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MAYZE YIELD AND CHANGES IN THE CHEMICAL ATTRIBUTES OF SOIL FERTILIZED WITH MALT SLUDGE

RENDIMIENTO DE MAÍZ Y CAMBIOS EN LOS ATRIBUTOS QUÍMICOS DEL SUELO FERTILIZADO CON LODO DE MALTA

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ABSTRACT

Contextualization: The malt house's sludge is an organic matter which contains nutrients for plants. Therefore, its utilization as organic fertilizer is an alternative to landfilling, because during the handling the sludge does not have contact with pathogenic organisms and trace metals.

Knowledge gap: There are only a few studies to appraise the malt house's sludge as an organic fertilizer. In contrast, most of the studies are conducted with sewage sludge generated by the urban wastewater treatment system.

Purpose: To appraise the corn's productivity and the fertility of the soil fertilized with sludge's portions in comparison with mineral fertilization.

Methodology: The study was conducted based on randomized blocks design with five ways of treatment (T_1 = no fertilization; T_2 = mineral fertilization; T_3 = 24 Mg ha^{-1} of sludge; T_4 = 48 Mg ha^{-1} of sludge and T_5 = 72 Mg ha^{-1} of sludge) and four repetitions. During the sowing were distributed nine seeds per linear meter at a spacing of 0,80 cm between rows. After one hundred days from sowing, the cobs of ten plants located in the useful portion plot were collected in order to remove the grains. The grains were placed in an oven at 65 °C, until they reached constant weight to determine the dry mass. The productivity was estimated by extrapolating the grain dry mass data of the useful plot to one hectare. Soil samples were collected to assess soil fertility. The results were submitted to variance analysis and the differences between the averages to the Tukey test at 5%.

Results and conclusions: The grain productions obtained with 24, 48 and 72 Mg ha^{-1} of sludge were 18,67, 28,00 and 40,66% higher than that observed with mineral fertilization. The results of grain yields with the doses of sludge were in the average of productivity observed in Brazil. The dosages of sludge increased the availability of phosphorus from 26,7 mg dm^{-3} in the soil with mineral fertilization to 94,0 mg dm^{-3} with 72 Mg ha^{-1} of sludge, respectively. According to these results it can be concluded that the sludge has agronomic quality, and the dose of 24 Mg ha^{-1} optimized the productivity of maize.

Keywords: Agricultural Production, Mineral Nutrients, Organic Sludge, Plant Nutrition, Substantiable Agriculture

RESUMEN

Contextualización: el lodo de malta es un material orgánico que contiene nutrientes para las plantas, así que su utilización como fertilizante orgánico se presenta como una alternativa a los vertederos, ya que durante el procesamiento los residuos no entran en contacto con los organismos patógenos ni con los metales pesados.

Vacío de conocimiento: son escasos los estudios para evaluar los lodos de maltería como abono orgánico; por otro lado, la mayoría de los trabajos se han realizado con lodos de saneamiento generados por el sistema de tratamiento de efluentes y sanitarios urbanos.

