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Original Article

Effect of liquid swine effluent on the initial growth of forage corn under greenhouse conditions

Efeito do efluente líquido de suínos no crescimento inicial do milho forrageiro em condições de estufa

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Abstract

The use of organic effluents from livestock farming as biofertilizers for agriculture represents a viable solution for the management of swine waste. The research aimed to evaluate the effect of swine liquid effluent on the growth of hybrid corn for forage purposes. A pot experiment was designed to determine the effect of liquid effluent applications of treatments 21 days after planting. The biofertilizer treatments applied to the irrigation water in the pots were 0.00 (control), 9.45, 18.90, 28.35, 37.80 and 47.25 m^3 ha^{-1}. Applications of 37.80 and 47.25 m^3 ha^{-1} improved stem diameter, foliage, and total fresh weight. For root fresh weight and root volume, the highest values occurred with applications of 18.90 to 47.25 m^3 ha^{-1}. The nutrient content (N, P, K) of corn treated with swine liquid effluent showed an incremental trend in foliage and roots, as well as the absorption of macronutrients due to the effect of the treatments. Liquid swine effluent showed a promising role as an organic fertilizer for the cultivation of maize for forage purposes, promoting higher biomass production and macronutrient uptake.

Keywords: *Zea mays*, swine liquid effluent, nutrient content, macronutrient uptake, biofertilizers.

Resumo

A utilização de efluentes orgânicos da pecuária como fertilizante para a agricultura representa uma solução viável para o manejo dos dejetos suínos. O objetivo da pesquisa foi avaliar o efeito do efluente líquido de suínos no crescimento do milho híbrido para fins forrageiros. Um experimento em vasos foi desenhado para determinar o efeito das aplicações de efluentes líquidos dos tratamentos, 21 dias após o plantio. Os tratamentos biofertilizantes aplicados na água de irrigação dos vasos foram: 0,00 (controle); 9,45; 18,90; 28,35; 37,80 e 47,25 m^3 ha^{-1}. As aplicações de 37,80 e 47,25 m^3 ha^{-1} melhoraram o diâmetro do caule, o peso fresco da folhagem e o peso fresco total. Para peso fresco de raiz e volume de raiz, os maiores valores ocorreram com aplicações de 18,90 a 47,25 m^3 ha^{-1}. O teor de nutrientes (N, P, K) do milho tratado com efluente líquido de suínos apresentou uma tendência de aumento na folhagem e nas raízes, assim como a absorção de macronutrientes em função dos tratamentos. Os efluentes líquidos de suínos mostraram um papel promissor como fertilizante orgânico para culturas forrageiras de milho, promovendo o aumento da produção de biomassa e a absorção de macronutrientes.

Palavras-chave: *Zea mays*, efluentes líquidos de suínos, teor de nutrientes, absorção de macronutrientes, biofertilizantes.

1. Introduction

In Peru, pork is the third most consumed meat after chicken (50.3 kg/inhabitant./yr) and beef (6.1 kg/inhabitant/yr); thus, by 2019 its consumption *per capita* reached 5.5 kg/inhabitant/yr. At the national level, its production has been increasing slowly, showing a sustained growth at an annual rate of 3.2%, mainly due to higher consumption, improvements in production conditions, better control of the health of this species and the possibilities of placement in the Chinese market (Contreras, 2020).

In the production process of this type of meat, effluents are produced consisting of liquids from the washing of feces, urine and food remains, which can cause environmental contamination affecting the quality of soil and water, both surface and groundwater (Renan et al., 2012; Bison Pinto et al., 2014; Carrizo et al., 2014; Canesi, 2019; Castaldelli et al., 2024). The physical, chemical and biological characteristics of these effluents are related to the feed, the utilization of nutrients by the digestive system (which

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varies according to their growth stage), as well as to the amount of water used on the farm, being that the animals eliminate a good part of the nutrients contained in the feed through feces and urine (Canesi, 2019). Barros et al. (2019) refer that annually each female housed on the farm produces excretion of 85.70, 49.60 and 46.90 kg year^{-1} of N, $P_2O_5$and K_2O, respectively. Liquid swine effluent (LSE) is rich in organic matter, nitrogen and phosphorus mainly and also contains various micronutrients, which leads to the fact that it can be used as fertilizers for plants, thus replacing synthetic fertilizers (Rabasedas et al., 2014).

