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SOIL SCIENCE

Chemical properties of Oxisol cultivated with corn in management systems of soil irrigated with swine production wastewater

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Abstract: Waste generated from agribusiness, such as swine production, can be used in agricultural soil; however, certain technical criteria should be followed. The objective of this study was to evaluate the effects of different depths of irrigation with swine wastewater (SW), associated with the soil management system, on soil chemical attributes after two corn crop cycles. The experiments were conducted in the field, in an arrangement with two soil management systems (conventional tillage system – CTS and no-tillage system – NTS) and five depths of irrigation with SW (50%, 75%, 100%, 125% and 150% of evapotranspiration from the crop – ETc). Soil samples were collected at depths of 0–0.1 and 0.1–0.2 m to determine the pH, Ca, Mg, K, Na, Al, P, Fe, Cu and Zn at the end of each crop cycle. Soil nutrient contents increased with the application of SW irrigation in the two crop cycles and in the depths of 0–0.1 and 0.1–0.2 m, mainly with an increase of irrigation depths. No effect of the management systems was observed for the majority of the nutrients evaluated. The content of the heavy metals Cu and Zn remained below the critical limits established by the Brazilian Regulations.

Key words: Biofertilizer, conservationist management, irrigation management, no-tillage system, soil fertility.

INTRODUCTION

Swine wastewater (SW) is a byproduct generated in pig farming, through the process of anaerobic digestion. During this process, anaerobic bacteria degrade the organic matter of the waste, thus generating various byproducts: biogas, soil biofertilizer and liquid biofertilizer (or SW). Due to its chemical composition, characterized by a higher content of N, P, K, Ca, Mg, Fe, Zn, Cu and organic matter (OM), SW has potential for use in agriculture (Cabral et al. 2011). The use of SW in agricultural crops has been identified by researchers as an alternative to supply nutrients to crops, besides supplying water for proper development (Gomes et al. 2018, Lima et al. 2019).

The use of SW in agriculture requires constant soil monitoring due to the high concentrations of heavy metals, especially Cu and Zn, added to animal feed as antibiotics and growth promoters (Popovic & Jensen 2012). In this sense, updated knowledge of the effect of animal manure on soil chemistry is necessary, in order to use it effectively and reduce its adverse environmental impacts (He et al. 2016).

Therefore, to obtain good agronomic and environmental results with the agricultural use of SW, it is necessary to carry out frequent chemical analyses to characterize the soil and SW. These analyses make it possible to assess changes in the soil and the potential for using this residue in agriculture (Côrrea et al. 2011). If used correctly, SW can act as a conditioner for the soil's chemical, physical and biological properties, minimizing the impacts on ecosystems resulting from its improper disposal and/or usage. On the other hand, excessive use, without criteria and monitoring, can cause various environmental risks such as accumulation of toxic elements (Xu et al. 2013), groundwater contamination (Pessuto et al. 2016), polluted gas emissions, nutrient imbalance, salt accumulation and soil sealing (Bedbabis et al. 2014).

Soil degradation has been a constant concern of the scientific community due to it reducing crop productivity, increasing production costs and causing damage to the environment. One of the most effective alternatives for soil conservation is the use of the no-tillage system (NTS) (Lamas et al. 2016).

NTS is a soil conservation management system which has as its characteristics no revolving of the soil, use of crop rotation and sowing under straw. It is a system that controls erosion, decreasing soil losses. Studies have shown that using this management system instead of the conventional one can improve the biological, chemical and physical attributes of soil (Dorneles et al. 2015, Bünemann et al. 2018) due to the soil cover provided by live and dead plants, which reduces erosion, water and loss of soil and nutrients, in addition to promoting the accumulation of OM on the soil surface and reducing greenhouse gas emissions (Oliveira et al. 2015, Schmidt et al. 2019).

Therefore, the objective of this study was to evaluate the effects of different depths of irrigation with SW, associated with two soil management systems, on the soil chemical attributes after two cycles of corn crop for silage production.

MATERIALS AND METHODS

Characterization of the experimental area

The experiment was conducted at the Federal Institute of Espírito Santo (Ifes) – Alegre, located in the municipality of Alegre in the southern region of the state of Espírito Santo, Brazil. The climate of the region, according to the Köppen classification, is "Cwa" type, which is a humid subtropical climate, cold and dry winter, with an average annual temperature of 23 °C and an average annual precipitation of 1,341 mm (Lima et al. 2008).

Two successive cycles of corn crop were cultivated for silage production, considered as independent experiments. The first cycle was conducted from 01/02/2018 to 04/07/2018. The second cycle was from 4/13/2018 to 7/21/2018, totaling 96 days of cultivation in each cycle. The accumulative rainfall during the first and second cycles of corn crop was 555 and 133.5 mm, respectively.

The soil located in the experiment was Oxisol, of medium texture. Before setting up the experiment, chemical characterization of the soil was done at depths of 0–0.1 and 0.1–0.2 m (Table I).

Table I. **Chemical characterization of the soil before the experiment.**

Depth of soil (m)	Attributes										
	pH	P	K	Na	Fe	Cu	Zn	Al	Ca	Mg	H+Al
	H_2O	--------------- mg dm^{-3} ---------------						--------- cmol$_c$ dm^{-3} ----------			
0-0,1	5.8	34.1	61.6	4.1	104.9	0.5	15.6	0.0	2.1	0.5	3.5
0,1-0,2	5.9	30.3	60.6	4.0	98.8	0.5	14.5	0.0	2.3	0.5	3.2

Swine production wastewater

The SW used in the experiment came from the anaerobic digestion process that occurred in the biodigester installed in the swine production facility at the Ifes campus in Alegre. Before setting up the experiment, an SW sample was collected for chemical analysis (Table II).

Experimental design

The experiment was set up in strip, and the statistical principles used were according to Duarte (1996). This consisted of two soil management systems (conventional tillage system – CTS and NTS) and five depths of irrigation with SW (L1 = 50%, L2 = 75%, L3 = 100%, L4 = 125% and L5 = 150% of evapotranspiration from the corn crop – ETc), with three replications. The experimental plots had dimensions of 10 × 10 m (100 m^2).

Two reference plots, each using one of the two soil management systems, were installed to the side of the experiment, irrigated at 100% of ETc but using water. The reference plots are not part of the experimental design of this study and were implemented only for non-statistical comparison with the data generated in the experimental plots.

