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SWINE WASTEWATER: IMPACTS ON SOIL, PLANT, AND LEACHATE

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ABSTRACT: The use of animal-origin residues as a nutrient source without prior and proper investigations on their positive and negative impacts can affect the quality of agricultural soils and the environment into which they are inserted. In this sense, the aim of this study was to assess the impact of swine wastewater and mineral fertilization application on soil, soybean crop, and leachate characteristics. The experiment was developed in drainage lysimeters under field conditions. The following doses of swine wastewater were applied: 0, 100, 200, and 300 m^3 ha^{-1}, both with and without mineral fertilization. Swine wastewater application contributed to increasing soil nutrients; however, a special attention should be paid to Cu^+ and Zn^+ accumulation, which may interfere with soil quality in the long-term. In addition, Na^+, K^+, and N can be leached into groundwater and cause impacts on water quality. Wastewater supplied soybean crop requirements with some nutrients such as K^+ and Zn^{2+}, without the need for an additional mineral supplementation. Thus, once the above conditions are monitored, swine wastewater can be applied to soil.

KEYWORDS: pig slurry, soil fertility, leachate, water reuse.

INTRODUCTION

The increasing grain production, especially soybeans and corn, tends to provide support for the hog-raising sector. Globally, before being independent production units, these economical activities should be considered as an integrated system between farming and livestock. Besides of that, crop rotations are part of such system, therefore a special attention needs to be paid when residues are deposited in the soil.

Hog raising is among the main farming activities in Brazil, with the South region accounting for around 60% of the total production (17.0% in Paraná State, 19.3% in Rio Grande do Sul State, and 25.1% in Santa Catarina State) (ABIPECS, 2012). Despite its economic and social importance, this livestock activity generates large amounts of residues, which require an environmentally correct disposal.

Being aware of the environmental impacts caused by wastewater dumping into water bodies, as well as the growing concerns about environmental quality, hog producers, and academic researchers have sought for specific solutions for waste treatment and reuse, preventing this activity from causing impacts on the environment. Even though there have several available technologies for wastewater treatment, its disposal onto soils is widely practiced, being used as fertilizers in grain cropping and pastures (Smanhotto et al., 2010).

In cases where these residues are applied at the same sites and at frequencies exceeding the maximum solute retention capacity of the soil and maximum plant absorption, nutrients and/ or other chemicals may be leached into water bodies. Although the presence of macro and micronutrients in swine wastewater may reduce the use of chemical fertilizers, this residue might become a potential pollutant if managed inadequately. Therefore, besides its potential as a fertilizer, other aspects such as application quantity and frequency – which vary with soil type, as well as residue nature and composition, climatic conditions and crop species, should be also investigated.

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Several studies have reported the impact of wastewater disposal on soil (Sampaio et al., 2010; Rosa et al., 2017), leachate (Prior et al., 2009; Maggi et al., 2011; Lourenzi et al., 2014b), drained (Dal Bosco et al., 2008b; Doblinski et al., 2010; Wang et al., 2013), crops (Kessler et al., 2013a; Kessler et al., 2013b; Passarin et al., 2016; Lourenzi et al., 2014a), and biota (Tessaro et al., 2013; Brooks et al., 2014; Castaldelli et al., 2015; Tessaro et al., 2016).

The main negative effects of effluent use are related to water contamination by nitrogen and phosphorus (Smanhotto et al., 2010; Kessler et al., 2014), besides the accumulation of copper and zinc on soil surface (Dal Bosco et al., 2008a; Lucas et al., 2013; Legros et al., 2013). Yet the positive effects are the increase of organic matter and nutrients in the soil (Assmann et al., 2007). Furthermore, there are still some concerns about antimicrobial agents applied on a large scale and in an unbiased manner, which, when detected in wastewater, may lead to a genetic resistance of microorganisms, and then becoming environmental contaminants (Liu et al., 2013; Moura et al., 2016; Bilotta et al., 2017).

Studies regarding environmental and agricultural impacts should consider the main interfering factors from wastewater application on the soil in an integrated and non-isolated manner, as in most of the above-mentioned studies. In this sense, the aim of this study was to identify whether a continuous swine wastewater application meets the soybean nutritional requirements, in addition to verifying the occurrence of excessive nutrient leaching.