Studies in various countries have shown that agricultural productivity improves significantly, provided that LSE is properly managed; otherwise, it can cause microbiological contamination of agricultural products and the water table, accumulation of toxic elements, nutrient imbalance, salinization and waterproofing of the soil (Choudhary et al., 1996; Renan et al., 2012; Pfarr et al., 2020).

It is important to consider that the effectiveness of SLE as a fertilizer depends directly on the characteristics of the soil in which it is applied. Sandy soils, such as the one used in this study, tend to benefit more from the use of organic fertilizers due to their low water and nutrient retention capacity. In this context, the effluent acts as an additional source of organic matter, improving soil structure and promoting a more favorable environment for root growth. The improved soil structure results in a higher water-holding capacity, which is crucial for initial plant development, especially under greenhouse conditions where evapotranspiration can be high. In addition, it improves other soil properties (Beltrão, 2021; Alvarenga et al., 2022).

The use of SLE as a fertilizer in corn cultivation represents a viable solution for waste management in swine farming (Matias et al., 2023) because, in addition to reducing the environmental impact associated with the improper disposal of these residues, the controlled application of this agricultural by-product can contribute significantly to the sustainability of agricultural activities. Previous studies highlight that the use of SLE not only reduces dependence on synthetic fertilizers, but also contributes to the improvement of soil physical and chemical properties, such as moisture retention and availability of essential nutrients (Pfarr et al., 2020). This aspect is particularly relevant in regions where access to agricultural inputs is limited or where soil degradation compromises agricultural productivity (Moraes et al., 2023).

Despite the observed benefits, it is essential to recognize the potential challenges associated with the use of liquid swine effluent. One of the main risks is over-application, which can lead to the accumulation of nutrients in the soil, especially nitrogen and phosphorus, resulting problems such as leaching into adjacent water bodies and eutrophication. In addition, the inadequate application of SLE can favor the development of pathogens or introduce heavy metals into the agricultural system, compromising the quality of the food products and the ecosystem health (Fraser-Gálvez et al. 2023). Therefore, sustainable management practices and continuous monitoring are essential to ensure that the benefits of SLE use are optimized without compromising environmental integrity.

Given this context, the present study aimed to evaluate the effect of liquid swine effluent on the initial growth of corn forage crops. The results of this research can provide valuable information for the utilization of this livestock by-product and its potential application as a sustainable alternative to synthetic fertilizers.

2. Materials and Methods

2.1. Experimental conditions

The research was carried out in the mesh house-type greenhouse of the Universidad Nacional José Faustino Sanchez Carrion, district of Huacho, province of Huaura, region Lima, Peru, with coordinates of 11°06’33” LS and 77°36’30” LO, at 42 masl, during May to August 2023.

The air temperature decreased in both the maximum and minimum values during the time of the investigation. Thus, in May the maximum was 26.14 °C with a minimum of 19.07 °C, while in September it was 23.01 °C and 16.94 °C, respectively (Figure 1).

Soil from arid land was collected at a depth of 30 cm; a soil sample was sent to the laboratory of the Instituto Nacional de Investigación Agraria (INIA-Huaral, Lima) for analysis. According to the results, the soil presented a sandy textural class, alkalinity, absence of salts, low organic matter content, high phosphorus and low potassium (Table 1).

After the analysis, the soil was homogenized and sieved. Subsequently, samples of 3 dm^3 were separated, standardised by weighing on a precision balance to the nearest 0.01 g and placed in plastic pots with a capacity of 4 dm^3.

Five seeds of the hybrid corn variety DK 7088, purchased from a local supplier, were placed in each pot. Fifteen days after sowing, the surplus seedlings were eliminated, leaving 3 in each pot, considering a density of 11.34 plants m^2. The treatments were applied 21 days after planting. The pots were irrigated with running water daily to maintain constant soil moisture.

The SLE was obtained from the pig farm facilities of the Escuela Profesional de Ingeniería Zootécnica, Universidad Nacional José Faustino Sánchez Carrión (UNJFSC) and sent to the laboratory of the Instituto Nacional de Investigación Agraria (Huaral) for analysis. The results of the SLE analysis are shown in Table 2.

