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Chemical attributes of the soil in agroforestry systems subjected to organic fertilizations

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The reuse of organic byproducts in agroforestry systems is a sustainable proposal, since, in addition to preserving the natural resources, it has allowed the fertilization of the soils, obtaining a reduction of costs with mineral fertilizers. Therefore, the objective of this research was to evaluate the chemical attributes of the soil after two years of successive fertilizations using cattle manure and sewage sludge in agroforestry systems. The study was conducted in Goiânia, state of Goiás, Brazil. The experimental design used randomized blocks on a 2 x 4 factorial (cultivation systems and fertilizations), with four repetitions. The cultivation systems were: agroforestry and monoculture systems. The fertilizations used were: cattle manure, sewage sludge, mineral fertilizer and control (no fertilization). Regardless of the cultivation system, the fertilizations with sewage sludge increases the calcium, phosphor and zinc contents of the soil, as well as the pH values, sum of bases and cation exchange capacity, at 0-10cm depth. However, the potassium contents are lower in relation to the use of mineral fertilizers, both at 0 to 10 cm depth and at 0 to 20 cm. Teak plants in agroforestry systems presents similar heights to the monoculture plants, and they are higher on fertilizations with sewage sludge. The soybean grain productivity in the agroforestry system presents similar outputs in relation to the use of sewage sludge and mineral fertilizers. Therefore, it is recommended for farmers to adopt agroforestry systems and the organic fertilization practice with sewage sludge, associating the quality of the chemical attributes of the soil, the growth of forest species and soybean grain yields.

Key words: *Tectona grandis*, sewage sludge, cattle manure, intercropping systems, soybeans.

INTRODUCTION

The increase in the productivity of forest cultures by area unit is the current objective in order to meet the worldwide growing demand for wood (Smitha et al., 2016). However, the conventional agricultural systems

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with monocultures must undergo transformations into systems that consider associations among agroecosystems (agroforestry systems), since these are sustainable methods for the production of food and forest products (Bonaudo et al., 2014), intending to soften the emission of greenhouse gases and offer improvements to the chemical attributes of the soil (Buller et al., 2015). However, most forest species cultivated have a high capacity to extract nutrients, causing significant impacts to the chemical attributes of the soils (Pelissari et al., 2012), and this high nutrient consumption may be intensified in agroforestry systems due to the introduction of new production components, such as annual grain production cultures.

In order to reduce the high subjection to mineral fertilizers, the use of organic byproducts may be a sustainable alternative (Smitha et al., 2016). One highlight is cattle manure, since it offers benefits to the chemical attributes of the soil, helping to increase mineralization and the availability of nutrients to the plants (Tejada et al., 2008), mainly due to its capacity to interact with metals and metal oxides and hydroxides, creating organometallic compounds, in addition to potentiate the nitrogen and phosphor stocks (Muraishi et al., 2011)

Another byproduct, from an urban origin, sewage sludge has been deeply investigated regarding the potential improvements of the chemical attributes of the soil (Ricci et al., 2010; Bittencourt et al., 2012; Costa et al., 2014; Cavalcanti et al., 2015). However, concerns have emerged since it leads to a significant concentration of heavy metals on the soil (Nascimento et al., 2014; Albuquerque et al., 2015). Considering these questions, the search for solutions for an adequate destination for this byproduct has been considered vital, and agricultural recycling seems like the most promising alternative from the economic and environmental perspective (Barbosa et al., 2007).

The accelerated growth of the global population and the increase of the livestock farming production in intensive systems are responsible for the generation of large amounts of sewage sludge and cattle manure, respectively in Brazil. Managing these solid residues, specially sewage sludge, is one of the greatest challenges of the Brazilian municipalities, which face problems related to the environmental issue, combined to the financial difficulties of the country (Ricci et al., 2010). However, reusing these residues for agricultural purposes is a sustainable proposal, since it preserves human health and the environment considering that it would otherwise be likely to inadequate disposal (Bonini et al., 2015), while, at the same time, it allows the fertilization of the soils, offering cost reductions on mineral fertilizers.

The application of organic fertilizers in a successive manner during the first years of implementation of agroforestry systems may promote the growth of forest species and increase the grain yield in annual cultures. Therefore, the objective of this research was to evaluate the chemical attributes of the soil after two years of fertilizations with cattle manure and sewage sludge on agroforestry systems.

MATERIALS AND METHODS

Characterization of the experimental area

The study was conducted in Goiânia, state of Goiás, Brazil (16°36' 09.57'' S and 49°16' 52.55'' W). The region has an Aw climate (Megathermal) or tropical savanna climate, with dry winters and rainy summers, according to the Köppen classification. The studied area has an altitude of 730 m, average annual rainfall of 1600 mm, with annual minimal and maximal temperatures of 15.2 and 30.4°C, respectively.

The soil was classified as typical distroferric Red Latosol (Embrapa, 2013). The chemical analysis of the soil before implementing the experiment showed, at a 0 to 20cm depth, the following contents: Ca^{2+}: 1.0 $cmol_c\ dm^{-3}$, Mg^{2+}: 0.3 $cmol_c\ dm^{-3}$, K^+: 33mgdm^{-3}, P (Mehlich I): 2.1 mg dm^{-3}, Organic Matter: 11 g dm^{-3}, Al^{3+}: 0.1 $cmol_c\ dm^{-3}$, H+Al^{3+}: 2.4 $cmol_c\ dm^{-3}$ and pH ($CaCl_2$): 4.9. The textural analysis of the soil showed 430, 110 and 460 g kg^{-1} of clay, silt and sand, respectively (Embrapa, 2009).

The research area showed signs of degradation due to the reduced cultivation of the fodder species (*Urochhoa Decumbens*). In the crop season 2013 to 2014, agroforestry system was adopted and cultivation of teak (*Tectona grandis* Linn. F.) intercropped with millet (*Pennisetum glaucum*) was introduced. While in the forthcoming season (2014 to 2015), teak was intercropped with soybean (*Glycine Max*).

Experimental design

The transplanting of teak seeding was conducted with the help of a furrower to open holes (average depth of 35 to 40 cm), and seeds were manually placed. The teak forest was grown with plant-to-plant space of 2 m and row-to-row distance 6m, containing four rows with sixteen plants each, at a total population of sixty-four plants, occupying a total area of 768 m^2. The experimental design used was the randomized block design (RBD) on a 2 x 4 factorial (cultivation systems and fertilizations), with four repetitions. The cultivation systems followed were either agroforestry or monoculture. The fertilizations composed of cattle manure, sewage sludge, mineral fertilizer and control (no fertilization).