MATERIAL AND METHODS

Experimental area location and characterization

The experiment was carried out in Cascavel, Paraná state, Brazil. The geographical coordinates of this area are 24°48′ S and 53°26′ W, with an altitude of 760 m.

The regional climate is a humid subtropical climate (Cfa) with an annual average rainfall of 1800 mm, warm summers, frosts infrequent, and rains concentrated in summer, but with no defined dry season. This municipality presents an average temperature of 20 °C and average relative air humidity of 75%. Figure 1 shows the meteorological data of rainfall, average temperature, cultural treatments, and period of the soybean cultivation cycle.

The soil of the experimental area is classified as an Oxisol (Haplorthox). Twenty-four drainage lysimeters were installed in the experimental area, eight per row, spaced 0.4 m vertically and 0.6 m horizontally (longitudinal and transversal). Each drainage lysimeter had a volume of one m^3 and an area of 1.60 m^2 (depth of 0.91 m and diameter of 1.43 m) and composed an experimental plot.

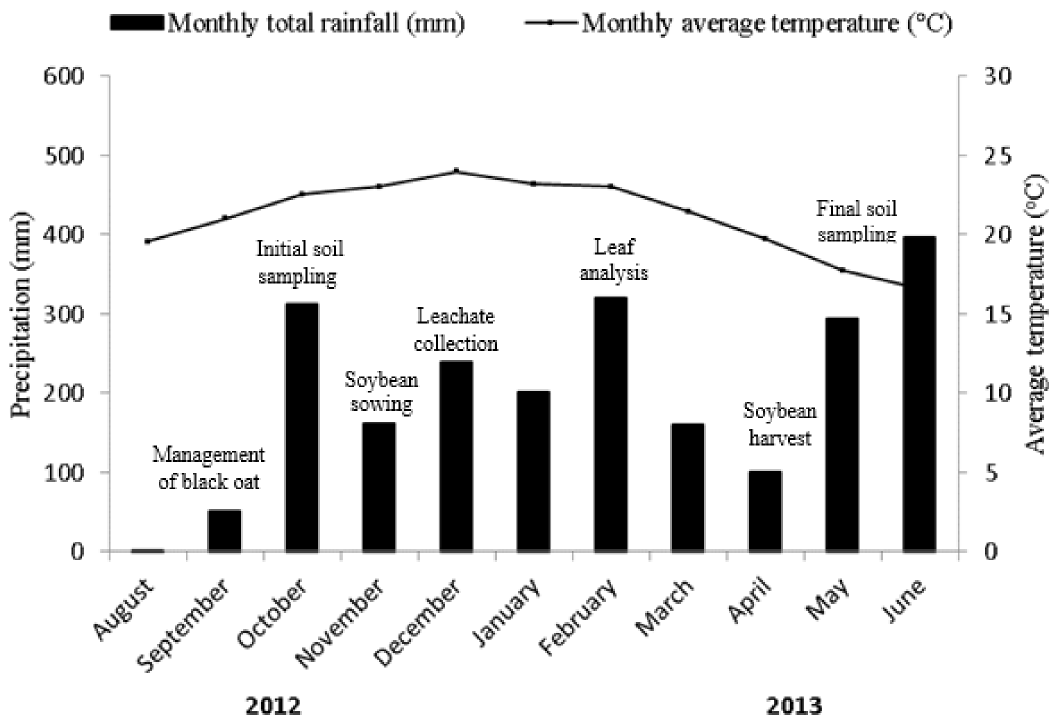

FIGURE 1. Monthly rainfall (mm) and average temperature (°C) in 2012 and 2013 obtained at the SIMEPAR's Meteorological Station.

Swine wastewater application

Swine wastewater (SW) was collected from a farm in the district of Três Bocas, in Toledo (PR), Brazil. This rural property has an integrated biosystem for treating residues. The samples were taken from a channel before the entrance of wastewater into a biodigester feed tank. After being collected, the wastewater samples were chemically characterized (Table 1).

TABLE 1. Characterization of the swine wastewater applied before soybean cultivation.