Experiment setup and implementation

The plots were fixedly demarcated in the experimental area, so that each maize cultivation cycle was carried out in the same location, in order to evaluate the accumulated effect of irrigation with SW and of the soil management systems over time.

The NTS is characterized by no revolving of the soil, with crop rotation and sowing on the straw. Thus, during the fallow period of the soil, there was self-sowing of velvet bean (*Stizolobium aterrimum*), a legume indicated because it produces a large amount of dry matter (6–9 t ha^{-1}). In order to benefit only from the fertility present in the soil, the legume was not fertilized. Irrigation was performed with raw water. When the velvet beans reached the flowering stage, cutting was done, and the residues were deposited in the soil.

In the plots under the CTS, plowing and harrowing took place before planting the corn.

Hybrid corn was used for planting; it was sown at a spacing of 0.8 × 0.2 m, using a seed-fertilizer drill with four rows and 5 cm planting depth, establishing a stand with five plants per meter (62,500 plant ha^{-1}). Each plot consisted of 12 planting lines, 10 m long (100 m^2).

Chemical soil fertilization was done based on soil fertility and the nutritional demand of corn for all treatments (Prezotti et al. 2007). Planting fertilization in the two crop cycles consisted of 45 kg ha^{-1} of urea, 450 kg ha^{-1} of simple superphosphate and 100 kg ha^{-1} of potassium chloride. Two topdressing fertilizations were carried out; the first one had N (145 kg ha^{-1} of urea) and K_2O (100 kg ha^{-1} of potassium chloride) and the second fertilization only had N (145 kg ha^{-1} urea). There was no need to lime the soil. Weed control was carried out through manual weeding and semi-mechanized mowing.

Table II. Chemical characterization of swine production wastewater used to irrigate corn crops.

Analyzed parameter	pH	Fe	Na	Zn	Cu*	PO_4^{3-}	K	Ca	Mg	B	Mn	NO_{3-}	NH_4^+
	-	mg L^{-1}											
	7.8	0.5	50.0	0.1	<0.05	61.8	210.0	54.4	12.0	0.4	0.2	2.3	511.0

*** < Limit of quantification.**

Irrigation system and management

Irrigation management was performed using irrigâmetro® technology (Oliveira & Ramos 2008), installed close to the experimental area. Evapotranspiration readings were done every 24 h, thus evaluating the need for irrigation at each stage of crop development. During the experiment, rainfall was monitored with the aid of a rain gauge attached to the irrigameter. When precipitation was less than evapotranspiration in the 24 h period, the rain volume was deducted from the irrigation depth. In situations where precipitation was higher than the crop's evapotranspiration, irrigation was not performed.

The calculation of the irrigation depths (L1 to L5) was performed based on the reading of the irrigameter, which established the time required for the application of L3, corresponding to 100% of the ETc. The calculated time required for the application of the other four irrigation depths (L1 = 50%, L2 = 75%, L4 = 125% and L5 = 150%) was done by the rule of three. In the two corn crop cycles, at 100% ETc, SW was applied via irrigation, a total of 1,436.70 and 886.70 m^3 ha^{-1}, respectively. The difference in the application of SW between the cultivation cycles is related to the evapotranspiration of the culture, which is higher in the periods of the year with higher temperatures. The average temperature recorded in the first and second cultivation cycles was 26.3 and 21.5 °C, respectively.

The irrigation system used was a conventional semi-permanent sprinkler installed in the middle of each plot. A motor pump set was integrated into the system, which was responsible for pumping the SW into the experimental area through a main slope pipe. This delimited the areas under NTS and CTS. Ten side lines were also installed, five on each side. Each pair of lines had six impact sprinklers (micro-sprinklers) with a 3.2 × 2.4 mm nozzle.

Soil collection and data analysis

At the end of each cultivation cycle, random soil samples were collected in the central lines of corn planting in each plot, totaling a useful sampling area of 38 m^2 $plot^{-1}$. The soil was sampled at depths of 0–0.1 and 0.1–0.2 m; 10 simple samples were collected from each plot, which, after being homogenized, gave rise to a composite sample. In these samples, the following soil chemical attributes were evaluated: pH (in water), Ca, Mg, K, Na, Al, P, Fe, Cu and Zn (Embrapa 2017).

Statistical analysis

Statistical analysis was performed considering the soil depths and crop cycles as independent factors. The flow, seasonal distribution and water quantity are factors causing spatial variability in soil attributes, since they can condition environments with different characteristics to interference from the movement of exchangeable bases, thus the soil depths being independent factors. The independence of the crop cycles is due to the variation in rainfall, environment temperature and volume of SW applied in each crop cycle. Among these limitations, interpretation of the results was performed separately for each soil depth and corn crop, no comparison occurring between these factors.

Analysis of variance was used to evaluate the significance of the interaction between the depth of irrigation with SW and soil management systems, as well as isolation from the same factors. In cases of significant interaction, a study of the breakdown of irrigation depths was carried out within each management system (CTS and NTS), through regression analysis. The choice of the best-fit statistical model was based on the degree of significance of the regression and on the coefficient of determination of each model with significant adjustment. Evaluation of the influence of the management systems, within each irrigation depth, was performed by the F test of the analysis of variance. The isolated effects of these factors were studied for the variables where no significant interaction was observed between irrigation depth and management system. Statistical analysis was performed with the aid of R statistical software (R Core Team 2016).

RESULTS AND DISCUSSION

The statistical analysis of the data of the interaction between the depths of irrigation with SW and soil management systems, in two corn crop cycles for the soil chemical attributes (pH, P, K, Na, Ca, Mg, Al, Fe, Cu and Zn) is shown in Tables III, IV, V and VI.

Soil acidity (pH and Al)

In general, the statistical analysis presented no significant interaction between the depth of irrigation with SW and soil management systems for the pH values at a depth of 0–0.1 m, in the two crop cycles (Tables III and V). At a depth of 0.1–0.2 m, in the first and second cycles (Tables IV and VI), there was a significant interaction; however, this interaction did not maintain a pattern, oscillating between the management systems and irrigation depths. This may be related to the short implantation period of the NTS, since studies conducted for a longer period have reported significant increases in soil pH (Caires et al. 2002).

