Australian Journal of Crop Science
AJCS
AJCS 9(5):431-437 (2015) ISSN:1835-2707

Chemical attributes of soil fertirrigated with biodigester effluent of swine origin

Arthur Floresta Coletto[1], Risely Ferraz de Almeida[2*], Joseph Elias Rodrigues Mikhael[3], Beno Wendling[1], Reginaldo Camargo[1]

[1]Institute of Agricultural Sciences, ICIAG, University Federal of Uberlandia - UFU, Uberlandia, MG, Brazil
[2]Agrarian and Veterinarian Faculty, São Paulo State University (FCAV/UNESP), Department of Exact Sciences, Jaboticabal, SP, Brazil
[3]School of Plant, Environmental and Soil Sciences Office 104 M.B. Sturgis Hall, LSU Campus, Brazil

***Corresponding author: rizely@gmail.com**

Abstract

Swine production is a significant and growing part of Brazilian agriculture. Our objective was to determine nutrient availability in the soil after swine waste applications to pastureland and eucalyptus forestland and then compare these levels to those in the Cerrado (the Brazilian savannah). We concluded that applications of swine waste increased macro/micronutrient availability. Applications of swine waste were associated with higher concentrations of aluminum (Al^{+3}), hydrogen and aluminum (Al+H), total organic carbon and microbial biomass carbon in the Cerrado and higher nutrient concentrations in pastures and eucalyptus stands. The topography and seepage rates should be considered when using pig manure as a soil fertilizer. Applications of pig manure increase macro and micronutrient availability in the soil. Applications in the Cerrado are related to higher concentrations of Al, Al+H, total organic carbon and soil microbial biomass, whereas applications to pasture and Eucalyptus sites lead to higher nutrient concentrations. None of the soil-use types examined in the study have characteristics similar to natural Cerrado. Pasture 1 was the most dissimilar to Cerrado, followed by Pasture 3, 4 and 2 and Eucalyptus.

Keywords: Swine production; Soil fertility; Wastewater.

Introduction

Swine production in Brazil is an important part of the agricultural sector and ranks fourth in the world in production and export numbers (Mapa, 2014). The state of Minas Gerais is the fourth largest producer in Brazil and accounts for just over 8.5% of total production (Abipecs, 2011). As swine production increases, swine waste also increases (Losinger and Sampath, 2000). Waste production varies depending on production phase; however, daily waste per animal averages 8.6 liters over the entire production cycle in Brazil (Embrapa, 2004). Swine waste is composed of not only feces and urine, but also water spilled during drinking and cleaning, waste feed, hair, dust and other materials associated with raising the animals (Konzen, 1998). As a soil fertilizer, pig manure provides nutrients for the soil (Rotkittikhuna et al., 2007). Pig manure is frequently added directly to the soil as a cost effective fertilizer (Bernal et al., 2009). Nevertheless, improper use can harm the soil by clogging macropores, which can seal the soil surface and hinder the entrance of water and gas exchange between atmosphere and soil (Yin et al., 2014). Improper use can also lead to soil salinization, heavy metal pollution of the soil (Lu et al., 2014; Cang et al., 2004; Wang et al., 2013) and plants and the spread of pathogens to animals and humans (Lu et al., 2014; Toth and Feng, 2011). Therefore, the use of this type of waste in the soil should be carried out only after appropriate analysis of the soil and waste and consideration of site-specific physical and chemical characteristics. It is important to perform detailed studies of soil and waste treatment before its use on crops (Silva, 2011).

Thus, the objective of this study was to evaluate nutrient availability in the soil after applications of pig manure to pasture and eucalyptus stands and compares these values to those of Cerrado (Brazilian savannah) soils.

Results and discussion

Univariate statistical: Total organic carbon (TOC) and Soil microbial biomass (SMB)

Cerrado had the highest average TOC values, which were 58.5% higher than those of the lowest average TOC values in Pasture 1 (Fig. 2A). The TOC values of the Eucalyptus soil were also high, but statistically different from those of Cerrado (Fig. 2A). High TOC concentrations in the soil surface of Cerrado and Eucalyptus are due to the addition of litter and from the permanence and decay processes (Roscoe and Machado, 2002). These results agree with those found in a comparison of Cerrado with areas occupied by eucalyptus for 34 years and highly grazed pasture (Lima et al., 2008). Just as the TOC levels in the Cerrado were high, the C-SMB quantities were also high (Fig.2B). This increase in C-SMB is a result of better moisture conditions in the soil (Table 1). According to Almeida et al (2014a), higher concentrations of plant matter in the soil lead to greater microorganism activity. Espindola et al (2001) studied Planossol planted with *Paspalum notatum* Flugge cv., and also found that high interference in SMB was associated with high moisture (precipitation rate). In addition to these factors, De-Polli and Guerra (1999) found a strong relationship between organic

Table 1. Gravimetric moisture, sulfur ($S\text{-}SO_4$), sum of bases (SB), aluminum (Al^{+3}) and hydrogen plus aluminum (H+Al) in the soil with different soil use types in the Triangulo Mineiro region of Brazil: Native Cerrado (CE), *Eucalyptus* sp. (EU) and four *Brachiária decumbes* pasture areas (P1, P2, P3 and P4).