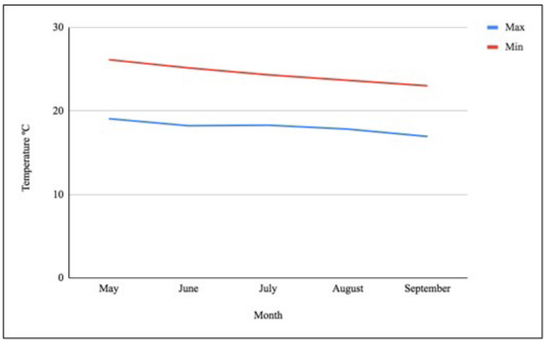

Figure 1. Maximum and minimum air temperature. Meteorological station at Universidad Nacional José Faustino Sánchez Carrión (Huacho, Lima).

Table 1. Characteristics of the soil used in the research.

Texture	EC (mS/m)	pH	OM (%)	N (%)	P (mg kg^{-1})	K (mg kg^{-1})	$CaCO_3$ (%)
Sandy	13.50	8.70	1.40	0.02	13.69	86.16	4.42

Source: Laboratory of the National Institute for Agrarian Innovation (Huaral).

Table 2. Chemical and nutritional analysis of swine liquid effluent.

Parameter	Unit	LC	Results
pH	pH unit	--	6.3
Electrical conductivity	dS/m	--	8.4
Total Solids	g/L		42.06
Organic matter	g/L	--	6.75
N	mg/L	--	741.03
P_2O_5	mg/L	--	148.15
K_2O	mg/L	--	459.23
CaO	mg/L	--	1850.43
MgO	mg/L	--	617.63
C/N	ratio	--	5.28

Source: Laboratory of the National Institute for Agrarian Innovation (Huaral).

2.2. Application of treatments of swine liquid effluent

The applications of SLE according to each treatment were carried out 21 days after planting. The treatments were: 0.00 (control), 9.45, 18.90, 28.35, 37.80 and 47.25 m^3 ha^{-1}, respectively.

2.3. Evaluation of traits in hybrid maize DK 7088.

At 60 days after planting, the plant materials (foliage and roots) were weighed fresh and separated in paper bags to be dried in an oven with forced air circulation at 70°C for 72 hours until reaching constant weight. After drying, they were weighed with a 0.01 g scale and then sent to the foliar analysis laboratory of the Universidad Nacional Agraria La Molina (Lima).

2.4. Statistical analysis

The data collected were subjected to analysis of variance ($p \leq 0.05$) and when significant differences were identified, the means were compared with the Scott-Knott statistical test at 5%. The analyses were performed with the help of the statistical software SISVAR version 5.6 (Ferreira, 2011).

3. Results

According to the results obtained from the analysis of variance for plant height, stem diameter, root fresh weight, foliage fresh weight, total fresh weight and root volume (Table 3), significant differences were found among the different SLE treatments.

Table 4 shows that SLE applications had a positive effect on all the variables evaluated, significantly outperforming the control. Thus, applications of 37.80 and 47.25 m^3 ha^{-1} improved stem diameter, foliage fresh weight and total fresh weight. For root fresh weight and root volume, the highest values occurred with applications of 18.90 to 47.25 m^3 ha^{-1}.

For root, foliage and total dry weight, significant differences were found among the different treatments according to the analysis of variance (Table 5).

Comparing the averages for root, leaf and total dry weight (Table 6), the highest values occurred with applications of 18.90 to 47.25 m^3 ha^{-1}; while the control reached the lowest values.

Concerning the nutrient content in the foliage (Figure 2), it can be seen that when the amount of liquid swine effluent applied is increased, the content of nitrogen, phosphorus and potassium in the foliage also increases. This occurs because the amount and availability of these nutrients from the SLE are increased, which are absorbed by the root system and directed to the foliage. In the case of roots (Figure 3), above 18.90 m^3 ha^{-1} the percentage content of potassium decreases and then remains almost constant; for nitrogen, something similar occurs from 28.35 m^3 ha^{-1}, the percentage content remains almost constant; and for phosphorus, the percentage content remains ascending.