Table III. Effect of different soil management systems (conventional tillage system – CTS and no-tillage system – NTS), within each depth of irrigation with SW, on pH, P, K, Na, Ca, Mg, Al, Fe, Cu and Zn values at a depth of 0–0.1 m.

Attribute	Systems	Irrigation depth with SW											
		First cycle						Second cycle					
		Ref.	50%	75%	100%	125%	150%	Ref.	50%	75%	100%	125%	150%
pH (H_2O)	CTS	4.4	5.1	5.5	5.0	4.7	5.4	4.6	4.8	5.4	4.5	4.4	4.4
	NTS	4.8	5.1	5.5	4.5	4.4	4.6	4.8	4.7	4.9	4.3	4.3	4.1
Al^{3+} ($cmol_c\ dm^{-3}$)	CTS	0.10	0.08	0.07	0.17	0.22	0.07	0.20	0.03	0.0	0.22	0.23	0.23
	NTS	0.10	0.13	0.02	0.30	0.32	0.22	0.15	0.10	0.03	0.23	0.27	0.28
Ca^{2+} ($cmol_c\ dm^{-3}$)	CTS	2.6	3.2	2.3	1.7	1.4	2.7	1.9	2.4	2.9	1.8	2.0	3.5
	NTS	1.8	2.2	3.1	0.9	1.1	1.2	1.3	2.7	1.1	1.0	2.1	1.3
Mg^{2+} ($cmol_c\ dm^{-3}$)	CTS	0.6	0.6	1.1	0.8	0.7	1.1*	0.5	0.9	1.3	0.6	0.7	0.8
	NTS	0.7	0.9	1.4	0.5	0.6	0.6	0.5	0.8	1.0	0.6	0.7	0.6
K^+ ($mg\ dm^{-3}$)	CTS	82.0	173.0	192.6	177.6	175.3	185.0	84.0	255.6*	274.6	274.6*	268.6	305.1*
	NTS	68.0	167.3	183.0	143.0	179.6	167.3	69.0	228.5	297.5*	247.0	299.3*	268.6
Na^+ ($mg\ dm^{-3}$)	CTS	0.0	5.6	6.6	4.6	5.6	8.6	1.0	24.6	29.3	33.3	30.3	34.5
	NTS	0.0	4.6	4.3	3.6	4.0	4.0	0.0	22.0	28.3	26.3	24.0	26.6
P ($mg\ dm^{-3}$)	CTS	33.4	95.2	81.9	93.9	107.6	127.3	21.6	49.9	47.2	89.4*	99.7*	95.1
	NTS	27.9	53.3	55.1	33.3	40.1	85.8	40.5	55.7	57.5	62.0	50.5	86.7
Fe^{2+} ($mg\ dm^{-3}$)	CTS	98.3	143.2	138.8	142.7	177.8	179.4*	100.3	156.0	155.6	156.4	179.1	178.9
	NTS	95.4	154.7	173.5*	153.3	168.2	161.0	99.4	150.0	147.9	201.8	211.4	211.0
Cu^{2+} ($mg\ dm^{-3}$)	CTS	1.1	3.9	3.1	3.3	4.0	4.1	1.1	4.8	5.0	5.0	5.0	5.0
	NTS	1.3	2.3	1.8	2.7	2.7	2.5	1.2	4.1	4.6	4.5	4.9	5.1
Zn^{2+} ($mg\ dm^{-3}$)	CTS	7.7	12.3	11.6	12.1	13.5	14.9	7.5	14.5	16.1	18.2	19.7	19.7
	NTS	6.8	11.9	10.5	10.7	11.8	10.8	7.0	17.4	17.6	17.2	17.4	17.3

***Indicates significantly different averages between soil management systems at 5% probability by the F test; Ref.: reference plot irrigated with 100% of ETc with water, used only as a comparison.**

The initial soil pH at a depth of 0–0.1 m of 5.86 (Table I) was close to the range considered as optimal (6.0 to 6.5) by Malavolta et al. (2002). Soil acidification (0–0.1 m) was observed in the reference plots (Table III) at the end of the two corn crop cycles, with a pH ranging from 4.45 to 4.67. This soil acidification in the reference plots is partly due to the urea-based nitrogen fertilization carried out at planting and topdressing, in the two corn crop cycles. Soil acidification occurs during the process of nitrification due to the release of hydrogen ions (H^+) (Tosta 2009). According to Malavolta (2006), the crop period itself promotes soil acidification, due to the leaching and absorption of bases by the crops, as well as root exudation of organic acids.

After the two corn crop cycles, in general, an increase in soil pH was observed in relation to the reference plots, regardless of the soil management system. Quilu et al. (2017) found an increase in soil pH on application of SW, which could be due to the high concentration of sodium bicarbonate in SW. Therefore, SW can reduce soil acidity, as the wastewater bicarbonate neutralizes the H^+ ions in the soil, in addition to reacting with Al^{3+} in a bi-hydrolysis reaction.

Table IV. Effect of different soil management systems (conventional tillage system – CTS and no-tillage system – NTS), within each depth of irrigation with SW, on pH, P, K, Na, Ca, Mg, Al, Fe, Cu and Zn values at a depth of 0.1–0.2 m.

