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Swine farm wastewater and mineral fertilization in corn cultivation

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Key words:
fertigation
water reuse
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ABSTRACT

In the long run, swine wastewater can provide benefits to the soil-plant relationship, when its use is planned and the potential environmental impacts are monitored. The objective of this study was to investigate the effects of continuous application of swine wastewater, associated with mineral fertilization, after six years of management in no-tillage and crop rotation (14 production cycles), on the chemical conditions of the soil and the corn crop. The doses of wastewater were 0, 100, 200, 300 m^3 ha^{-1} during the cycle. The effects of the association between mineral fertilization at sowing and swine wastewater were evaluated simultaneously. Swine wastewater at the dose of 100 m^3 ha^{-1} promoted availability and absorption of P, K^+, Mg^{2+} and Zn^{2+} without causing toxicity to plants or damage to the soil, constituting a viable, low-cost alternative of water reuse and fertilization for farmers. The nutrients N, P, K^+ and B must be complemented with mineral fertilization. Special attention should be directed to the accumulation of Zn^{2+} in the soil along the time of swine wastewater application.

Palavras-chave:
fertirrigação
reúso da água
dejetos suínos

Água residuária de suinocultura e adubação mineral no cultivo do milho

RESUMO

Em longo prazo a água residuária da suinocultura pode oferecer benefícios à relação solo-planta, quando planejado o uso e monitorados possíveis impactos ambientais. O objetivo do trabalho foi investigar os efeitos da aplicação continuada de água residuária de suinocultura associada com adubação mineral após seis anos de manejo em plantio direto e sucessão de culturas (14 ciclos de produção) acerca das condições químicas do solo e da cultura do milho. As doses de água residuária foram 0, 100, 200, 300 m^3 ha^{-1} durante o ciclo. Simultaneamente foram avaliados os efeitos da associação de adubação mineral na semeadura com água residuária de suinocultura. A água residuária da suinocultura na dose de 100 m^3 ha^{-1} proporcionou disponibilidade e absorção de P, K^+, Mg^{2+} e Zn^{2+} sem causar toxicidade às plantas ou danos ao solo constituindo viabilidade de reúso de água e fertilização alternativa de baixo custo ao produtor. Os nutrientes N, P, K^+ e B devem ser complementados com adubação mineral. Atenção especial deve ser direcionada ao acúmulo de Zn^{2+} no solo, ao longo do tempo de aplicação de água residuária da suinocultura.

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Introduction

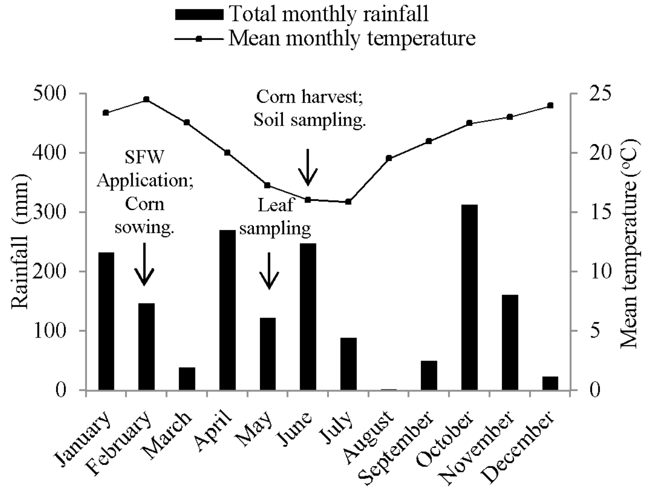
Swine farm wastewater (SFW), although rich in organic matter, macro and micronutrients (N, P, K^+, Ca^{2+}, B, Cu^{2+}, Fe^{2+}, Zn^{2+} and others), is also rich in Na^+, a non-essential nutrient to plants. Na^+ excess in the soil can hamper water uptake by roots and be toxic to plants (Munns & Tester, 2008); however, under adequate planning, SFW is efficient for crop fertigation, allowing the reduction of the application of commercial fertilizers (Cabral et al., 2011).

