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A tool for effluent characterization and design of Natural Treatment Systems for Wastewater (NTSW) for livestock farms with high organic load in isolated island environments.

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Abstract:

The high organic load of the effluent generated in these farms has an important environmental impact, which is amplified in insular or isolated territories. The application of natural treatment systems of wastewater (NTSW) has demonstrated their suitability in these environments, but their design lacks proper characterization and sizing tools for their adequate operation. This work proposes a series of strategies and tools for the design and characterization of NTSW. As an application, an inventory, characterization, sizing, and design is carried out in 9 pig farms with a high environmental impact located on the island of Gran Canaria (Spain). The proposed tools in this work are based on a collection of experimental data over a five-year period of application of NTSW in real farms. This work contributes to facilitate the design and implementation of NTSW in farms located in isolated, island or similar size environments.

Keywords:

Wastewater treatment; natural systems; livestock farms; characterization.

1. Introduction

1.1. Waste generation and characterization overview

Livestock wastes in general, and pig wastes in particular, is made up of a dry part, formed by animal excrement, food remains, bedding, and a liquid part. This mixture is called slurry [1, 2]. Pig slurry is a source of multiple mineral constituents: primary macroelements or nutrients (N, P, K), secondary macroelements (Mg, Ca, Na) and trace elements (Cu, Zn, Mn, Fe, S, B, Mo). The availability of macroelements in slurry for crops is good (N, P) and even comparable to that of mineral fertilizers [3], [4].

The new Spanish legal framework establishing basic rules for the management of intensive and extensive pig farms can be found in Royal Decree 306/2020, of February 11. This Royal Decree (hereinafter referred to as RD306) focuses on environmental issues with respect to the protection of water, soil and air, and on the fight against climate change. Livestock farm effluent with a high organic load has a strong environmental impact that 35 is amplified in island territories.

In turn, slurry may have different properties at any given time due to various factors inherent to production, such as the number of heads, number of sows, piglet, fattening pig. As well as, the form of exploitation, type and management of the farmer, varied diet, cleanliness, the season of the year, emptying of the reception pits and the climate [5– 7].

This is the reason for the interest in developing a characterization tool bases on historical data on the operation of these systems in livestock farms. As indicated by [8, 9], an interesting basic characterization is carried out based on one or several parameters that are easy to determine in situ, leaving other more complex parameters for the laboratory. Likewise, the excessive or unfavourable application of slurry on land can lead to losses of nitrogen and phosphorus by percolation and runoff into surface and subsurface water bodies [8]–[10]. Excess phosphorus and nitrogen in the form of ammonium (NH_4^+), nitrate (NO_3^-) and nitrite (NO_2^-), in waters can accelerate the aging of aquatic ecosystems [11–15]. Ammonia (NH_3) is recognized as one of the most important toxic gases present in swine facilities and has profound effects on pig performance [16] and responds to its toxicity by altering in the barriers and defence mechanisms of the respiratory tract, facilitating the entry of pathogens, and increasing the likelihood of respiratory diseases [17].

Therefore, for a basic characterization of the effluent that allows the sizing of the treatment plant by means of NTSW, the flow rate (Q), chemical oxygen demand (COD), conductivity (EC), total nitrogen (TN) and ammonia (NH_3) are defined.

However, when it comes to dimensioning these systems, there are no tools applicable to agricultural and livestock farms in isolated territories, and they are limited to adaptations based on experience in small communities and rural settlements [29 -30].

1.2. Treatment systems for wastewater

Different slurry treatment systems have been proposed with the aim of reducing the pollutant load so that the treated waste can be reused as fertilizer or safely discharged into the sewage system [18, 19].

Conventional systems involve treating the effluent by means of concentrated physicochemical and biological processes in which the hydraulic retention time (HRT) is relatively short, and a stable operation can be ensured within preestablished and carefully controlled parameters. These have been implemented with varying degrees of success, but numerous problems have been reported, associated especially but not exclusively with the modes of operation and the costs of the system [18, 20–25].

Many pig farms have very tight profit margins and have few human resources due to direct competition with other more suitable production sectors, making on-farm effluent treatment necessary [19, 22, 26 - 27].

Natural treatment systems of wastewater (NTSW) employ effluent storage with a longer HRT which depends on the load applied and the climatic conditions, with the organic matter degraded though the activity of heterotrophic bacteria present in the natural environment. The treatment is carried out by passing the effluent through various types of ponds, artificial wetlands and anaerobic digesters, each of which facilitates a series of natural processes. Such systems have been successfully applied in rural community settings and small settlements with a population equivalent below 1000 [1, 2, 28].