The experimental units were constituted as 6 m wide and 4 m long, at a total area of 24 m^2, and experimental units were constituted by two plants of the forest species on the central position, in addition to the spaces where the sowing of the annual cultures was conducted. For the useful area, 0.5 m on the edges of the borders was disregarded, totaling 15 m^2.

Experimentation in 2013 to 2014

The liming was conducted at the time of teat transplanting using dolomitic limestone (Total Relative Neutralizing Power of 92%) at 20 g per hole while 0.476 Mg ha^{-1} was used between rows to increase the base saturation to 50% (Souza and Lobato, 2004).

The soil fertilization for the holes where teak seedlings were planted for the treatments corresponding to mineral fertilizers was conducted using monoammonium phosphate, offering 15 g of P_2O_5 plant^{-1} and, 30 days after transplanting, the fertilization was

Table 1. Chemical analysis of cattle manure and sewage sludge used for the experiment during the first (2013) and second year (2014), Goiânia, Goiás, Brazil.

Year	N	P	K	Ca	Mg	S	B	Cu	Fe	Mn	Zn	OM	H_2O
			-------------------- g kg^{-1}--------------------					--------------- mg kg^{-1}---------------				----- % -----	
						Cattle manure							
1°	0.64	0.14	3.12	0.34	0.08	0.09	0.26	32	170	4	5	0.8	97
2°	0.54	0.08	2.16	0.42	0.05	0.08	0.25	25	145	2	3	0.6	98
Year						**Sewage sludge**							
1°	30.3	12.4	1.2	121.0	20.1	8.00	0.45	122.0	1850	112	1430	22	64
2°	21.6	7.3	1.6	89.0	19.0	10.0	0.80	151.0	1500	148	3500	19	67

OM: Organic matter; H_20: Umidade.

conducted with 15 g of N (urea) and 10 g of K_2O $plant^{-1}$ (potassium chloride). The millet seed was sown in between the rows (ADE 300). The treatments with mineral fertilizers were applied on the sowing furrow at 100 kg P_2O_5 ha^{-1} as monoammonium phosphate, 60 kg K_2O ha^{-1} as potassium chloride and 20 kg N ha^{-1} as urea. The fertilization was also conducted with 60 kg ha^{-1} of N (urea) 25 days after sowing.

The treatments corresponding to sewage sludge and cattle manure were conducted as broadcast seeding on the total area, and the applications were made both for the teak plants and on the areas between the rows, however, only after the application of these byproducts the millet was sown. A thick paste application was used with 30 Mg ha^{-1} for sewage sludge and a liquid application of 400 m^{-3} ha^{-1} for cattle manure (Table 1).

The teak monoculture treatments remained on a single culture, only on the agroforestry area the millet was cultivated on an intercrop. The objective was to create some foliage for the posterior soy cultivation (2014 to 2015 crop).

Experimentation in 2014 to 2015 season

In November 2014, the teak plants that corresponded to the treatments with mineral fertilizers received applications of 30 g of N (urea), 30 g of P_2O_5 (monoammonium phosphate) and 15 g of K_2O (potassium chloride). Soybeans were sown in between the rows of the agroforestry system (Nidera Y2123) with 0.5 m of spacing between the plants, and population of 17 seeds per meter.

The treatments that corresponded to mineral fertilizers were conducted with 120 kg ha^{-1} of P_2O_5 (monoammonium phosphate) and 60 kg ha^{-1} of K_2O (potassium chloride), in addition to 40 kg ha^{-1} of K_2O (potassium chloride) for covering. The treatments that corresponded to organic fertilizations with cattle manure and sewage sludge were conducted using the same doses and application technique of the previous crop.

Analyzed variables

In February 2015, a soil sampling was conducted with the help of a screw auger, at depths of 0 to 10 and 10 to 20 cm, and six simple samples were collected at each portion in order to constitute a compound sample. The chemical attributes of the soil were evaluated such as phosphorus and potassium (extracted by Mehlich I), calcium and magnesium (extracted by KCl), determined by EDTA titration, potential acidity ($H+Al^{3+}$) and pH ($CaCl_2$), according to Embrapa (2011). The sums of the bases, the cation exchange capacity and bases saturation were calculated. The organic matter contents of the soil were determined through the oxidation method with dichromate and spectrophotometer reading (Embrapa, 2009). The total micronutrient contents and heavy metals were extracted on a nitro-perchloric acid solution (HNO_3 + $HClO_4$) and then they were determined by atomic absorption (Embrapa, 2011).

The soybean crop was grown up to 105 days, and four linear meters of the soy plants were sampled on two central lines of the useful area. Subsequently, the soybean plants were threshed, and the grains were sent to the laboratory for measurement of humidity, reaching values of 13%. Grain moisture was measured by the oven drying method, under atmospheric pressure. Based on sample mass measurement, moisture content was calculated as a function of water mass reduction during drying. The difference between the mass value after removal from the oven and the mass value before sampling, multiplied by 100, yields the percentage of humidity. The beans were weighted on an analytical scale and the average productivity data were transformed into kilograms per hectare (kg ha^{-1}). At that time, the growth of the teak plants was also evaluated by quantifying the height and diameter values at chest height (established at 1.3 m from the soil), through a hypsometer and a dendrometer, respectively.

Univariate and multivariate statistical analyses

The univariate statistical analysis of the data was conducted through the analysis of variance (F Test) and when significant results were obtained, the means were compared through Tukey's test ($p<0.05$ or 0.01), using the statistical program Sisvar (Statistical Analysis System, version 5.6) (Ferreira, 2011). The data were also analyzed through multivariate methods: hierarchical grouping method (HGM) and Principal Component Analysis method (PCA), at the following soil depths: 0 to 10 cm and 10 to 20 cm.

The objective of the hierarchical grouping method was to simultaneously analyze the variables on each use of the soil. Initially, the data had to be standardized in order to obtain a null mean and constant variance (Sneath and Sokal, 1973). Ward was used as an algorithm to obtain the groupings of similar accesses. On this method, the distance between two groups is defined as the sum of squares for all variables (Hair et al., 2005). The results of the analyses were shown in groups on the PCA biplot, which assisted in the identification and interpretation of access groupings.

PCA sized the set of variables according to the characteristics in order to observe the relations among the variables on the coordinate axes. These new orthogonal axes identified as main components and the values of the new score variables of the main components or main coordinates (Piovesan, 2009). The criterion by

Kaiser (1958) was used to select the components, considering the eigenvalues above 1. These conditions generate components with a relevant amount of information on the original variables. Then, the results were shown on Biplot graphs that related the variables to the cultivation systems and fertilizations.