Regarding nutrient uptake (Figure 4), as the amount of SLE applied increases, there is an increase in the uptake of nitrogen, phosphorus and potassium. This result reflects

Table 3. Mean squares for plant height (PH), stalk diameter (SD), root fresh weight (RFW), foliage fresh weight (FFW), total fresh weight (TFW) and root volume (RV) of hybrid maize DK 7088 treated with SLE under greenhouse conditions.

Sources	dF	Mean squares					
		PH (cm)	SD (mm)	RFW (g)	FFW (g)	TFW (g)	RV (cm^3)
Treatments	5	439.08**	25.86**	1627.88**	1441.11**	6071.51**	1506.64**
Error	24	12.19	1.58	148.82	48.53	276.76	124.54
Total	29						
CV (%)		6.04	8.64	23.70	16.16	17.59	21.25
Means		57.79	14.53	51.46	43.11	94.58	52.51
r^2		0.88	0.77	0.70	0.86	0.82	0.72

r^2 coefficient of determination, CV (%) coefficient of variation. **Significant at $p < 0.01$.

Table 4. Scott-Knott test for plant height (PH), stem diameter (SD), root fresh weight (RFW), foliage fresh weight (FFW), total fresh weight (TFW) and root volume (RV) of hybrid corn DK 7088 treated with LSE under greenhouse conditions.

SLE (m^3 ha^{-1})	PH(cm)	SD (mm)	RFW	FFW	TFW	RV
			------------------------- g plant^{-1} ----------------------			--- cm^3 plant^{-1} --
47.25	67.93 a	17.33 a	70.34 a	62.53 a	132.87 a	70.67 a
37.80	64.87 a	16.36 a	67.76 a	60.26 a	128.02 a	66.00 a
28.35	62.13 a	14.89 b	53.57 a	46.11 b	99.68 b	57.10 a
18.90	56.30 b	14.27 b	55.45 a	40.26 c	95.71 b	56.00 a
9.45	53.43 b	13.46 c	39.07 b	31.11 c	70.18 c	42.00 b
0.00	42.10 c	10.88 d	22.62 b	18.43 d	41.05 d	23.33 c

Means with a common letter are not significantly different ($p > 0.05$).

Table 5. Summary of mean squares for root dry weight (RWW), foliage dry weight (FW) and total dry weight (TWD) of hybrid maize DK 7088 treated with SLE under greenhouse conditions.

Sources	dF	RWW (g)	FW (g)	TWD (g)
Treatments	5	17.16*	27.66**	86.03**
Error	24	2.2	2.57	6.97
Total	29			
CV (%)		19.63	21.11	17.44
Means		7.55	7.59	15.24
r^2		0.62	0.69	0.72

r^2: coefficient of determination. *Significant at $p < 0.05$; **Significant at $p < 0.01$.

the agronomic efficiency of SLE in the uptake of these nutrients by plants, showing a consistent increase in plants treated with SLE compared to those that did not receive the treatment. This result suggests that the effluent not only supplies the necessary nutrients but also improves the efficiency of uptake, possibly due to the presence of organic matter that facilitates the availability of these nutrients in the soil. The presence of organic matter, in addition to acting as a source of nutrients, contributes to the formation of stable aggregates, which are essential for proper soil aeration and drainage (Tuzzin et al., 2014).

4. Discussion

The responses found in DK 7088 corn treated with LSE under greenhouse conditions can be explained by the fact

Table 6. Scott-Knott test for root dry weight (RWW), foliage dry weight (FW) and total dry weight (TWD) of hybrid maize DK 7088 treated with SLE under greenhouse conditions.

SLE (m^3 ha^{-1})	RWW	FW	TWD
	------------------ g plant^{-1} ------------------		
47.25	9.09 a	9.69 a	18.78 a
37.80	8.74 a	9.96 a	18.70 a
28.35	7.97 a	7.94 a	15.91 a
18.90	8.55 a	8.40 a	16.95 a
9.45	6.82 a	5.53 b	12.35 b
0.00	4.13 b	4.04 b	8.18 c

Means with a common letter are not significantly different ($p > 0.05$).