However, when it comes to sizing such systems, there are no tools available for agricultural and livestock farms in isolated territories, with sizing limited to adaptations based on local farmer experience [29 - 30].

1.3. Geographic and primary sector overview

The island of Gran Canaria has a total 136 pig farms, the majority of which are small and family production. However, 10% of these farms account for more than 90% of the census and are industrial farms, in some cases close to environmental protection zones and are shown in Figure 1. For many years, livestock waste has been used as fertilizer in fields or farmland. However, in recent years, the gradual disappearance of these small farms and the increase in intensive livestock farming, the high number of animals per farm and the abandonment of traditional systems have led to a greater fluidity and dilution of the waste generated, thus increasing its volume, but there is not always enough arable land for its correct disposal [30].

Figure 1. Study pig farms in Gran Canaria

According to the applicable Spanish legislation, which establishes basic rules for the management of intensive pig farms, farms can be classified according to their productive capacity, which can be self-consumption farms, reduced farms and industrial farms, a self-consumption farm is considered a farm when it is used for the breeding of animals exclusively for family consumption, with a maximum production per year of 3 fattening pigs and without having a breeding farm; a reduced farm is one that houses a maximum number of 5 breeding animals, being able to keep a number of no more than 25 fattening animals.

This legislation also establishes standards for the management of livestock waste on the farm and the production of manure (theoretical maximum) by livestock unit (LSU). This unit is established for purposes of comparison between livestock species, classifying farms according to this value. By way of example, the corresponding LSU is 0.30 for boars with a waste production of 6.12 m^3/place/year, 0.96 for closed cycle sows with a waste production of 17.75 m^3/place/year, and 0.02 for piglets from 6 to 20 kg with a waste production of

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0.41 m^3/place/year. This classification distinguishes between family farms, which may not house more than the equivalent of 5 LSUs, and industrial farms, which are farms with a capacity of up to 120 LSUs.

1.4. Objective

The objective and the novelty of this work is the proposal of a series of strategies and tools for the design and characterization the effluents of NTSW in livestock farms. As an application, an inventory, characterization, and sizing will be carried out for the pig farms with the greatest impact located on the island of Gran Canaria.

2. Materials and Methods

2.1. Model

In this article, the methodology was adapted from that shown and applied [18], in which a study of the water-energy-waste nexus is developed, considering parameters of waste generation, consumption and occupied surface. The integral model is shown in Figure 2, for the evaluation of livestock farms in Gran Canaria, also considering the parameters of greenhouse gas emissions (GHG).

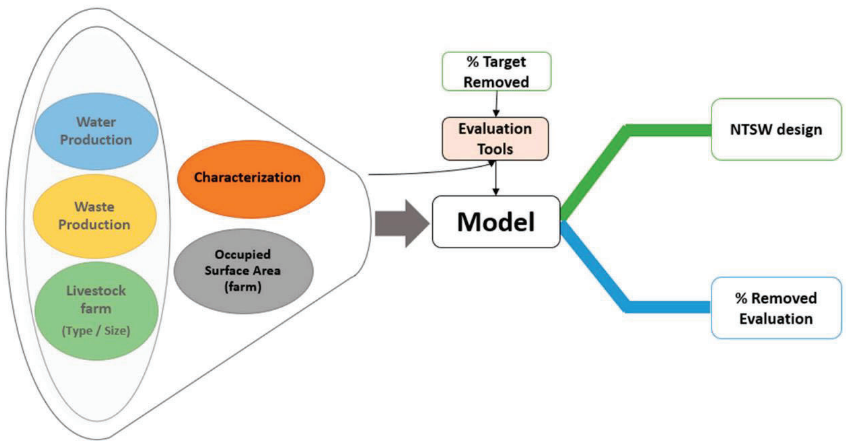

Figure 2. Model

2.2. Waste generation and characterization

Numerous authors have indicated the need to have tools to characterize livestock waste and to monitor parameters that are easy to apply and measure on the farm itself [1, 31–33].

Therefore, the waste generated in each farm was characterized considering the following variables: Q, COD, EC, TN and NH_3 from historical data.

The Q has been characterized by means of the correlation between the effluent flow rate and the number of sows with a correlation coefficient of 0.976 [2]. On the other hand, it was carried out according to Royal Decree 306/2020, of February 11, which includes the manure production (theoretical maximum) by type of livestock. As for COD, the correlation between input COD and Q; with a correlation coefficient of 0.575 [2].