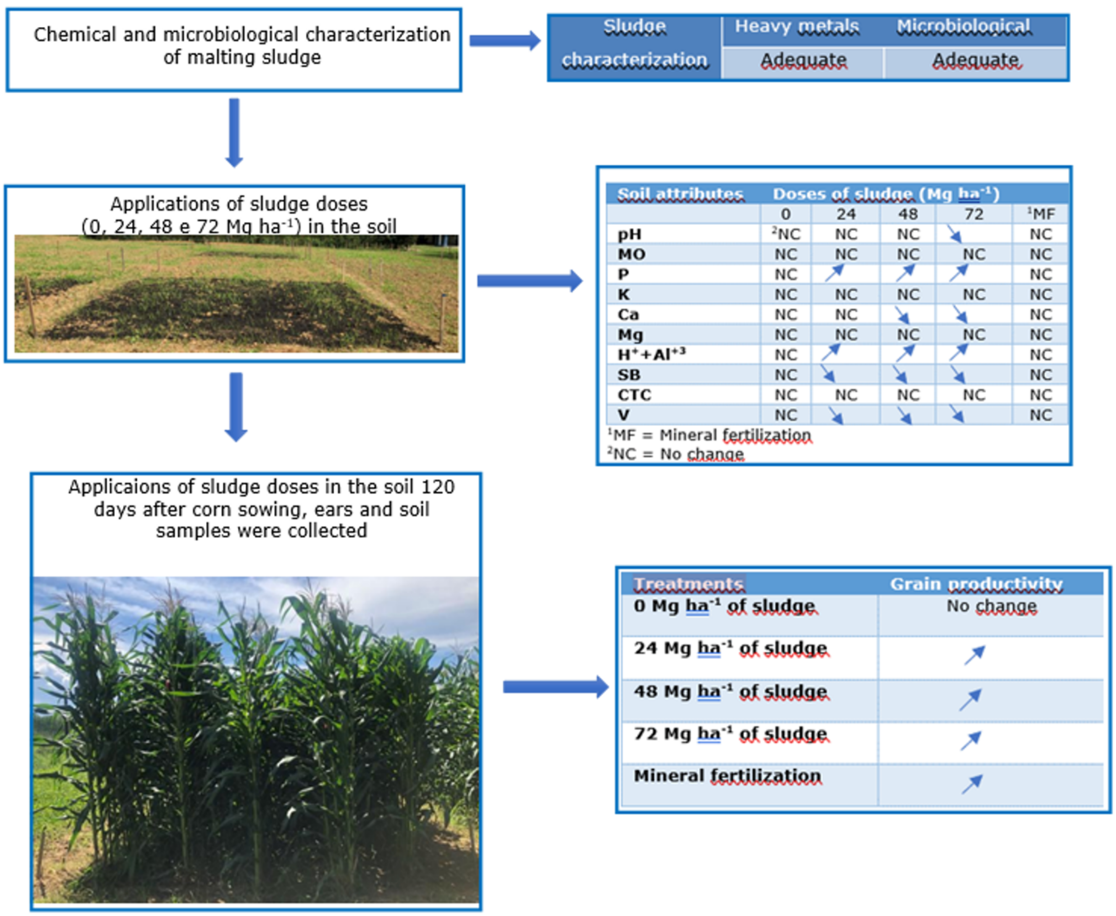
Propósito: evaluación del rendimiento del maíz y de la fertilidad del suelo fertilizado con dosis de lodos en comparación con la fertilización mineral.

Metodología: el experimento se realizó en un diseño de bloques al azar con cinco tratamientos (T_1 = sin fertilización; T_2 = fertilización mineral; T_3 = 24 Mg ha^{-1} de lodos; T_4 = 48 Mg ha^{-1} de lodos y T5 = 72 Mg ha^{-1} de lodos) y cuatro repeticiones. En la siembra se distribuyeron 9 semillas por metro lineal y un espaciado de 0,80 cm entre hileras. A los 100 días después de la siembra, se recogieron las espigas de diez plantas situadas dentro de la parcela útil para extraer los granos. Los granos se introdujeron en una estufa a 65 °C hasta alcanzar un peso constante para determinar la masa seca. El rendimiento se estimó extrapolando los datos de masa seca de los granos de la parcela útil a una hectárea. Se recogieron muestras de suelo para evaluar su fertilidad. Los resultados se sometieron a análisis de varianza y las diferencias entre medias a la prueba de Tukey al 5%.

Resultados y conclusiones: el rendimiento de grano obtenido con 24, 48 y 72 Mg ha^{-1} de lodos fue 18,67, 28,00 y 40,66% superior a los observados con fertilización mineral. Los rendimientos de grano con las dosis de lodos estuvieron dentro del rendimiento medio observado en Brasil. Las dosis de lodo aumentaron la disponibilidad de fósforo de 26,7 mg dm^{-3} en el suelo con fertilización mineral a 94,0 mg dm^{-3} con 72 Mg ha^{-1} de lodo, respectivamente. Sobre la base de estos resultados, se desprende que los lodos tienen calidad agronómica y que la dosis de 24 Mg ha^{-1} optimizó la productividad del maíz.

Palabras clave: agricultura sostenible, nutrición de las plantas, nutrientes minerales, producción agrícola

GRAPHICAL ABSTRACT



Source: authors.

