

**CORN FERTILIZATION USING SWINE WASTEWATER AND SOIL-WATER
ENVIRONMENTAL QUALITY**Doi: <http://dx.doi.org/10.1590/1809-4430-Eng.Agric.v37n4p801-810/2017>**DANIELLE M. ROSA¹, SILVIO C. SAMPAIO^{2*}, PÂMELA A. M. PEREIRA³,
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ABSTRACT: Soil application of swine wastewater for nutrient cycling may represent a correct destination of these residues and reduction in production costs. However, when applied to soil, such residue may cause environmental impacts. This study aimed to analyze the chemical characteristics of the soil, corn, and leachate after successive swine wastewater applications associated with mineral fertilization. The experiment was developed in drainage lysimeters under field conditions. Wastewater doses applied were 0, 100, 200, and 300 m³ ha⁻¹ with and without mineral fertilization. The results were submitted to analysis of variance and Tukey's test. After nine years of application, a special attention should be taken regarding water quality from a dose of 200 m³ ha⁻¹ since some elements may leach into the soil. In addition, a synchronism between residue application and crop requirements needs to be taken into account. Doses of 200 and 300 m³ ha⁻¹ are considered as satisfactory to meet corn nutritional requirements. Moreover, an increase in fertility characteristics was observed, but a caution regarding Cu and Zn contents should be taken since these elements produce a cumulative effect in the soil.

KEYWORDS: liquid residue of swine, no-tillage, water reuse.

INTRODUCTION

Favorable regions for hog raising require in loco scientific studies on the environmental impact inherent to this activity since residue application in corn crop is common. Hog raising and corn production are practically inseparable in these regions from the economic point of view. In this case, a great availability of swine residues used as fertilizer is found in these farms, increasing soil contents of nitrogen, organic matter, exchangeable Ca, K, and Mg due to pH increase (Lourenzi et al., 2014 a), and inorganic phosphorus (Ceretta et al., 2010; Lourenzi et al., 2014a,b). However, the nutrient concentration may exceed the assimilation capacity of soil and plant when not absorbed by the soil-plant system at the same rate at which they are applied, becoming contaminants and causing environmental impacts.

In this sense, continuous application of swine wastewater in the soil, without considering the soil support capacity, may cause soil contamination, mainly by Cu and Zn (Lucas et al., 2013), which can reduce growth and yield of crops in long term, in addition to impacts caused to water bodies by nitrate leaching and entrainment of nitrogen and phosphorus. This implies the need to monitor soil and water quality in order to guarantee the benefits of the use of swine residues in improving soil quality.

Due to biogeochemical cycles (hydrological, nitrogen, phosphorus, carbon, and sulfur cycles), factors that interfere with environmental and agronomic impacts on soil-water-plant-atmosphere extracts should be studied in a most integrated way and in the medium and long term. Among them, there are effects on agricultural crops (Berenger et al., 2008; Kessler et al., 2013a; Kessler et al., 2013b; Gómez-Garrido et al., 2014; Passarin et al., 2016), soil chemical (Pereira et al., 2016), physical (Oliveira et al., 2015), and biological characteristics (Tessaro et al., 2013; Brooks et al., 2014; Castaldelli et al., 2015; Moura et al., 2016). Besides, there is the leaching (Prior et al., 2009;

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Maggi et al., 2011) and entrainment of ions (Wang et al., 2013), ammonia volatilization, and nitrous oxide emission (Gonzatto et al., 2013).

However, most of the studies related to swine wastewater application are carried out in short term. The experimental area used in this study has a nine-year history of experimentation, which induces to treatment stability and data reliability. In this sense, this study focused on determining the interference of successive applications of swine wastewater, mineral fertilization, and their association with soil, plant, and leachate chemical characteristics after a nine-year period of experimentation.

MATERIAL AND METHODS

Location, characterization, and history of the experimental area

The experimental area was located at the geographical coordinates 24°48' S and 53°26' W, with an altitude of 760 m. Regional climate is classified as subtropical humid (Cfa), with an average annual precipitation of 1800 mm, warm summers, infrequent frosts, a tendency of rainfall concentration in summer months, and no defined dry season. The municipality presents an average temperature of 20 °C and average air relative humidity of 75%. Figure 1 shows the meteorological data of precipitation and average temperature, in addition to cultural practices carried out during corn cultivation cycle.