For EC there is no significant correlation between conductivity and Q or COD, but there is a significant correlation with organic matter (Morg). For this reason, Morg was characterized by the correlation between Morg and COD with a correlation coefficient of 0.945 [2]. On the other hand, conductivity was calculated by the correlation between EC and Morg with a correlation coefficient of 0.938 [2].

Finally, the TN generated was characterized by correlation with an r=0.74 [31,34] and the generated NH_3 was characterized by the correlation with a correlation coefficient of 0.91 [31, 34].

Variable	unit	Correlation
Q	m^3/day	$Q=4.425+3.029\times10^{-7}\cdot(No.Sow)^3$
COD	mg/L	$COD=7{,}995.901+360.593\cdot(Q)^2-10.134\cdot(Q)^3$
Morg	mg/L	$Morg=162.505+0.273\cdot(COD)$
EC	dS/m	$EC\ (dS/m)=0.009\cdot(Morg)-8.4\times10^{-7}\cdot(Morg)^2$
TN	mg/L	$TN=83.79\cdot EC^{1.25}$
NH_3	mg/L	$NH_3=39.89\cdot EC^{1.343}$

2.3 Livestock farms.

The 9 selected farms on the island of Gran Canaria have from 15 to 220 sows (3.75 a 55 UGM), the farms total 4,442 animals, representing 94% of the total census on the island [35]. The farms have between 1,180 and 82, 065 m^2 of available land [36].

2.4 Natural Treatment Systems.

For the application of the NTSW, the starting point was the articles [1, 28] which study three livestock farms, one of which is our reference farm [2]. The criteria used for the design were the characteristics of the farms, Q, COD and EC.

2.5 Initial characterization and design of the treatment system.

For the application of the NTSW, the same rotary sieve (50mm) has been applied (and in the case of the digester and ponds plus wetlands, based on the data obtained in these articles, their behavior has been studied according to the needs of the farms studied [1, 2, 28]. The digester is more suited for a high removal of COD 2.33 %/day and ponds plus wetlands system is more suitable for a removal of EC 1.5%/day [2, 28]. To start, set the number of sows of the farm, set a depuration target (measured in COD and EC reduction) and characterize the waste generated, Q, COD, EC, NT, NH_3. A mechanical separation system is applied [21] and we study the behavior it has on the waste. With this final waste, we start to design the digester starting from 1 chamber with the desired volume (22, 10 and 5 m^3) [2, 28], considering the Q of the farm, with a % removal of COD and EC according to the volume of the chamber. As digester data we obtain COD, EC, hydraulic retention time (HRT) and total volume (V_{dig}) and we check if the livestock farm, due to its location and available surface, it is possible and necessary to apply a pond + wetland. For the application of a pond plus wetland we start from the criterion of the location of the farm, considering if it has a nearby population, since this process releases bad odours, and if it is in areas with a high percentage of rainfall and high altitude, being open systems more influenced by climatic conditions (temperature, humidity, rainfall, and evaporation). If it is not possible to design the pond, it is observed whether the results obtained meet the objective. If so, the digester is designed, if not, another chamber is added to the digester and so on.

In terms of its design, it is based on a 15-day HRT, thus setting the maximum volume of the basin (V_{Lag}), a COD removal rate of 1.34 %/day and an EC removal rate of 1.51 %/day [2]. With the results obtained we check if it meets the target. If the COD is high to the target, The volume of the digester would be increased by adding a chamber and so on, if the EC is high to the target we would increase the volume of the pond + wetland. The decision tree is shown in Figure 3, to characterize the natural depuration systems of livestock farms in Gran Canaria.