	Soil Moisture	$S\text{-}SO_4$*	Al^{+3}*	H+Al*	SB*
	g. g^{-1}	*mg dm*$^{-3}$		*cmol*$_c$ *dm*$^{-3}$	
Cerrado (CE)	1.63	2.74 B	1.07 A	7.72 A	0.89 D
Eucalyptus (EU)	1.5	51.75 A	0.02 B	4.67 B	3.70 A
Pasture 1 (P1)	0.49	12.25 B	0.00 C	3.30 C	1.94 C
Pasture 2 (P2)	0.42	13.50 B	0.00 C	4.07 AB	3.09 B
Pasture 3 (P3)	1.08	16.75 B	0.00 C	3.22 C	2.25 C
Pasture 4 (P4)	1.36	40.50 A	0.00 C	3.50 C	2.99 B

* Significant results without interactions between variables, individual uppercase letters in columns (with averages by usage type) are statistically different Tukey ($p<0.05$).

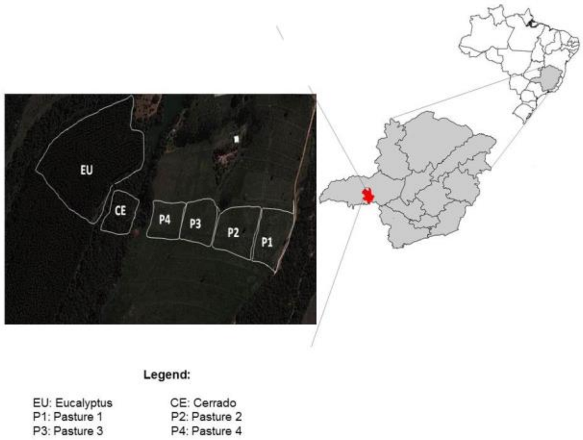

Fig 1. Map showing the site location Cerrado, Eucalyptus and pasture (P1, P2, P3 and P4) located at the Fazenda da Tenda farm in the municipality of Uberlandia, Triangulo Mineiro region, Minas Gerais, Brazil.

Table 2. Availability of boron (B), copper (Cu), iron (Fe), manganese (Mn), zinc (Zn) and pH (H_2O) in the soil under different types of soil use in the Triangulo Mineiro region of Brazil: Native Cerrado (CE), *Eucalyptus* sp. (EU) and four *Brachiária decumbes* pasture areas (P1, P2, P3 and P4).

Soil use	B	Cu	Fe	Mn	Zn	Na
			-------------------- mg dm^{-3} --------------------			
CE	0.08 B	1.90 D	244.00 A	9.82 BC	3.47 F	-
EU	0.23 A	16.12 A	179.50ABC	24.45 A	177.95A	-
P1	0.10 B	5.60 C	109.50 C	14.05 B	65.05E	-
P2	0.16AB	15.75 A	155.00AB	21.67 A	162.42B	-
P3	0.12 B	6.17 C	236.50 C	6.62 C	98.42 D	-
P4	0.22 A	10.60 B	230.25 BC	7.00 C	144.27 C	-
DMS:	0.02	3.37	80.54	1.17	3.09	-

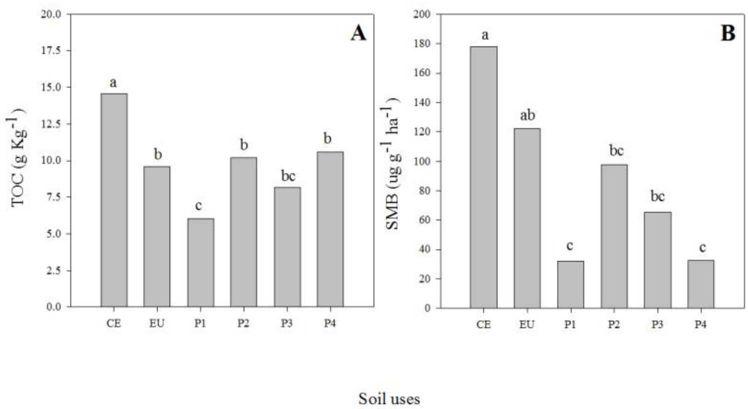

Fig 2. Carbon organic of soil total-TOC (**A**) and Microbial Biomass-SMB (**B**) under different soil use types in the Triangulo Mineiro region of Brazil: Native Cerrado (CE), *Eucalyptus* sp. (EU) and four *Brachiária decumbes* pasture areas (P1, P2, P3 and P4). In the Fig., TOC: CV – 14.64; DMS – 9.86 and SMB: CV – 39.82 and DMS – 88.04.