Attribute	Systems	Irrigation depth with SW											
		First cycle						Second cycle					
		Ref.	50%	75%	100%	125%	150%	Ref.	50%	75%	100%	125%	150%
pH (H_2O)	CTS	4.7	5.4	5.6	5.3*	4.9	5.8*	4.8	5.3	5.8*	4.8*	4.7	5.1*
	NTS	4.8	5.5	5.7	4.5	4.8	4.88	4.8	5.5	5.2	4.3	4.7	4.4
Al^{3+} ($cmol_c\ dm^{-3}$)	CTS	0.05	0.02	0.07	0.07	0.17	0.0	0.15	0.0	0.0	0.12	0.12	0.08
	NTS	0.10	0.05	0.0	0.28*	0.07	0.12	0.15	0.02	0.0	0.27	0.10	0.27
Ca^{2+} ($cmol_c\ dm^{-3}$)	CTS	1.6	2.9*	2.3	1.9*	1.8	2.8*	2.0	2.4	3.1*	2.1	2.3	2.9*
	NTS	1.8	2.4	3.3*	0.9	1.8	1.2	2.1	2.9	0.5	0.8	2.3	1.3
Mg^{2+} ($cmol_c\ dm^{-3}$)	CTS	0.6	0.9	1.0	0.6*	0.6	1.1*	0.6	1.1	1.3	0.8	0.8	1.1
	NTS	0.6	0.9	1.4*	0.4	0.7	0.6	0.6	0.8	1.1	0.5	0.7	0.6
K^+ ($mg\ dm^{-3}$)	CTS	49.0	85.0	106.0	109.0	110.0	130.0	48.0	110.3	189.0	169.0	185.3	205.3
	NTS	46.0	83.3	116.6	115.0	109.6	121.6	53.0	104.3	143.6	162.3	168.0	160.6
Na^+ ($mg\ dm^{-3}$)	CTS	0.0	7.6	7.6	5.6	8.0	11.0	0.0	11.3	19.3	19.0	21.3	28.08*
	NTS	0.0	8.6	3.3	0.0	12.3	2.6	0.0	11.6	15.6	16.3	19.0	13.3
P ($mg\ dm^{-3}$)	CTS	12.8	67.1*	60.3*	83.6*	70.5*	127.1*	19.0	34.8	37.9	58.1	83.8*	79.8*
	NTS	12.4	10.6	18.1	11.1	11.3	13.3	23.0	33.1	33.8	48.1	46.4	54.0
Fe^{2+} ($mg\ dm^{-3}$)	CTS	95.0	159.8	154.2	157.4	194.5	197.3	94.2	169.7	161.3	186.4	211.8	218.6
	NTS	93.5	154.9	148.7	170.0	171.8	178.7	93.9	181.6	162.3	208.8	212.7	218.9
Cu^{2+} ($mg\ dm^{-3}$)	CTS	0.9	2.7	2.7	3.0	3.3	3.2	0.9	4.0	3.9	4.3	4.3	4.3
	NTS	1.0	2.2	2.3	3.1	3.1	3.2	1.1	3.8	4.1	4.1	4.2	4.5
Zn^{2+} ($mg\ dm^{-3}$)	CTS	6.0	9.2	8.4	9.9	10.1	10.3	6.9	15.8	14.1	17.5	15.8	18.5
	NTS	5.9	7.7	8.3	8.5	8.8	8.94	6.2	12.8	13.4	12.1	14.0	14.9

***Indicates significantly different averages between soil management systems at 5% probability by the F test; Ref.: reference plot irrigated with 100% of ETc with water, used only as a comparison.**

When analyzing the equations in Tables V and VI, referring to soil pH, it is possible to observe a tendency of soil acidification with the increase depths of irrigation with SW. According to Barros et al. (2005), this effect may be related to the soil moisture, where higher levels of water in the soil favor the nitrification process, which consequently leads to the release of H^+ and reduces the pH. Rosa et al. (2017) found a decrease in the pH of soil cultivated with soy that received volumes of 0, 100, 200 and 300 m^3 ha^{-1} of SW. The change in the soil pH with SW may also be related to the low buffering capacity of the soil (Scherer et al. 1984).

The pH values measured at a depth of 0–0.1 m (Table III) ranged from 4.7 to 5.5 in the CTS, and from 4.4 to 5.5 in the NTS. In the second crop, the pH varied from 4.4 to 5.4 in the CTS, and from 4.1 to 4.9 in the NTS. According to Prezotti et al. (2007), pH values in water of less than 5.0 indicate high acidity, and values between 5.0 and 5.9 denote medium acidity. Even though there was no statistical difference in pH values between soil management systems, the results show that in the CTS the soil was highly acidic at almost all depths of irrigation with SW in the first crop, and at all depths in the second crop. It is noteworthy that velvet beans were planted in the NTS plots, preceding the first crop, with the planting of corn carried out on the remaining cultural. Lopes (1998) stated that legumes release H^+ ions into their rhizosphere when

Table V. **Regression equations adjusted between chemical soil attributes as dependent variables of depth of irrigation with SW, at a depth of 0–0.1 m, in different soil management systems (CTS and NTS).**

Attribute	Systems	First cycle			Second cycle		
		Equation	R^2	SS	Equation	R^2	SS
pH (H_2O)	CTS	-0.0047x + 5.4960	0.24	* [1/]	-0.0073x + 5.3530	0,56	* [1/]
	NTS						
Al^{3+} ($cmol_c$ dm^{-3})	CTS	0.0012x + 0.0417	0.25	* [1/]	0.0024x - 0.0808	0.73	* [1/]
	NTS						
Ca^{2+} ($cmol_c$ dm^{-3})	CTS	$0.0003x^2 - 0.0728x + 5.8517$	0.69	* [1/]	2.12 [2/]		ns [1/]
	NTS						
Mg^{2+} ($cmol_c$ dm^{-3})	CTS	0.0032x + 0.5973	0.28	ns	-0.0033x + 1.1842	0.34	* [1/]
	NTS	-0.0057x + 1.4053	0.38	*			
K^+ (mg dm^{-3})	CTS	0.0067x + 173.7333	0.007	ns [1/]	0.372x + 238.57	0.65	*
	NTS				$0.0110x^2 + 2.5344x + 138.8333$	0.34	*
Na^+ (mg dm^{-3})	CTS	5.20 [2/]		ns [1/]	27.95 [2/]		ns [1/]
	NTS						
P (mg dm^{-3})	CTS	$0.0105x^2 - 1.8235 + 141.3993$	0.95	* [1/]	0.5713x + 19.1687	0.78	*
	NTS				$0.0060x^2 - 0.9884x + 93.386$	0.62	*
Fe^{2+} (mg dm^{-3})	CTS	0.4451x + 111.9353	0.74	*	0.5064x + 124.2833	0.87	* [1/]
	NTS	162.19 [2/]		ns			
Cu^{2+} (mg dm^{-3})	CTS	3.09 [2/]		ns [1/]	4.81 [2/]		ns [1/]
	NTS						
Zn^{2+} (mg dm^{-3})	CTS	12.04 [2/]		ns [1/]	17.54 [2/]		ns [1/]

CTS: Conventional tillage system; NTS: no-tillage system; SS: statistical significance; ns: not significant; *significant by F test at 5% probability; [1/]non-significant interaction between soil management systems; [2/]means are statistically equal.

they are actively fixing atmospheric nitrogen and that during the decomposition of organic residues deposited on the soil in an NTS, there is also a release of H^+ ions. This explains the decrease in soil pH at the end of the experiment in the plots under NTS, compared to the initial characterization (Table I) and to the CTS.