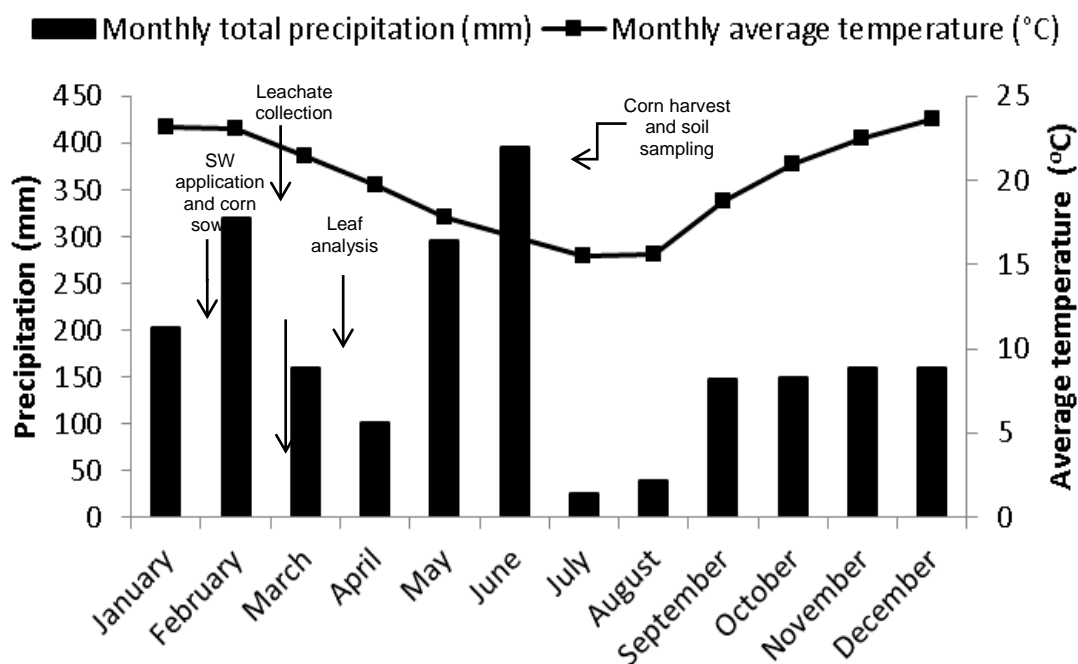


FIGURE 1. Monthly precipitation (mm) and average temperature (°C) in 2014 obtained at the SIMEPAR Meteorological Station.

The soil of the experimental area was classified as an Oxisol (Haplorthox). In the area, 24 drainage lysimeters were distributed in three lines, spaced 0.4 m vertically and 0.6 m horizontal (longitudinal and transversal). Each drainage lysimeter presented a volume of 1 m³ and an area of 1.60 m² (depth of 0.91 m and diameter of 1.43 m) and composed an experimental plot.

Swine wastewater application

Swine wastewater (SW) used was collected on a rural property that has an integrated biosystem of manure treatment. The collection was carried out in the channel prior to wastewater entrance in the biodigester. SW was applied manually and evenly distributed throughout the lysimeter area. Table 1 shows the data of SW characterization.

TABLE 1. Swine wastewater characterization.

Parameter	Parameter	Parameter	Parameter
pH (CaCl ₂)	7.8	Cu ⁺² (mg L ⁻¹)	3.7
N (mg L ⁻¹)	1050	Zn ⁺² (mg L ⁻¹)	4.7
N _{org} (mg L ⁻¹)	978.6	Fe ²⁺ (mg L ⁻¹)	22
N _{inorg} (mg L ⁻¹)	71.4	Mn ⁺² (mg L ⁻¹)	4.6
NH ₄ ⁺ (mg L ⁻¹)	69.3	B (mg L ⁻¹)	1.2
NO ₃ ⁻ + NO ₂ ⁻ (mg L ⁻¹)	2.1	S (mg L ⁻¹)	53
TOC (mg L ⁻¹)	1988	Turbidity	1601
P (mg L ⁻¹)	181	EC (μ S m ⁻¹)	6360
K ⁺ (mg L ⁻¹)	483	COD (mg L ⁻¹)	12132
Na ⁺ (mg L ⁻¹)	167	ST (mg L ⁻¹)	59300
Ca ²⁺ (mg L ⁻¹)	480	FS (mg L ⁻¹)	15000
Mg ²⁺ (mg L ⁻¹)	68	VS (mg L ⁻¹)	43300

TOC – Total organic carbon; EC – Electric conductivity; COD – Chemical oxygen demand; TS – Total solids; SF – Fixed solids; VS – Volatile solids.