matter accumulation in the soil, nutrient cycling and energy flow. The difference in average TOC and SMB between Cerrado and Eucalyptus, which both had high surface soil levels of organic material and moisture, results from the lower quality of the organic litter in the Eucalyptus area. According to Pulrolnik et al. (2009), dry litter from Eucalyptus is nutritionally poor, especially in phosphorus and potassium, and includes twigs of varying sizes. This low nutrient availability in the soil is conditioned by lower organic material decomposition rates and lower nutrient availability for SMB (Cobo et al., 2002). TOC and SMB concentrations were lower in pasture areas than in Cerrado and Eucalyptus. This difference was greatest in Pasture1 and lower in Pasture 2 and Pasture 4 (Fig.2A). Lower C levels in pasture soils than in Cerrado and Eucalyptus soils were also found by Almeida et al (2014b) in pastures with Turkey litter applications in the Triangulo Mineiro region of Brazil. High TOC and SMB concentrations in Pasture2 and 4 are characteristics of root development and distribution that improves bonding between mineral particles and the aggregate. Additionally, grasses generally have higher C:N rations and help provide more carbon to the soil due to rhizome deposition, root death and lower microbiota involvement (Coutinho et al., 2010).

Univariate statistical: Nutrient availability in the soil

The highest concentrations of macronutrients (K^+, Ca^{+2} e Mg^{+2}) were in the Eucalyptus area and the lowest in the Cerrado area with values that were 75.60%, 72.50% and 78.40% lower for K^+, Ca^{+2} and Mg^{+2} than those of Eucalyptus (Fig. 3). Consequently, the sum of bases (SB) in the soil was higher in Eucalyptus, followed by Pasture 4 and 2. Cerrado had the lowest concentrations of SB and S-SO_4 (Table 1). Among pasture areas, K^+ availability was lowest in Pasture 1 and ranged from 0.37 to 0.39 $cmol_c\ dm^{-3}$ of K^+ in the other pasture areas. Mg^{+2} and Ca^{+2} were highest in Pasture 2 (0.90 and 1.8 $cmol_c\ dm^{-3}$, respectively) followed by Pasture 4 (0.83 and 1.77 $cmol_c\ dm^{-3}$, respectively) (Fig. 3).

The highest average P concentrations were in Pasture 2, Pasture 4 and Eucalyptus and the lowest in Cerrado (7.07 mg dm^{-3}). Not only did Cerrado have lower available P, but also had lower pH in water (Fig.4), a high concentration of Al^{+3} and H + Al (Table 1) and a high correlation between P and soil pH (r=0.728). In general, available P is highest when pH is between 6.0 and 6.5 because phosphorus fixation is lowest at these pH levels (Malavolta, 2006). Higher nutrient levels in pastures are due to pig manure applications that contribute P, K^+, Ca^{+2}, Mg^{+2}. Pig manure possesses these nutrients because of contributions from the pig diet, which especially influences P and K^+. K^+ is highly water-soluble and is therefore more highly concentrated in the urine of these animals. This solubility can lead to seepage losses from manure storage areas (Konzen, 1998). Some authors affirm that long-term use of high concentrations of pig manure can cause soil salinization due to nutrient accumulation (Girotto, 2007; Seganfredo, 2000). Thus, manure application quantities should be monitored. Regarding micronutrients, Cerrado and Pasture 3 had high quantities of Fe, whereas Cerrado had the lowest levels of Zn, B and Cu. Conversely, Eucalyptus had the highest levels of B, Cu, Fe, Mn and Zn (Table 2), averaging 0.23, 16.12, 179.50, 24.45 and 177.95 mg dm^{-3}, respectively. Eucalyptus may have higher levels of micronutrients because of nutrients leached from higher elevations and transported to the lower elevation of Eucalyptus (Fig. 3). This explanation is strengthened given that manure applications were the same at all sites. Some studies have shown that soils receiving pig manure applications have movement of elements that potentially cause misbalance and damage in the deepest layers of the soil. These conditions require changes in how manure is used as a fertilizer in agropastoral production (Konzen, 2003). Zn levels varied significantly among pasture sites. These levels were highest in Pasture 2 and 59.94%, 39.40% and 11.17% lower at Pasture 1, 3 and 4 respectively (Table 2). Copper levels were lowest in Pasture 1 and 3 and highest in Pasture 2. B concentration was highest in Pasture 4 but did not vary significantly in the other pasture sites, oscillating between 0.10 and 0.16 mg dm^{-3}. Pasture 4 and 3 had the lowest concentrations of Mn. Mn levels were 50.17% and 52.88% higher in Pasture 1 and 67.69% and 69.45% higher in Pasture 2 than in Pasture 4 and 3, respectively (Table 2). Na^+ was not found in these sites. Konzen (2003) worked with a red Oxisol in the Cerrado (Patos de Minas, MG) and also found high Cu and Zn concentrations in soil with increasing applications of pig manure (45, 90 and 135 $m^3\ ha^{-1}$) over three successive years. The same study reported Cu and Zn values that varied between 1 and 22 mg kg^{-1} and 1.2 a 2.8 mg kg^{-1} of soil, respectively. Even though micronutrient levels in the Cerrado soil were high, they were not toxic because, according to Boletim 100 (Raij et al., 1997) B and Cu levels were below 3.0 and 50.0 mg kg^{-1} of soil, respectively. Nevertheless, Zn and Fe concentrations are still considered toxic because they were greater than 130 and 100 mg kg^{-1} of soil, respectively (Raij et al., 1997). Thus, the quantities of pig manure applications are associated with high Zn and Fe levels in the 0.0-0.2 m layer of the soil. Lower applications are recommended given that Zn is extremely harmful to animal and human health. For pastures with intensive grazing, Konzen (2003) recommends pig manure applications from 150 to 180 $m^3\ ha^{-1}$ per year, divided into 5-9 applications.