Regarding exchangeable acidity (Al^{3+}) (Tables III and IV), there was no significant interaction with the management systems; however, an increase in Al^{3+} levels in the soil was observed at a depth of 0–0.1 m compared to the values found before the experiment (Table I). Analyzing the equations related to Al^{3+} (Table V), the influence of SW irrigation on the increase in the content of this element in the soil was observed. A similar effect was observed at a depth of 0.1–0.2 m (Table VI).

There is a direct relationship between pH values and Al^{3+} content in this study: a decrease in pH promoted an increase in Al^{3+}. This is a worrying factor due to the toxic effect of this element that can reduce the crop yield. However, according to Salet (1998), in soil under consolidated NTS with low pH, the Al^{3+} content may indicate the concentration of the element in solution in a non-toxic form (low activity), even if present at higher levels than those indicated as harmful. This decrease in the activity of Al^{3+} in solution depends on the OM content, the type of binder present and the complex formed between OM and Al^{3+} in soil.

Table VI. Regression equations adjusted between chemical soil attributes as dependent variables of depth of irrigation with SW, at a depth of 0.1–0.2 m, in different soil management systems (CTS and NTS).

Attribute	Systems	First cycle			Second cycle		
		Equation	R^2	SS	Equation	R^2	SS
pH (H_2O)	CTS	$0.0002x^2 - -0.0316x + 6.8160$	0.28	ns	$-0.0063x + 5.8200$	0.33	*
	NTS	$-0.0096x + 6.0740$	0.53	*	$-0.0111x + 5.9693$	0.67	*
Al^{3+} (cmol$_c$ dm^{-3})	CTS	0.06 [2/]		ns	$0,0018x - 0,0800$	0.60	* [1/]
	NTS	$-0.00003x^2 + 0.0077x - 0.2767$	0.21	*			
Ca^{2+} (cmol$_c$ dm^{-3})	CTS	$0.0004x^2 - 0.0869x + 6.3727$	0.90	*	2.36 [2/]		ns
	NTS	$-0.0153x + 3.4713$	0.39	*	$0.0005x^2 - 0.0960x + 6.0873$	0.33	*
Mg^{2+} (cmol$_c$ dm^{-3})	CTS	$0.0001x^2 - 0.0240x - 1.9313$	0.41	*	$-0.0027x + 1.1917$	0.26	* [1/]
	NTS	$-0.0055x + 1.3700$	0.31	*			
K^+ (mg dm^{-3})	CTS	$0.3273x + 75.9$	0.73	* [1/]	$0.6467x + 95.133$	0.71	* [1/]
	NTS						
Na^+ (mg dm^{-3})	CTS	$0.0010x^2 - 0.1901x + 14.5667$	0.18	* [1/]	$0.1413x + 5.6667$	0.87	*
	NTS				13.33 [2/]	ns	
P (mg dm^{-3})	CTS	$0.0103x^2 - 1.5449x + 120.0733$	0.79	*	$0.5443x + 4.4927$	0.88	*
	NTS	12.90 [2/]		ns	$0.2171x + 21.3907$	0.86	*
Fe^{2+} (mg dm^{-3})	CTS	168.76 [2/]		ns [1/]	$0.5469x + 138.5383$	0.80	* [1/]
	NTS						
Cu^{2+} (mg dm^{-3})	CTS	2.90 [2/]		ns [1/]	4.18 [2/]		ns [1/]
	NTS						
Zn^{2+} (mg dm^{-3})	CTS	9.04 [2/]		ns [1/]	14.94 [2/]		ns [1/]
	NTS						

CTS: Conventional tillage system; NTS: no-tillage system; SS: statistical significance; ns: not significant; *significant by F test at 5% probability; [1/]non-significant interaction between soil management systems; [2/]means are statistically equal.

Bases (Ca, Mg, K, Na) and P

Analyzing the Ca^{2+} and Mg^{2+} content, a responsive behavior compatible with the pH data was observed. According to Pavinato & Rosolem (2008), adding vegetation and animal residues to soil with a pH less than 6.0 usually increases the content of Ca^{2+} and Mg^{2+} in the solution, which was observed in this study. The data presented in Tables III and IV, relating to all soil depths and crop cycles, indicate that there was a general increase in Ca^{2+} and Mg^{2+} when compared to the soil analysis before the experiment (Table I). These results are due to the Ca and Mg in SW (Table II). Maggi (2010) also observed in their study that using SW increased the content of Ca^{2+} and Mg^{2+} in the soil.

The type of management system did not affect the Ca^{2+} at a depth of 0–0.1 m, for either of the two corn crop cycles or at different depths of irrigation with SW. In relation to the reference plots, there was a 13% decrease in the content of Ca^{2+} (CTS) and a 5.5% decrease (NTS) in the first crop cycle. However, the use of SW in the second cycle led to an increase of Ca^{2+} in the soil at a depth of 0–0.1 m, when compared to the reference: 32.5% in the CTS, and 26% in the NTS. Cabral et al. (2011) also noted a decrease in Ca^{2+} after applying SW to Dystric Nitosol.

It is noteworthy that the SW used in the present study had low concentrations of Ca (54.4 mg L^{-1}) and Mg (12.0 mg L^{-1}). In the studies by Oliveira et al. (2004), Cabral et al. (2011) and Silva (2018), the concentrations of Ca and Mg in the SW were, respectively, 548 and 63 mg L^{-1}; 265 and 76.6 mg L^{-1}; and 5,400 and 500 mg L^{-1}. Considering the composition of the SW applied, with a low Ca concentration and a neutral or slightly basic pH (Table II), the factor responsible for the changes in the Ca and Mg content in the soil exchange complex was the high volumes of SW applied at the different irrigation depths.

Despite the different responses of the Ca^{2+} and Mg^{2+} content in the two cultivation cycles irrigated with SW, in general, negative regression coefficients were observed (Tables V and VI), demonstrating a decrease in the content of these nutrients with an increase of irrigation depths. Mattias (2006) found an increase in the content of Ca^{2+} and Mg^{2+} in soil that received SW application, but this content was not higher than in soils that did not receive SW, a fact that, according to the author, is possibly related to greater growth and absorption of nutrients by plants at sites with SW application.