1 INTRODUCTION

During the malting process, barley grains (*Hordeum vulgare* L.) are macerated and alternately submitted to both dry and wet periods where the leaching and hydration of the grains takes place. Further, the grains are submitted to germination, where the activation of enzymes and the solubilization of carbohydrates and proteins is observed, which results in the production of green malt that is dried and roasted and the effluent is treated in the activated sludge treatment system and after passing through the filter press, the malt plant sludge is produced (Muzzolon et al., 2021). The sludge is an organic material which contains in its chemical composition essential nutrients for agricultural plants, therefore its use as an organic fertilizer presents itself as an alternative to landfill disposal, because its generation results from a process without contact with pathogenic organisms and heavy metals (Miranda, 2013). Despite these qualities, studies to evaluate the efficiency of malt sludge as an organic fertilizer for agricultural crops are scarce or even non-existent, on the other hand, most works are carried out with sewage sludge generated by the urban wastewater treatment system (Baioui et al., 2017; Cerón et al., 2017; Gonçalves et al., 2019; Abreu-Júnior, et al., 2019; Ippolito, et al., 2021). Those studies have shown promising results of the application of sewage sludge doses in the increase of grain yields of several crops, increments in the uptake of macronutrients and micronutrients and improvements in soil fertility. Regarding sewage sludge application and grain yield, some researchers observed that productivity increased with the doses of sewage sludge applied to the soil and the highest values were obtained with doses ranging between 15 and 30 Mg ha^{-1} of sludge (dry basis) (Bremm et al., 2012; Gonçalves et al., 2019).

Among the effects of sewage sludge on the chemical composition of the soil, Trannin et al. (2008) found that soil fertility improved with the application of sewage sludge at doses greater than 12 Mg ha^{-1} (dry basis). Similar results were also observed by other authors who reported the increase of nitrogen (Pires et al., 2015), phosphorus (Bonini et al., 2015), organic matter (Ippolito et al., 2021) and cation exchange capacity (Pereira et al., 2015) when compared with soil from areas without sludge application and with mineral fertilization. According to Stehouwer (2000), these results are associated with the fact that one ton of sludge may, depending on its composition, add about 37 to 50 kg of nitrogen and 13 to 24 kg of phosphorus to the soil. Sewage sludge also presents in its composition significant amounts of magnesium, sulfur, and micronutrients such as iron, copper, zinc, and manganese that are sufficient to meet the needs of most agricultural crops, even when applied in doses below 10 Mg ha^{-1} of (dry basis) in the soil (Bremm et al., 2012; Bittencourt et al., 2017). These differences in the doses of sewage sludge in terms of nutrient supply and soil fertility are related to the system of treatments, the chemical composition of the sludge, the types of soil and the crop used (Bueno et al. 2011; Coscione et al. 2014).

However, potassium, due to its low concentration in the sludge composition, resulting from its high solubility in water, has been the element that does not increase with increasing doses of sludge applied to the soil (Andreoli et al., 2014; Nobile et al., 2014; Gonçalves et al., 2019).

In addition, some authors have also reported that the use of sewage sludge as an organic fertilizer could replace or even reduce the use of nitrogen and phosphate fertilizers applied to agricultural crops (Bittencourt et al., 2017; Gonçalves et al., 2019). Knopik et al. (2018) conducting a survey in areas where sewage sludge was applied at a dose of 7 Mg ha^{-1} (dry basis) between 2012 to 2016 found that farmers reduced the purchase of fertilizers and limestone, as an average contribution to the soil of 912 kg ha^{-1} of organic carbon, 582 kg ha^{-1} of total calcium, 160 kg ha^{-1} total nitrogen, 143 kg ha^{-1} of magnesium, 24 kg ha^{-1} of phosphorus, 22 kg ha^{-1} of Sulphur, 6 kg ha^{-1} of sodium, 4 kg ha^{-1} of potassium and of 2,15 kg ha^{-1} and 0,76 kg ha^{-1}, respectively for the micronutrients zinc and copper.

Based on the exposed, this work aimed to evaluate maize productivity and soil chemical attributes fertilized with doses of malt sludge in comparison with mineral fertilization.

