Chemical attributes of a Hapludox soil after nine years of pig slurry application

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Abstract – The objective of this study was to evaluate the pig slurry application effects on chemical attributes of a Hapludox soil managed under no-tillage system. Treatments consisted of 50, 100 and 200 m^3 ha^{-1} per year of pig slurry application, and a control with replacement of P and K exported through harvested grains. Attributes related to soil chemical reaction, exchange complex, and nutrient contents were determined in soil samples collected in the ninth year of experimentation from 0–0.025, 0.025–0.05, 0.05–0.10, 0.10–0.20, 0.20–0.40 and 0.40–0.60 m soil depths. The continuous application of high doses of pig slurry on the Oxisol surface under no-tillage acidifies the soil and increases Al, P, Cu, and Zn contents down to 0.2-m depth, and K levels down to 0.6-m depth.

Index terms: acidification, micronutrients, no-tillage system, soil fertility, soil pollution, soil quality.

Atributos químicos de um Latossolo Vermelho após nove anos de aplicação de dejeto líquido de suínos

Resumo – O objetivo deste trabalho foi avaliar os efeitos da aplicação de dejeto líquido de suínos sobre os atributos químicos de um Latossolo Vermelho, sob sistema de plantio direto. Os tratamentos consistiram da aplicação de 50, 100 e 200 m^3 ha^{-1} por ano de dejeto líquido de suínos, e de um controle, com reposição das quantidades de P e K exportadas nos grãos colhidos. Os atributos relacionados à reação química do solo, ao complexo de troca do solo e aos teores de nutrientes foram determinados em amostras de solo coletadas no nono ano de experimentação, a 0–0,025 e 0,025–0,05; 0,05–0,10, 0,10–0,20, 0,20–0,40 e 0,40–0,60 m de profundidade do solo. A aplicação contínua de altas doses de dejeto líquido de suínos na superfície de Latossolo Vermelho em sistema plantio direto acidifica o solo e aumenta os teores de Al, P, Cu e Zn, a 0,20 m de profundidade, e os de K a 0,60 m de profundidade.

Termos para indexação: acidificação, micronutrientes, sistema de plantio direto, fertilidade do solo, poluição do solo, qualidade do solo.

Introduction

Physical and chemical composition of pig slurry (PS) varies among farms and production systems, but it seems to be a close relationship between PS dry matter and its phosphorus or nitrogen contents (Scherer et al., 1996). These authors also determined that about 66% N, 33% P and almost all K in PS were in the mineral fraction. Pig slurry can also show high levels of micronutrients, especially Fe, Mn, Cu and Zn (Scherer, 1997; Mattias et al., 2010), the last two are commonly mixed to the feed in order to control diseases and to promote faster animal growth.

High amounts of PS application on soils with unknown capacity of nutrient cycling increases the risk of damaging the environment (Choudhary et al., 1996; Girotto et al., 2010) through nutrient losses by runoff, contamination of surface water (Ceretta et al., 2005; Bertol et al., 2007), and nitrate leaching to groundwater (Basso et al., 2005; Houlbrooke et al., 2008). The continued application of PS usually results in increased levels of nutrients in the soil, but has little effect on the content of organic matter (OM) and soil pH (Scherer et al., 2007, 2010; Cassol et al., 2011; Lourenzi et al., 2011).

The effects of the continued application of PS on soil chemical properties are relatively well known, especially on macronutrient cycling, organic matter contents, and pH. Choudhary et al. (1996) observed that manure application increases the levels of N, P, K, Ca, Mg, and Na in the soil but causes an excessive leaching of NO_3-N, P, and Mg. Ceretta et al. (2003) reported high levels of P, Ca and Mg in the topsoil after an intensive application of PS on an Ultisol surface with natural pasture. Scherer et al. (2007) observed increasing levels of P, K, Ca, and Mg in the soil surface, but found no effects on variables related to soil acidity, organic matter and cation exchange capacity. Scherer et al. (2010) reported high levels of soil P and K in the soil surface layers, especially up to 0.05-m depth, but no effect of PS on the OM content and on soil nutrient availability. The authors observed greater movement of P to deeper layers in Cambisols and Inceptisols than in Oxisols. Cassol et al. (2011) informed an increase in concentrations of P up to 0.06-m soil depth and of K up to 0.41-m soil depth, on an Oxisol, but no significant changes in pH in water or in exchangeable Al and Mg, despite the increasing levels of exchangeable Ca in the 0–0.02 m soil layer. Lourenzi et al. (2011), however, observed that accumulation of Ca and Mg in the surface layers of an Alfisol decreases Al saturation and increases base saturation, OM, and pH in deeper layers.