According to Prezotti et al. (2007), Ca^{2+} levels of < 1.5, 1.5–4.0 and > 4.0 $cmol_c$ dm^{-3} are classified as low, medium and high, respectively. Even with the application of SW at 50% above the water demand of the corn crop, a high content of Ca^{2+} in the soil was not observed.

The levels of Mg^{2+} before the experiment were close to the limit of the low classification (< 0.5 $cmol_c$ dm^{-3}) (Prezotti et al. 2007). At the end of two corn crop cycles, the Mg^{2+} content in the soil was in the classification range of medium (0.5 to 1.0 $cmol_c$ dm^{-3}) or high (> 1.0 $cmol_c$ dm^{-3}), even without application of lime to the soil in the two corn cultivation cycles, showing the effect of SW on magnesium supply to the soil. Changes in Mg^{2+} content did not follow a pattern, with different responses as a function of soil depth, cropping cycle and depths of irrigation with SW.

According to Medeiros et al. (2011), the agricultural use of SW improves soil fertility, increasing K, P, Ca and Mg in the soil. This may replace the use of mineral fertilizer over time, establishing a connection between different production sectors due to nutrient cycling.

The available K^{+} content in the soil suffered heavy additions in the two corn crops cycles in the different soil management systems at both soil depths, being higher than the levels found in the reference plots (Tables III and IV). The K^+ content at depths of 0–0.1 and 0.1–0.2 m before the experiment (Table I) was 61.67 and 60.67 mg kg^{-1}, respectively. In the reference plots, the observed K^+ content varied between 82 (CTS) and 68 (NTS) mg kg^{-1}, and between 84 (CTS) and 69 (NTS) mg kg^{-1} in the first and second cycles of corn cultivation, respectively, at a depth of 0–0.1 m. (Table III). At a depth of 0.1–0.2 m, the K^+ content ranged from 49 (CTS) to 46 mg kg^{-1} (NTS) in the first cycle (Table III); and from 48 (CTS) to 53 mg kg^{-1} (NTS) in the second cycle (Table IV). These results show that the topdressing with fertilizer carried out with potassium chloride was not efficient in increasing the K^+ content in the soil and/or indicate high nutrient absorption by the corn plants.

Significant differences in the K^+ content were observed in the regression analysis ($p \leq 0.05$) at the two soil depths, except for the depth of 0–0.1 m in the first cycle of corn cultivation. The effects of the irrigation depths are presented in Tables V and VI. The interaction between irrigation depths and management system was significant at a depth of 0–0.1 m in the two corn crop cycles. At a depth of 0.1–0.2 m there was no effect of the soil management system on K^+ content. In this case, only the isolated effect of SW irrigation depths on K^+ levels was evaluated, which showed a linear response to the increase in SW depth applied via irrigation.

Considering the high potassium concentrations in SW, it is necessary to be aware of a possible leaching of K^+, as already reported by Rosa et al. (2017) and Silva (2018), since it is a monovalent cation with high mobility in the soil, especially when considering the high volumes of SW applied via irrigation.

The Na^+ content was not affected by the soil management system (Tables III and IV) at all depths of irrigation, both soil depths and in both crop cycles, except only for application of SW at 150% of ETc at a depth of 0.1–0.2 m, in the second cycle, where the Na^+ content was higher in the soil under CTS.

Despite the absence of influence of the management systems, there was an increase in the Na^+ content in the soil, corroborating the results of Pereira Junior (2016) who observed a 400% and 1.022% increase in Na^+ content after applying 200 and 800 m^3 ha^{-1}, respectively, of SW to soil collected from *Corymbia citriodora* crown projection. A high concentration of Na^+ in the soil solution, compared to Ca^{2+} and Mg^{2+}, can cause deterioration of the soil structure, dispersion of colloids and subsequent macropore clogging, causing a decrease in water and gas permeability (Silva 2018).

The Na^+ content did not present significant responses to the different SW treatments applied in the 0–0.1 m layer (Tables V and VI) and at a depth of 0.1–0.2 m, in the plot under NTS, in the second cycle of cultivation (Table VI). Comparing the Na^+ content in soil at the end of the first and second cultivation cycles, it is possible to observe an increase, regardless of soil depth (Tables III and IV). Queiroz et al. (2004) and Medeiros et al. (2011) also reported Na^+ accumulation in soil from SW application.

Even with phosphate fertilization, carried out in the first and second cycles, the P content in the soil decreased when comparing the values for the reference plots (Tables III and IV) with those observed in the soil before the experiment (Table I).

Prezotti et al. (2007) classified the available P content in loamy texture soil as low (< 40 mg L^{-1}), medium (40–60 mg L^{-1}) or high (> 60 mg L^{-1}). SW was fundamental to increasing the P content, changing its classification from low, before the experiment, to medium or high, in the two corn crop cycles and soil management systems. Therefore, SW increases the P content in soil and acts as a source of this nutrient for corn crop.

The management systems influenced the P content in the soil, except at the depth of 0–0.1 m, in the first cycle (Table III), where there was no difference between CTS and NTS in the plots treated with SW. At the other soil depth, significant differences were observed between corn crop cycles. In the first cycle, the highest P content was observed in the plots under CTS, regardless of the depth of irrigation with SW, at a depth of 0.1–0.2 m (Table IV). In the second cycle, CTS showed a higher P content for 100% and 125% (0–0.1 m) and 125% and 150% irrigation (0.1–0.2 m) (Tables III and IV).

P is an element with low mobility in the soil, especially in tropical and subtropical climates, moving short distances by diffusion, the movement being influenced directly by the water content in the soil. Therefore, greater irrigation with SW might promote greater movement of P along the soil profile (Costa et al. 2006, Berwanger et al. 2008). The movement of soil through plowing and harrowing, before the two corn crops were planted, may have contributed to the highest P content observed in the CTS up to a depth of 0.2 m.

A significant interaction between the depths of irrigation with SW and management system was observed for the P content, except for the depth of 0–0.1 m in the first corn crop cycle. The P content showed linear and quadratic responses to the increase in SW irrigation depth, except at a depth of 0.1–0.2 m in NTS, in the first cultivation cycle, where there was no significant response for P content (Tables V and VI).

The results found in this study corroborate those of Berwanger et al. (2008), who observed an increase in the concentration of P in soil due to increased application of SW. This behavior was also observed by Queiroz et al. (2004); with SW application, the available P content increased over time in relation to the initial condition in soil.