RESULTS AND DISCUSSION

Macronutrients, organic matter and absorptive complex of the soil

The highest phosphorus contents (P) in the soil were observed at the 0 to 10 cm depth on fertilizations with sewage sludge (SS) ($p<0.05$), with an addition of 82% when compared to the control treatment (no fertilization) (Table 2). P showed the same behavior on the principal component analysis (PCA) with a high correlation with the SS treatment. The result of this behavior on biplot are close points between P and SS on the 0 to 10 cm layer (Figure 1). P and the other nutrients could not be evaluated on PCA and on the hierarchical grouping method (HGM), since they showed low variance.

These P increments on the 0 to 10 cm layer occurred due to the high supply of this element on the soil solution, since, according to the chemical composition of SS, 238 and 147 kg ha^{-1} of P were applied in the 2013 to 2014 and 2014 to 2015 crops, respectively. Increases on the P contents on the soil with the use of SS were also observed on intercropping cultures with eucalyptus and grass species, and the use of 30 Mg ha^{-1} offered 560 kg ha of P in the crops soils (Bonini et al., 2015). This confirms that, if the practice is ongoing, fertilization with SS may lead to the accumulation of labile P on the soil (Ricci et al., 2010; Bittencourt et al., 2012; Costa et al., 2014).

The monoculture system showed a higher P content (Table 2) at the 0 to 10 cm depth (16.2 mg dm^{-3}) in relation to the agroforestry system (11.22 mg dm^{-3}). This result probably occurred due to the fact that the forest systems on intercrops with annual cultures extract part of the available P on the soil solution, and most of it is exported on the grain crops.

The highest potassium contents (K^+) on the soil occurred on the agroforestry system with the use of mineral fertilizations ($p<0.05$), both at the 0 to 10 cm depth as at 10 to 20 cm (Table 2). On PCA, it was observed that K^+ showed no specific relationship across the treatments, since the vector related to K^+ showed a distance from all treatments on biplot (Figure 1). In addition, K^+ was the only element whose variability remained on CP2 and with a correlation value of 0.84 (Table 4).

These high K^+ contents on the soil on the agroforestry system might have occurred due to the successive potassic fertilization sin the millet (60 kg ha^{-1} of K_2O) and soybean intercropping (100 kg ha^{-1} of K_2O), for the 2013-2014 and 2014-2015 seasons, respectively, which increased exchangeable K^+ content of soil solution. On the other hand, the reduced K^+ contents observed on the monoculture occurred due to the fact that this system was not fertilized in between the rows of forest species, since there was no intercropped specie with annual cultures.

The fertilizations with sewage sludge showed the lowest K^+ content of the soil, with a variation between 37.0 and 43.7 mg dm^{-3} (Table 2). This inverse relationship was also observed on the multivariate analysis with inversed axes on biplot between K^+ and the SS fertilization (G2, Figure 1).

The SS fertilization was statistically similar to the control treatment (no fertilization), this is probably due to the fact that this byproduct composed of less concentration of K, since they offered only 23 and 32 kg ha^{-1} of K_2O on the first and second year, respectively. The main question is that this fertilization source showed no adequate levels of K^+ for an agricultural production demand on tropical soils. However, it is common for researches not to observe increments on the K^+ contents of the soil with SS fertilizations (Barbosa et al., 2007), usually, recommendations for new mineral fertilizations are necessary when only this organic byproduct is used as a potassic source (Ribeirinho et al., 2012).

The highest Ca^{2+} contents on the soil were observed on fertilization with SS, at the 0 to 10 cm depth ($p<0.05$). However, the Mg^{2+} contents showed no significant interactions ($p>0.05$) among the cropping systems and the fertilizations (Table 2). The fertilization with SS (G2) showed a high correlation with the Ca^{2+} and Mg^{2+} contents on biplot, as well as the pH values of the soil (Figure 1).

Increments on the Ca^{2+} contents on the soil occurred because SS goes through a treatment with quicklime (CaO) or hydrated lime [$Ca(OH)_2$] during the chemical stabilization processes, and it becomes a byproduct with a high concentration of this element. These results are in agreement with Zuba Junio et al. (2012), who observed increases on the Ca^{2+} contents on the soil at 0 to 10 cm depths, with the use of SS, reaching contents of 5.49 cmol$_c$ dm^{-3}.

The use of cattle manure (CM) showed low Ca^{2+} contents on the soil when compared to SS, yet, it was statistically similar ($p>0.05$) to the control treatment (no fertilization). This is probably due to the insufficient Ca^{2+} contents observed on CM (0.34 and 0.42 g kg^{-1}, during the first and second year, respectively). However, the lowest Ca^{2+} increments on the soil occurred with the use of mineral fertilizers, and it was even lower than the control treatment. The lack of Ca^{2+} on the mineral fertilizers N-P-K and the export of exchangeable bases on the crop of millet (2013-2014 crop) and soybean grains (2014-2015 crop) promoted reductions on the contents of this element on the soil solution.

The fertilization with SS promoted increments on the pH values and a reduction on the potential acidity ($H+Al^{3+}$) of the soil at the 0 to10 cm depth ($p<0.05$) (Table

Table 2. Effects of fertilizations on the chemical properties of the soils and theirs macronutrients contents in cultivation systems in 2015.