Recently, there is a greater concern as to the accumulation of micronutrients in soils due to PS applications, especially of Cu and Zn (Girotto et al., 2010; Scherer et al., 2010; Cassol et al., 2011). These elements have been shown to accumulate in bioavailable forms in the soil. However, there are few studies about the “semi-total” or “environmentally available” contents of these nutrients in the soil. Guiding values of soil quality as to the presence of chemicals have been established only recently in Brazil, through the Resolution No. 420 of the Conselho Nacional do Meio Ambiente (Brasil, 2009). According to this resolution, the maximum values accepted in agricultural soils for Cu and Zn are 200 and 450 mg kg^{-1}, respectively, determined by 3050B or 3051 of the USEPA-SW-846 methods (United States Environmental Protection Agency, 1996) or other equivalent procedures.

The objective of this study was to evaluate the pig slurry application effects on chemical attributes of a Hapludox soil managed under no-tillage system.

Materials and Methods

The experiment was carried out at the demonstrative field of the Cooperativa Regional Agropecuária de Campos Novos (Copercampos), at 27°22'59"S and 51º15'33"W, at 896 m altitude, in a Rhodic Hapludox (Latossolo Vermelho distroférrico típico, in the Brazilian classification) (Solos do Estado de Santa Catarina, 2004), and Cfb climate according to Köppen classification (Pandolfo et al., 2002). The experiment was installed at field, managed with crop rotation and no-tillage for more than 10 years, with the following soil attributes at the 0–0.20 m soil depth: 5.8 pH in water; 45 g kg^{-1} soil organic matter; 0.0, 0.5, 4.7, and 2.9 cmol$_c$ dm^{-3} of exchangeable Al, K, Ca and Mg respectively; and 10.0, 10.5 and 1.7 mg dm^{-3} of extractable P, Cu and Zn (Mehlich 1), respectively.

During the nine years of experimentation, a three-year-crop rotation was used, with the following annual sequence, all sowed by direct drilling: black oat (*Avena strigosa* Schreb.) + common vetch (*Vicia sativa* L.) / corn (*Zea mays* L.), black oat/soybean [*Glycine max* (L.) Merr.]; and black oat/common bean (*Phaseolus vulgaris* L.). Treatments consisted of 50, 100 and 200 m^3 ha^{-1} per year pig slurry doses, half of each were manually applied before sowing of winter crops, and the other half were applied before the summer crops. As a control, it was used a treatment with no pig slurry application but replacing the amounts P and K exported through harvests. In this control treatment, the nutrients were applied in a single dose (in the form of triple superphosphate and potassium chloride) before sowing the subsequent summer crop. Treatments were applied in three replicates, in plots measuring 6x5 m, in a randomized block design.

Pig slurry was obtained from an anaerobic lagoon reservoir, in a pig finishing farm located in Campos Novos, Santa Catarina state, Southern Brazil. Average composition of PS used in the 18 applications (two applications per year) was: 7.1 pH; 4.67, 0.68, 1.55, 1.02 and 0.59 kg m^{-3} of total N, P, K, Ca, and Mg, respectively; and 37 g m^{-3} of total Cu and 71 g m^{-3} of total Zn.