2 MATERIALS AND METHODS

The experiment was developed during 120 days in an experimental area of the Pilot Farm of the Department of Agricultural Sciences of the University of Taubaté (UNITAU), Taubaté, São Paulo,Brazil, located at an altitude of 577 masl and with the geographical coordinates 23º02’34” S and 45º31’02” W. The climate is of type Cwa (Sub-tropical), with summer rains and an average annual precipitation of 1,300 mm (Fisch, 1995). The area has a medium-textured dystrophic Red-Yellow Latosol (Embrapa, 2006) or Ferralsol (IUSS Working Group WRB, 2015).

Figure 1 presents the monthly pluviometric rainfall averages for the period between planting (October 2021) and harvesting (February 2022) of the maize. Around 941.60 mm of rain was provided during the period, thus there was no need to irrigate the maize crop, as the water provided by the rain was above the 800 mm figure considered adequate for maize development (Embrapa, 2004).

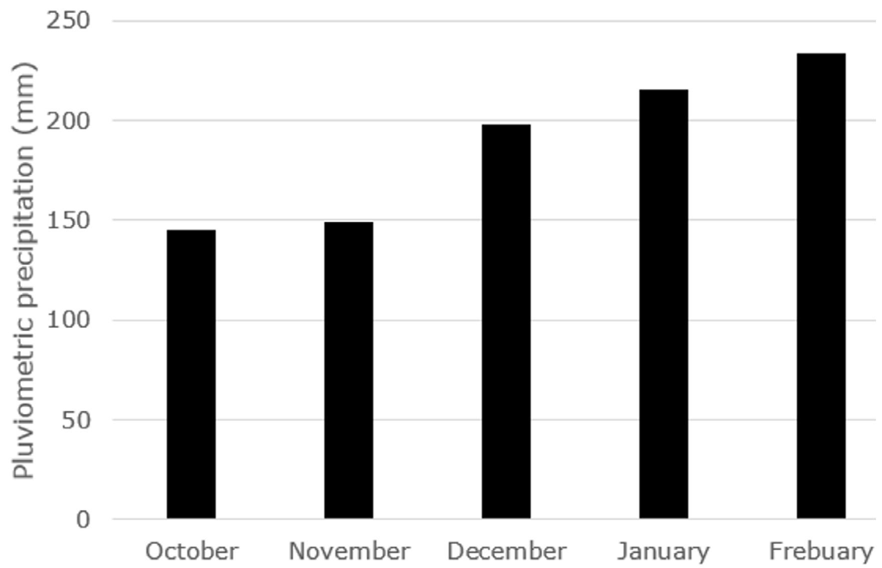


Figure 1. Monthly values of the accumulated pluviometric precipitation during the experimental period from October 2021 to February 2022

Source: authors.

The malt sludge was obtained from the Industrial Effluent Treatment Plant of the company Malteria Soufflet Brasil Ltda, located in Taubaté, in the State of São Paulo, Brazil. For the chemical characterization of the sewage sludge (Table 1) six single samples were collected at different points of the waste mass, which were homogenized and pooled into one composite sample.

The levels of heavy metals and the most probable number (MPN) of thermotolerant coliforms and *Salmonella* sp. in the malt sludge (Table 1), meet the limits stipulated by CETESB Technical Standard P.4230/2021 which establishes the limits and procedures for the application of sludge in agricultural areas in the State of São Paulo, Brazil.

For the initial chemical characterization of the soil, four simple soil samples were collected randomly in the 0-20 cm depth layer. After being collected the samples were mixed and homogenized to compose a composite sample to be evaluated for soil fertility, according to the methodology proposed by Raij et al. (2001). The soil presented the following chemical composition: pH ($CaCl_2$) = 5,5; nitrogen (g kg^{-1}) = 0,67; phosphorous (mg dm^{-3}) = 24; organic matter (g dm^{-3}) = 14,4; potassium (mmolc dm^{-3}) = 4,0; calcium (mmolc dm^{-3}) = 25; magnesium (mmolc dm^{-3}) = 14; hydrogen + aluminum (mmolc dm^{-3}) = 25; sum of bases (mmolc dm^{-3}) = 43,0; cation exchange capacity (mmolc dm^{-3}) = 68,0 and base saturation (%) = 63. The same procedures were used to collect the soils in the 20 plots after 100 days of maize sowing.