The large amount of SFW daily produced often becomes excessive, exposing soil and water to contamination if it is not properly managed. The eutrophication, the contamination by heavy metals and the residues of antibiotics present in swine excreta (Condé et al., 2012; Regitano & Leal, 2010) are some of the impacts resulting from its inadequate management.

Since nutrients are not totally assimilated by plants and, consequently, can accumulate and leach in high concentrations along the soil profile, the responses of the soil-plant relationship to the addition of SFW require long-term monitoring studies. Many of these studies describe positive (Sampaio et al., 2010; Maggi et al., 2011; Kessler et al., 2013b; Kessler et al., 2014) and negative (Doblinski et al., 2010; Sampaio et al., 2010; Meneghetti et al., 2012; Smanhotto et al., 2013; Tessaro et al., 2013) influences of SFW reuse on soil and its biota, plants, leachate and on runoff. Therefore, the challenge in wastewater management is to develop adequate application protocols, in order to minimize the polluting power of the activity and potentiate its efficiency as a liquid fertilizer. Given the above, this study aimed to investigate the effects of continuous application of SFW, associated with mineral fertilization, during six years of uninterrupted cultivation under no-tillage management, on the chemical conditions of the soil and the corn crop.

Material and Methods

The experiment was carried out at the field, in the city of Cascavel-PR, Brazil (24° 48’ S; 53° 26’ W). The soil in the region is classified as typical distroferric Red Latosol, with clayey texture (EMBRAPA, 2013). Rainfalls and mean temperatures during the 2012/2013 agricultural year are shown in Figure 1.



SFW - swine farm wastewater

Figure 1. Observed rainfall and mean monthly temperature in 2012 at Cascavel, PR

In all the production cycles, SFW doses were applied at once before sowing, in the doses of 100, 200 and 300 m^3 ha^{-1}. The SFW was collected from the outlet of a stabilization pond from the 1° to the 6° production cycle and from the outlet of the biodigester from the 7° to the 13° cycle. In the 14° cycle, referring to the present study, the application of raw SFW started, which was collected from the channel before the inlet to the biodigester and the stabilization ponds (Table 1). SFW collections were performed always in the same farm and in all the production cycles, minimizing the variations in its characteristics between the studied years. The swine farm that provided SFW has approximately 500 sows for piglet production and is equipped with a biodigester in an integrated system of treatment ponds.

The doses were combined with the presence (P) and the absence (A) of mineral fertilization (MF) (NPK formulation, 8:20:20). Thus, two factors (SFW and MF) were obtained, with 4 doses of SFW and 2 doses of MF, totaling eight treatments, defined as: 0-A (environmental control); 0-P (agronomic control); 100-A; 100-P; 200-A; 200-P; 300-A and 300-P, each of which evaluated in three replicates.

The production cycles from 2006 to 2012 were: corn (1°), soybean (2°), oatmeal (3°), soybean (4°), oatmeal (5°), baby corn (6°), corn (7°), oatmeal (8°), soybean (9°), corn (10°), soybean (11°), corn (12°), oatmeal (13°) and corn (14°). The amounts of nutrients from SFW and MF, applied in the experimental plots of the current and the previous 13 production cycles, accumulated, were estimated in order to characterize the history of each experimental plot (Table 2).

Composite soil samples were collected at the end of the cycle in each experimental plot in the layer of 0-20 cm, using a Dutch auger. Then, the samples were air-dried and analyzed for the available contents of total N, N_{org}, N_{inorg}, NO_3^-, NO_2^-, NH_4^+, Mn^{2+}, Cu^{2+}, Zn^{2+}, Fe^{2+}, Ca^{2+}, Mg^{2+}, K^+, Na+, P (Mehlich 1), organic matter (OM), aluminum (Al^{3+}), total acidity ($H^+ + Al^{3+}$), sum of bases (SB), base saturation (V), aluminum saturation (m), cation exchange capacity (CEC), pH water (1:2.5) and EC (1:5), according to the methodology of EMBRAPA (2009).

