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GOOD PRACTICES FOR REDUCING LAND POLLUTION IN THE AREA OF SWINE FARMS WITH LIQUID MANURE

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Abstract

The pollution of surface or underground water sources is done by physical, chemical, and biological means, the ecological effects manifesting themselves through the modification of abiotic factors and implicitly all trophic levels. Evacuated unprocessed, untreated and accidentally ending up in emissions or on the ground, the liquid wastes contribute to the heating of the water and the decrease of oxygenation degree determined by the acceleration of the organic mass decomposition phenomena and on the soil by degrading its quality by increasing the amount of nitrogen. These effects the more visible in the researched area, Arad County in the vicinity of swine farms and especially in the area of former treatment plants belonging to disused farms, where the waters of the area, due to the activity of aerobic microorganisms, flourished and some species of fauna and flora even disappeared if the discharged faeces, after a certain processing the CBO5 parameter had 45.1-55.0 mg·L^{-1}.

Key words*: environmental pollution, good practices, manure, swine.*

INTRODUCTION

Swine holdings as production units are equipped with accommodation spaces, utility annexes, and specific means of transport, in which coordination is ensured by managers, specialists, and highly qualified workforce. To be functional, holdings must be in areas authorized by environmental bodies, and, outside the fenced premises, they may also have areas of land intended for crop production. The mechanism of operation of the management system is based on a set of laws, principles, methods, and procedures that make up the methodological elements. The technical, economic, and social organization of pork production takes place in the conditions of a great diversity of types and forms, so farms can be classified by:

- orientation of production and nature of activity;
- integration of production by branch;
- technical-economic profile.

The establishment of a performing professional pig holding requires, from the point of view of Integrated Production Management, investments in land procurement for the construction of shelters, investments in exploitation technology, mechanization and automation of farm activities, control of the microclimate in shelters, provision of fodder resources, water and energy, manure management (Deviney et al., 2021), and implementation of measures to protect natural environmental factors and avoidance of environmental risk. Major investments are needed for the construction of modern wastewater and slurry treatment plants, for the avoidance of environmental risk, as well as in the management of the environment and the qualification of the human resource, and the development of procedures related to:

- management of environmental risk;
- integration in the management of the environment and Total Quality Management;
- implementation of the best management in the meat industry, production, processing, distribution, and capitalization on the market.

To achieve the most efficient investment in professional integrated pig farms, it is necessary to analyse some elements that condition the technological processes of production, and the viability and economic efficiency of the holding. For the establishment of an integrated performance pig holding, it is necessary to follow the following steps (Das et al., 2023):

- knowing the climate and economic factors around the holding;
- choosing the location: road network, electricity, source of water supply, and feed resources;
- using efficiently manure and waste water as organic fertilizers;
- elaborating the technological project;
- conducting technical, economic, and social studies;
- elaborating the execution project;
- constructing shelters and utilities;
- equipping the holding with performing means;
- implementing the integrated management system;
- populating with genetic material.

The choice of area and location of the holding is an important decision considering that, once built, the shelters can no longer be moved to another site. For a good site and with few environmental risks, it is necessary to know the factors that can influence the evolution of the farm:

Technical and technological factors:

- risk of pollution, which needs measures of optimal dimensioning of the farm and of the systems of collection, storage, treatment, and disposal of manure;
- climate factors, of which minimum and maximum air temperatures, daytime and nighttime temperatures per periods and seasons (Ahmed et al., 2013), and relative humidity will be analysed. The direction of the prevailing winds is analysed to establish the thickness of the shelter walls, the orientation of shelter placement, and the need for the formation of protective curtains;
- quality of the site: the soil must be compact, stable, sloping, and away from emissaries to avoid accidental leakage;
- drinking water, which is necessary for the pigs and for technological and human consumption and must be sufficient and at great depths to avoid pollution;
- pluviometric regime;
- feed resources, which depend on the size and method of procurement (purchase or own production) (Andretta et al., 2021);
- national power grid or own sources;
- transport network.

Socio-economic factors:

- availability of human and feed resources;
- competition in the area;
- traditions regarding the consumption of pork;
- market trends;
- possibilities of capitalization of finished production.