Parameter		Parameter	
pH ($CaCl_2$)	6.89	Fe^{2+} (mg L^{-1})	27.4
N (mg L^{-1})	707.0	Mn^{+2} (mg L^{-1})	7.1
N_{org} (mg L^{-1})	266.7	B (mg L^{-1})	1.27
N_{inorg} (mg L^{-1})	440.3	S (mg L^{-1})	37.11
NH_4^+ (mg L^{-1})	419.3	Turbidity	3140
$NO_3^- + NO_2^-$ (mg L^{-1})	21.0	EC (µS m^{-1})	4470
TOC (mg L^{-1})	2916.3	COD (mg L^{-1})	10320
P (mg L^{-1})	33.01	CODf (mg L^{-1})	3200
K^+ (mg L^{-1})	265.0	TS (mg L^{-1})	20000
Na^+ (mg L^{-1})	16.8	FS (mg L^{-1})	2300
Ca^{2+} (mg L^{-1})	236.0	VS (mg L^{-1})	17700
Mg^{2+} (mg L^{-1})	67.0	DTS (mg L^{-1})	2500
Cu^{2+} (mg L^{-1})	8.3	DFS (mg L^{-1})	1500
Zn^{2+} (mg L^{-1})	39.0	DVS	1000

TOC – Total organic carbon; TS – Total solids; FS – Fixed solids; VS – Volatile solids; COD – Chemical oxygen demand; CODf – Filtered chemical oxygen demand; DTS – Dissolved total solids; DFS – Dissolved fixed solids; DVS – Dissolved volatile solids.

Description of treatments

SW was applied before soybean sowing, only once, manually, and evenly distributed throughout the lysimeter area. The established SW doses were 0, 100, 200, and 300 m^3 ha^{-1}. The adopted methodology allows obtaining a history of the area since 2006 (Prior et al., 2009).

In addition, mineral fertilization (MF) effect on sowing was also assessed. Therefore, the treatments consisted of four SW doses associated or not with MF, totaling eight treatments in a 4 × 2 factorial scheme. The treatment 0SW–A was the environmental control and received neither SW nor MF. Yet the treatment 0SW–P consisted of an agronomic control and received no SW, albeit received MF at the recommended dose. Treatments were applied according to the order established by Prior et al. (2009).

Implantation of commercial cultivation – Soybean

Corn, oat, and soybeans have been grown annually under no-tillage system since the experiment implantation in 2006. These crops were applied with SW and MF at different production cycles: corn (2006, 1st), soybeans (2006, 2nd), black oat (2007, 3rd), soybeans (2007, 4th), black oat (2008, 5th), baby corn (2008, 6th), corn (2009, 7th), black oat (2009, 8th), soybeans (2009, 9th), corn (2010, 10th), soybeans (2010, 11th), corn (2011, 12th), black oat (2011, 13th), corn (2012, 14th), black oat (2012, 15th), and soybeans (2012, 16th). The data presented in this study refer to the soybean cultivar BRS 283 (16th production cycle). Table 2 shows the total amount of nutrients applied via SW and MF, both up to the 15th production cycle and in the 16th production cycle.

TABLE 2. Total nutrients (kg ha^{-1}) applied via mineral fertilization and swine wastewater, per treatment, in the previous 15 production cycles and in the current cycle (16th).

	Previous cycle							
	Mineral fertilization			Swine wastewater				
	N	P	K	N	P	K	Cu	Zn
0SW–A	0	0	0	0	0	0	0	0
0SW–P	697.5	640	595	0	0	0	0	0
100SW–A	0	0	0	725.3	153.53	453.63	78.68	43.14
100SW–P	697.5	640	595	725.3	153.53	453.63	78.68	43.14
200SW–A	0	0	0	1462.6	306.74	905.26	157.31	86.28
200SW–P	697.5	640	595	1462.6	306.74	905.26	157.31	86.28
300SW–A	0	0	0	2202.9	349.75	1328.89	235.99	129.41
300SW–P	697.5	640	595	2202.9	349.75	1328.89	235.99	129.41
	Current cycle (16th)							
	Mineral fertilization			Swine wastewater				
	N	P	K	N	P	K	Cu	Zn
0SW–A	0	0	0	0	0	0	0	0
0SW–P	0	50	50	0	0	0	0	0
100SW–A	0	0	0	70.70	0.33	2.65	0.83	0.39
100SW–P	0	50	50	70.70	0.33	2.65	0.83	0.39
200SW–A	0	0	0	141.40	0.66	5.30	1.66	0.78
200SW–P	0	50	50	141.40	0.66	5.30	1.66	0.78
300SW–A	0	0	0	212.10	0.99	7.95	2.49	1.17
300SW–P	0	50	50	212.10	0.99	7.95	2.49	1.17