Table 1. Physical-chemical characterization of the swine farm wastewater* (SFW) applied in corn cultivation (14° production cycle)

Parameters		Parameters	
pH	7.60	Mn^{2+} (mg L^{-1})	1.9
N (mg L^{-1})	105	B (mg L^{-1})	0.64
N_{org} (mg L^{-1})	7	S (mg L^{-1})	9.17
N_{inorg} (mg L^{-1})	98	EC (μ S m^{-1})	3650
NH_4^+ (mg L^{-1})	84	COD (mg L^{-1})	2160
NO_3^- + NO_2^- (mg L^{-1})	14	COD Filt (mg L^{-1})	1440
TOC (mg L^{-1})	530	Turbidity (NTU)	400
P (mg L^{-1})	34.22	TS (mg L^{-1})	3500
K^+ (mg L^{-1})	171.6	FS (mg L^{-1})	1400
Na^+ (mg L $^{-1}$)	68	VS (mg L^{-1})	2100
Ca^{2+} (mg L $^{-1}$)	99	TDS (mg L^{-1})	990
Mg^{2+} (mg L $^{-1}$)	64.2	FDS (mg L^{-1})	360
Cu^{2+} (mg L^{-1})	0.50	VDS (mg L-1)	630
Zn^{2+} (mg L^{-1})	6.32	SAR	1.30
Fe^{2+} (mg L^{-1})	9.2		

*(APHA, 1998): pH - Hydrogen ionic potential; N_{org} - Organic nitrogen; N_{inorg} - Inorganic nitrogen; NH_4^+: Ammonium; NO_3^- - Nitrate; NO_2^- - Nitrite; TOC - Total organic carbon; Na^+- Sodium; Ca^{2+} - Calcium; Mg^{2+} - Magnesium; Fe^{2+}- Iron; Mn^{2+} - Manganese; B - Boron; S - Sulfur; EC - Electrical conductivity; COD - Chemical oxygen demand; COD Filt - Filtered chemical oxygen demand; TS - Total solids; SF - Fixed solids; SV - Volatile solids; TDS - Total dissolved solids; FDS - Fixed dissolved solids; VDS - Volatile dissolved solids; SAR - Sodium adsorption ratio

Table 2. Nutrients applied to the soil through swine farm wastewater (SFW) and mineral fertilization (MF) during the 14° production cycle and the total applied in the previous cycles

SFW doses (m^3 ha^{-1})	Mineral fertilization			Organic fertilization				
	N	P	K^+	$N^{\#}$	P	K^+	Cu^{2+}	Zn^{2+}
Nutrients applied in corn cultivation - kg ha^{-1} (14° production cycle)								
0 A	0	0	0	0	0	0	0	0
0 P	120	80	90	0	0	0	0	0
100 A	0	0	0	9.80	3.42	17.16	0.05	0.63
100 P	120	80	90	9.80	3.42	17.16	0.05	0.63
200 A	0	0	0	19.60	6.84	34.32	0.10	1.26
200 P	120	80	90	19.60	6.84	34.32	0.10	1.26
300 A	0	0	0	29.40	10.26	51.48	0.15	1.90
300 P	120	80	90	29.40	10.26	51.48	0.15	1.90
Nutrients applied - kg ha^{-1} (1° to 13° production cycles)*								
0 A	0	0	0	0	0	0	0	0
0 P	528	560	505	0	0	0	0	0
100 A	0	0	0	655	141	401	76	24
100 P	528	560	505	655	141	401	76	24
200 A	0	0	0	1322	281	800	152	49
200 P	528	560	505	1322	281	800	152	49
300 A	0	0	0	1992	421	1171	227	73
300 P	528	560	505	1992	421	1171	227	73

$^{\#}$ N Available; *Sum; N - Nitrogen; P - Phosphorus; K^+ - Potassium; Cu^{2+} - Copper; Zn^{2+} - Zinc; A - Environmental control; P - Agronomic control

Leaf sampling and analysis for macro and micronutrients were performed according to the methodology described by Malavolta et al. (1997).