Scherer et al. (2010), evaluating the effect of the continued application of SW on soil chemical properties in the western region of the state of Santa Catarina, Brazil, verified that the available P content increased significantly in the surface soil layers. These authors showed that successive applications of manure, sometimes in amounts higher than the crop demands, result in nutrient accumulation on the soil surface. This effect is more pronounced in the case of areas with consolidated NTS, in which the manure is successively applied to the soil surface, without incorporation.

Micronutrients (Fe, Cu and Zn)

The Fe^{2+} content was statistically equal in the two management systems, at different soil depths and during the two corn cultivation cycles, with homogeneous distribution in the soil profile.

The National Council for the Environment – CONAMA, a consultative and deliberative body of the national environmental system in Brazil, established resolution N° 420/2009 (CONAMA 2009), which states the reference values to prevent damage to the soil quality after applying liquid or solid residues. Regarding the metals Cu and Zn, their content in soil cannot exceed the limits of 200 and 450 mg kg^{-1}, respectively. When comparing the values established by CONAMA with those obtained in this study (Tables III and IV), it was observed that regardless of the depth of irrigation with SW, the soil depth and the management system used in the two corn crop cycles, the soil did not become contaminated with Cu and Zn, in relation to the maximum levels of the elements allowed by the legislation of Brazil. There were also no significant effects determined by regression analysis (Tables V and VI).

Scherer et al. (2010) and Girotto et al. (2010) worked with long-term application of SW and concluded that Cu and Zn accumulate mainly in the superficial layers of the soil. However, throughout the experiment, the authors found no concentrations above the values established by CONAMA (2009).

Soil to which SW has been applied should be monitored for the amount of the heavy metals Cu and Zn it contains as they can accumulate, especially in acid soil. According to Sodré et al. (2001), acidity determines greater mobility of metals in the soil, while pH conditions above 6.0 favor their retention, especially in soils with a high degree of weathering, where the functional groups of the surface of the colloidal components are mostly pH-dependent (Silva 2018).

CONCLUSIONS

1) The association of different depths of irrigation with SW and soil management systems provided increased values of pH, Ca^{2+}, Mg^{2+}, K^{+}, Na^{+}, Al^{3+}, P, Cu^{2+}, Fe^{2+} and Zn^{2+} at the different depths evaluated.

2) High volumes of SW increased the P, K^{+}, Al^{3+} and Fe^{2+} levels in different soil management systems, at depths of 0–0.1 and 0.1–0.2 m.

3) The application of SW under the different management systems (CTS and NTS) did not increase the Cu^{2+} and Zn^{2+} content in the soil above the limits established in the legislation, even after two corn crop cycles.

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REFERENCES

BARROS FM, MARTINEZ MA, NEVES JC, MATOS AD & SILVA DD. 2005. Características químicas do solo influenciadas pela adição de água residuária da suinocultura. Rev Bras Eng Agric Ambient 9: 47-51.

BEDBABIS S, ROUINA BB, BOUKHRIS M & FERRARA G. 2014. Effect of irrigation with treated wastewater on soil chemical properties and infiltration rate. J Environ Manage 133: 45-50.

BERWANGER AL, CERETTA CA & RHEINHEIMER DS. 2008. Alterações no teor de fósforo no solo com aplicação de dejetos líquidos de suínos. Rev Bras Cienc Solo 32: 2525-2532.

BÜNEMANN EK ET AL. 2018. Soil quality – a critical review. Soil Biol Biochem 120: 105-125.

CABRAL JR, DE FREITAS OS, REZENDE R, MUNIZ AS & BERTONHA A. 2011. Impacto da água residuária de suinocultura no solo e na produção de capim-elefante. Rev Bras Eng Agríc Ambient 15: 823-832.

CAIRES EF, BARTH G, GARBUIO FJ & KUSMAN MT. 2002. Correção da acidez do solo, crescimento radicular e nutrição do milho de acordo com a calagem na superfície em sistema plantio direto. Rev Bras Cienc Solo 26: 1011-1022.

CONAMA - CONSELHO NACIONAL DO MEIO AMBIENTE. 2009. Resolução CONAMA nº 420, de 28 de dezembro de 2009. [accessed 2020 April 22]. http://www.mma.gov.br/port/conama/res/res09/res42009.pdf.

CÔRREA JC, NICOLOSO RS, MENEZES JFS & BENITES VM. 2011. Critérios técnicos para recomendação de biofertilizante de origem animal em sistema de produção agrícolas e florestais. Embrapa Suínos e Aves, Concórdia (SC), Brasil, technical release, p. 486.

COSTA JPV, BARROS NF, ALBUQUERQUE AW, MOURA FILHO G & SANTOS JR. 2006. Fluxo difusivo de fósforo em função de doses e da umidade do solo. Rev Bras Eng Agric Ambient 10: 828-835.

DORNELES ED, LISBOA BB, ABICHEQUER AD, BISSANI CA, MEURER EJ & VARGAS LK. 2015. Tillage, fertilization systems and chemical attributes of a Paleudult. Sci Agric 72(2): 175-186.

DUARTE JB. 1996. Princípios sobre delineamentos em experimentação agrícola. [Specialization Work] Goiânia (GO), Brasil: Universidade Federal de Goiás. (Unpublished).

EMBRAPA - EMPRESA BRASILEIRA DE PESQUISA AGROPECUÁRIA. 2017. Manual de métodos de análise de solo. 3nd ed. Brasília (DF), Brasil.

GIROTTO E, CERETTA CA, BRUNETTO G, SANTOS DRD, SILVA LSD, LOURENZI CR, LORENSINI F, VIEIRA RCB & SCHMATZ R. 2010. Acúmulo e formas de cobre e zinco no solo após aplicações sucessivas de dejeto líquido de suínos. Rev Bras Cienc Solo 34: 955-965.

GOMES EP, SANCHES AC, DE JESUS FLF, DE ALBUQUERQUE WAGN, JUNIOR MAPO, DE SOUZA DJP & AZEVEDO EPG. 2018. Application of swine wastewater for irrigation of Tifton 85 grass: Part I-productivity and nutritional quality. Aust J Crop Sci 12(3): 486.

HE Z, PAGLIARI PH & WALDRIP HM. 2016. Applied and Environmental Chemistry of Animal Manure: A Review. Pedosphere 26: 779-816.