Chemical analysis

Soil samples were collected before sowing and after harvest at each plot (lysimeter) at a depth of 0–20 cm for determining pH, OM, P (Mehlich), K^+, Ca^{2+}, Mg^{2+}, CEC, Cu^{2+}, Zn^{2+}, Na^+, EC, total N, inorganic N, organic N, NO_3^-, and NH_4^+ (Raij, 2011). Regarding the particle size analysis, soil presented 59.0, 146.2, and 794.8 g kg^{-1} of sand, silt, and clay, respectively.

Leachate samples were collected from each plot (lysimeter) after SW application. Samples were stored in plastic bottles under refrigeration at 5 °C and subsequently submitted to analyses of pH, electrical conductivity, total N, NO_3^-, NO_2^-, P, Cu, Zn^{2+}, Ca^{2+}, Mg^{2+}, Na^+, and K^+.

For leaf analysis, soybean leaves were collected at the phenological stage R2 from ten plants per experimental plot. These leaves were dried in an air circulation oven at 65 °C until constant weight, being subsequently ground. Nitrogen content was determined by the Kjeldahl method (Tedesco et al., 1995). Phosphorus, sulfur, potassium, calcium, and magnesium were determined by extraction via wet (nitro-perchloric digestion) with a subsequent reading of phosphorus and sulfur by colorimetry, potassium by using a flame photometer, and calcium and magnesium in an atomic absorption spectrophotometer. Copper, iron, manganese, and zinc contents were determined as the macronutrients and reading in an atomic absorption spectrophotometer (Tedesco et al., 1995).

Statistical analysis

The experiment was conducted in the field, in a randomized complete block design, under a 4x2 factorial scheme with three replications. Four SW doses (0, 100, 200, and 300 m^3 ha^{-1} in the cycle) and two MF levels (absence and presence of MF at sowing) were used. Before performing the analysis of variance, the descriptive analysis of data and verification of normality of errors were carried out. Data were transformed for parameters with a non-normal distribution of errors. When significant effects were observed at 5% probability in the treatment, the Tukey's test ($p < 0.05$) was used to compare the means. A T-test was conducted among the averages of soil prior to experiment implantation (initial) and after crop harvest (final). In addition, the significant parameters were submitted to regression analysis to explain swine wastewater doses.

RESULTS AND DISCUSSION

In the soil analysis performed before soybean cultivation, a difference was observed only for contents of P, K^+, Na^+, Cu^{2+}, and Zn^{2+} (Table 3). After soybean harvest, a difference was observed only for pH and contents of P, Mg^{2+}, K^+, Na^+, Cu^{2+}, and Zn^{2+}. For the other nutrients, no difference was observed between treatments. The interaction between SW and MF was not significant.

Considering the soil after soybean cultivation, SW application reduced pH values (Table 3). This can be attributed to the high ammoniacal nitrogen value via SW, which can be oxidized to NO_3^- by the microbial nitrification process, producing an acidifying effect on the medium (Cassol et al., 2012). In addition, in soils with pH close to neutrality, a reduction in pH values due to base leaching along the well-drained soil profile and inserted in regions with frequent and significant rainfall may be observed (Adeli et al., 2008), as in the western region of Paraná (Figure 1). The clayey Oxisol (794.8 g kg^{-1} clay) has a good drainage due to its physical structuring inherent to the high contents of iron oxides and other cementing agents. Soil contents of P and K^+ (Table 3) were positively influenced by MF presence after soybean cultivation, justified by the NPK base of MF, which added P and K^+ to the medium.