Soil samples were taken at three points per plot, at the end of the ninth year of experimentation, from 0–0.025, 0.025–0.05 and 0.05–0.10-m soil depths, with a shovel, and from 0.10–0.20, 0.20–0.40 and 0.40–0.60-m soil depths, with an auger. The samples were analyzed following Tedesco et al. (1995). For the determination of semi-total Cu and Zn, the 3050B method of the United States Environmental Protection Agency (1996), with minor modifications, was used, while the extractable concentration of these nutrients were determined with 0.1 mol L^{-1} HCl.

Analysis of variance was performed for each sampled layer, with statistical significance of treatments determined by the F test. The means were plotted in graphs to depict nutrient distribution in the soil profile. For some attributes, the result of 100 m^3 ha^{-1} per year PS were not used because they showed distortion from the overall tendency, i.e., they were almost the same as 50 m^3 ha^{-1} PS per year.

Results and Discussion

Organic matter showed a content gradient in depth, but was not significantly changed by treatments (Figure 1), similarly to what was observed by Scherer et al. (2010), but different from Lourenzi et al. (2011), who observed an increased level of organic matter at deeper layers, after nineteen applications of doses from 0 to 80 m^3 ha^{-1} PS. The use of PS resulted in a significant reduction of pH in water up to 0.20-m soil depth (Figure 1 B), probably related to the nitrification of NH_4^+ (Aita et al., 2007). According to Ernani (2008), the net addition of hydrogen ions in the soil solution is increased if NO_3^- is not absorbed by plants, since, in this case, roots would not release hydroxyl to the soil solution. This is particularly important for the PS from anaerobic lagoons; which has 40–70% of the mineral nitrogen in the ammonium form (Scherer et al., 1996). Thus, continuous application of PS, at high doses, can result in higher liming costs. However, Scherer et al. (2007) found no significant changes in soil acidity and related attributes, after four years of superficial application of PS in an Oxisol. Lourenzi et al. (2011) even observed an increase in pH in the surface layer, after nineteen semestral applications doses from 0 to 80 m^3 ha^{-1} per year PS, on the surface of an Ultisol.

Exchangeable Al and its saturation of the soil exchange capacity significantly increased from 0.05 to 0.20-m soil depths due to PS application (Figure 1). Sum of bases and base saturation, however, decreased in all layers up to 0.20-m soil depth. Increases in exchangeable Al can be explained by the observed pH decrease, and the reduction in the sum of bases and base saturation agree with the decreasing levels of Ca and Mg observed in the soil (Figure 2) due to PS application. In the present research, the decrease in these cations was not reversed by increasing the exchangeable K levels. Opposite results were observed by Lourenzi et al. (2011), after a similar period of superficial application of PS in an Ultisol.

Considering only the simplified balance of nutrients due to PS applications and exportation in grains, increasing soil contents of Ca and Mg were expected, since the total amounts applied via PS were higher than those exported by crop grains (Veiga et al., 2011). Moreover, Ca and Mg did not increase their levels in the lower layers.

Extractable P had its contents increased at 0.10-m depth, due to PS application (Figure 2). Exchangeable K had an even higher increase in its contents, at deeper layers. For these nutrients, the accumulation observed agrees with the estimated balance between the amounts added via PS and exported in grains, as determined by Veiga et al. (2011). In the two upper layers (up to 0.05 m), exchangeable K did not increase substantially, probably because the exchange charges were already saturated with this cation, which was not the case in the layers below this depth.

Phosphorus is adsorbed at specific sites and, according to Hooda et al. (2001) and Berwanger et al. (2008), their saturation is proportional to the amount of pig slurry applied. According to Basso et al. (2005), significant losses of P may occur through leaching at high doses of PS application. Therefore, the increased content of P at 0.10-m depth could be explained by an eventual partial saturation of the specific adsorption sites of P in the two upper layers, which would have resulted in leaching and accumulation of P in the layers immediately below. According to Gatiboni et al. (2008) and Ceretta et al. (2010), P added to soil via PS is accumulated mainly in inorganic forms, which are labile and represent a potential risk of contamination of superficial and groundwater. In conservation tillage systems, like no-tillage, P concentration in runoff are higher, but total losses are smaller (Bertol et al., 2004).