The main objectives of this scientific approach are: finding new methods of managing waste from pig farms to avoid environmental degradation in the farm area; the regulation of the livestock according to the affordability of the environmental factors and the monitoring of the quality of the environment in the area of the pig farms to avoid their degradation.

MATERIALS AND METHODS

Because pig farms with classic production technologies involve low investments in manure management, they have environmental problems caused by the exceeded values of nitrites and nitrates in surface and deep water (Luo et al., 2019), by their administration on the lands around the farms as organic fertilizers in large quantities unprocessed properly by separation to increase the production. In this scientific approach, the authors sought solutions for the implementation of modern processing and management technologies by incorporation into the soil in controlled dilutions to reduce their negative effects on the environmental (Yost et al., 2022). Statistical data obtained in this scientific approach represent the results of the samples from 4 drills made during the years 2020, 2021, and 2022, twice a year, in the first and second semester: they represent the database subjected to statistical processing using SAS Studio [SAS]. Although the values of the samples are within the parameters, to test the differences between the values determined by two groups, the T-two sample test was used, respectively the Mann-Whitney nonparametric equivalent.

For the data distributed in three groups (annual series) and four groups (determined by drilling in different locations), the One-Way ANOVA procedure and the Kruskal Wallis nonparametric test were used. Multiple post hoc comparisons were performed using the Tukey test for the parameters followed, pH values, chemical oxygen consumption - potassium permanganate method (CCOMn), ammoniacal nitrogen, nitrite and nitrate quantity, phosphorus, and chlorides (Chen et al., 2020).

RESULTS AND DISCUSSIONS

Quality indicators for groundwater and surface water around the pig farms highlight the degree of pollution and the management of solid and liquid manure management over a certain period (Abrantes Pinto De Brito et al., 2022). The evolution of the water quality parameters at the control drills, around the farms where solid manure was administered and near the wastewater management stations from the farm are presented over a period of three years in the tables below.

Groundwater quality in the farm area is presented in Tables 1 to 4.

Table 1. Groundwater quality at drilling (F1) in the manure storage area

Item	UM	2020		2021		2022	
		1st Semester	2nd Semester	1st Semester	2nd Semester	1st Semester	2nd Semester
Water pH	pH	7.40	7.45	7.30	7.50	7.20	7.45
Chemical oxygen consumption - potassium permanganate method	$mg\text{-}O_2 \cdot L^{-1}$	6.35	4.50	2.20	5.80	2.00	3.20
Ammoniacal nitrogen	$mg \cdot L^{-1}$	0.25	0.10	0.20	0.10	0.20	0.30
Nitrites	$mg \cdot L^{-1}$	0.50	0.40	0.40	0.30	0.10	0.20
Nitrates	$mg \cdot L^{-1}$	2.40	2.20	0.40	2.30	0.50	1.50
Total phosphorus	$mg \cdot L^{-1}$	0.01	0.03	0.20	0.10	0.20	0.47
Chlorides	$mg \cdot L^{-1}$	9.50	36.50	22.50	12.40	22.30	28.30

Table 2. Groundwater quality at drilling (F_2) in the area where slurry was used in 2020 to increase agricultural production on sole 1 (S1)

Item	UM	2020		2021		2022	
		1st Semester	2nd Semester	1st Semester	2nd Semester	1st Semester	2nd Semester
Water pH	pH	7.10	7.00	7.20	7.40	7.40	7.50
Chemical oxygen consumption - potassium permanganate method	$mg\text{-}O_2 \cdot L^{-1}$	3.30	4.20	1.50	1.70	1.70	1.80
Ammoniacal nitrogen	$mg \cdot L^{-1}$	0.40	0.30	0.20	0.35	0.20	0.35
Nitrites	$mg \cdot L^{-1}$	0.45	2.50	0.35	0.20	0.38	0.18
Nitrates	$mg \cdot L^{-1}$	3.30	0.80	2.60	0.50	0.90	0.30
Total phosphorus	$mg \cdot L^{-1}$	0.06	0.04	0.10	0.10	0.08	0.15
Chlorides	$mg \cdot L^{-1}$	40.50	38.20	13.50	19.30	17.30	22.20