TABLE 3. Soil characteristics before and after being submitted to soybean cultivation and application of swine wastewater and mineral fertilization in the 16th crop cycle.

Test of means and analysis of variance														
SW and MF	pH		P (1)		Mg^{2+} (2)		K (2)		Na^{+} (2)		Cu^{2+} (3)		Zn^{+2} (3)	
	Int.	Fin.	Int.	Fin.	Int.	Fin.	Int.	Fin.	Int.	Fin.	Int.	Fin.	Int.	Fin.
0	7.55 aA	7.50 aA	7.95 bA	14.21 A	35.16 A	33.60 B	2.01 bA	1.60 bA	047 A	0.34 A	6.78 B	7.9 bA	2.73 cA	2.11 bB
100	7.24 A	7.39 abA	17.91 aA	12.30 A	27.60 A	32.63 A	3.70 abA	2.53 abA	0.72 A	0.31 B	7.53 A	8.33 abA	7.96 bA	3.91 ab B
200	6.83 A	7.14 abA	24.86 aA	6.70 B	30.50 A	31.40 A	4.61 abA	3.51 abA	0.63 A	0.33 B	8.55 B	9.41ab A	9.88 abA	6.00 a B
300	6.73 A	6.91 bA	11.58 abA	14.80 A	30.83 A	29.33 A	6.53 aA	4.11 aB	0.82 A	0.31 A	9.75A	9.68 aA	13.75 a A	6.45 aB
A	7.29 A	7.37 A	6.01 bA	4.56 bB	31.50 A	33.15 aA	3.25 bA	2.19bA	0.66 A	0.2 bB	8.01 B	8.75 A	7.90 A	4.50 B
P	6.88 A	7.10 A	25.14 aA	19.44 aA	30.50 A	30.33 bA	5.18 aA	3.69 aB	0.66 A	0.3 aB	8.29 B	8.90 A	9.25 A	4.75 B
MF	3.21	4.55	6.45*	20.42*	0.01	6.78*	10.77*	7.79*	0.00	6.34*	0.27	0.21	21.39	0.12
SW	2.67	4.21*	78.04*	0.34*	0.74	2.88	7.75*	4.24*	2.95	0.20	5.98*	4.15*	1.85*	8.53*
MF × SW	0.99	2.14	1.10	1.55	0.64	1.39	2.24	2.03	0.75	0.63	1.01	1.13	2.59	0.25
CV (%)	8.00	1.95	14.93	33.06	18.42	4.25	19.13	44.73	31.96	2.59	15.81	11.61	28.27	36.32

Regression analysis (final soil)							
Equation	pH	P	Mg^{2+}	K^{+}	Na^{+}	Cu^{2+}	Zn^{2+}
SW	−0.0009x + 7.521	0.0008x + 4.446	−0.0055x + 33.996	0.0153x + 0.6466	0.001x + 0.29	0.001x + 0.29	0.00376x + 8.1933
MF	−0.0030x + 7.55	−0.0085x + 20.716	0.0156x + 31.7	0.02715x + 1.415	0.0035x + 0.1323	0.00359x + 0.13233	0.0091x + 7.5433
p-value							
SW	0.17	0.89	0.22	0.00	0.99	0.99	0.24
MF	0.03	0.85	0.09	0.07	0.21	0.21	0.00
R^2							
SW	0.09	-0.09	0.05	0.74	-0.1	-0.1	0.04
MF	0.30	-0.09	0.17	0.21	0.06	0.06	0.76

Data showing non-normality were transformed into $\sqrt{x+1}$ or log x. Means followed by different lowercase letters in the column differ statistically from each other by the Tukey's at 5% significance. Means followed by uppercase letters in the rows compared by the T-test at 5% significance the initial and final soils of the experiment within each factor. A: MF absence; P: MF presence; *Significant at 5%; CV: Coefficient of variation. Int. = Initial; Fin. = Final; (1) mg dm^{-3}; (2) mmolc dm^{-3}; (3) mg kg^{-1}. Coefficient of determination (adjusted R^2).