The experiment was set in a randomized block design, in a 4 x 2 factorial scheme with three replicates, totaling 24 experimental plots, each one with area of 1.60 m^2, three rows and spacing of 0.40 x 0.50 m. The data were initially subjected to Shapiro-Wilk normality test and data transformation ($\sqrt{(x+1)}$), when necessary, and then subjected to analysis of variance and Tukey test at 0.05 probability level.

RESULTS AND DISCUSSION

The content of N_{inorg} in the soil after corn cultivation was lower for the treatment 200 P in comparison to the others, since it was more absorbed by corn plants, as observed in Table 3, which shows that the highest contents of absorbed N occurred for the presence (P) of mineral fertilization (MF). The inorganic form of N occurs in the soil as the form assimilable by plants. The low supply of this nutrient is considered as one of the factors that limit crop yield (Kappes et al., 2009).

The follow-up analysis of the interaction for P shows that the absence and the presence of MF in the different treatments promoted increase of this nutrient directly to the SFW doses, except for the dose 200 P. Phosphorus is an important factor in plant nutrition, but its availability is low due to the mechanism of retention that acts under the presence of Fe^{2+} and Al^{3+} oxides, as occurs in Latosols, in which the contents of Fe^{2+} oxides is very high, due to the type of the soil. P retention occurs when the adsorption sites are saturated with the phosphate ion in high-energy bonds. However, the maximum adsorption capacity of P causes more phosphate ions to be adsorbed with lower binding energy, which are more easily released to the soil solution (Santos et al., 2008). According to CQFSRS/SC (2004), the content of P is equivalent to the maximum crop yield (6 to 12 mg dm^3) in the treatments 200 P and 300 A. It should be pointed out that the Brazilian legislation does not recognize P as a chemical contaminant of the soil, but its excess poses

Table 3. Analysis of variance and means comparison test for soil chemical parameters (14° production cycle)

SFW and MF	N	Fe^{2+}	Mn^{2+}	Zn^{2+}	Na^+	NH_4^+	$NO_3^- + NO_2^-$	N_{org}	OM	pH	EC	CEC	V
§ 0	1400 a	24.83 a	47.33 a	2.68 b	1.05 a	19.88 a	25.67 a	1355 a	24.00 a	7.59 a	0.048 a	118.83 a	100.0 a
§ 100	1353 a	24.00 a	55.67 a	4.85 ab	1.13 a	16.97 a	29.17 a	1307 a	28.00 a	7.44 a	0.046 a	112.50 a	93.00 a
§ 200	1388 a	24.00 a	54.33 a	7.62 ab	1.38 a	17.55 a	29.47 a	1341 a	27.33 a	7.23 a	0.047 a	116.00 a	92.33 a
§ 300	1447 a	26.83 a	56.50 a	10.20 a	1.41 a	16.38 a	30.33 a	1400 a	28.50 a	6.73 a	0.055 a	117.00 a	81.17 a
A	1394 A	24.42 A	56.00 A	5.97 A	1.16 A	17.55 A	29.61 A	1347 A	28.58 A	7.41 A	0.044 A	114.67 A	92.92 A
P	1400 A	25.42 A	50.92 A	6.71 A	1.32 A	17.84 A	27.71 A	1355 A	25.33 A	7.08 A	0.055 A	117.50 A	90.33 A
¶SFW	0.25	0.40	1.41	6.13*	3.56	0.88	1.45	0.35	2.29	1.57	0.48	0.09	1.38
¶MF	0.01	0.22	1.85	0.50	2.70	0.00	1.19	0.01	5.87	1.29	3.10	0.12	0.17
¶SFWxMF	0.59	1.09	0.48	0.61	0.57	1.53	2.38	0.56	0.70	0.05	2.09	1.25	0.48
SD	169.6	4.87	9.43	4.15	0.27	4.13	4.81	167.9	3.81	0.72	16.47	18.19	15.72