Tratament	P	K^+	Ca^{2+}	Mg^{2+}	OM	pH	$H+Al^{3+}$	BS	CEC	V
	--- mg kg^{-1} ---		--- $cmol_c\ dm^{-3}$ ---		%		--------- $cmol_c\ dm^{-3}$ ---------			%
Layer	**0-10 cm**									
	Agroforestry systems									
C. manure	2.5 ^{bA}	51.0 ^{bA}	2.7 ^{bA}	0.9	1.8	5.3 ^{bB}	1.3 ^{aA}	3.6 ^{bB}	5.0 ^{bB}	73 ^{bB}
S. sludge	11.2 ^{aB}	41.2 ^{cA}	6.2 ^{aA}	0.6	2.2	6.3 ^{aB}	1.1 ^{aA}	6.9 ^{aA}	8.0^{aA}	83 ^{aA}
M. fertilizer	2.2 ^{bA}	65.2 ^{aA}	2.0 ^{bB}	1.0	1.6	4.7 ^{cB}	2.0 ^{bB}	2.8 ^{cB}	4.8 ^{bB}	58 ^{cB}
Control	2.0 ^{bA}	36.5 ^{cB}	3.0 ^{bA}	0.9	1.6	5.1 ^{bB}	1.4 ^{aA}	3.6 ^{bB}	5.1 ^{bB}	71 ^{bA}
Layer	**Monocultures**									
C. manure	3.2 ^{bA}	52.7 ^{aA}	4.2 ^{bA}	1.1	1.8	5.9 ^{bA}	1.1 ^{aA}	5.6 ^{bA}	6.7 ^{bA}	82 ^{aA}
S. sludge	16.2 ^{aA}	43.7 ^{cA}	6.5 ^{aA}	0.6	2.1	6.7 ^{aA}	1.0 ^{aA}	6.9 ^{aA}	7.9 ^{aA}	87 ^{aA}
M. fertilizer	3.7 ^{bA}	51.7 ^{abB}	3.5 ^{bcA}	0.9	1.6	5.6 ^{bcA}	1.2 ^{aA}	4.6 ^{cA}	6.1^{bcA}	75 ^{bA}
Control	2.1 ^{bA}	45.7 ^{bcA}	3.0 ^{cA}	1.0	1.7	5.5 ^{cA}	1.2 ^{aA}	4.2 ^{cA}	5.7 ^{cA}	74 ^{bA}
F	6.8**	19.8**	4.2*	1.7$^{n.s.}$	1.4$^{n.s.}$	3.4*	3.1*	9.4**	8.1**	11.9*
V.C.	22.0	6.2	14.1	14.6	4.7	3.4	17.8	8.7	6.3	3.8
Layer	**10-20 cm**									
	Agroforestry systems									
C. manure	1.7	32.7 ^{bA}	2.2	0.6	1.7	5.2	1.9	2.7	4.3	63
S. sludge	7.5	37.0 ^{bA}	5.1	0.6	1.5	6.5	1.2	5.7	6.9	82
M. fertilizer	1.5	78.5 ^{aA}	1.5	0.5	1.6	5.5	2.0	2.3	4.2	55
Control	2.0	33.2 ^{bA}	0.6	0.6	1.5	5.0	1.5	2.7	4.1	64
Layer	**Monocultures**									
C. manure	1.8	36.0 ^{aA}	2.9	0.7	1.5	1.3	1.3	3.7	5.0	71
S. sludge	7.5	37.0 ^{aA}	4.5	0.6	1.7	1.2	1.2	5.2	6.4	81
M. fertilizer	2.5	43.0 ^{aB}	2.3	0.6	1.6	1.4	1.4	3.1	4.7	65
Control	1.2	31.7 ^{aA}	2.4	0.7	1.5	1.5	1.5	3.2	4.7	65
F	2.6 $^{n.s.}$	3.3*	0.5 $^{n.s.}$	0.3 $^{n.s.}$	0.6 $^{n.s.}$	1.6 $^{n.s.}$	2.1 $^{n.s.}$	0.7 $^{n.s.}$	0.6 $^{n.s.}$	0.8 $^{n.s.}$
V.C.	20.3	34.1	38.1	15.6	14.8	10.5	26.7	29.9	19.1	11.9

Means followed by different lowercase letters on the same row (comparison between fertilization methods within the same crop system) and uppercase letters on the column (comparison between crop systems) differ from each other according to Tukey's test ($p<0.01$ or 0.05). V.C: Variation coefficient; n.s., *, ** – not significant at 5%; significant at 5% and significant at 1% of probability according to the F test, respectively.

2). These results occurred due to the fact that, after a chemical stabilization, this byproduct is highly alkaline (Costa et al., 2014), yet, due to the fact that it adds high levels of Ca^{2+} to the soil solution, this promotes changes to the acidity properties of the soils. Corroborating with these results, Bittencourt et al. (2012) reported that SS increased the Ca^{2+} contents and the pH values of the soil solution, in addition to a significant reduction of $H+Al^{3+}$. However, some researchers have observed the opposite, with reductions on the pH values and increases on the $H+Al^{3+}$ content, using sewage sludge, however, they used byproducts without chemical stabilization (Cavalcanti et al., 2015).

The use of mineral fertilizers reduced the pH values and increased the $H+Al^{3+}$ values at the 0 to 10 cm depth on the agroforestry system, as verified on PCA (Figure 1), this is probably due to the removal of bases during the crop, as previously observed. In addition to the use of nitrogenous mineral fertilizers for the millet culture on the 2013 to 2014 crop (80 kg ha^{-1} of N as urea) and on the teak plants (45 g of N $plant^{-1}$, in the form of urea in two years), this promotes a reduction of the pH values on the soil solution due to the reactions that release H^+ ions on the transformation process of ammonium into nitrate (Cantarella, 2007), and it may intensify, mainly when the source of N used is urea (Malavolta, 2006; Almeida et al., 2015).

The agroforestry system showed a reduction on the sum of bases (SB) values and the cation exchange capacity (CEC) on fertilizations with CM, mineral fertilizer and control treatment ($p<0.05$). However, it maintained similar values to the monoculture when the fertilization

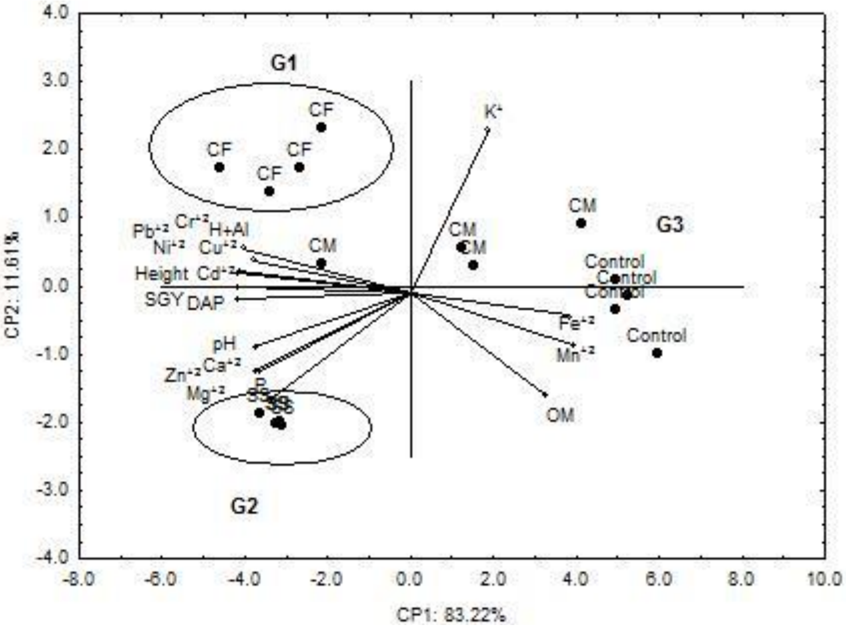

Figure 1. Principal component analysis (PCA) in agroforestry systems and Monocultures subjected to different fertilizations, at the 0-10 cm depth.

occurred with SS, this shows the capacity of this byproduct to maintain high levels of bases on the exchange complex on the soil solution, as also observed by the increments on the saturation of bases (V%). These higher V% values are in accordance with the pH increases of the soil solution with the use of SS, which is explained by the replacement of H^+ and Al^{+3} ions by the exchangeable bases (Ca^{+2}, Mg^{2+} and K^+) on the exchange sites of the soil colloids (Bonini et al., 2015).