Mg^{2+} content (Table 3) was higher under MF absence after soybean harvest. Although small, this difference, which is related to the low CV of data, should be considered. This lower availability under the presence of fertilization with NPK may be due to the reaction between P and Mg^{2+}, forming magnesium phosphate and precipitating Mg^{2+}, making it unavailable.

K^{+} content in the soil increased as SW doses increased, as observed by the significant regression analysis and adjusted coefficient of determination (0.74) (Table 3). SW has a high K^{+} content (Table 1), with a greater plant availability.

After soybean cultivation, the average contents of Na^{+} were similar in the SW doses and different when MF was considered, being higher under MF presence. Medeiros et al. (2011) observed an increase in Na^{+} content in plots treated with swine wastewater. However, a special attention should be paid because successive wastewater applications may cause soil salinization. In this sense, this phenomenon may be a limiting factor for SW use, although the wastewater applied in our experiment had a low salinity (Table 1), with an EC between 0 and 270 µS cm^{-1} (EPA, 1981). In addition, the region, where the experiment was conducted, presents a good rainfall, intense agriculture, and deep soils, making salinization process uncommon.

The elements Cu^{2+} and Zn^{2+} presented a similar behavior, i.e. their contents increased as SW doses increased (Table 3). In this case, 0SW dose presented the lowest value, demonstrating Cu^{2+} and Zn^{2+} accumulation in the soil, i.e. the supplied content is greater than plant assimilation (Lucas et al., 2013). Cu^{2+} and Zn^{2+} exceeded the maximum limits of 0.8 and 1.20 mg dm^3 (Raij, 2011), respectively, even in the plot with 0SW dose. Cu^{2+} and Zn^{2+} are accumulated in soil mainly in their bioavailable forms. Cu^{2+} is found in the organic and mineral soil phases whereas Zn^{2+} is found only in the mineral phase (Girotto et al., 2010). These elements are used in animal feed as a supplement, without being fully absorbed and therefore excreted in high amounts, remaining in SW (Table 1). In this case, the accumulation occurred in nine years of experimentation in the same area and with the same treatments. In the current experiment, treatments with 300 m^3 ha^{-1} added 2.49 and 1.17 kg ha^{-1} of Cu^{2+} and Zn^{2+}, respectively. For all previous experiments carried out in these same plots, the total applied reached 235.99 and 129.41 kg ha^{-1} of Cu^{2+} and Zn^{2+} (Table 2), respectively.

These metals are usually associated with organic compounds, mainly linked to humic substances. Therefore, after SW application, organic compounds need to be mineralized to release metals, favoring their accumulation in soil superficial layers and hence their transference by surface runoff (Girotto et al., 2010; Scherer et al., 2010). However, when added to soil via SW, metals present little mobility, being accumulated at higher quantities in the superficial layer without major environmental risks due to leaching (Table 4) (Scherer et al., 2010).

When comparing the soil means before experiment implantation (initial) with the soil after crop harvest (final), Cu^{2+} and Zn^{2+} contents stood out. An accumulation of Cu^{2+} was observed in the soil since its value found in the final soil was higher whereas a reduction was observed in Zn^{2+}, which is mainly due to the absorbed by the plant (Table 5).

The contents of N, Na^+, and K^+ of the leachate increased as SW doses increased (Table 4). The presence of MF influenced only K^+ content. For the other nutrients, no difference was observed.

TABLE 4. Characteristics of leachate collected during soybean cultivation after wastewater application in the 16th production cycle.

SW and MF	N	Na^+	K^+
		Mean test	
	mg L^{-1}	mg L^{-1}	mg L^{-1}
0	0.38 b	0.00 b	0.43 b
100	0.50 ab	0.01 ab	0.51 b
200	0.52 ab	0.02 ab	0.63 ab
300	0.74 a	0.03 a	0.84 a
A	0.50 a	0.01 a	0.45 b
P	0.57 a	0.02 a	0.75 a
MF	0.76	3.82	26.33*
SW	4.29*	3.72*	9.11*
MF × SW	1.53	0.79	1.78
CV (%)	32.81	0.77	23.92
		Regression analysis	
Equation			
SW	0.001156x + 0.269333	0.0000573x + 0.001746667	0.0011257667x + 0.2611
MF	0.00061x + 0.4743333	0.000120133x + 0.002946667	0.001424667x + 0.536466667
p-value			
SW	0.001	0.001	0.001
MF	0.267	0.030	0.014
Coefficient of determination (Adjusted R^2)			
SW	0.60	0.41	0.63
MF	0.03	0.32	0.41

Data showing non-normality were transformed into $\sqrt{x+1}$. Means followed by different letters differ statistically from each other by the Tukey's test at 5% significance. A: MF absence; P: MF presence; *Significant at 5%; CV: Coefficient of variation.