Table 3. Groundwater quality at drilling (F_3) in the area where slurry was used in 2020 to increase agricultural production on sole 2 (S2)

Item	UM	2020		2021		2022	
		1st Semester	2nd Semester	1st Semester	2nd Semester	1st Semester	2nd Semester
Water pH	pH	7.20	7.20	7.30	7.60	7.10	7.40
Chemical oxygen consumption - potassium permanganate method	$mg\text{-}O_2 \cdot L^{-1}$	11.50	12.20	2.00	1.70	1.70	1.60
Ammoniacal nitrogen	$mg \cdot L^{-1}$	0.50	0.30	0.08	0.03	0.03	0.22
Nitrites	$mg \cdot L^{-1}$	0.10	1.80	0.08	0.08	0.10	0.30
Nitrates	$mg \cdot L^{-1}$	1.45	0.85	3.20	3.80	0.60	0.20
Total phosphorus	$mg \cdot L^{-1}$	0.008	0.007	0.090	0.33	0.20	0.38
Chlorides	$mg \cdot L^{-1}$	88.40	40.20	28.80	22.40	20.20	13.10

Table 4. Groundwater quality at drilling (F_4) in the area where slurry was used in 2020 to increase agricultural production - on sole 3 (S3)

Item	UM	2020		2021		2022	
		1st Semester	2nd Semester	1st Semester	2nd Semester	1st Semester	2nd Semester
Water pH	pH	7.20	7.50	7.10	7.40	7.00	7.30
Chemical oxygen consumption - potassium permanganate method	$mgO_2 \cdot L^{-1}$	2.20	3.80	2.60	3.50	2.00	1.85
Ammoniacal nitrogen	$mg \cdot L^{-1}$	0.45	0.30	0.20	1.60	0.70	0.95
Nitrites	$mg \cdot L^{-1}$	0.50	2.70	0.20	0.09	0.40	1.22
Nitrates	$mg \cdot L^{-1}$	0.40	0.70	13.44	5.20	0.60	0.10
Total phosphorus	$mg \cdot L^{-1}$	0.07	0.09	0.10	0.25	0.20	0.30
Chlorides	$mg \cdot L^{-1}$	56.20	67.20	12.50	23.50	17.80	24.20

Table 5. Evolution of nitrate values at control drillings (S_1, S_2, S_3)

Item	Indicator analysed	UM	Value determined	
			1st Semester ($mg \cdot L^{-1}$)	2nd Semester ($mg \cdot L^{-1}$)
Storage pools	Nitrates	$mg \cdot L^{-1}$	0.10- 2.40	0.20-2.30
Control drill sole 1			0.35- 3.30	0.18-2.50
Control drill sole 2			0.08- 3.20	0.08-3.80
Control drill sole 3			0.20-13.44	0.09-5.20

Evolution of nitrate values at control drillings

The evolution of nitrate concentrations from control drills on soils fertilized with pig manure to increase agricultural production highlights the influence of fertilizers from slurry on groundwater, as shown by the data presented in Table 5.

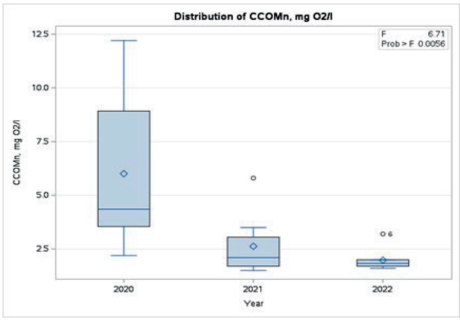
Comparing the results obtained based on the measurements made per semesters over 3 years around the pig farm from Arad County, it follows that, although the surveyed area is in "a vulnerable and potentially vulnerable to pollution area" in both semesters:

- there were no exceeding permissible limits of pollution: the pH of the water reached values of 7.00-7.50 (the allowed pH limits are between 6.50-8.50) although they used pig manure to increase agricultural production on the investigated soils, with a crop rotation every 3 years;
- there were no exceeding permissible limits of pollution due to compliance with dilutions to avoid pollution of the environmental;
- there was mechanical separation of coarse manure while maintaining it in the drying beds and of the liquid manure in storage pools until using them as fertilizers; they were discharged after processing 45.1-55.0 $mg \cdot L^{-1}$ CBO_5;
- there was variation of nitrites during the analysis period due to weather conditions (high number of precipitations), which determined the increase of groundwater concentrations;
- there was a permeable soil that favoured the rapid accumulation of nitrates in the water;
- there was a variation of the level of chlorides in water during the semesters of the analysed period, reaching values between 6.20-88.40 $mg \cdot L^{-1}$, the highest quantities being in 2020 in all 3 control drills on the soils where liquid manure from pigs had been administered.