SFW and MF	m	SB	Al^{3+}	$H^+ + Al^{3+}$	ESP	SFW x MF	N_{inorg}	P	K^+	Ca^{2+}	Mg^{2+}	Cu^{2+}
§ 0	0.00 a	118.83 a	0.00 a	0.00 a	0.94 a	# 0 A	43.80 a A	2.57 a A	1.13 b B	69.67 a A	43.67 a A	7.17 a A
§ 100	0.90 a	104.83 a	0.35 a	7.50 a	0.95 a	# 0 P	47.30 a A	5.90 b A	2.87 d A	62.00 a A	43.33 a A	3.07 b B
§ 200	0.15 a	106.50 a	0.07 a	9.50 a	1.07 a	# 100 A	47.30 a A	3.17 a B	1.67 b B	64.33 a A	46.67 a A	7.40 a A
§ 300	2.95 a	93.83 a	1.32 a	23.0 a	1.33 a	# 100 P	44.97 a A	17.67 a A	6.17 c A	63.67 a A	43.67 a A	3.07 b B
A	0.10 A	106.58 A	0.03 A	8.00 A	1.06 A	# 200 A	53.70 a A	4.37 a A	2.60 b B	75.00 a A	45.33 a A	3.37 b A
P	1.90 A	105.42 A	0.83 A	12.0 A	1.09 A	# 200 P	40.30 a B	6.57 b A	10.37 a A	51.33 a B	38.67 a A	3.37 ab A
-	-	-	-	-	-	# 300 A	43.80 a A	7.17 a B	6.20 a B	39.00 b B	27.67 b B	3.43 b A
-	-	-	-	-	-	# 300 P	49.63 a A	22.40 a A	8.43 b A	61.00 a A	39.00 a A	3.77 a A
¶SFW	0.85	1.19	0.84	1.38	2.41	SFW	0.07	9.65*	59.69*	10.20*	8.93*	50.86*
¶MF	1.65	0.02	1.66	0.09	0.06	MF	0.56	33.33*	166.43*	0.46	0.04	233.13*
¶SFWxMF	0.46	1.44	0.56	0.36	1.12	¶SFWxMF	4.32*	3.96*	19.10*	16.86*	4.86*	93.56*
SD	3.48	23.21	1.57	19.04	0.31	SD	5.86	7.73	3.24	11.55	6.89	1.77

¶F value; *Significant at 0.05 by Tukey test; §Means followed by the same letters in the column do not differ statistically; # Means followed by the same lowercase letters in the row do not differ for the follow-up analysis of SFW inside MF and means followed by the same uppercase letters in the column do not differ for the follow-up analysis of MF inside SFW; SD – Standard deviation; Transformed data ($\sqrt{(x+1)}$): Mn^{2+}, Zn^{2+}, NH_4^+, $NO_3^- + NO_2^-$, pH, EC, CEC, V, m, Al^{3+}, $H^+ + Al^{3+}$, N_{inorg}, Ca^{2+}, Cu^{2+} and P; ESP – Exchangeable sodium percentage; V, m and ESP expressed in percentage (%); EC expressed in dS m^{-1}; Al^{3+}, $H^+ + Al^{3+}$, SB, CEC, Ca^{2+}, Mg^{2+}, K^+ and Na^+ expressed in $mmol_c$ dm^{-3}; total N, NH_4^+, $NO_3^- + NO_2^-$, organic N, inorganic N, P, S, Cu^{2+}, Mn, B, Fe^{2+} and Zn^{2+} expressed in mg dm^{-3}; OM expressed in g dm^{-3}; A - Environmental control; P - Agronomic control risks of eutrophication of water bodies (Lourenzi et al., 2013), as observed in the treatments 100 P and 300 P, which reached levels higher than the recommended ones.

In the absence of MF, the addition of SFW doses contributed to the increase of K^+ in the soil in all the evaluated treatments. In the presence of MF, K^+ contents also increased in the treatments with 0, 100 and 200 m^3 ha^{-1} of SFW, decreasing in the treatment with the addition of 300 m^3 ha^{-1} of SFW, which may have occurred in response to the competitive inhibition caused by Ca^{2+} and Mg^{2+} at this dose, added to the soil by the SFW. The content of K^+ in the soil is classified as medium (limit between 1.6 and 3.0 $mmol_c$ dm^3) for the treatments 100 P, 200 P, 300 A and 300 P, according to the agronomic threshold described by Raij (2011), indicating that SFW used in isolation is sufficient to replenish this nutrient to the soil. In excess, K^+ can result in competition with Ca^{2+} and Mg^{2+}, and cause deficiency to plants (Malavolta et al., 1997). Doblinski et al. (2010) and Kessler et al. (2013b), in experiments using SFW in soybean and oatmeal, respectively, also observed increase of K^+ in the soil.