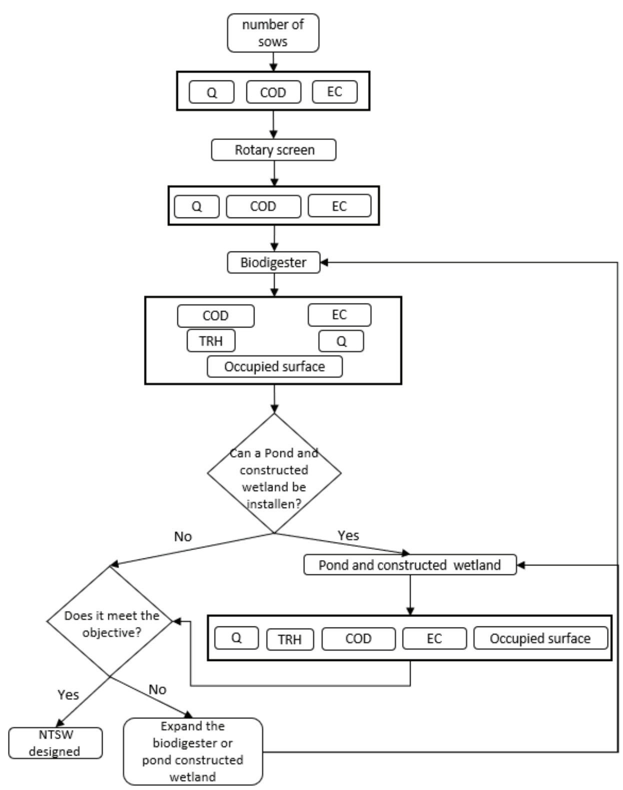

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Figure 3. Decision tree.

3. Results and discussion

3.1. Types of farms and waste

This study has focused on 9 farms which, due to their characteristics, type of farm and number of sows, require a treatment system. From the farms studied, the waste generated was characterized, obtaining COD values between 24,078 and 8,049 mg/L, EC between 23 and 16 dS/m and between 2,625 and 1,704 mg/L of NH_3 generated. The selected farms have an available plot between 1,180 and 82,065 m^2, with different soil types and according to the Gran Canaria 2017 management plan could be built on the evaluated soils. By size and type of soil an NTSW can be implemented in the farms. These data are reflected in Table 1.

As mentioned above, to propose a natural depuration treatment system, it is necessary to know the waste generated in each farm, i.e., the slurry Q, COD, EC, TN NH_3.

The slurry flow rate was characterized by two criteria, by correlation and/or by Royal Decree 306/2020, February 11. The choice of one method or the other was based on the type of farm (intensive-confined or semi-confined) and the number of sows. These criteria are since an intensive-confined farm stores more manure than a semi-confined farm. However, intensive-confined farms have been characterized according to the Royal Decree. The reason for this choice is because, although they are industrial farms, the number of sows is lower than the other farms and in the case of using the criterion of number of sows, an error of 62-92% is made, resulting in over-dimensioning the capacity of the NTSW of the farms.

The COD values obtained are in the range between 24,078 and 7,999 mg/L. The mean value is within the range of the observed values of 5,000 and 25,000 mg/L [37], between 28,000 y 13,200 mg/L [38], between 14,200 y 9,400 mg/L [32].

The EC values found are in the range between 16,3 y 23 dS/m. Previous studies have found values, among 13.2 y 33.2 dS/m [31] and from to 9.9 y 25 dS/m [32] hence these results are considered valid.

Table 1. Characterization of farms and livestock wastes

Farm	X	Y	Z	Available area (m^2)	Type of farms	UGM (unit)	Q (m^3/day)	COD (mg/L)	Morg (mg/L)	EC (dS/m)	NT (mg/L)	NH_3N (mg/L)
1	458,08	3,091,56	249.26	18,935	intensive-confined	109.45	7.52	24078.48	6699.93	22.59	4127.14	2625.67
2	455,82	3,084,34	119.28	58,642	intensive-confined	84.5	5.15	16186.60	4545.45	23.55	4347.77	2776.77
3	446,11	3,102,56	705.20	4,516	intensive-confined	70.13	4.62	14705.19	4141.02	22.86	4189.40	2668.25
4	456,59	3,086,37	248.09	1,180	semiconfined	32.13	1.76	9056.79	2599.01	17.72	3045.65	1894.32
5	446,85	3,110,52	330.13	6,885	semiconfined	18.32	1.00	8346.36	2405.06	16.79	2847.08	1761.95
6	440,65	3,096,39	1216.72	10,089	intensive-confined	32.05	1.67	8953.96	2570.94	17.59	3017.58	1875.57
7	457,82	3,085,47	97.72	82,065	intensive-confined	50.95	2.60	10262.17	2928.08	19.15	3356.81	2103.01
8	434,67	3,081,32	202.11	5,931	semiconfined	14.8	0.81	8228.20	2372.80	16.63	2813.02	1739.31
9	445,53	3,097,59	1026.85	35,541	semiconfined	7.27	0.39	8049.96	2324.14	16.38	2761.10	1704.84

Finally, the TN generated was characterized by giving values between 2,746 y 4,347 mg/L and the NH_3 generated between 1,694 y 2,625 mg/L. The results obtained from the calculations performed high values of ammonia, which may affect health and productivity as described by several authors. [39 – 43], It is necessary to adequately manage livestock waste. Table 1 shows the results obtained in this study in the different farms.