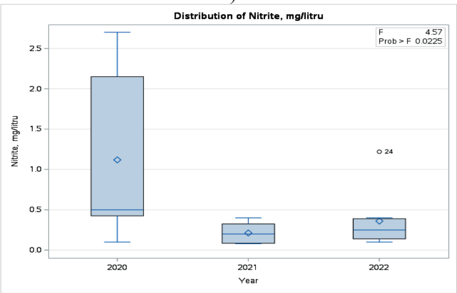
The statistical processing regarding the values of the measured parameters with the ANOVA test produced statistically significant differences during the three years (2020, 2021 and 2022) in the case of CCOMn values with $p = 0.0056$, $F = 6.71$ (Figure 1a), nitrites $p = 0.0225$, $F = 4.57$ (Figure 1b), nitrates $p = 0.0376$, $F = 3.85$ (Figure 1c), phosphorus $P = 0.0008$, $F = 10.24$ (Figure 1d) and chlorides $P = 0.0011$, $F = 9.57$ (Figure 1e).

The significant differences between the groups determined in the three years are also confirmed by the application of the Kruskal Wallis nonparametric test. Thus, the values obtained were $p = 0.002$ with a.m. $2 = 11.90$ for CCOMn, $p = 0.018$ with a.m. $2 = 9.06$ for nitrites, $p = 0.019$ with a.m. $2 = 7.87$ for nitrates, $p = 0.0004$ with a.m. $2 = 15.54$ for phosphorus and $p = 0.013$ with a.m. $2 = 8.66$ for chlorides. If in the case of CCOMn, nitrites and chlorides there is a decreasing trend in value, in the case of phosphorus there was an increase in value during the three years (2020, 2021 and 2022).

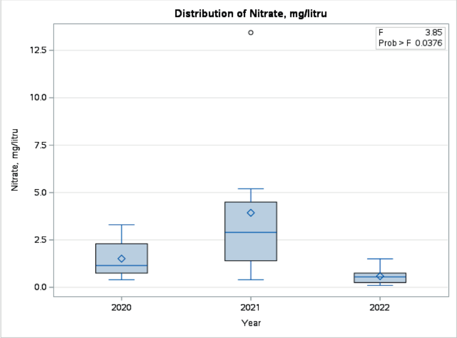
Specifically, in 2020, the average value of phosphorus content was about 0.03 $mg \cdot L^{-1}$.



a)



b)



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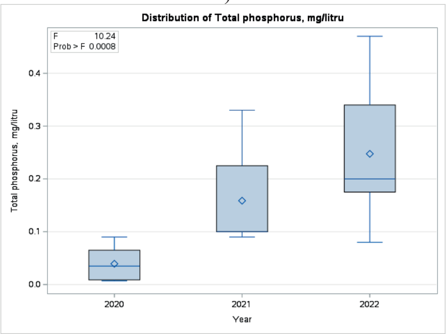

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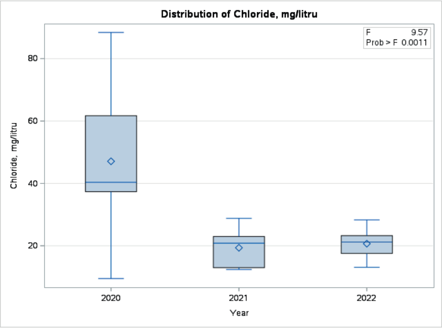

e)

Figure 1. Boxplot charts showing the variation of the value of the parameters followed over the three years (2020, 2021, 2022). *Source:* authors' own representation of statistical data using SAS Studio-One Way ANOVA

Multiple comparisons using the Tukey test show significant differences between the phosphorus value of 2020 and the other years, each individually. Regarding the nitrite value, it was about 1.18 $mg \cdot L^{-1}$ in 2020, being significantly lower in 2021, when the average value reaches about 0.21 $g \cdot L^{-1}$ ($p = 0.026$, according to the Tukey post hoc test).