LAMAS FM, FERREIRA ACB, DE LA TORRE EDJR & STAUT LA. 2016. Sistema plantio direto e convencional: efeito na produtividade de fibra de três cultivares de algodoeiro. Rev Agric Neotrop 3: 34-40.

LIMA CJGS, PEREIRA LS, SANTOS TOS, PINTO SN, RODRIGUES AC & NUNES LAPL. 2019. Soil changes and yield of maize fertilized with swine Wastewater. Rev Caatinga 32: 167-178.

LIMA JSS, SILVA AS, OLIVEIRA RB, AVELINO RC & XAVIE AC. 2008. Variabilidade temporal da precipitação mensal em Alegre - ES. Rev Cienc Agronom 39: 327-332.

LOPES AS. 1998. Manual internacional de fertilidade do solo. 2ª ed. Piracicaba (SP), Brasil.

MAGGI CF, DE FREITAS OS, SAMPAIO SC & DIETER J. 2011. Lixiviação de nutrientes em solo cultivado com aplicação de água residuária de suinocultura. Rev Bras Eng Agric Ambient 15: 170-177.

MALAVOLTA E, PIMENTEL GF & ALCARDE JC. 2002. Adubos e adubações. 1ª ed., São Paulo: NBL Editora.

MALAVOLTA E. 2006. Manual de nutrição de plantas, 1ª ed., São Paulo: Ceres.

MATTIAS JL. 2006. Metais pesados em solos sob aplicação de dejetos líquidos de suínos em duas microbacias hidrográficas de Santa Catarina. [Doctoral thesis] Santa Maria (RS), Brasil: niversidade Federal de Santa Maria.

MEDEIROS SD, GHEYI HR, PÉREZ-MARIN AM, LOUREIRO SFA & DANTAS FP. 2011. Características químicas do solo sob algodoeiro em área que recebeu água residuária da suinocultura. Rev Bras Cienc Solo 35: 1047-1055.

OLIVEIRA D, DE LIMA RP, VERBURG J & ERNST E. 2015. Qualidade física do solo sob diferentes sistemas de manejo e aplicação de dejeto líquido suíno. Rev Bras Eng Agric Ambient 19: 280-285.

OLIVEIRA RA & RAMOS MM. 2008. Manual do irrigâmetro. 1ª ed., Viçosa: UFV.

OLIVEIRA RA, FREITAS WS, CARDOSO JC, GALVÃO FAP & CECON PR. 2004. Efeito da aplicação de águas residuárias de suinocultura nas características nutricionais do milho. Rev Bras Milho Sorgo 3: 357-369.

PAVINATO OS & ROSOLEM CA. 2008. Disponibilidade de nutrientes no solo: decomposição e liberação de compostos orgânicos de resíduos vegetais. Rev Bras Cienc Solo 32: 911-920.

PEREIRA JUNIOR AM. 2016. Uso de água residuária de suinocultura em sistema agroflorestal. [master's thesis] Uberlândia (MG), Brasil: Universidade Federal de Uberlândia. (Unpublished).

PESSUTO J, SCOPEL BS, PERONDI D, GODINHO M & DETTMER A. 2016. Enhancement of biogas and methane productionby anaerobic digestion of swine manure withaddition of microorganisms isolated from sewagesludge. Process Saf Environ Prot 104: 233-239.

POPOVIC O & JENSEN LS. 2012. Storage temperature affects distribution of carbon, VFA, ammonia, phosphorus, copper and zinc in raw pig slurry and its separated liquid fraction. Water Res 46: 3849-3858.

PREZOTTI LC, GOMES JA, DADALTO GG & OLIVEIRA JA. 2007. Manual de Recomendação de Calagem e Adubação para o estado do Espírito Santo – 5ª Aproximação. Vitória: SEEA/Incaper/CEDAGRO.

QUEIROZ FM, MATOS AT, PEREIRA OG & OLIVEIRA RA. 2004. Características químicas de solo submetido ao tratamento com esterco líquido de suínos e cultivados com gramíneas forrageiras. Cienc Rur 34: 1487-1492.

QUILU C, XUELING W, LIGEN X, YUHUA Z & QIFA Z. 2017. High-quality, ecologically soud remédiation of acidic soil using bicarbonate-rich swine wastewater. Scientific Rep 7: 1-6.

ROSA DR, SAMPAIO SC, PEREIRA PAM, MAULI MM & REIS RRD. 2017. Swine wastewater: impacts on soil, plant, and leachate. Eng Agricola Jaboticabal 37: 928-939.

SALET RL. 1998. Toxidez de alumínio no sistema plantio direto. [Doctoral thesis] Porto Alegre (RS), Brasil: Universidade Federal do Rio Grande do Sul.

SCHERER EE, CASTILHOS EG, JUCKSCH I & NADAL R. 1984. Efeito da adubação com esterco de suínos, nitrogênio e fósforo em milho. Florianópolis: Embrapa, 26 p. (Technical Bulletin, 24).

SCHERER EE, NESI NC & MASSOTTI Z. 2010. Atributos químicos do solo influenciados por sucessivas aplicações de dejetos suínos em áreas agrícolas de Santa Catarina. Rev Bras Cienc Solo 34: 1375-1383.

SCHMIDT R, MITCHELL J & SCOW K. 2019. Cover cropping and no-till increase diversity and symbiotroph: saprotroph ratios of soil fungal communities. Soil Biol Biochem 129: 99-109.

SILVA MAAPA. 2018. Aplicação de água residuária de suinocultura após dois anos sucessivos em sistema agroflorestal. (Master's degree) Uberlândia (MG), Brasil: Universidade Federal de Uberlândia. (Unpublished).

SODRÉ FF, LENZI E & COSTA AC. 2001. Utilização de modelos físico-químicos de adsorção no estudo do comportamento do cobre em solos argilosos. Quimica Nov 24: 324-330.

R CORE TEAM. 2016. A language and envirommet for statistical computing. Vienna (W), Austria: RFS Computing.

TOSTA MS. 2009. Adubação nitrogenada na produção e na qualidade de frutos de maracujazeiro amarelo. (Master's degree) Mossoró (RN), Brasil: Universidade Federal Rural do Semiárido. (Unpublished).

XU Y, YU W, MA Q & ZHOU H. 2013. Accumulation of copper and zinc in soil and plantwithin ten-year application of different pig manure rates. Plant Soil Environ 59: 492-499.

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