3.2 Natural treatment system.

From [2, 28] the characteristics of the farms, where they are located, flow, COD, EC and according to current local legislation sets a maximum discharge target of 1600 mg/L COD and 2500 µS/cm EC the NTSW sizing has been proposed for each farm.

For farm 1, an NTSW consisting of a rotary screen, homogenizer tank and digester has been proposed. In the case of the sieve, it has been designed the same as that of the reference farm, giving a reduction percentage of 45% and an EC reduction percentage of 7.5%. As for the digester, starting with 4 chambers and a chamber volume of 22 m^3, with a COD reduction percentage of 30%, a necessary volume of 96.82 m^3 and a hydraulic retention time of 13 days was obtained. However, the result of this design did not meet the objective. For this reason, 6 more chambers were added, increasing the COD reduction percentage to 77% and an HRT of 33 days.

In the case of farm 2, the same criteria are used, and the digester is also increased to a HRT of 26 days and a COD reduction percentage of 59.84%. In these two farms it was decided to increase the digester instead of installing a pond and wetlands, like the reference plant, because the digester has a higher percentage of COD reduction than the pond plus wetlands and because the area where these farms are located has low precipitation and therefore does not favour the degradation of organic matter in the pond.

For farms 4, 5, 6, 6, 7, 8 and 9, a NTSW consisting of a rotary screen, homogenizer tank and digester has also been designed. In these cases, the screen is the same for all, but the digester varies in terms of number of chambers, chamber volume and HRT, depending on the effluent conditions. All farms with an average of 25 HRT and an average COD reduction % of 61% meet the discharge criteria. However, farms 5, 6 and 9, due to their location, could be equipped with pond with wetlands. Therefore, for these farms it would be recommended to install a pond and wetland, even if they meet the objective, since this would improve the final discharge conditions. Appendix A shows the results obtained in this study in the different farms.

4. Conclusions

- The characterization of the parameters Q, COD, EC, NT, NH_3
- of the farms studied in Gran Canaria indicates the importance of adequate treatment in the farm itself to minimize the environmental impact that this activity supposes for the environment.
- NTSW are suitable and provide a viable treatment alternative for the livestock waste produced.
- There is no single NTSW model for all pig farms as the type, flow, organic load, location and climatic conditions of each one will dictate the conditions of its design.
- The proposed decision strategy tools for the design of NTSW have proven to be a useful tool for the sizing of the farms considered in the study.

5. Nomenclature

Q	flow rate
COD	chemical oxygen demand
EC	electrical conductivity
TN	total nitrogen
NH3	ammonia
GHG	greenhouse gas emissions
Morg	organic matter
N_o Sow	number of sows
LSU	livestock unit
HRT	hydraulic retention time

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Conflicts of Interest: The authors declare no conflict of interest.

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Appendix A

Table 2. Proposed NTSW design.

	Effluent			Solid-liquid separation				Biodigester							
Farm	**Q (m^3/day)**	**COD (mg/L)**	**EC (dS/m)**	**% removal COD (%)**	**% removal EC (%)**	**COD (mg/L)**	**EC (dS/m)**	**% removal COD (%/day)**	**% removal EC (%/day)**	**HRT_{dig} (day)**	**$V_{chamber}$ (m^3)**	**V (m^3)**	**Chambers (units)**	**COD (mg/L)**	**EC (dS/m)**
1	7.520	24,078.48	22.59	45	7.45	13,243.16	20.91	2.3	0.2	33	22	96.8	10	1,341.49	20.25
2	5.154	16,186.60	23.55	45	7.45	8,902.63	21.80	2.3	0.2	26	22	66.4	5	1,625.21	21.05
3	4.624	14,705.19	22.86	45	7.45	8,087.85	21.16	2.3	0.2	18	22	59.5	3	2,165.91	20.42
4	1.759	9,056.79	17.72	45	7.45	4,981.23	16.40	2.3	0.2	25	22	22.7	1	925.22	15.56
5	1.000	8,346.36	16.79	45	7.45	4,590.50	15.54	2.3	0.2	35	22	12.9	1	391.03	14.45
6	1.670	8,953.96	17.59	45	7.45	4,924.68	16.28	2.3	0.2	26	22	21.5	1	879.70	15.43
7	2.604	10,262.17	19.15	45	7.45	5,644.19	17.72	2.3	0.2	21	22	33.5	2	1,290.86	16.97
8	0.812	8,228.20	16.63	45	7.45	4,525.51	15.39	2.3	0.2	25	10	10.5	1	849.63	14.61
9	0.389	8,049.96	16.38	45	7.45	4,427.48	15.16	2.3	0.2	26	5	5.0	1	806.52	14.38

Table 3. Proposed NTSW design.