For the other parameters, namely the values of the pH and $NH4^+$, respectively, no significant differences were observed between the groups determined by the three years in which the statistical observations were made. Differences between the groups determined for the 4 drills were also tested and, in all situations, except $NH4^+$, there were no statistically significant differences between the values of the parameters monitored. In the case of $NH4^+$, ANOVA showed values such as $p = 0.015$, $F = 4.41$ (Figure 2). Significant differences were also confirmed by the Kruskal-Wallis nonparametric Test, $p = 0.0038$ with $\chi 2 = 8.39$. To concretely track the differences in $NH4^+$ values, multiple comparisons between groups were additionally applied, using the Tukey test. Samples from drilling 4 show higher significantly different values from those from drilling 1 and 3. The other values, even if they show slight differences in $NH4^+$ content, have no statistical significance regardless of which drill they come from.

The authors also examined whether the values of the measured parameters in the first part of the year differ from those in the second part. Thus, aggregating all the data of the period 2020-2022 relating to the first semester and then, all the data measured in the second semester, the differences between the groups have no statistical significance, with one exception. We refer here to the pH values which for the first semester had an average value of 7.20 significantly different from the average value of 7.39 for the data of the second semester during the three years (Figure 3). The T-two sample test indicates the value p = 0.0049, i.e. significantly different values. Also, the Mann Whitney nonparametric test confirms the existence of differences between semesters, p = 0.01.

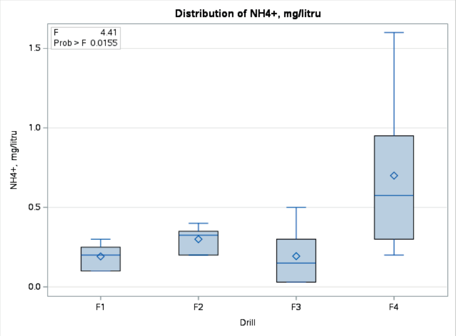

Figure 2. Boxplot diagram of NH4+ values in the four drills. *Source:* authors' own representation of statistical data using SAS Studio-One Way ANOVA

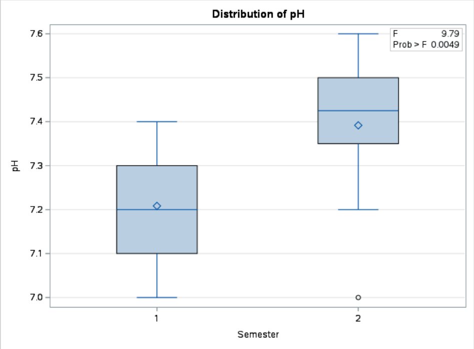

Figure 3. Boxplot diagram of the pH values between the two semesters, cumulative for the period 2020-2022. *Source:* authors' own representation of statistical data using SAS Studio-One Way ANOVA

Studies show that the concentration of pig herds in the past in large units in the past, without analysing the degree of environmental tolerability, determined over time the deterioration of the quality of groundwater and surface waters, the causes of the deterioration of the environmental factors in the farms being multiple:

- concentration and high density of pigs in farms, in relation to the soils existing around them;
- location of farms near surface water sources and on permeable soils, with groundwater web at shallow depth;
- positioning farms on sloping sites that favour runoff;
- improper management of manure in particular quantities stored and administered as organic fertilisers;
- use of solid uncontrolled swine manure resulting in massive accumulation of nitrates in soil and groundwater;
- lack of investment in production technologies, where water management must be controlled to reduce the quantities of liquid manure (Yang et al., 2020);
- hydraulic discharge of slurry corresponding to pollution of surface and underground waters;
- lack of efficient plants for treatment, storage, and management of manure.