The soil organic matter contents (SOM) showed no significant interaction between the fertilizations and the culture systems (p>0.05), both at the 0-10 cm and the 10-20 cm depths (Table 2). The SOM contents were higher for the treatments that used SS, however, the statistical analysis was not able to detect significant changes (p<0.05) for the soil organic matter after two years with organic fertilizations, which, in a way, could explain several changes to the dynamics of the chemical attributes of the soil. These results show that there is not a direct relationship between the source of organic fertilization and the culture system adopted, since both the agroforestry system and the monoculture received the same organic matter loads from CM and SS.

Cation micronutrients and heavy metals in the soil

The zinc contents (Zn^{2+}) showed an increase with high correlation on the SS fertilizations at the 0 to10 cm depth (p<0.05) (Table 3 and Figure 1). The increments on the Zn^{2+} contents on the soil with the use of SS have been observed on several researches on tropical soils (Zuba Junio et al., 2012; Nascimento et al., 2014; Cavalcanti et al., 2015) and, depending on the chemical characteristic of this organic fertilizer, the supply of the micronutrient may reach levels higher than 4 kg ha^{-1} (Albuquerque et al., 2015).

The excessive supply of Zn^{2+} on the soil solution with SS fertilizations did not promote visual toxicity symptoms on the plants, reduced growth on teak plants or grain productivity (Figures 2A, B and 3), since, during the chemical stabilization process of this organic fertilizer large amounts of calcium oxide (CaOH) are added, and when applied on the soil, it promotes an increase of pH, promoting the partial precipitation of Zn^{2+} on the soil solution (Nascimento et al., 2014).

However, when the culture systems are compared, the Zn^{2+} contents were reduced on the CS system, this is probably due to the higher nutritional demand on the previous millet and soybean cultures, on the 2013-2014 and 2014-2015 crops, respectively (Souza and Lobato, 2004).

The copper, iron, manganese, lead, cadmium, chrome and nickel contents did not show significant interactions across the culture systems and fertilizations (p>0.05), both at the 0-10 cm and the 10-20 cm depths (Table 3). In addition, these micronutrients also did not show a significant relationship to none of the evaluated treatments on biplot (Figure 1).

Zn^{2+} contents were reduced on the CS system, this is probably due to the higher nutritional demand on the previous millet and soybean cultures, on the 2013-2014

Table 3. Contents of cation micronutrients and heavy metals in the soil in cultivation systems subjected to different fertilizations, in Goiânia, state of Goiás, Brazil, 2015.

Tratament	Zn^{2+}	Cu^{2+}	Fe^{2+}	Mn^{2+}	Pb^{2+}	Cd^{2+}	Cr^{2+}	Ni^{2+}
	mg dm^{-3}							
Layer	**0-10cm**							
	Agroforestry systems							
C. manure	3.85^{bA}	3.87	64.47	33.47	0.012	0.012	0.015	0.010
S. sludge	6.60^{aB}	4.45	77.62	33.92	0.017	0.010	0.010	0.012
M. fertilizer	2.72^{bA}	4.85	62.62	28.87	0.015	0.012	0.012	0.015
Control	3.17^{bA}	3.55	60.72	29.02	0.017	0.017	0.015	0.010
Layer	**Monocultures**							
C. manure	4.17^{bA}	4.25	66.20	35.77	0.010	0.012	0.015	0.012
S. sludge	10.8^{aA}	4.35	74.55	31.45	0.012	0.012	0.010	0.015
M. fertilizer	3.57^{bA}	3.37	66.85	38.00	0.017	0.015	0.012	0.010
Control	3.15^{bA}	4.30	63.40	34.05	0.012	0.012	0.015	0.015
F	8.52**	$2.86^{n.s.}$	$1.52^{n.s.}$	$2.26^{n.s.}$	$0.97^{n.s.}$	$1.2^{n.s.}$	$0.90^{n.s.}$	$2.10^{n.s.}$
V.C.	19.70	19.79	5.38	13.83	35.19	34.78	27.76	33.81
Layer	**10-20cm**							
	Agroforestry systems							
C. manure	2.15	4.07	57.97	31.20	0.012	0.012	0.015	0.012
S. sludge	5.67	4.00	79.55	32.52	0.012	0.012	0.010	0.015
M. fertilizer	2.47	3.87	42.47	22.02	0.015	0.015	0.010	0.015
Control	2.10	3.55	51.05	28.37	0.015	0.012	0.010	0.012
Layer	**Monocultures**							
C. manure	2.17	3.70	54.87	34.80	0.015	0.010	0.015	0.012
S. sludge	5.92	4.02	83.90	37.92	0.015	0.012	0.015	0.015
M. fertilizer	2.45	3.80	58.30	36.10	0.012	0.015	0.010	0.012
Control	1.65	3.85	50.35	32.15	0.010	0.010	0.012	0.010
F	$0.89^{n.s.}$	$0.18^{n.s.}$	$1.49^{n.s.}$	$0.62^{n.s.}$	$0.95^{n.s.}$	$0.20^{n.s.}$	$0.91^{n.s.}$	$0.16^{n.s.}$
V.C.	14.18	23.56	7.94	28.0	40.29	35.99	29.18	38.55

Means followed by different lowercase letters on the same row (comparison between fertilization methods within the same crop system) and uppercase letters on the column (comparison between crop systems) differ from each other according to Tukey's test ($p<0.01$ or 0.05). V.C: Variation coefficient; n.s., *, ** – not significant at 5%; significant at 5% and significant at 1% of probability according to the F test, respectively.

and 2014-2015 crops, respectively (Souza and Lobato, 2004).