Extractable Zn and Cu had their levels increased by PS application, up to 0.20 -m soil depth (Figure 3). Accumulation was higher for Zn than for Cu, which is probably associated with the amount of the applied elements (Table 1). Similar results were obtained by Scherer et al. (2010) in fields from western Santa Catarina, by Mattias et al. (2010) in two microcatchments with different climatic conditions in the same state, by Girotto et al. (2010) in an Ultisol and by Cassol et al. (2011) in an Oxisol, in experiments with continuous PS application. According to Girotto

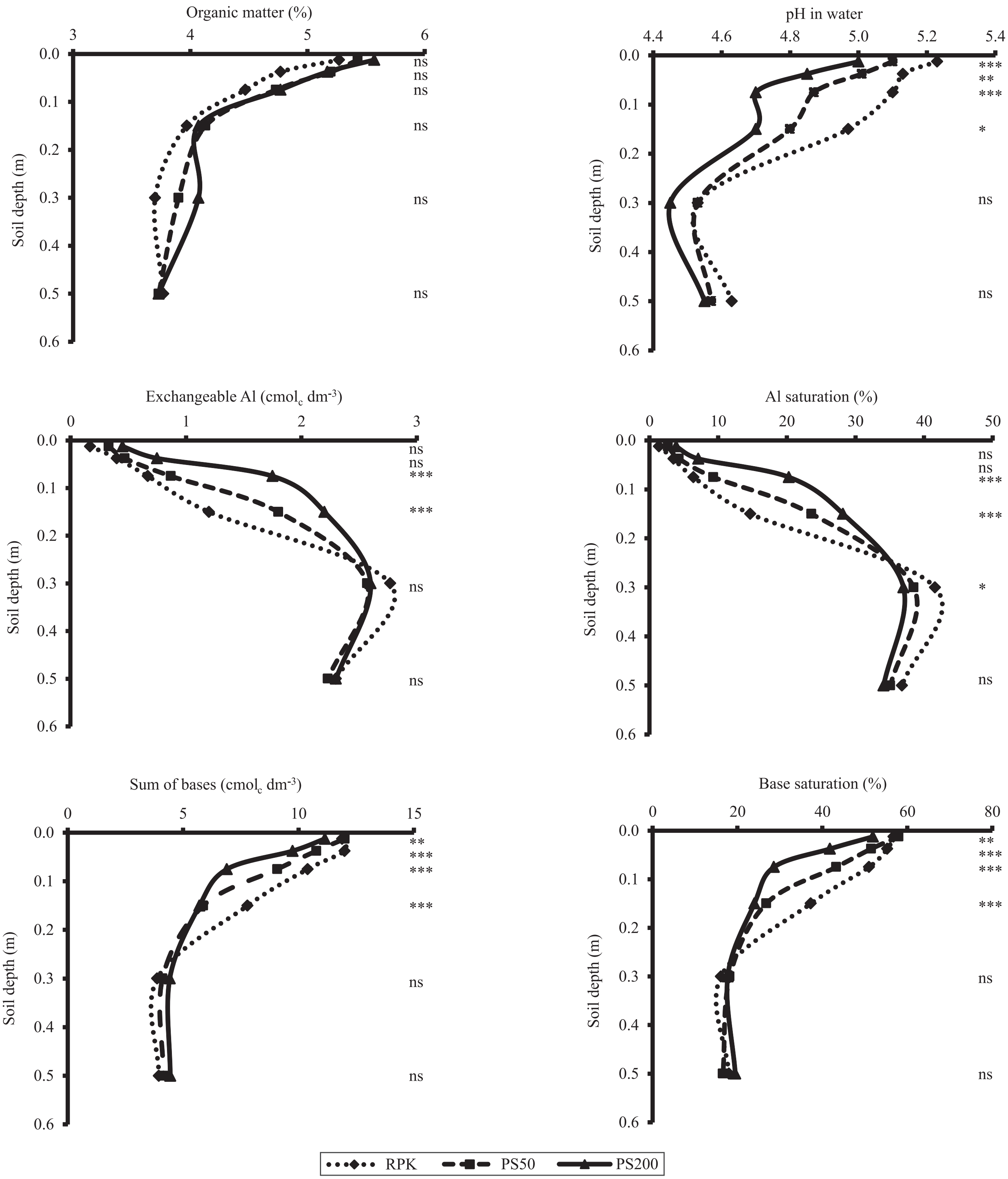

Figure 1. Organic matter content and attributes related to the pH and exchange complex in the profile of an Oxisol, nine years after replacement of K + P exported by crop grains (RPK), and after application of pig slurry. PS50 and PS200, respectively, doses 50 and 200 $m^3\ ha^{-1}$ per year of pig slurry from the anaerobic lagoons. [ns]Nonsignificant. *, ** and ***significant at 5, 1 and 0.1% probability, respectively.

at al. (2010), Cu and Zn added by PS are accumulated in the soil in bioavailable forms, either linked to the organic (Cu) and the mineral (Zn) fractions.

Increased levels of semi-total Zn and Cu in the superficial layers were also observed (Figure 3), despite the low total amount of these elements applied over the nine years of experimentation. This shows that Zn and Cu may be transferred to the aquatic environment by runoff, and they can be accessed by decomposing organisms and accumulate in the food chain. The levels of semi-total Zn in the superficial layer were very close to the reference value established by the Conama resolution 420 for agricultural soils, which is 450 mg kg^{-1} (Brasil, 2009). This indicates that, with continued PS application, this limit can easily be exceeded in this soil, which originally has a high-Zn content (Hugen, 2010). As to semi-total Cu, it was observed higher levels of this element compared to that established by the Conama resolution (200 mg kg^{-1}), even without the application of PS. This result shows that the 200 mg kg^{-1} reference value cannot be applied to the soil used in this study. This also may be the case in other soils with similar parental materials, such as extrusive igneous rock rich in ferromagnesian minerals (olivine, pyroxenes and amphiboles), with high-Cu and Zn concentrations in their composition (Hugen, 2010). The decrease of semi-total Zn and Cu