	Pond + constructed wetlands							NTSW		
Farm	**HRT (day)**	**% removal COD (%/day)**	**COD (mg/L)**	**% removal EC (%/day)**	**EC (dS/m)**	**V (m^3)**	**Surface (m^2)**	**V (m^3)**	**Surface (m^2)**	**HRT (day)**
1	-	-	-	-	-	-	-	96.83	83.61	33.35
2	-	-	-	-	-	-	-	66.36	44.12	25.68
3	15	1.34	1,730.56	1.51	15.79	69.37	46.24	128.91	73.42	33.00
4	-	-	-	-	-	-	-	22.65	14.88	25.38
5	15	1.34	312.43	1.51	11.18	15	10	27.88	21.63	49.88
6	15	1.34	702.88	1.51	11.93	25.04	16.7	46.54	31.20	41.05
7	-	-	-	-	-	-	-	33.53	18.51	21.32
8	-	-	-	-	-	-	-	10.45	6.82	25.19
9	15	1.34	644.41	1.51	11.12	5.84	3.89	10.85	7.23	40.72

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References

[1] C. A. Mendieta-Pino, A. Ramos-Martin, S. O. Perez-Baez, and S. Brito-Espino, “Management of slurry in Gran Canaria Island with full-scale natural treatment systems for wastewater (NTSW). One year experience in live-stock farms,” J Environ Manage, vol. 232, pp. 666–678, 2019, doi: https://doi.org/10.1016/j.jenvman.2018.11.073.

[2] C. A. Mendieta-Pino, S. O. Pérez-Báez, A. Ramos-Martín, F. León-Zerpa, and S. Brito-Espino, “Natural treatment system for wastewater (NTSW) in a livestock farm, with five years of pilot plant management and monitoring,” Chemosphere, vol. 285, p. 131529, Sep. 2021, doi: 10.1016/J.CHEMOSPHERE.2021.131529.

[3] H. G. V. Penha et al., “Nutrient accumulation and availability and crop yields following long-term application of pig slurry in a Brazilian Cerrado soil,” Nutr Cycl Agroecosyst, vol. 101, no. 2, pp. 259–269, 2015, doi: 10.1007/s10705-015-9677-6.

[4] M. C. Villar, V. Petrikova, M. Díaz-Raviña, and T. Carballas, “Recycling of organic wastes in burnt soils: combined application of poultry manure and plant cultivation,” Waste Management, vol. 24, no. 4, pp. 365–370, 2004, doi: https://doi.org/10.1016/j.wasman.2003.09.004.

[5] B Riaño and M C García-González, “On-farm treatment of swine manure based on solid-liquid separation and biological nitrification-denitrification of the liquid fraction,” J Environ Manage, vol. 132, 2014.

[6] W. Antezana et al., “Composition, potential emissions and agricultural value of pig slurry from Spanish commercial farms,” Nutr Cycl Agroecosyst, vol. 104, no. 2, pp. 159–173, Sep. 2016, doi: 10.1007/S10705-016-9764-3.

[7] M. Sánchez and J. L. González, “The fertilizer value of pig slurry. I. Values depending on the type of operation,” Bioresour Technol, vol. 96, no. 10, pp. 1117–1123, Jul. 2005, doi: 10.1016/j.biortech.2004.10.002.

[8] C. P. Dionisi et al., “Monitoring of physicochemical parameters of soils after applying pig slurry. Analysis of its application in short and long periods in the province of Córdoba, Argentina,” Microchemical Journal, vol. 159, p. 105545, Dec. 2020, doi: 10.1016/j.microc.2020.105545.

[9] O. Thygesen, J. M. Triolo, and S. G. Sommer, “Indicators of Physical Properties and Plant Nutrient Content of Animal Slurry and Separated Slurry,” Biol Eng Trans, vol. 5, no. 3, pp. 123–135, 2012, doi: 10.13031/2013.42273.

[10] A. Cavanagh, M. O. Gasser, and M. Labrecque, “Pig slurry as fertilizer on willow plantation,” Biomass Bioenergy, vol. 35, no. 10, pp. 4165–4173, Oct. 2011, doi: 10.1016/j.biombioe.2011.06.037.

[11] Y. Hou, G. L. Velthof, J. P. Lesschen, I. G. Staritsky, and O. Oenema, “Nutrient Recovery and Emissions of Ammonia, Nitrous Oxide, and Methane from Animal Manure in Europe: Effects of Manure Treatment Technologies,” Environ Sci Technol, vol. 51, no. 1, pp. 375–383, Jan. 2017, doi: 10.1021/acs.est.6b04524.