Description of treatments

The adopted option was to continue with the doses applied in the experimental area in order to form a history since 2006. Thus, the established SW doses were 0, 100, 200, 300 m³ ha⁻¹ based on nitrogen content, as defined by Prior et al. (2009). In the first years of use of the experimental area, SW received a treatment with biodigester and stabilization ponds (Prior et al., 2009; Maggi et al., 2011; Smanhotto et al., 2013). Subsequently, SW received a biodigester treatment (Kessler et al., 2013a; Kessler et al., 2013b; Castaldelli et al., 2015; Lucas et al., 2013). In this study, SW was used without treatment since previous studies indicate the possibility of using crude SW.

In addition to the doses of SW application, the effect of mineral fertilization (MF) was assessed on sowing. Therefore, the treatments applied to plots in this experiment consisted of four SW doses associated or not with MF, totaling eight treatments. Treatment 1 (OSW–A) was called environmental control and received no SW and MF. Treatment 2 (OSW–P) was denominated as an agronomic control because it received MF at the recommended dose for the cultivar but no SW. Treatment 3 (100SW–A) received an SW dose of 100 m³ ha⁻¹ but no MF. Treatment 4 (100SW–P) received an SW dose of 100 m³ ha⁻¹ and MF. Treatment 5 (200SW–A) received an SW dose of 200 m³ ha⁻¹ but no MF. Treatment 6 (200SW–P) received an SW dose of 200 m³ ha⁻¹ and MF. Treatment 7 (300SW–A) received an SW dose of 300 m³ ha⁻¹ but no MF. Treatment 8 (300SW–P) received an SW dose of 300 m³ ha⁻¹ and MF.

Implantation of commercial corn cultivation

Corn, oat, and soybean have been cultivated annually under no-tillage system since the experiment implantation in 2006. The experimental area has a history of SW and MF application in corn (2006, 1st production cycle), soybean (2006, 2nd), black oat (2007, 3rd), soybean (2007, 4th), black oat (2008, 5th), baby corn (2008, 6th), corn (2009, 7th), black oat (2009, 8th), soybean (2009, 9th), corn (2010, 10th), soybean (2010, 11th), corn (2011, 12th), black oat (2011, 13th), corn (2012, 14th), black oat (2012, 15th), soybean (2012, 16th), corn (2013, 17th), soybean (2013, 18th), and corn (2014, 19th). The data presented in this study refer to the corn hybrid CD316 (19th production cycle). Table 2 shows the total applied nutrients through SW and MF applications until the 18th and 19th production cycles.

TABLE 2. Total nutrients (kg ha⁻¹) applied through mineral fertilization and swine wastewater, per treatment, in the previous 18 production cycles, and in the current cycle (19th).

	Previous cycles							
	Mineral fertilization (kg ha ⁻¹)			Swine wastewater (kg ha ⁻¹)				
	N	P	K	N	P	K	Cu	Zn
0SW-A	0	0	0	0	0	0	0	0
0SW-P	937.5	850	825	0	0	0	0	0
100SW-A	0	0	0	827.6	185.9	493.8	80.2	44.5
100SW-P	937.5	850	825	820.1	185.9	493.8	80.2	44.5
200SW-A	0	0	0	1667.2	371.5	985.6	160.4	89
200SW-P	937.5	850	825	1659.7	371.5	985.6	160.4	89
300SW-A	0	0	0	2509.8	446.9	1449.4	240.6	133.4
300SW-P	937.5	850	825	2502.3	556.9	1449.4	240.6	133.4
	Current cycle (19th)							
	Mineral fertilization (kg ha ⁻¹)			Swine wastewater (kg ha ⁻¹)				
	N	P	K	N	P	K	Cu	Zn
0SW-A	0	0	0	0	0	0	0	0
0SW-P	120	80	90	0	0	0	0	0
100SW-A	0	0	0	97.8	18.1	48.3	0.37	0.47
100SW-P	120	80	90	97.8	18.1	48.3	0.37	0.47
200SW-A	0	0	0	195.7	36.2	96.6	0.74	0.94
200SW-P	120	80	90	195.7	36.2	96.6	0.74	0.94
300SW-A	0	0	0	293.5	54.3	144.9	1.11	1.41
300SW-P	120	80	90	293.5	54.3	144.9	1.11	1.41