The copper, iron, manganese, lead, cadmium, chrome and nickel contents did not show significant interactions across the culture systems and fertilizations ($p>0.05$), both at the 0-10 cm and the 10-20 cm depths (Table 3). In addition, these micronutrients also did not show a significant relationship to none of the evaluated treatments on biplot (Figure 1). Although the copper and zinc contents are above the levels found on agricultural soils of tropical regions, these results were observed even for the control treatment (no fertilization). Basically, the contents of all micronutrients were kept at acceptable levels on the soil solution for agricultural production and environmental preservation, and they are in accordance with the Brazilian specifications by the National Environmental Council (Brasil, 2006).

Phytotechnical variables: Growth and production of plants

The height of the teak plants increased after two years with SS fertilizations ($p<0.05$), and values that were 15 and 12% higher in relation to the use of CM and mineral fertilizer were observed, respectively (Figure 2). These results probably occurred due to the higher P and Ca^{2+} supply on the soil solution (Table 1).

Table 4. Correlation coefficient of the main components (CP1 and CP2) of the variables.

Variable	CP1 (83.22%)	CP2 (11.61%)
Ca^{2+}	-0.92	-0.35
Mg^{2+}	-0.97	0.19
$H+Al^{3+}$	-0.93	0.31
K^+	0.51	0.84
P	-0.84	-0.51
Organic matter	0.72	-0.61
pH	-0.92	-0.20
Zn^{2+}	-0.89	-0.34
Cu^{2+}	-0.89	0.26
Mn^{2+}	0.90	-0.22
Plant height	-0.97	0.19
Diameter of teak plants	-0.99	0.11
Productivity	-0.98	0.03

Phosphorus (P), potassium (K^+), calcium (Ca^{+2}), magnesium (Mg^{+2}), hydrogenionic potential (pH), potential acidity ($H+Al^{3+}$), zinc (Zn^{2+}), copper (Cu^{2+}), iron (Fe^{2+}), manganese (Mn^{2+}), lead (Pb^{2+}), cadmium (Cd^{2+}), chrome (Cr^{2+}) and nickel (Ni^{2+}) on the culture systems subjected to different fertilizations, at the 0-10 cm depth.

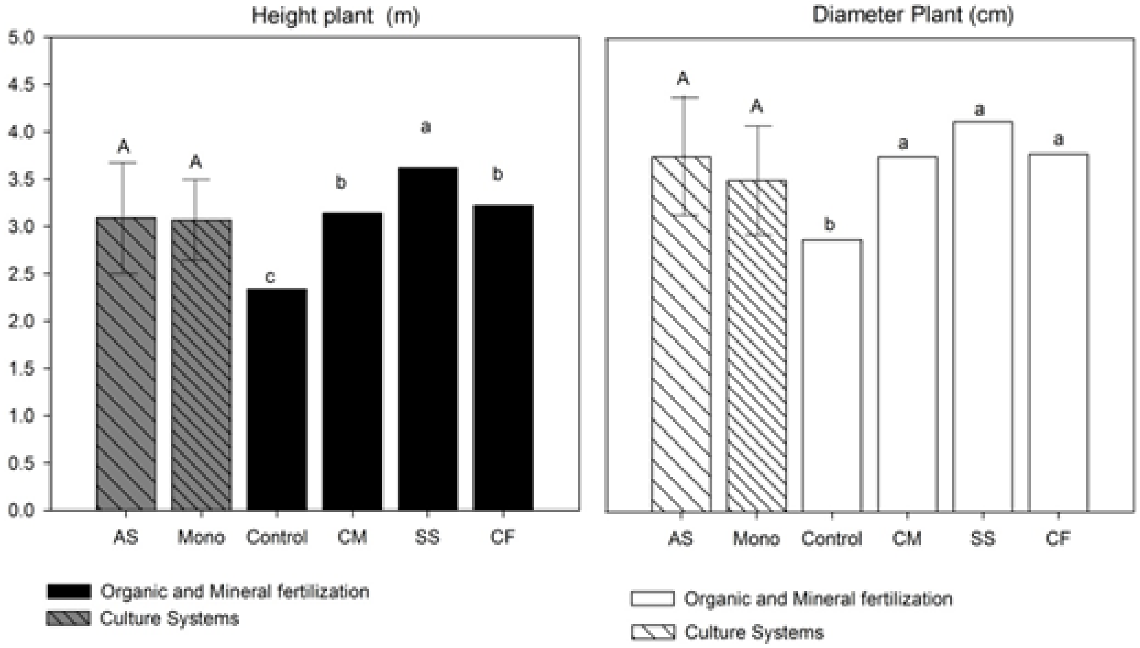

Figure 2. Height (m) and diameter (cm) of teak plants on culture systems with soybean (AS) or monoculture (Mono), subjected to different fertilizations (Control; Cattle manure-CM; Sewage sludge-SS and Mineral fertilizer-CF), *cerrado* region, Goiânia, Goiás, 2015. On the graph: bars identified with different uppercase letters (Plant height: F: 0.03 and Plant diameter: Variation coefficient: 3.23) and lowercase letters (Plant height: F: 56.57 and Plant diameter: Variation coefficient: 14.53) show a significant difference across the treatments, according to the F test ($p<0.01$).

When absorbed by the radicular system of the plants, P and Ca^{2+} are responsible for the primary growth (Malvolta, 2006). P is extremely important for the initial growth of teak plants, mainly when offered on organic fertilizers (Smitha et al., 2016). In addition, teak is considered as a calcicolous plant, that is, it absorbs high