Table 1. Chemical composition and pathogenicity characteristics of malt sludge

Topic	Results	(1)Limits
Arsenic (mg kg^{-1})	< 0,05	75
Cadmium (mg kg^{-1})	< 2	0,5
Cooper (mg kg^{-1})	< 2	4.300
Chrome (mg kg^{-1})	< 2	500
Lead (mg kg^{-1})	< 3	840
Mercury (mg kg^{-1})	< 0,001	57
Nickel (mg kg^{-1})	< 6	75
Selenium (mg kg^{-1})	< 0,01	100
Zinc (mg kg^{-1})	< 1	7.500
pH	7,0	5,5 – 7,0
Kjeldahl nitrogen (mg kg^{-1})	16.562,50	-
Ammoniacal nitrogen (mg kg^{-1})	41,5	
Inorganic nitrogen (nitrite + nitrate) (mg kg^{-1})	<10,0	
Phosphor (mg kg^{-1})	9,8	-
Potassium (mg kg^{-1})	334,4	-
Sodium (mg kg^{-1})	43,3	-
Organic carbon (%)	11,5	-
Moisture (%)	88,40	-
Thermotolerant coliforms (NMP/g ST)	83,05	1.000
Salmonella sp (NMP/4g ST)	Ausente	3

(1) Technical Standart CETESB P.4230/2021

Source: authors.

The experimental design used was in randomized blocks with five treatments and four repetitions, being the size of the parcels of 25 m^2 (5 x 5 m). The treatments used were without sludge application (0 Mg ha^{-1}); with mineral fertilization (AM); 24, 48 and 72 Mg ha^{-1} of sludge (dry base). The doses of 24, 48 and 72 Mg ha^{-1} of sludge provided 120: 240 and 360 kg ha^{-1} of nitrogen, respectively.

The twenty experimental plots were marked out and then 2,0 Mg ha^{-1} dolomitic limestone was applied, plowed, and harrowed to a depth of 20 cm of soil. After 50 days, the sludge was superficially applied and distributed in each plot in quantities of 24, 48 and 72 Mg ha^{-1} (dry base) and then, with the aid of a rotary hoe the sludge was incorporated to a soil depth of 20 cm. In the treatment with mineral fertilization, 20 kg ha^{-1} of nitrogen, 50 kg ha^{-1} of phosphorus (P_2O_5) and 30 kg ha^{-1} of potassium (K_2O) fertilizers were applied at planting; and 40 days after maize emergence, 100 kg ha^{-1} of nitrogen fertilizer was applied as stipulated by Cantarella et al. (2022). One week after the application of sludge, the hybrid Agroceres 1015 maize was sown with the mechanical distribution of eight to nine seeds per linear meter and with spacing of 0,80 cm between rows and when the seedlings were about 20 cm tall, thinning was performed, leaving five to seven plants per linear meter. Two central rows were left in each plot to be used to collect the plants to determine the grain yield of the corn crop.

To evaluate the maize yield, the cobs of 10 plants located within the useful plot were randomly collected at 100 days after sowing. Later the cobs were placed in a forced ventilation (Universal – mod 449L) oven at 65 °C, until reaching constant weight and weighed to obtain the dry mass of the grains. The productivity was estimated by extrapolating the dry mass data of the grains from the area occupied by the ten plants to one hectare.

During the development of the maize cultivation, two applications of herbicide (atrazine) were made to control the invasive plants and two preventive applications of fungicide (pyraclostrobin + epoxiconazole) were made to avoid leaf diseases.

The results were statistically evaluated by analysis of variance and the effects of the treatments were tested using the F test. When statistical significance was achieved, means were compared using the Tukey test, with a probability of error of 5%. The data was analyzed by the software "SAS for Windows" (SAS, 2002)

RESULTS AND DISCUSSION 3

The results of maize grain yield estimated in kg ha^{-1} are presented in Figure 2, it can be observed that the grain yield varied significantly with the mineral fertilization (ADM) and the doses of malt sludge (24, 48 and 72 Mg ha^{-1}) applied to the soil, when compared with the plots without fertilization. The lowest values of grain yield were verified in the soil without malt sludge and the highest values in the treatments with mineral fertilization and the doses of sludge. The grain yields obtained with the doses of 24, 48 and 72 Mg ha^{-1} of sludge were higher than the value observed in the plot with mineral fertilization recommended for corn culture.