[12] O. Oenema, D. Oudendag, and G. L. Velthof, “Nutrient losses from manure management in the European Un-ion,” Livest Sci, vol. 112, no. 3, pp. 261–272, Dec. 2007, doi: 10.1016/j.livsci.2007.09.007.

[13] S. O. Petersen et al., “Recycling of livestock manure in a whole-farm perspective,” Livest Sci, vol. 112, no. 3, pp. 180–191, Dec. 2007, doi: 10.1016/j.livsci.2007.09.001.

[14] N. Ramankutty et al., “Trends in Global Agricultural Land Use: Implications for Environmental Health and Food Security,” Annu Rev Plant Biol, vol. 69, no. 1, pp. 789–815, Apr. 2018, doi: 10.1146/annurev-arplant-042817-040256.

[15] G. Li, G. Huang, H. Li, M. K. van Ittersum, P. A. Leffelaar, and F. Zhang, “Identifying potential strategies in the key sectors of China’s food chain to implement sustainable phosphorus management: a review,” Nutr Cycl Agroecosyst, vol. 104, no. 3, pp. 341–359, Apr. 2016, doi: 10.1007/s10705-015-9736-z.

[16] R. Zimmerman, “La Higine de las naves es la clave para reducir el amoníaco,” 3tres3. 2000. [Online]. Available: https://www.3tres3.com/articulos/la-higiene-de-las-naves-es-la-clave-para-reducir-el-amoniaco_337/

[17] M. R. Muirhead and T. J. L. Alexander, Managing Pig Health: A Reference for the Farm, 2nd, ilistra ed. 2013.

[18] S. Lopez-Ridaura, H. van der Werf, J. M. Paillat, and B. le Bris, “Environmental evaluation of transfer and treatment of excess pig slurry by life cycle assessment,” J Environ Manage, vol. 90, no. 2, pp. 1296–1304, Feb. 2009, doi: 10.1016/j.jenvman.2008.07.008.

[19] X. Flotats, A. Bonmatí, B. Fernández, and A. Magrí, “Manure treatment technologies: On-farm versus central-ized strategies. NE Spain as case study,” Bioresour Technol, vol. 100, no. 22, pp. 5519–5526, Nov. 2009, doi: 10.1016/j.biortech.2008.12.050.

 https://doi.org/10.52202/069564-0164

[20] X. Font, N. Adroer, M. Poch, and T. Vicent, “Evaluation of an Integrated System for Pig Slurry Treatment,” Journal of Chemical Technology & Biotechnology, vol. 68, no. 1, pp. 75–81, Jan. 1997, doi: 10.1002/(SICI)1097-4660(199701)68:1<75::AID-JCTB593>3.0.CO;2-C.

[21] M. Hjorth, K. v. Christensen, M. L. Christensen, and S. G. Sommer, “Solid—liquid separation of animal slurry in theory and practice. A review,” Agron Sustain Dev, vol. 30, no. 1, pp. 153–180, Mar. 2010, doi: 10.1051/agro/2009010.

[22] J. Alvarez, “Characterization of pig slurry and their treatment efficiency in central Spain,” 2006.

[23] C. León-Cófreces, M. C. García-Gonzalez, M. Acítores, and M. P. Pérez-Sangrador, “Development of a pig slur-ry treatment system with SBR and MBR technology,” 2006.

[24] L. Deng, C. Cai, and Z. Chen, “The treatment of pig slurry by a full-scale Anaerobic-Adding Raw Wastewater-Intermittent Aeration Process,” Biosyst Eng, vol. 98, no. 3, pp. 327–334, Nov. 2007, doi: 10.1016/j.biosystemseng.2007.08.001.

[25] L. M. Ferreira, “Pilot scale experience of anaerobic co-digestion of pig slurry with fruit wastes on site operation in a pig farm with a mobile plant,” 2009.

[26] W. Antezana et al., “Composition, potential emissions and agricultural value of pig slurry from Spanish commercial farms,” Nutr Cycl Agroecosyst, vol. 104, no. 2, pp. 159–173, Mar. 2016, doi: 10.1007/s10705-016-9764-3.

[27] Y. Hou et al., “Stakeholder perceptions of manure treatment technologies in Denmark, Italy, the Netherlands and Spain,” J Clean Prod, vol. 172, pp. 1620–1630, Jan. 2018, doi: 10.1016/j.jclepro.2016.10.162.