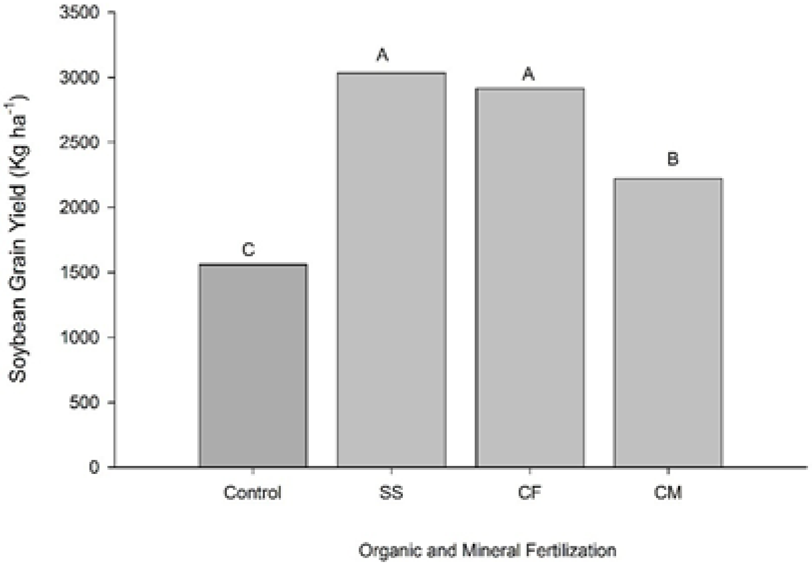

Figure 3. Soybean grain yield (kg ha^{-1}) on a intercropping culture system with and soy (AS) subjected to different fertilizations (Control; Cattle manure-CM; Sewage sludge-SS and Mineral fertilizer-CF), *cerrado* region, Goiânia, Goiás, 2015. On the graph: bars identified with different uppercase letters (F=214.35** Variation coefficient: 3.84)show a significant difference across the treatments, according to the F test ($p<0.05$).

amounts of Ca^{2+} on the soil solution (Ribeiro et al., 2006). Researchers have reported that the Ca^{2+} supply positively influences the growth parameters of teak (Favare et al., 2012), and this is considered as one of the most limiting elements for the nutrition of this species (Ribeiro et al., 2006).

The diameter of the teak plants showed increments of 23, 30 and 24% with fertilizations with CM, SS and mineral fertilizer, respectively, in relation to the control treatment ($p<0.05$) (Figure 2). Both the height and diameter of teak plants showed no differences in relation to the culture systems ($p>0.05$) (Figure 2). This result was also observed on PCA, with the lack of association among the phytotechnical variables (Figure 1). The fact that the agroforestry system showed a growth (height and diameter of the teak plants) of the teak plants that was similar to the monoculture is a positive factor for the sustainable production models. This is because it optimizes the use of areas for a diversified production, both of forest species and bean cultures. In certain agrosystems, intercropping may promote competition and reduce the growth of the tree species and the yield of grain cultures; this fact was not observed on this research.

The quantified soybean grain yield equivalent to single cultures inserted on the agroforestry system showed higher yields with SS and CF fertilizations ($p<0.05$), showing values of 3.035 and 2.915 kg ha^{-1}, respectively (Figure 3). The productivity results obtained are considered close to the Brazilian means on single production systems with soy beans on the 2014-2015 crop, estimated at 3.016 kg ha^{-1}, according to the National Supply Company (Conab, 2015). The use of SS has also shown an increase on the productivity of sunflower seeds (Albuquerque et al., (2015), in addition to similar productivities when mineral fertilizers are used on cultures for the production of castor beans (Cavalcanti et al., (2015).

Grouping of treatments and variables

After the correlation among all variables and treatments studied on PCA, the same group division on the grouping analysis was observed (results integrated to the biplot). On the biplot, the creation of 3 well defined groups is observed (G1, G2 and G3), as seen on Figure 1. It is noteworthy that, for this response, we used the variables obtained on the 0-10 cm soil layer.

The G1 and G2 groups, represented on SS and mineral fertilizer (CF), respectively, showed well defined, dissimilar and isolated characteristics in relation to each other. However, group G3 showed the control and CM groups with no distinction and high similarity in relation to each other (Figure 1). With these results, we may state that for the chemical attributes of the soil and the phytotechnical characteristics, the use of CM is equivalent to the control treatment (no fertilization) up to the second culture year. This is partially justified by the low content of nutrients on the CM characterization

(Table 1), since this organic byproduct was applied in the liquid state, with high humidity of 97 and 98%, on the first and second year of application, respectively. On PCA, we may observe that he variability of the nutrients and the phytotechnical variables were maintained on CP1 (83.22%), except the K^+ contents. The variance of this nutrient was retained on CP2 (11.61%), according to Table 3.

The Ca^{2+}, Mg^{2+}, P, Cu^{2+} contents and the phytotechnical characteristics related to height, diameter of the teak plants and grain productivity showed values with negative correlations of -0.92, -0.97, -0.84, -0.89 and -0.97, -0.99 and -0.98, respectively. On the other hand, organic matter and Mn^{2+} showed positive correlations of 0.72 and 0.90, respectively (Table 4). The variables that showed negative correlation values showed the same behavior in relation to the axes. The same behavior may be observed with the positive correlation values, however, they remain on the opposite direction of the axis (Figure 1 and Table 4).

Under these conditions, it may be stated that the treatments with SS, CM, mineral fertilizer and control showed different nutrient contents on the soil after two years of culture with different correlations among the nutrients (Figure 1). Considering these results, the advantages of using SS in relation to mineral fertilizers are also noteworthy, and it has a great potential to replace them on agroforestry systems. In addition to preserving the natural resources, since the low levels of heavy metals on the soil are maintained, it would also enable animals to graze on fodder plants, since it is right after the second year that some rural properties change the production systems used, with the option of changing from the agroforestry system (AF) and becoming a crop-farming-forestry integration system (CFFi), however, rather intensified due to the insertion of the new animal component.

Conclusions

Regardless of the culture system, after two years with successive fertilizations, sewage sludge increases the calcium, phosphorus and zinc contents on the soil, as well as the pH, sum of bases and cation exchange capacity values, at the 0 to 10 cm depth. However, the potassium contents are lower in relation to the use of mineral fertilizers, both at the 0 to 10 cm and the 10 to 20 cm depths. Teak plants on agroforestry systems show similar heights to the monoculture plants, and they are higher on fertilizations with sewage sludge. Moreover, the productivity of soy beans on the agroforestry system shows similar yields in relation to the use of sewage sludge and mineral fertilizers. Therefore, farmers are encouraged to adopt agroforestry systems and the practice of organic fertilization with sewage sludge, associating the quality of the chemical attributes of the soil, the growth of forest species and the yield of soy beans.

Conflict of Interests

The authors have not declared any conflict of interests.

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REFERENCES

Albuquerque HC, Zuba Junio GR, Sampaio RA, Fernandes LA, Zonta E, Barbosa CF (2015).Yield and nutrition of sunflower fertilized with sewage sludge. Rev. Bras. Engenharia Agríc. Ambiental 19(6):553-559.

Almeida RF, Silveira CH, Mota RP, Arruda EM, Naves ER, Souza LC, Mendonça ES, Wendling B (2015). Sugarcane residue incubated in soil at different temperatures and nitrogen fertilization. Aust. J. Crop Sci. 9(8):781-789.