Assessed parameters

Soil samples were collected from each plot (lysimeter) at a depth of 0–20 cm for determining pH, OM, P (Mehlich), K⁺, Ca²⁺, Mg²⁺, CEC, Cu²⁺, Zn²⁺, Na⁺, EC, total N, inorganic N, organic N, NO³⁻, and NH⁴⁺ according to the methodologies described by Rajj (2011). Soil used in the experiment presented 5.90% of sand, 14.62% of silt, and 79.48% of clay.

Leaf analyses of macro and micronutrients were performed at all plots in order to assess the crop nutrition: P, N, K⁺, Ca²⁺, Mg²⁺, S, Fe, Na⁺, Cu²⁺, B, Zn²⁺, and Mn.

Leachate samples were collected from each plot (lysimeter) after SW application, without considering the first precipitation. Samples were stored in plastic bottles under refrigeration for the analyses of pH, electrical conductivity, total N, NO³⁻, NO²⁻, P, Cu, Zn²⁺, Ca²⁺, Mg²⁺, and K⁺.

Experimental design and statistical analysis

The experimental design was a randomized complete block design in a 4 × 2 factorial scheme with three replications. Four SW doses (0, 100, 200, and 300 m³ ha⁻¹ in the cycle) and two MF levels (absence and presence at sowing time) were used. Before performing the analysis of variance, a descriptive analysis of the data and verification of normality of errors were carried out. In the parameters with no normal distribution of errors, a data transformation was performed. When significant effects of treatment were found, the Tukey's test (p<0.05) was performed in order to compare the means and, in some cases, regression.

Only significant parameters at 5% are shown in the result tables. Non-significant variables are described in the text with the variation range of the mean in parentheses (lowest–highest observed value).

RESULTS AND DISCUSSION

Soil

The means of pH (6.41 to 7.15), OM (25.6 to 28.8 g dm⁻³), S (5.5 to 16.8 mg dm⁻³), Al (0 to 0.8 mmolc dm⁻³), H+Al (5.1 to 35.5 mmolc dm⁻³), Ca²⁺ (53.5 to 58.6 mmolc dm⁻³), Mg²⁺ (26.3 to 31.8 mmolc dm⁻³), SB (83.3 to 92.3 mmolc dm⁻³), BS (72.5 to 94.8%), Mn (81.1 to 91.7 mg dm⁻³), Fe (19, 1 to 26.6 mg dm⁻³), NH₄⁺ (3.0 to 4.2), NO₃⁻+NO₂⁻ (5.3 to 7.7), Norg (1135 to 1529), and Ninorg (8.4 to 10.9) presented no statistical difference. No interaction was observed between swine wastewater (SW) and mineral fertilization (MF). Thus, the isolated factors are discussed.

SW used in the experiment influenced all significant factors studied (Table 3); in addition, there was a progressive increase according to SW doses, except for Na.

TABLE 3. Chemical characteristics of soil submitted to application of swine wastewater and mineral fertilization in the 19th crop cycle.

SW and MF*	TN	Norg	P	K ⁺	CEC	Na ⁺	Cu ²⁺	Zn ²⁺
			mg dm ⁻³	mmolc dm ⁻³	mmolc dm ⁻³	mg dm ⁻³	mg dm ⁻³	
0	1143	1135 b	6.50 c	1.53 c	97.5 b	0.26 b	6.0 b	3.8 c
100	1213	1203 ab	14.50 bc	1.77 bc	106.86 ab	0.46 a	7.70 ab	17.7 b
200	1516	1529 a	29.33 ab	1.98 ab	107.66 ab	0.39 ab	9.78 a	39.1 a
300	1540	1529 a	34.50 a	2.20 a	123.33 a	0.39 ab	10.61 a	44.5 a
A	1470 a	1494 a	11.33 b	1.64 b	111.41	0.42	8.6	25.0
P	1236 b	1227 b	31.08 a	2.09 a	106.25	0.34	8.45	27.55
MF	5.33*	8.41*	21.16*	26.27*	4.59	3.82	0.03	0.16
SW	4.08*	5.88*	10.25*	10.71*	1.06*	4.03*	6.32*	28.3*
MF × SW	1.74	1.20	0.47	0.30	0.47	0.76	0.21	0.24
CV (%)	18.29	16.60	25.22	11.47	11.29	27.09	23.79	4.84