Reducing the negative effects of pollution requires environmental management risk measures; in this regard, the authors propose the following for the implementation of management measures to reduce the pollution of soil and surface and groundwater for the pig farms in the investigated area:

- Applying codes of good practices for the use as fertilizers of solid or liquid manure, to stimulate crop production:
  - establishing the optimal period of soil integration of liquid swine manure;
  - controlling the maximum quantities of solid manure administered as fertilisers;
  - using swine manure according to soil quality: creditworthiness, texture, permeability;
  - refusing to use slurry on sloping land or near water resources.
- Using modern methods of storing liquid or solid manure from pigs by:
  - designing pools with sufficient storage capacities until treatment, dilution, and administration;
  - sealing storage platforms for solid manure;
  - preventing purine infiltration on land near sewage treatment plants, and treatment and storage of manure;

- reducing the amount of manure by controlling the nutritive level of water, using biological material that produces less manure.

- Monitoring the quantities of manure by:
  - optimizing the size of farms and categories of pigs;
  - investing in the treatment, storage, and distribution of manure;
- Improving the way of evacuation and storage at the treatment and storage stations for manure:
  - transport logistics;
  - evacuation, storage, treatment, and dilution techniques;
  - analysis of manure composition;
- Using environmentally friendly production technology systems by:
  - using species that restore soil structure (Jiménez-de-Santiago et al., 2022);
  - cultivating plants that restore soil quality;
  - rotating fertilized soils with solid or liquid organic fertilizers incorporated into the soil;
  - controlling dilution, scattering, or embedding mode;
  - reducing the risk of pollution by nitrite reduction methods through: periodic analyses of manure to be used as fertiliser; controlled application according to the amount of precipitation and optimal season; use on high permeability land and surface water table;
- Environmental risk management to reduce pollution by:
  - controlling soil nitrate by mapping;
  - fertilizing by GIS;
  - differentiating soil fertilization by nitrate load;
  - setting the optimum nitrogen and phosphorus levels depending on: soil quality in the area where swine manure is used; the degree of tolerability of environmental factors depending on the period of use in time of swine manure for the growth of plant productions;
  - monitoring the quantity and quality of water from manure;
  - applying solid manure on soil by controlling the quantities and quality of manure;
  - improving irrigation methods with diluted manure, depending on: soil permeability and water retention capacity; period of administration and type of culture;
  - controlling the amounts of nitrates, which can be processed by plants used in the previous crop and reserves in the soil.
- Independent monitoring of environmental factors, tracking their evolution and their effects over time:
  - air quality - the amount of ammonia and hydrogen sulphide on the farms, treatment plants and land fertilized with manure as organic fertilizers;
  - quality of manure distributed as fertilizer and possible effects on agricultural land;
  - water protection against nitrate pollution by grassed protective curtains;
  - physico-chemical measurements through the analysis of samples from the monitoring of control drills, to know the degree of pollution and pollution prevention measures;
  - analysis of soil quality indicators around treatment plants, manure storage and soils where solid or liquid manure from pigs was distributed to increase production;
- Implementing the best management to improve environmental risk management through:
  - periodic quality control of natural environmental factors on the farms;
  - improvement of production technologies to reduce the quantities of manure;
  - reduction of the quantities of manure used as organic fertilizers by using them to obtain biogas.
- Improving the management of the flow of information on the quality of environmental factors, through:
  - monitoring the activities of pig farms;
  - controlling the quantity and quality of manure;
  - checking the management of manure by administrative bodies.