According to the statistical analysis, the contents of Ca^{2+} and Mg^{2+} in the presence of MF did not differ between treatments. However, these contents decreased in the absence of MF, unlike K^+ data, justifying the competitive inhibition between Ca^{2+}/Mg^{2+} and K^+. The presence of MF in the treatment 300 P resulted in the increase of these nutrients in the soil. The contents of Ca^{2+} and Mg^{2+} in the soil are considered as high, above 7 $mmol_c$ dm^3 and 8 $mmol_c$ dm^3, respectively, according to Raij (2011). Despite the expressive contents of K^+, Ca^{2+} and Mg^{2+}, the ESP was lower than 7%, which characterizes this soil as normal (Queiroz et al., 2010).

The metals Zn^{2+} and Cu^{2+}, present in swine diet as growth promoters, are found in significant concentrations in the manure and are directly transferred to the soil during fertigation, as observed in the behavior of Zn^{2+}, which increased with the SFW doses. Cu^{2+} contents decreased in the treatments with absence of MF. In the presence of MF, the opposite occurred and the treatments 100 P, 200 P and 300 P were statistically equal. Cu^{2+} behavior in the presence of MF can be explained by the adsorption induced by the P present in the MF (Lucas, 2011). In addition, these elements may have been adsorbed due to the presence of iron oxides and OM, and to the pH reduction, factors that directly hamper its bioavailability and mobility in the system (Mellis et al., 2004). High Cu^{2+} contents can cause phytotoxic effects (Sodré et al., 2014) and contaminate surface waters when transported through the sediments (Girotto et al., 2010). According to CQFSRS/SC (2004), the contents of Zn^{2+} and Cu^{2+} in the soil are considered as adequate for annual crops (> 0.5 mg dm^3 and > 0.4 mg dm^3, respectively). However, the accumulation of Zn^{2+} in the soil over the years not only can cause plant toxicity, but also change it from micronutrient to an environmental contaminant if it reaches 450 mg kg^{-1} (CONAMA, 2009).

The values of N, N_{org}, $NO_3^- + NO_2^-$, NH_4^+, Mn^{2+}, Fe^{2+}, Al^{3+}, H^++Al^{3+}, SB, V, m, CEC, pH and EC did not show significant differences between the treatments composed of the factors SFW and MF.

The behavior of leaf N was influenced by the presence of MF (Table 4), and corn requirements (27 – 35 g kg^{-1}) during its development (Malavolta et al., 1997) were only met in the treatment of 300 m^3 ha^{-1}.

The supply of P from the addition of SFW and, simultaneously, the presence of MF, was sufficient to provide plants with at least 2 g kg^{-1}. Likewise, K^+ contents increased with the SFW doses in the presence of MF, since the treatments 100, 200 and 300 m^3 ha^{-1} were similar according to the statistical test, evidencing the minimum content required by the crop, which varies from 17 to 35 g kg^{-1} (Raij, 2011). In a similar experiment, Kessler et al. (2014) also observed significant values of P and K^+ in corn leaf diagnosis.

Mg^{2+} plays an important role in crop development and contributes to biochemical activities and photosynthesis. The decrease in Mg^{2+} can be due to the competition with Ca^{2+} for the same exchange sites, in the absorption by the roots (Salvador et al., 2011). Another possibility is that Mg^{2+} may have been assimilated in lower proportion by plants, because of the higher K^+ absorption, which can reduce the absorption of other nutrients when assimilated in high concentrations. In all the treatments supplied by SFW, Mg^{2+} contents are within the minimum limit required by corn plants, in the range of 1.5-5 g kg^{-1} (Raij, 2011), and are consistent with the results obtained by Kessler et al. (2013a) in the cultivation of soybean with SFW and MF.

