of sows can be impacting the carbon footprint in swine production? *Livestock Science*, v. 250, p. 104594, 2021.

PIÑEIRO, C.; MORALES, J.; RODRÍGUEZ, M.; APARICIO, M.; MANZANILLA, E. G.; KOKETSU, Y. Big (pig) data and the internet of the swine things: a new paradigm in the industry. *Animal frontiers*, v. 9, n. 2, p. 6-15, 2019.

RECKMANN, K.; TRAULSEN, I.; KRIETER, J. Life Cycle Assessment of pork production: A data inventory for the case of Germany. *Livestock Science*, v. 157, n. 2-3, p. 586-596, 2013.

RIGOLOT, C.; ESPAGNOL, S.; POMAR, C.; DOURMAD, J. Y. Modelling of manure production by pigs and NH₃, N₂O and CH₄ emissions. Part I: animal excretion and enteric CH₄, effect of feeding and performance. *Animal*, p. 1401-1412, 2010.

RIGOLOT, C.; ESPAGNOL, S.; ROBIN, P.; HASSOUNA, M.; BÉLINE, F.; PAILLAT, J. M.; DOURMAD, J. Y. Modelling of manure production by pigs and NH₃, N₂O and CH₄ emissions. Part II: effect of animal housing, manure storage and treatment practices. *Animal*, p. 1413-1424, 2010.

ROCHA, L. O.; SILVA, J. L.; RODRIGUES, C. P. F.; MASCARENHAS, A. G.; NUNES, R. C. Glicerina Bruta nas rações para leitões na fase de creche. *Ciência Animal Brasileira*, p. 51-59, v. 17, n.1, 2016.

ROSTAGNO, H.S.; ALBINO, L.F.T.; HANNAS, M. L. Tabelas brasileiras para aves e suínos: composição de alimentos e exigências nutricionais. 4.ed. Viçosa: UFV, 488p, 2017.

RUVIARO, C. F.; DE LEIS, C. M.; FLORINDO, T. J.; DE MEDEIROS FLORINDO, G. I. B.; DA COSTA, J. S.; TANG, W. Z.; SOARES, S. R. Life cycle cost analysis of dairy production systems in southern brazil. *Science of The Total Environment*, v. 741, p. 140273, 2020.

SHAKOOR, A.; SHAKOOR, S.; REHMAN, A.; ASHRAF, F.; ABDULLAH, M.; SHAHZAD, S. M.; ALTAF, M. A. Effect of animal manure, crop type, climate zone, and soil attributes on greenhouse gas emissions from agricultural soils—A global meta-analysis. *Journal of Cleaner Production*, v. 278, p. 124019, 2021.
WHAT IS THE CONTRIBUTION OF PIGLET WASTE IN THE FIRST WEEK AFTER WEANING TO GREENHOUSE GAS EMISSIONS?

SILVA, D. J; QUEIROZ, A. C. Análise de alimentos: métodos químicos e biológicos. 3.ed. Viçosa, MG: Editora Universitária, p.166, 2006.

TULLBERG, J.; ANTILLE, D. L.; BLUETT, C.; EBERHARD, J.; SCHEER, C. Controlled traffic farming effects on soil emissions of nitrous oxide and methane. Soil and Tillage Research, v. 176, p. 18-25, 2018.

VALENTIM, J. K.; MENDES, J. P.; CALDARA, F. R.; PIETRAMALE, R. T. R.; GARCIA, R. G. Meta-analysis of relationship between weaning age and daily weight gain of piglets in the farrowing and nursery phases. South African Journal of Animal Science, v. 51, n. 3, p. 332-338, 2021.

WANG, M.; WANG, L.; TAN, X.; WANG, L.; XIONG, X.; WANG, Y.; WANG, Q.; YANG, H.; YIN, Y. The developmental changes in intestinal epithelial cell proliferation, differentiation, and shedding in weaning piglets. Animal Nutrition, v. 9, p. 214-222, 2022.

XIA, F.; MEI, K.; XU, Y.; ZHANG, C.; DAHLGREN, R. A.; ZHANG, M. Response of N2O emission to manure application in field trials of agricultural soils across the globe. Science of the Total Environment, v. 733, p. 139390, 2020.

XIONG, X.; TAN, B.; SONG, M.; JI, P.; KIM, K.; YIN, Y.; LIU, Y. Nutritional intervention for the intestinal development and health of weaned pigs. Frontiers in veterinary science, v. 6, p. 46, 2019.

Zhai, H.; Luo, Y.; Ren, W.; Schyns, G.; Guggenbuhl, P. The effects of benzoic acid oils on growth performance, nutrients digestibility, and colonic microbiota in nursery pigs. Animal Feed Science and Technology, v. 262, p. 114426, 2020.

Eng. Agric., v.30, p.319-327, 2022