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

The increase in N content, both total and organic, when SW was applied is expressive, especially for corn crops, as this element is the most required. This element is found in a high concentration in SW (Table 1). However, N content added is almost entirely organic (about 99%) and its release for plant absorption is slow and occurs during crop development.

The P content in 0WS plots was considered very low, in 100SW and 200SW was low, and in 300SW was medium (Raij, 2011). Successive applications of swine wastewater increase P accumulation in the predominantly labile fractions of soil, which are available for plants (Ceretta et al., 2010). In this case, P increased 2.2, 4.5, and 5.3 times at the doses 100SW, 200SW, and 300SW, respectively, when compared to the treatment 0ARS. The relevance of this increase is important for commercial crop production since P is an element of low availability in these regions, proving this nutrient addition via SW application. However, attention should be taken regarding the transfer of this nutrient in the form drained because it represents a potential risk of water contamination (eutrophication).

The content of K⁺ increased as a function of SW doses. According to Raij (2011), we may classify as low K⁺ values in 0SW plots and medium in the other ones. As seen in Table 1, SW is rich in K⁺, which is readily available to plants but being partly leached (Table 5).

A higher content of P and K was observed in the presence of MF. This is justified by the presence of these elements in the fertilizer formulation, an NPK-based fertilizer. The content of total and organic N was higher in MF absence probably because in the presence of fertilizer a higher growth and absorption can be observed.

An increase in soil cation exchange capacity (CEC) was observed with SW application, which indicates that this soil has a good capacity to retain cations in an exchangeable form. This increase is related to the addition of organic matter via SW.

The content of Na^+ was higher in the dose 100SW and no progressive increase was observed possibly due to K^+ saturation, which occupies the same adsorption site. However, despite the low salinity (Table 1), successive SW applications may cause soil salinization, which is a limiting factor for this kind of application. This ion has a strong adsorption to colloids, which can lead to soil sodification. However, this problem was unnoticed because the highest concentration found (exchangeable sodium percentage, $\text{ESP} = 0.49\%$) was lower than the limit for characterizing a sodic soil ($\text{ESP} > 7\%$). In addition, the region presents a good precipitation, intense agriculture, and deep soils, such conditions make this process uncommon.

The contents of Cu^{2+} and Zn^{2+} increased as a function of SW doses (Table 3). However, all observed values exceeded the maximum limits of 0.8 and 1.20 mg dm^{-3} (Raij, 2011), respectively, including in the treatment 0SW, proving that these elements are significantly accumulated in the soil (Lucas et al., 2013). Concentrations of 1.1 and 1.4 kg ha^{-1} of Cu^{2+} and Zn^{2+} (Table 2) were added, respectively, in the treatments with 300 $\text{m}^3 \text{ha}^{-1}$. At all previous experiments, at these same plots, the total applied reached approximately 240 and 133 kg ha^{-1} of Cu^{2+} and Zn^{2+} , respectively. These elements are used in hog diets in order to increase feed conversion. However, they are excreted in larger amounts than those absorbed by the animals, which explains the high concentration in SW (Table 1). These elements are usually associated with organic compounds, mainly linked to humic substances. Thus, after SW application, the organic compounds need to be mineralized before being released, favoring the accumulation in the soil superficial layers and hence their transfer by surface runoff (Giroto et al., 2010; Scherer et al., 2010). However, when added to the soil via SW, these elements present a little mobility, accumulating in larger quantities in the superficial layer without greater environmental risks due to leaching (Table 5) (Scherer, 2010).