CONCLUSIONS

The research carried out per semester during the three years, in the area of a pig farm, highlights the fact that, although the area under analysis is in a vulnerable and potentially vulnerable area to pollution of surface or underground water sources, the permissible limits of pollution have not been exceeded. The use of liquid pig manure to increase agricultural production on the investigated soils, with a rotation of application every 3 years and compliance with dilutions, made it possible not to exceed the permissible limits of the pH of the water, reaching values of 7.00-7.50. The pH values which, for the first semester, had an average value of 7.20 significantly different from the average value of 7.39 for the data of the second semester during the three years, the T test indicates the value p = 0.0049, i.e. significantly different values; likewise, the Mann Whitney nonparametric test confirms the existence of differences between semesters, p = 0.01, due to the use in the past of mechanically separated solid manure as organic fertilizers with concentrations of 45.1-55.0 $mg \cdot L^{-1}$ CBO5 to increase plant yields. Testing the differences between the groups determined for the 4 drills in all situations, except NH_4^+, did not reveal statistically significant differences between the values of the parameters followed only in the case of NH_4^+, p = 0.015, F = 4.41, the significant differences being confirmed by the Kruskal-Wallis nonparametric Test, p = 0.0038 with $\chi 2$ = 8.39, differences of NH_4^+ values, for multiple comparisons between groups, resulting that the samples of drilling 4, sole 3, indicate higher values and significantly different from those drills 1 and 3, the other values, even though they have slight differences in NH_4^+ content, they have no statistical significance regardless of the drill they come from. Studies show that the concentration of pig herds in the past in large units, without analysing the degree of environmental tolerability determined over time the deterioration of the quality of environmental factors. The causes of the presented situation are: (a) multiple high density of pigs on farms, (b) improper location of farms near surface water sources and on permeable soils and improper management of manure especially the quantities stored and administered as organic fertilizers and the lack of efficient treatment, (c) storage and management stations for manure.

REFERENCES

Abrantes Pinto De Brito, S., Diniz Duarte, G., da Silva Sobral, F.E. & Lindsey Christoffersen, M. (2020). Environmental impacts of swine farming. *Environmental Smoke*, *5*(3), 1-6. https://doi.org/10.32435/envsmoke.2022531-6.

Ahmed, S., Mickelson, S.K., Pederson, C.H., Baker, J.L., Kanwar, R.S., Lorimor, J.C. & Webber, D.F. (2013). Effects of swine manure rate, timing, and method of application on post-harvest soil nutrients and crop yield in a corn-soybean rotation. *Transactions of the American Society of Agricultural and Biological Engineers*, *56*(22), 395-408. https://doi.org/10.13031/2013.42678.

Andretta, I., Hickmann F.M.W., Remus, A., Franceschi, C.H., Mariani, A.B., Orso, C., Kipper, M., Létourneau-Montminy, M.P. & Pomar, C. (2021). Environmental impacts of pig and poultry production: Insights from a systematic review. *Frontiers in Veterinary Science*, *8*, 1-14. https://doi.org/10.3389/fvets.2021.750733.

Chen, B., Koziel, J.A., Banik, C., Ma, H., Lee, M., Wi, J., Meiirkhanuly, Z., O'Brien, S.C., Li, P., Andersen, D.S., Białowiec, A., Parker, D.B. (2020). Mitigation of odor, NH_3, H_2S, GHG, and VOC emissions with current products for use in deep-pit swine manure storage structures. *Frontiers in Environmental Science*, *8*, 1-17. https://doi.org/10.3389/fenvs.2020.613646.

Das, S., Liptzin, D. & Maharjan, B. (2023). Long-term manure application improves soil health and stabilizes carbon in continuous maize production system. *Geoderma*, *430*, 1-14. https://doi.org/10.1016/j.geoderma.2023.116338.

Deviney, A., Classen, J., Bruce, J. & Sharara, M. (2021). Sustainable swine manure management: A tale of two agreements. *Sustainability*, *13*(1), 15. https://dx.doi.org/10.3390/ su13010015

Jiménez-de-Santiago, D.E., Almendros, G., Bosch-Serra, A.D. (2023). Structural changes in humic substances after long-term fertilization of a calcareous soil with pig slurries. *Soil Use and Management*, *39*(4), 1-13. https://doi.org/10.1111/sum.12896.

Luo, W., O'Brien, P.L., Hatfield, J.L. (2019). Crop yield and nitrous oxide emissions following swine manure application: a meta-analysis. *Agricultural & Environmental Letters*, *4*(1), 1-5. https://doi.org/10.2134/ael2019.07.0024.

Yang, F., Han, B., Gu, Y., Zhang, K. (2020). *Scientific Reports, 10*, 1-10. https://doi.org/10.1038/s41598-020-72149-6.

Yost, J.L., Schmidt, A., Koelsch, R. & Schott, L.R. (2022). Effect of swine manure on soil health properties: A systematic review. *Soil Science Society of America Journal*, *86*, 450-486. https://doi.org/10.1002/saj2.20359.