[28] C. A. Mendieta-Pino, T. Garcia-Ramirez, A. Ramos-Martin, and S. O. Perez-Baez, “Experience of Application of Natural Treatment Systems for Wastewater (NTSW) in Livestock Farms in Canary Islands,” Water (Basel), vol. 14, no. 14, 2022, doi: 10.3390/w14142279.

[29] M. A. Belmont, E. Cantellano, S. Thompson, M. Williamson, A. Sánchez, and C. D. Metcalfe, “Treatment of domestic wastewater in a pilot-scale natural treatment system in central Mexico,” Ecol Eng, vol. 23, no. 4–5, pp. 299–311, Sep. 2004, doi: 10.1016/j.ecoleng.2004.11.003.

[30] L. Vera, G. Martel, and M. Márquez, “Two years monitoring of the natural system for wastewater reclamation in Santa Lucía, Gran Canaria Island,” Ecol Eng, vol. 50, pp. 21–30, Jan. 2013, doi: 10.1016/j.ecoleng.2012.08.001.

[31] A. Suresh, H. L. Choi, D. I. Oh, and O. K. Moon, “Prediction of the nutrients value and biochemical characteristics of swine slurry by measurement of EC – Electrical conductivity,” Bioresour Technol, vol. 100, no. 20, pp. 4683–4689, Oct. 2009, doi: 10.1016/j.biortech.2009.05.006.

[32] R. Moral, M. D. Perez-Murcia, A. Perez-Espinosa, J. Moreno-Caselles, C. Paredes, and B. Rufete, “Salinity, organic content, micronutrients and heavy metals in pig slurries from South-eastern Spain,” Waste Management, vol. 28, no. 2, pp. 367–371, 2008, doi: 10.1016/j.wasman.2007.01.009.

[33] R. Moral, J. Moreno-Caselles, M. D. Perez-Murcia, A. Perez-Espinosa, B. Rufete, and C. Paredes, “Characterization of the organic matter pool in manures.,” Bioresour Technol, vol. 96, pp. 153–159, 2005.

[34] A. Suresh and H. L. Choi, “Estimation of nutrients and organic matter in Korean swine slurry using multiple regression analysis of physical and chemical properties,” Bioresour Technol, vol. 102, no. 19, pp. 8848–8859, Oct. 2011, doi: 10.1016/j.biortech.2011.06.087.

[35] ISTAC, “ISTAC Instituto Canario de Estadística.” [Online]. Available: www.gobiernodecanarias.org/istac

[36] “IDE Canarias visor 4.5.1.” [Online]. Available: https://visor.grafcan.es/visorweb/

[37] J. E. Hall, “Nutrient Recycling : The European Experience - Review -,” Asian-Australas J Anim Sci, vol. 12, no. 4, pp. 667–674, Jun. 1999, doi: 10.5713/ajas.1999.667.

[38] C. A. Mendieta Pino, “Evaluación y modelización de sistemas de tratamiento no-convencional o natural para efluentes procedentes de explotaciones ganaderas de porcino en la isla de Gran Canaria,” 2015.

[39] T. D. Hamilton, J. M. Roe, C. Hayes, and A. J. Webster, “Effects of ammonia inhalation and acetic acid pretreatment on colonization kinetics of toxoginec Pasteurella multocida within upper respiratory tracs of swine.,” j. Clin. Microbiol, vol. 36,1260–12, 1998.

[40] T. Arango, R. Besteiro, V. G. Souto, M. R. Rodríguez, and M. D. Fernández, “Concentración de NH3 en relación con otras variables ambientales en alojamientos para lechones de 6 a 20 kg de p.v.,” VIII Congreso Ibérico de Agroingeniería, 2015.

[41] K. J. Donham, “Effects on Swine Health, Productivity, Human Health and the enviroment,” Toxicology, vol. 16, 2000.

[42] L. Fraile, A. Alegre, R. López-Jiménez, M. Nofrarías, and J. Segalés, “Risk factors associated with pleuritis and cranio-ventral pulmonary consolidation in slaughter-aged pigs,” Veterinary Journal, vol. 184, no. 3, pp. 326–333, 2010, doi: 10.1016/j.tvjl.2009.03.029.

[43] T. Wang, Q. He, W. Yao, Y. Shao, J. Li, and F. Huang, “The variation of nasal microbiota caused by low levels of gaseous ammonia exposure in growing pigs,” Front Microbiol, vol. 10, no. MAY, pp. 1–14, 2019, doi: 10.3389/fmicb.2019.01083.Table 4. Proposed NTSW designThis Appendix describes the Direct

 https://doi.org/10.52202/069564-0164