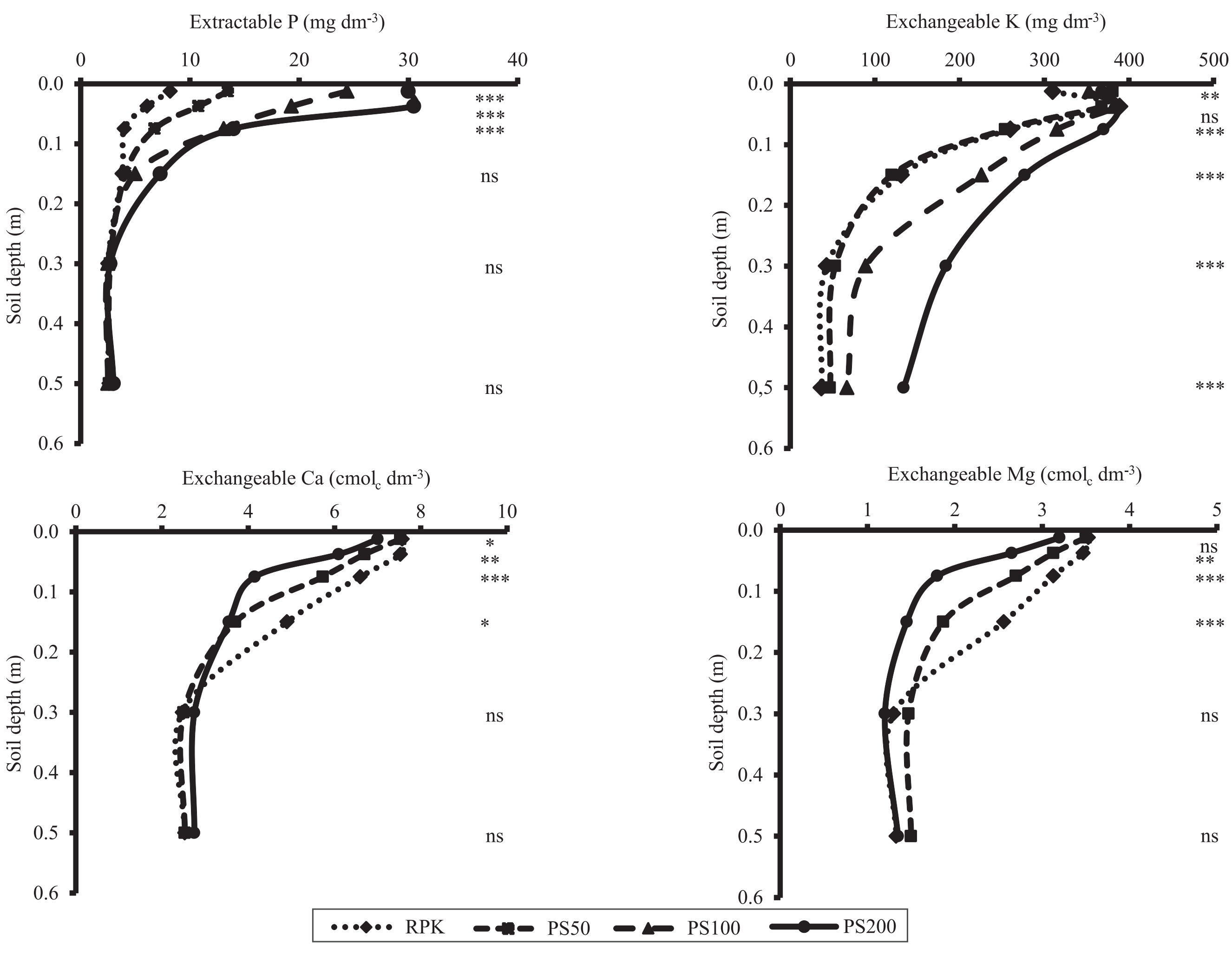

Figure 2. Content of extractable P and exchangeable K, Ca and Mg, in the profile of an Oxisol, nine years after replacement of K + P exported by crop grains (RPK), and after application of pig slurry. PS50, PS100 and PS200, respectively, doses of 50, 100 and 200 m^3 ha^{-1} per year of pig slurry from the anaerobic lagoons. ^{ns}Nonsignificant. *, ** and ***significant at 5, 1 and 0.1% probability, respectively.