The increased N is expected since it is one of the nutrients found in higher concentration in SW. Most of the N present in organic residues is in the organic form, which needs to be mineralized to NH_4^+, NO_3^-, and NO_2^-. NO_3^- is poorly adsorbed by soil and has a tendency to remain in solution, mainly in soil superficial layers, where the organic matter accentuates the electronegative character of soil particles and repels NO_3^-, which is leached more easily in the soil profile. Thus, it presents a contaminant and pollutant potential for the surface and groundwater, altering their quality (Smanhotto et al., 2013).

One of the main problems found with SW application in agriculture refers to the presence of nitrates in groundwater due to the excess of N disposed of in the soil (Sampaio et al., 2010). However, unlike most of the residues, nitrogen in SW is in the mineral form, reaching 50% of NH_4^+, NO_3^-, and NO_2 (Table 1).

Although close to zero, the increased Na^+ content in the leachate should be considered since little of this ion is normally leached due to its strong adsorption to colloids, which may lead to soil sodization. However, this problem was not observed in all treatments because the highest concentration observed, i.e. the percentage of exchangeable sodium (PES = 0.35%), was lower than the limit for characterizing sodic soils (PES > 7%).

In our study, K^+ accumulation was observed in the 0–20 cm soil layer (Table 3). Furthermore, the highest K^+ value in the highest SW doses can be justified by its high concentration in this type of effluent (Maggi et al., 2011) (Table 1). In wastewater, K^+ is completely in the mineral form, being 100% available at SW application time. However, when added to soil, K^+ forms an ionic bond with the surface functional groups (Kaminski et al., 2007), making its accumulation in the soil less representative. On the other hand, Scherer et al. (2007) reported the lack of K^+ accumulation in an Oxisol submitted to annual applications of 40 and 115 m^3 ha^{-1} of swine wastewater in a four-year period.

The contents of Mg^{2+} and Ca^{2+} presented the highest average values in the 0SW dose (Table 5), inverse to SW addition. This behavior may be because Mg^{2+} and Ca^{2+} compete for the same exchange site as K^+ (Medeiros et al., 2008), which was absorbed in a greater amount by plants.

TABLE 5. Leaf analysis of soybean submitted to the application of swine wastewater and mineral fertilization in the 16th production cycle.

SW and MF*	Mg^{2+} g kg^{-1}	P g kg^{-1}	Ca^{2+} g kg^{-1}	Zn^{2+} mg kg^{-1}	SW*MF#	K^+ g kg^{-1}	B mg kg^{-1}
0	5.36 a	2.81 b	11.77 a	19.47 b	0 A	11.15 cB	48.64 aA
100	4.12 b	3.20 ab	9.5 b	33.24 a	0 P	17.72 aA	32.43 bB
200	4.05 b	3.49 a	9.22 b	36.96 a	100 A	14.82 bB	51.08 aA
300	3.88 b	3.33 ab	8.16 b	42.25 a	100 P	18.07 aA	50.14 aA
A	4.94 a	3.01 b	10.42 a	35.53	200 A	17.90 abA	51.02 aA
P	3.76 b	3.40 a	8.90 b	30.43	200 P	20.45 aA	53.65 aA
–	–	–	–	–	300 A	19.96 aA	55.84 aA
–	–	–	–	–	300 P	19.79 aA	47.08 aB
MF	20.13*	7.4*	15.20*	2.81	MF	22.15*	16.51*
SW	6.11*	4.18*	15.19*	10.27*	SW	14.81*	14.94*
MF × SW	1.87	3.14	0.20	0.01	MF × SW	5.11*	8.70*
CV (%)	5.86	10.95	9.89	22.56	CV (%)	4.53	3.75
Regression							
Equation							
SW	-0.0072x6+0267	0.00377x+2.4503	0.01207x+12.235	0.0120x+12.2356		0.02949x+11.532	0.02153x+48.4166
MF	-0.0018x+4.028	3.3333x+3.4003	-0.0101x+10.4273	-0.0101x+10.4273		0.0086x+17.7146	0.04745x+38.7073
p-value							
SW	0.016	0.000	0.001	0.001		0.00	0.054
MF	0.007	0.997	0.001	0.001		0.11	0.032
Coefficient of determination (adjusted R^2)							
SW	0.39	0.69	0.63	0.63		0.88	0.25
MF	0.21	0.09	0.60	0.60		0.15	0.31