The comparison between the grain yield value obtained by mineral fertilization and the treatments of 24, 48 and 72 Mg ha^{-1} of malt sludge showed an increase of 18,67%, 28,00% and 40,66%, respectively, in the corn grain production. The results concerning the production suggest that the application of doses above 24 Mg ha^{-1} of sludge were efficient to replace the mineral fertilization recommended to meet the needs of the maize crop. This trend in the production of maize grains, observed with the sludge of malteria, are in agreement with the results of several authors in works with sewage sludge in which they verified a higher grain yield with doses between 15 and 30 Mg ha^{-1} of sludge on a dry basis (Bremm et al., 2012; Gonçalves et al., 2019).

Furthermore, in Figure 2 it is observed that the grain yield provided by the application of 24 Mg ha^{-1} of sludge was 3,940 kg ha^{-1}, with 48 Mg ha^{-1} was 4,250 kg ha^{-1} and with 72 Mg ha^{-1} was 4,670 kg ha^{-1}, these yield values were close and above the national average, which according to Souza et al. (2018) is 4,178 kg ha^{-1}. Chances are that this difference of almost a tonne in grain yield between the national average and mineral fertilisation may be related to any climatic, soil and metabolic factors not identified in this study, which may have acted during the development of the maize and altered the availability, absorption and translocation of the nutrients provided by mineral fertilisation. By converting the 3,3 Mg ha^{-1} grain yield with the amounts of nitrogen, P_2O_5 and K_2O supplied to the maize, it can be seen that of the 120 kg of N ha^{-1} the maize absorbed 66 kg of N ha^{-1}, of the 50 kg of P_2O_5 ha^{-1}, 33 kg of P_2O_5 kg ha^{-1} was absorbed and of the 30 kg of K_2O ha^{-1}, an average of 13,20 kg of K_2O ha^{-1} was exported to the grain, i.e. the nutrients were not absorbed in their entirety to provide a grain yield of around 4.178 kg ha^{-1} (Sousa and Lobato, 2004; Coelho, 2006).

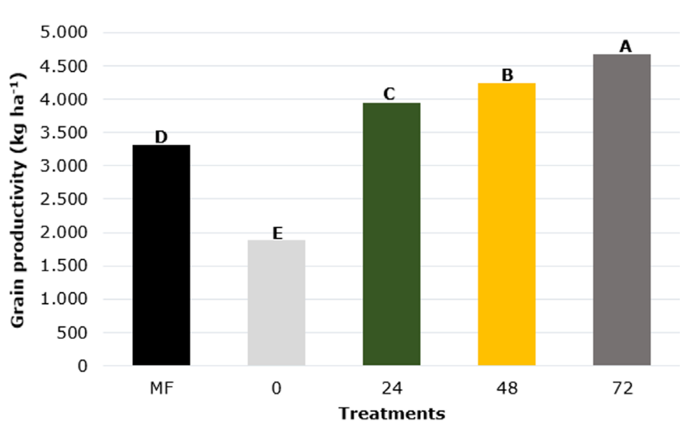


Figure 2. The production of maize grains determined in the plots with mineral fertilization (MF), without sludge (0 Mg ha-1) and with malt sludge at doses of 24, 48 and 72 Mg ha-1. (Averages followed by the same lower-case letter does not differ [p > 0,05] by Tukey test)

Source: Authors.

The values of maize grain yield obtained is probably due to the contribution of nutrients provided by the doses applied to the soil, because the addition of 24, 48 and 72 Mg ha^{-1} provided about 120, 240 and 360 kg ha^{-1} of total nitrogen, respectively.

In Table 2 are presented the results of the chemical composition of the soil without the addition of sludge (0 Mg ha^{-1}) and with applications of mineral fertilization and doses of sludge in the amounts of 24, 48 and 72 Mg ha^{-1}, it should be emphasized that dolomitic limestone was applied and incorporated in the soil of all treatments, so the values of pH and base saturation (V%) are higher and the potential acidity (H^{+}+Al^{+3}) is lower in the soil without the application of sludge (0 Mg ha^{-1}). It is verified that the addition of doses of malt sludge presented significant differences in the values of pH, phosphorus, potential acidity (H^{+} + Al^{+3}) and base saturation (V%) when compared with the values determined in the soil of the plots without the application of sludge and with mineral fertilization and the values of organic matter, potassium, magnesium and cation exchange capacity (CEC) showed no significant difference between treatments.