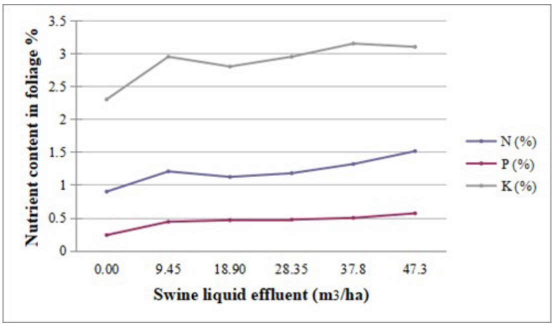

Figure 2. Nutrient content (%) of N, P, K in foliage of hybrid maize DK 7088 treated with SLE under greenhouse conditions.

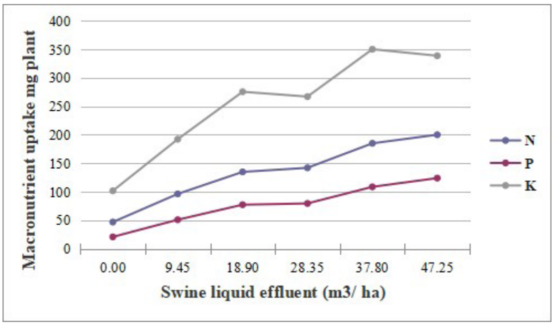

Figure 4. Macronutrient uptake (mg plant^{-1}) of hybrid maize DK 7088 treated with SLE under greenhouse conditions.

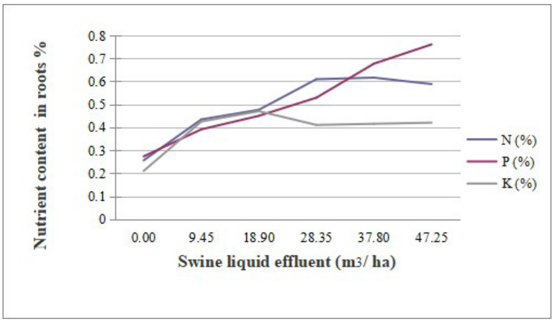

Figure 3. Nutrient content (%) in roots of hybrid corn DK 7088 treated with SLE under greenhouse conditions.

that this organic fertilizer contains considerable amounts of nutrients such as nitrogen, phosphorus and potassium, as mentioned by Embrapa (2019) which refers that a large part of the nutrients present in swine feed rations are eliminated in the form of feces and urine, excreting between 40 to 60% of nitrogen, 50 to 80% of calcium and phosphorus, and 70 to 95% of K, Na, Mg, Cu, Zn, Mn and Fe. Similarly, Moreno et al. (2020) mentioned that swine manure has high contents of nitrogen, phosphorus and potassium compared to other organic sources, which influences plant growth.

A similar result was reported by Alvarenga et al. (2022), who found that pig manure applications favored higher biomass production in corn crops. Likewise, they observed higher nutrient contents in the plant as in the case of nitrogen, phosphorus, calcium and magnesium, coinciding these results with those found in the present research.

Scherer (2006) reports that swine liquid effluent applications are more efficient than solid applications, due to the higher concentration of nitrogen in the ammoniacal form and that when applied to the crop, these are quickly utilized. Scherer (2011) mentions that liquid swine effluents promoted higher yields in corn and not in beans.

The agronomic efficiency of SLE was also reflected in plant nutrient uptake in DK 7088 corn under greenhouse conditions. Analysis of nutrient uptake data showed a consistent increase in nitrogen, phosphorus and potassium levels in effluent-treated plants compared to those that did not receive the treatment. This result suggests that the effluent not only supplies the necessary nutrients but also improves the efficiency of uptake, possibly due to the presence of organic matter that facilitates the availability of these nutrients in the soil. The presence of organic matter, in addition to acting as a source of nutrients, contributes to the formation of stable aggregates, which are essential for proper soil aeration and drainage.

5. Conclusions

According to the evidence presented, swine liquid effluent has a promising role as an organic fertilizer for growing corn for forage crops, promoting higher biomass production and macronutrient uptake. However, the success of this practice depends on a careful balance between dosage and soil management, as well as a thorough understanding of the dynamics of nutrient uptake by plants.

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