The contents of Zn^{2+} assimilated by corn showed significant increase as a function of the SFW doses. Mn^{2+} contents were stimulated by the presence of MF. According to Raij (2011), in all the evaluated treatments, the contents of these micronutrients met the requirements of the crop during its development (20 – 200 mg kg^{-1} and 15 – 100 mg kg^{-1}, respectively).

Although SFW increases the accumulation of B in the leaves, its contents were insufficient for growth and production only in the treatment with addition of 100 m^3 ha^{-1}. Contents

Table 4. Leaf analysis of corn subjected to the application of swine farm wastewater (SFW) and mineral fertilization (MF)

SFW and MF	N	P	K^+	Ca^{2+}	Mg^{2+}	S	Cu^{2+}	Fe^{2+}	Mn^{2+}	Zn^{2+}	B
§ 0	22.02 a	1.74 b	10.48 b	6.97 a	6.75 a	1.57 a	17.26 a	249 a	51.42 a	17.58 c	10.55 a
§ 100	22.58 a	2.06 ab	18.06 a	5.43 a	4.78 ab	1.57 a	27.48 a	247 a	46.92 a	28.50 bc	7.39 b
§ 200	22.96 a	2.23 ab	19.61 a	6.07 a	4.58 ab	1.78 a	38.94 a	309 a	48.67 a	35.67 b	10.64 a
§ 300	27.10 a	2.56 a	19.55 a	6.01 a	4.02 b	1.82 a	22.08 a	351 a	62.25 a	49.42 a	10.65 a
A	21.83 B	1.87 B	14.57 B	6.27 A	5.68 A	1.57 A	27.52 A	313 A	44.58 B	35.42 A	9.99 A
P	25.50 A	2.41 A	19.28 A	5.97 A	4.38 A	1.80 A	25.36 A	265 A	60.08 A	30.17 A	9.62 A
¶SFW	1.89	7.24*	12.74*	2.20	3.25*	1.01	1.80	2.87	1.64	23.40*	5.76*
¶MF	4.73*	17.94*	14.21*	0.50	3.27	3.13	0.58	2.50	8.39*	3.62	0.31
¶MFxSFW	0.99	1.52	1.56	0.32	0.43	0.64	2.43	0.36	1.55	0.39	2.31
SD	4.67	0.51	5.26	1.07	1.87	0.33	19.60	80.30	15.97	13.44	2.19

§ Means followed by the same letters in the column do not differ statistically; Transformed data ($\sqrt{(x+1)}$): K^+, Mg^{2+}, Fe^{2+} and Cu^{2+}; Macronutrients expressed in g kg^{-1} and micronutrients in mg kg^{-1}; A - Environmental control; P - Agronomic control; ¶F value.

considered as adequate are within the range of 10 – 25 mg kg^{-1}. Considered as an essential micronutrient, its deficiency can cause plant tillering, sharp decrease in size and bud dormancy breaking (Ferreira, 2012).

The leaf contents of Ca^{2+}, S, Cu^{2+} and Fe^{2+} did not differ between the treatments composed of the factors SFW and MF. According to the data, the application of 100 m^3 ha^{-1} of SFW is adequate, because it promoted minimum absorption of the main nutrients required during corn development, without causing toxicity to plants or negative impacts on the soil. The nutrients N, P, K^+ and B must be complemented with specific fertilization.

CONCLUSIONS

1. After six years of successive applications in no-tillage system, swine farm wastewater showed good results with respect to the supply of P, K^+ and Ca^{2+} in the soil and P, K^+, Mg^{2+} and Zn^{2+} in the plant.
2. The dose of 100 m^3 ha^{-1} of swine farm wastewater was considered as adequate for the supply of the nutrients P, K^+, Mg^{2+}, Zn^{2+} and Mn^{2+}, required by corn during its development and production.
3. Swine farm wastewater proved to be a promising, low-cost alternative for soil fertilization, but it can increase Zn^{2+} contents in the soil to toxic levels.
4. Complementary fertilization must be adopted for the supply of N, P, K^+ and B.

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