Table 2. Chemical characteristics of a dystrophic Yellow Red Latosol 120 days after fertilization with mineral fertilizer and sewage sludge doses

Tratamentos	pH	MO	P	K	Ca	Mg	H +Al^{+3}	SB	CEC	V
	($CaCl_2$)	(g.dm^{-3})	(mg dm^{-3})	---------------------(mmolc dm^{-3})----------------------------						(%)
0 Mg ha^{-1}	5,6a	14,2a	25,7c	3,7a	29,7a	14,5a	20,5b	47,8a	68,0a	70,2a
Ad. Mineral	5,4ab	13,5a	26,7b	3,5a	28,2b	13,7a	23,2b	45,7a	68,9a	65,5ab
24 Mg ha^{-1}	5,2abc	13,5a	42,0bc	3,3a	20,7bc	10,5a	29,0ab	34,5b	63,5a	54,5b
48 Mg ha^{-1}	5,0bc	12,7a	55,0b	3,1a	17,7c	9,2a	29,7ab	31,4b	61,1a	51,2b
72 Mg ha^{-1}	4,9c	12,5a	94,0a	2,8a	17,7c	10,7a	34,0a	38,8b	72,0a	51,7b
CV (%)	4,35	8,76	15,08	13,66	15,49	20,39	15,79	19,29	12,73	11,08

*Means followed by the same lowercase letter in the column do not differ [p > 0,05] by Tukey test.

Source: Authors.

It is worth highlighting that the organic matter content did not show significant increases in the plots with doses of malting sludge, chance because the time between incorporating the sludge and collecting the soil to determine the organic matter was only 120 days. Therefore, it is a short period of time to see a significant change in the organic matter content of the soil (Table 2). In this respect, Boeira et al. (2009) report that although sewage sludge has a relatively high organic carbon content, there is a significant consumption of organic matter in the soil soon after its application, until a new balance of the C/N ratio in the soil is reached. This is because organic residues added to the soil with a C/N ratio lower than 15:1, such as the malting sludge (C/N = 6.9:1) used in this study, tend to favour microorganisms in the processes of nitrogen mineralisation and immobilisation of the soil's native organic carbon and lead to a depletion in organic matter content (Fontaine et al., 2003). This tendency for the soil's organic matter to be consumed with the doses of sludge may explain the fact that the 48 Mg ha^{-1} and 72 Mg ha^{-1} plots showed organic matter levels with no significant variation between treatments, but with values lower than those observed in the plot with no sludge added.provide grain yields of around 4.178 kg ha^{-1} (Sousa and Lobato, 2004; Coelho, 2006).

When comparing the results of Table 2 with the limits stipulated by Technical Bulletin nº 100 of the Agronomic Institute of Campinas (IAC) it is possible to see that the pH values of the soil in the plots that received the doses of sludge are varying within the range classified as medium acidity, the phosphorus contents for annual crops are in the high to very high range and the base saturation values are oscillating within the range classified as medium (Cantarella et al., 2022).

In contrast, the potassium levels measured in the soils with the application of the sludge doses did not show significant differences in relation to the treatments without sludge and with mineral fertilization, this behavior of potassium after the application of sludge to the soil has been observed by several authors who claim that the low concentration of potassium in the chemical composition of sewage sludge is associated with the high solubility of potassium with water (Andreoli et al., 2014; Nobile et al., 2014; Gonçalves et al., 2019).

In Table 2, it is observed a tendency of pH reduction as the application exceeds the dose of 24 Mg ha^{-1} of sludge. Similar results were also verified by Boeira and Souza (2007) with cumulative application of 17 Mg ha^{-1} of sewage sludge and by Trannin et al. (2008) with 12 Mg ha^{-1}. These authors state that soil acidification may be associated with the process of mineralization of ammoniacal nitrogen existing in the sludge composition and that after coming into contact with nitrifying microorganisms, they transform NH^{+4} into NO^{-3} and release hydrogen into the soil solution. Furthermore, there are also oxidation reactions of the organic fraction that promote the dissociation of protons linked to the COOH and OH functional groups of organic matter and compounds containing sulfides that result in the release of CO_2, organic acids, and hydrogen into the soil (Boeira and Souza, 2007; Boeira and Maximiliano, 2009).