Leaf diagnosis

Non-significant means, such as those of P (2.33 to 2.58 g kg^{-1}), Ca^{2+} (5.85 to 7.45 g kg^{-1}), Mg^{2+} (6.28 to 7.36 g kg^{-1}), S (1.43 to 1.65 g kg^{-1}), Fe (262 to 322 mg kg^{-1}), and B (19.10 to 22.76 mg kg^{-1}), were dismissed from Table 4.

SW application influenced the content of N, K^+ , Cu^{2+} , and Zn^{2+} , increasing as a function of the dose (Table 4) as in the soil (Table 3).

A greater emphasis was given to N content for being the most required element by corn crops. Leaf N content was below that considered as adequate for the crop (27.5–32.5 g kg^{-1}) (Malavolta, 1980) at all treatments. Although this element is present in the soil (Table 3), about 99% is in the organic form and, therefore, unavailable to plants. Since SW application was performed before planting, the N mineralization rate was expected to be sufficient to meet crop demand at the times of greatest need. Because there was no such factor, topdressing was recommended even with the association of SW and MF.

The amount of K in corn leaves was adequate only in the treatments 200SW and 300SW, above 17.5 g kg^{-1} (Malavolta, 1980). In these treatments, a greater K contribution was observed via SW, as well as a greater availability of this element in the soil (Table 3).

The content of Cu^{2+} was below the ideal at all treatments (15–20 mg kg^{-1}) even though presenting an excess in the soil (Table 3). The content of Zn^{2+} was within an adequate range (15–50 mg kg^{-1}) (Malavolta, 1980). Therefore, although at high amounts in the soil, the elements Cu^{2+} and Zn^{2+} are unavailable to plants.

The content of Na^+ was higher in the treatments 200SW and 300SW (Table 4). A special attention should be taken since applications above 70 mg L^{-1} may cause damage to plant (Blum, 2003). In this study, the applied SW contained 167 mg L^{-1} of Na^+ (Table 1). The presence of MF promoted a higher absorption of Na^+ probably because of the element K^+ , applied via MF, occupied

more sites and more Na⁺ was free for absorption.

The content of Mn²⁺ presented higher values in the presence of SW, being adequate only in corn leaves of plots that received SW (50–150 mg kg⁻¹) (Raij, 2011). Thus, SW application is a source of Mn²⁺, supplying corn demands.

TABLE 4. Amount of nutrients in corn leaves submitted to swine wastewater application and mineral fertilization in the 19th crop cycle.

SW and MF*	N	K ⁺	Na ⁺	Cu ²⁺	Zn ²⁺	SW*MF [#]	Mn
	-----g kg ⁻¹ -----			-----mg kg ⁻¹ -----			mg kg ⁻¹
0	22.16 b	15.20 b	66.25 b	9.91 b	23 b	0–A	39.66 cA
100	24.26 ab	16.55 b	63.00 b	12.33 ab	28.85 ab	0–P	46.00 bA
200	25.43 ab	18.00 ab	78.25 ab	13.91 a	32.53 ab	100–A	74.83 bcA
300	26.13 a	21.31 a	95.25 a	14.08 a	40.26 a	100–P	65.50 aA
A	23.68	16.68	65.12 b	12.62	31.96	200–A	59.25 bA
P	25.31	18.85	86.25 a	12.50	30.35	200–P	69.75 aA
–	–	–	–	–	–	300–A	78.50 aA
–	–	–	–	–	–	300–P	60.83 abB
MF	3.50	4.22	4.56*	0.04	0.22	MF	22.36*
SW	3.95*	5.86*	9.55*	10.19*	4.51*	SW	0.86
MF × SW	1.85	1.37	2.05	1.31	0.12	MF × SW	5.87*
CV (%)	8.73	6.93	22.11	11.80	26.73	CV (%)	10.81

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

Leachate

The mean values of N (16.3 to 27.0 mg L⁻¹), P (0.08 to 0.09 mg L⁻¹), pH (6.7 to 6.8 mg L⁻¹), Mg (3.2 to 7.2 mg L⁻¹), Mn (0), Zn (0.03 to 0.05 mg L⁻¹), Cu (0.01 mg L⁻¹), Fe (0.02 to 0.03 mg L⁻¹), B (0.01 to 0.02 mg L⁻¹), NH₄⁻ (1.20 to 36 mg L⁻¹), and Norg (6.7 to 9.6 mg L⁻¹) have no statistical difference.