Barbosa GMC, Tavares Filho J, Brito OR, Fonseca ICB (2007).Efeito residual do lodo de esgoto na produtividade do milho safrinha. Rev. Bras. Ciênc. Solo 31(3):601-605.

Bittencourt S, Serrat BM, Aisse MM, Marin LMKS, Simão CC (2012). Application of sludges from water treatment plant and from sewage treatment plant in degraded soil. Engenharia Sanit. Ambient 17(3):315-324.

Bonaudo T, Bendahan AB, Sabatier R, Ryschawy J, Bellon S, Leger F, Magda D, Tichit M (2014). Agroecological principles for the redesign of integrated crop–livestock systems. Eur. J. Agron. 57:43-51.

Bonini CSB, Alves MC, Montanari R (2015). Lodo de esgoto e adubação mineral na recuperação de atributos químicos de solo degradado. Rev. Bras. Engenharia Agríc. Ambiental 19(4):388-393.

Brasil (2006) Ministério do Meio Ambiente. Conselho Nacional de Meio Ambiente. Resolução 375:1-32.

Buller LS, Bergier I, Ortega E, Moraes A, Bayma-Silva G, Zanetti MR (2015).Soil improvement and mitigation of greenhouse gas emissions for integrated crop–livestock systems: Case study assessment in the Pantanal savanna highland, Brazil. Agric. Syst. 137:206-219.

Cantarella H, Novais RF, Alvarez VVH, Barros NF, FontesRLF, Cantarutti RB, Neves JCL (2007). Nitrogênio. In: Fertilidade do Solo. Sociedade Bras. Ciênc Solo pp. 375-470.

Cavalcanti TFM, Zuba Junio GR, Sampaio RA, Carneiro JP, Oliveira ESA, Rodrigues MN (2015).Yield of castor bean fertilized with sewage sludge and potassium and magnesium sulphate. R. Bras. Eng. Agríc. Ambiental. 19(8):773-779.

Companhia Nacional de Abastecimento (2015). Acompanhamento da safra brasileira de grãos: Décimo levantamento. Brasília 2(10):1-109.

Costa VL, Maria IC, Camargo AO, Grego CR, Melo LCA (2014). Distribuição espacial de fósforo em Latossolo tratado com lodo de esgoto e adubação mineral. Rev. Bras. Engenharia Agríc. Ambiental 18(3):287-293.

Empresa Brasileira de Pesquisa Agropecuária (2009). Manual de análises químicas de solos, plantas e fertilizantes. 2.ed. Brasília: Embrapa Inf. Tecnol. 627 p.

Empresa Brasileira de Pesquisa Agropecuária (2011). Centro nacional de pesquisas de solos. Manual de métodos de análises de solos. 2.ed. Rio de Janeiro: Embrapa Solo 230 p.

Empresa Brasileira de Pesquisa Agropecuária (2013). Sistema Brasileiro de classificação de Solos. 3.ed. Rio de Janeiro: Embrapa

Solos 350 p.

Favare LG, Guerrini IA, Backes C (2012). Níveis crescentes de saturação por bases e desenvolvimento inicial de teca em um Latossolo de textura média. Ciênc. Florest. 22(4):693-702.

Ferreira DF (2011). Sisvar: um programa para análises e ensino de estatística. Rev. Symp. 6:36-41.

Hair JF, Anderson RE, Tatham RL, Black WC (2005). Análise multivariada de dados. 5ª ed. São Paulo. Bookman Editora 688 p.

Kaiser HF (1958). The varimax criterion for analytic rotation in factor analysis. Psychometrika 23(3):187-200.

Malavolta E (2006). Manual de nutrição mineral de plantas. São Paulo: Editora Agron. Ceres 638 p.

Muraishi CT, Alves MC, Silva Júnior A, Souza ZM (2011). Chemical attributes of a savannah Typic Hapludox soil under management systems. Acta Scientiarum. Agronomy 33(3):551-557.

Nascimento AL, Sampaio RA, Cruz SF, Zuba Junio GR, Barbosa CF, Fernandes LA (2014). Metais pesados em girassol adubado com lodo de esgoto submetido a diferentes processos de estabilização. R. Bras. Eng. Agríc. Ambiental 18(7):694-699.

Pelissari AL, Caldeira SF, Santos VS, Santos JOP (2012). Correlação espacial dos atributos químicos do solo com o desenvolvimento da teca em Mato Grosso. Pesqui. Florest. Bras. 32(71):247-256.

Piovesan P, Araújo LB, Dias CTS (2009). Validação cruzada com correção de autovalores e regressão isotônica nos modelos de efeitos principais aditivos e interação multiplicativa. Ciênc. Rural 39:1018-1023.

Ribeirinho VS, Melo WJ, Silva DH, Figueiredo LA, Melo GMP (2012). Fertilidade do solo, estado nutricional e produtividade de girassol, em função da aplicação de lodo de esgoto. Pesqui. Agropecuária Trop. 42(2):166-173.

Ribeiro FA, Macedo RLG, Venturim N, Morais VM, Gomes JE, Junior MY (2006). Efeitos da adubação de plantio sobre o estabelecimento de mudas de *tectona grandis* l.f. (teca). Rev. Científica Eletrônica Engenharia Florest. 4(7):1-13.

Ricci AB, Padovani VCR, Junior DRP (2010).Uso de lodo de esgoto estabilizado em um solo decapitado. II - atributos químicos e revegetação. Rev. Bras. Ciênc. Solo 4(2):543-551.

Smitha JK, Sujatha MP, Sureshkumar P (2016). Availability and uptake of P from organic and in organic sources of P in teak (*Tectona grandis*) using radio tracer technique. Afr. J. Agric. Res. 11(12):1033-1039.

Sneath PHA, Sokal RR (1973). Numeric taxonomy: the principles and practice of numerical classification. San Francisco: W.H.Freeman 573 p.

Souza DMG, Lobato E (2004).Cerrado: correção do solo e adubação. Planaltina, Distrito Federal: Embrapa Cerrados 416 p.

Tejada M, Gonzalez JL, García-Martínez AM, Parrado J (2008). Effects of different green manures on soil biological properties and maize yield. Bioresour. Technol. 99(6):1758-1767.

Zuba Junio GR, Sampaio RA, Nascimento AL, Carneiro JP, Santos LDT, Fernandes LA (2012). Produção de milho adubado residualmente com composto de lodo de esgoto e fosfato de Gafsa. Rev. Bras. Engenharia Agríc. Ambient.16(12):1289-1297.