Data showing non-normality were transformed into $\sqrt{x+1}$. *Means followed by different letters differ statistically from each other. A: MF absence; P: MF presence; *Significant at 5%; CV: Coefficient of variation. #Means followed by lowercase letters in the column do not differ from each other by the Tukey's test at 5% significance for SW breakdown within MF and means followed by the same uppercase letters in the column do not differ from each other by the Tukey's test at 5% significance for MF breakdown within SW.

P and Zn^{2+} presented increased values as SW increased. Zn^{2+} accumulation in soil (Table 3) was reflected in its leaf accumulation. On the other hand, in the 0SW plot, soybean plants presented a deficiency in Zn^{2+} since contents lower than 25 mg kg^{-1} characterize its deficiency in leaves (Malavolta et al., 1997).

Plants cultivated under MF absence presented a higher Mg^{2+} content due to the response of its highest content in the plots without MF in soil (Table 3) and Ca^{2+}. This is due to the inhibitory competitiveness between Ca^{2+}, Mg^{2+}, and K^+ (Pereira et al., 2016). In addition, P was higher under MF presence probably due to the presence and availability of this nutrient. However, these nutrients are within the normal range indicated by Raij (2011), which is from 3 to 10 g kg^{-1} for Mg^{2+}, 4 to 20 g kg^{-1} for Ca^{2+}, and 2.5 to 5 g kg^{-1} for P.

Under MF absence, K^+ presented a higher value when SW was applied. Its absorption may be related to its mineralization and readily availability to the plant when in wastewater. Under MF presence, no effect of SW was observed probably due to MF addition since it is the base of NPK. These results indicate the feasibility of SW as K^+ supply for soybean crops in the absence of MF.

At the doses 0SW and 100SW, the highest K^+ value was observed under MF presence whereas in the other doses no difference was observed. The recommended K^+ for soybean crop should be, on average, between 17 to 25 g kg^{-1} (Raij, 2011).

B content was lower at the dose 0SW and MF presence. The doses 0SW and 300SW presented the highest averages under MF absence. However, it is adequate for soybean development, whose recommended dose is from 21 to 55 g kg^{-1} (Raij, 2011).

In general, swine wastewater application contributes in increasing the nutrients in the soil. However, a special attention should be paid for of Cu^+ and Zn^+ accumulation, which may interfere with the long-term soil quality. N (mainly in NO_3^- form), Na^+, and K^+ were found in the leachate. Thus, these ions may leach and contaminate groundwater, causing impacts on water quality. Swine wastewater meets soybean crop requirements with some nutrients such as K^+ and Zn^{2+} without an additional mineral supplementation. However, the other nutrients should be associated and complemented with chemical fertilizers.

CONCLUSIONS

According to our study, swine wastewater can be applied to the soil given the monitored and studied conditions presented in this study:

1 – Swine wastewater application contributes to increasing soil nutrient contents, however, a special attention should be paid mainly to Cu^+ and Zn^+ accumulations, which may interfere with a long-term quality of the soil.

2 – The nutrients N, Na^+, and K^+ can be leached into groundwater and cause impacts on the quality of water resources.

3 – Swine wastewater meets the nutritional requirements of soybeans for some nutrients such as K^+ and Zn^{2+}, with no need for additional mineral supplementation.

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