Analyzing the leachate after SW application (Table 5), the factors NO₃⁻+NO₂⁻, Ninorg, K⁺, and EC increased as a function of the applied dose of SW.

TABLE 5. Amount of nutrients of the leachate collected after swine wastewater application and mineral fertilization in the 19th crop cycle.

SW and MF*	NO ₃ ⁻ +NO ₂ ⁻	Ninorg	Ca ²⁺	K ⁺	S	EC
	-----mg L ⁻¹ -----					μS cm ⁻¹
0	5.5 b	6.65 b	1.08 b	0.33 b	2.47	14.35
100	8.65 b	9.97 ab	1.08 b	0.63 ab	3.05	18.18
200	13.10 ab	14.38 ab	1.71 ab	1.19 ab	2.30	28.81
300	21.10 a	18.90 a	2.41 a	1.86 a	2.97	33.46
A	13.34	13.59	1.59	0.64 b	0.83 b	21.95
P	10.83	13.27	1.55	1.37 a	4.57 a	25.45
MF	1.22	0.75	0.01	5.51*	16.73*	0.52
SW	8.88*	4.28*	4.06*	4.53*	0.20	3.47*
MF × SW	0.81	0.51	1.39	0.251	0.11	0.18
CV (%)	46.01	50.53	49.01	19.04	32.23	49.94

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

This increase in N was expected because of its higher concentrations in SW (Table 1). In this study, the contents of NO₃⁻+NO₂⁻ and Ninorg increased 1.6, 2.4, and 3.8 times with the use of 100, 200, and 300 m³ ha⁻¹, respectively. This happened because this element has a high mobility and low retention in soils. NO₃⁻ is weakly adsorbed in the soil and has a tendency to remain in solution, mainly in superficial layers, where the organic matter accentuates the electronegative character of soil particles and repels NO₃⁻, which is leached more easily through the soil profile. Because of this, NO₃⁻ presents contaminant and pollutant potential of the surface and ground water, which can alter water quality (Smanhotto et al., 2013). One of the main problems found with SW application in agriculture is the presence of nitrates in ground water due to the excess of N disposed of in the soil (SAMPALIO et al., 2010). Water with a concentration higher than 10 mg L⁻¹ of NO₃⁻ and 1.0 mg L⁻¹ of NO₂⁻ is considered as contaminated and the consumption of water with concentrations above this limit can cause health problems (Brasil, 2005). In this case, the doses 200SW and 300SW may present a risk to the environment.

Furthermore, SW application occurred before crop sowing and there was no demand of N by corn, favoring the movement of NO₃⁻+NO₂⁻ and Ninorg in the soil profile. The beneficial effect of plants in this process of nutrient cycling is due to the absorption of mineral N from the percolated water. Thus, synchronism between SW application and crop requirements has to be respected.

The content of Ca²⁺ was higher at doses of 200SW and 300SW (Table 5). The amount of this element is high in soil, ranging from 53.5–58.6 mmolc dm⁻³. Because CEC was high (Table 3), the negative sites of soil were probably occupied with K⁺ and Mg²⁺ so that Ca²⁺ was free to be leached.

The content of K⁺ in the leachate increased as a function of the applied dose. The K⁺ present in the residues was completely in the mineral form, being 100% available at the time of wastewater application (Table 5). In addition, the higher K⁺ value in the highest SW doses can be justified by the high concentration of this element in this type of effluent (Maggi, 2011) (Table 1).

Wastewater application changed the electrical conductivity of the leachate (Table 5), which was higher according to the doses. The increase in EC from soluble salts is undesirable; however, the limit to fit leachate as freshwater Class I in Brazil is below 50 μm (Brasil, 2005).

The contents of K⁺ and S were higher in the presence of fertilization (Table 5) since both elements are present in formulated chemical fertilizers.

CONCLUSIONS

From a dose of 200 m³ ha⁻¹, fertility increases and meets the nutritional corn requirements. However, water quality must be taken into consideration since some chemical species can be leached, suggesting a synchronism between swine wastewater application and crop requirements. In addition, the levels of Cu²⁺ and Zn²⁺ should be monitored when swine wastewater is used associated with mineral fertilization.

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