The hydrogen ion released by the decomposition of the sludge may have solubilized the aluminum oxides and thus raised the $H+Al^{+3}$ and reduced the calcium and magnesium levels in the soil (Table 2) and consequently reduced the values of base saturation, because the $H^{+}+Al^{+3}$ promote the neutralization of cations Ca^{+2}, Mg^{+} and K^{+}, in the negative charges of colloids in the soil (Bonini et al., 2015). The decrease in soil pH corroborates the data obtained with the base saturation (V%) that were lower in the treatments with doses of malt sludge and mineral fertilization, explained by the replacement of exchangeable bases (Ca^{+2}, Mg^{+} and K^{+}) by H and Al^{+3} ions in the soil exchange sites.

When analyzing in Table 2 the phosphorus contents in the soils with application of the doses of malt sludge, the highest value of phosphorus was verified in the plot with the dose of 72 Mg ha^{-1} of sludge, followed by the plots that received the doses of 48 and 24 Mg ha^{-1} of sludge. The phosphorus contents determined in the soil for maize plants were considered very high (94 mg dm^{-3}) for 72 Mg ha^{-1} of sludge, high (55 mg dm^{-3}) for 48 Mg ha^{-1} of sludge and high (42 mg dm^{-3}) for 24 Mg ha^{-1} of sludge (Cantarella et al., 2022).

In this regard several authors have reported substantial increases in soil phosphorus contents when they used sewage sludge doses between 30 and 60 Mg ha^{-1} as a source of nutrients for agricultural crops (Bonini et al., 2015; Carvalho et al., 2015; Knopik et al., 2018). Alves and Souza (2008) found that this significant increase in soil phosphorus arising from the application of sewage sludge doses was related to the amounts of phosphorus added by the mass of sludge applied to the soil. In this present study, the amounts of phosphorus provided by the 24, 48 and 72 Mg ha^{-1} doses of sludge were not enough to cause the increases observed in the soil, as these doses provided an average of around 0,23, 0,47 and 0,70 kg of phosphorus ha^{-1}, respectively. Chances are that the high phosphorus levels in the soil are related to the solubilisation of insoluble phosphates in the soil, which were solubilised by the release of organic acids during the decomposition of the sludge in the soil, and to the H^{+} ions resulting from the mineralisation of ammoniacal nitrogen. These organic acids and H^{+} promote the dissolution of water-insoluble phosphates by the action of carbonic acids and by reducing the binding energy of phosphorus fixed in the soil, resulting in the formation of phospho-humic complexes and organic phosphates that increase the availability of phosphorus in the soil (Lobo et al., 2013; Costa et al., 2014).

4 CONCLUSIONS

The sludge presented levels of heavy metals and number of Thermotolerant coliforms and Salmonella sp compatible with the limits considered as adequate by the Brazilian legislation to be used as organic fertilizer. The application of the sludge caused a reduction in soil pH, which favored the formation of phosphate-humic complexes and organic phosphates that increased the availability of phosphorus in the soil. The sludge doses increased the corn grain yield and the smallest dose (24 Mg ha^{-1}) provided a higher yield than that obtained with mineral fertilization recommended for corn culture. Malt sludge at a dose of 24 Mg ha^{-1} can be safely used in agricultural areas, as it presented agronomic quality favourable to the cultivation of maize.

AUTHORSHIPS CONTRIBUTION

All authors have contributed in various ways to the development, execution, and conclusion of the project. **Paulo Fortes Neto**: Development, bibliography's revision , methodology, research, data analysis, writing and editing. **Nara Lúcia Perondi Fortes:** Methodology, research, data tabulation and analyses, review and editing. **Lucilene Carvalho Silva:** Methodology, oversight of financial and administrative resources.

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Conflicto de intereses
Los autores declaran no tener ningún conflicto de intereses.