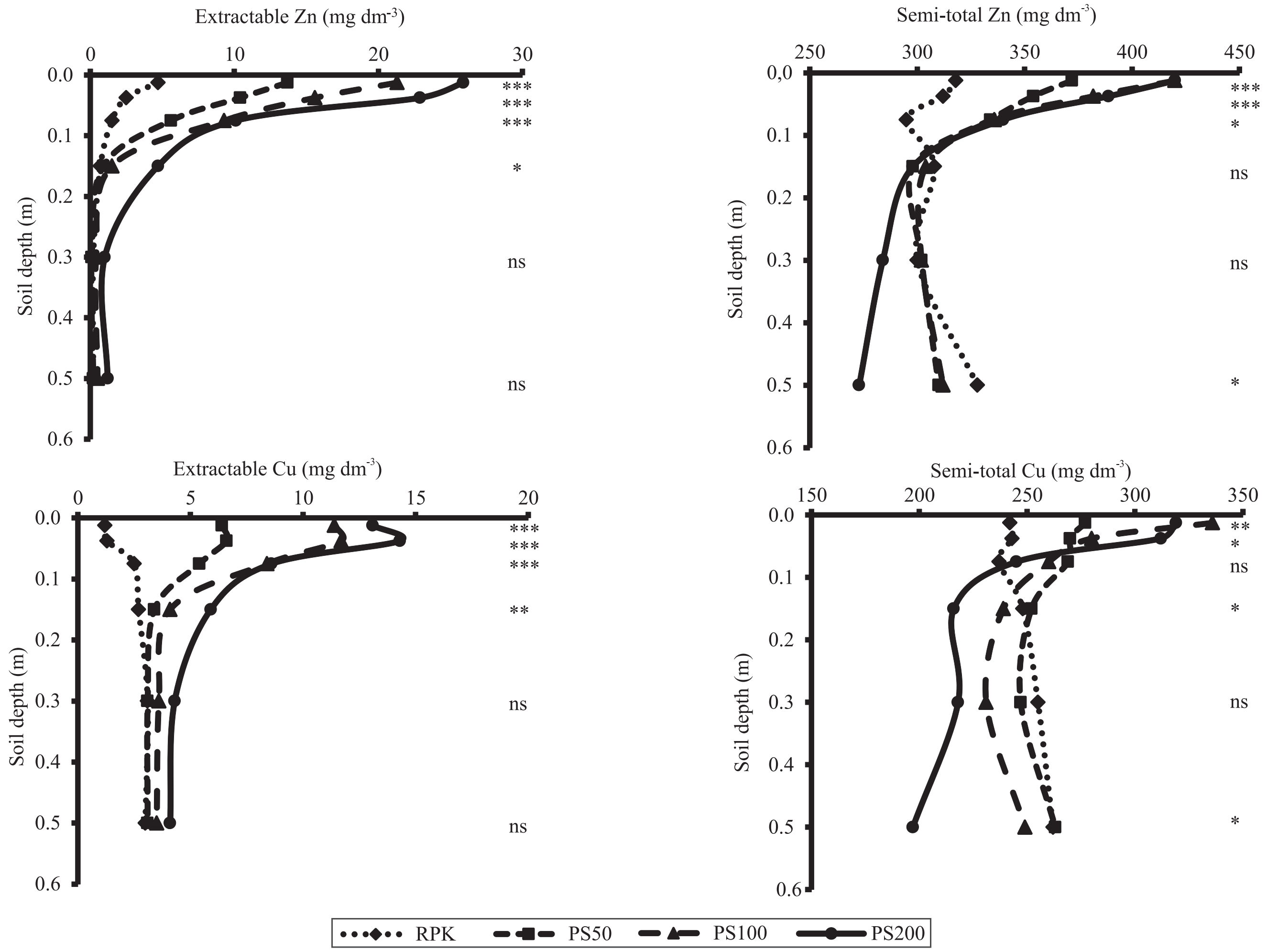

Figure 3. Content of extractable and semi-total Zn and Cu in the profile of an Oxisol, nine years after replacement of K + P exported by crop grains (RPK), and after application of pig slurry. PS50, PS100 and PS200, respectively, doses of 50, 100 and 200 m^3 ha^{-1} per year of pig slurry from the anaerobic lagoons. nsNonsignificant. *, ** and ***significant at 5, 1 and 0.1% probability, respectively.

Table 1. Estimated total amounts of nutrients applied to each treatment, along the nine years of experimentation.

Treatment(1)	N	P	K	Ca	Mg	Cu	Zn
	(kg ha-1)						
RPK	-	338	364	-	-	-	-
PS50	2,101	306	699	457	264	17	33
PS100	4,201	611	1,398	914	528	33	65
PS200	8,403	1,222	2,797	1,827	1,056	67	130

(1)RPK, replacement of P and K exported by crop grains; PS50, PS100 and PS200, respectively, 50, 100 and 200 m^3 ha^{-1} per year of pig slurry from the anaerobic lagoon.

in deeper layers is probably due to the complexation by organic compounds, mainly fulvic acids, and because of their high solubility in the soil solution (Amaral Sobrinho et al., 2009), which can result in the movement of these heavy metals, through percolation, to deeper layers, or even to groundwater.

Conclusion

Continuous application of high doses of pig slurry on the soil surface results in soil acidification and increasing levels of Al, P, Cu and Zn down to 0.20-m depth, and in K levels down to 0.60-m depth.

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