Multivariate Statistical: Nutrient availability in the soil

Hierarchical cluster analysis showed that the variables used in our study form 4 groups, with a cutoff line of 4.5. Cerrado and Pasture 1 were distinct from the other sites and were therefore isolated into Group 1 and 4. Similarities existed between Eucalyptus and Pasture 2 (Group 2) and Pasture 4 and 3 (Group 3) (Fig.5). Therefore, none of the soil-use types was similar to natural Cerrado. Pasture 1 was most dissimilar to Cerrado, followed by Pasture 3, 4 and 2, and Eucalyptus. The pasture distinction is due to their low concentrations of nutrients, TOC and SMB. Principal component analysis confirmed the groupings found in the principal component analysis (Fig.6). Variance was concentrated in the CP1 component (58.79% of the variance) followed by CP2 (24.38%). Together, these components accounted for 83.17% of total variance. These results are consistent with the criteria established by Sneath and Sokal (1973), which stipulates that the CP used for interpretation should explain at least 70% of data variation. In Table 3, the attributes with the highest correlation coefficients in the first principal component were Ca^{+2} (r = 0.94), Zn (r = 0.94), Al^{+3}(r = -0.92), Mg^{+2} (r = 0.90), P (r = 0.89), pH-H_2O (r = 0.88), Cu (r = 0.86), K^+ (r = 0.86), H+ Al^{+3}(r = -0.77), B (r = 0.75), COT (r = -0.6), S-SO_4 (r = 0.59), SMB (r = -0.54) and Mn (r = 0.50). Attributes in the second principal component were TOC (r = -0.71), SMB (r = -0.75) and Mn (r = 0.50). These correlations are shown in Table 3 and represented by vectors for each attribute in Fig.6. Among all the variables, Fe and S-SO_4 showed similar conditions under all soil-use types.

Table 3. Correlation coefficients of the principal components (CP1 and CP2) for: total organic carbon (TOC), microbial biomass carbon (C-SMB), pH (H_2O), phosphorus (P), potassium (K^+), calcium (Ca^{+2}), magnesium (Mg^{+2}), aluminum (Al^{+3}), hydrogen plus aluminum (H+Al), sulfur ($S\text{-}SO_4^{-2}$), boron (B), copper (Cu), iron (Fe), manganese (Mn), zinc (Zn) and cation exchange capacity (T) in the soil under different uses in the Triangulo Mineiro region of Brazil.

Variables	CP-1	CP-2	Variables	CP-1	CP-2
TOC	-0.6	**-0.71**	$H+Al^{+3}$	**-0.77**	-0.6
SMB	**-0.54**	**-0.75**	$S\text{-}SO_4$	**0.59**	-0.21
pH – H_2O	**0.88**	0.35	B	**0.75**	-0.46
P	**0.89**	-0.18	Cu	**0.86**	-0.46
K^+	**0.86**	-0.21	Fe	-0.42	-0.34
Ca^{+2}	**0.94**	-0.3	Mn	**0.50**	-0.50
Mg^{+2}	**0.90**	-0.34	Zn	**0.94**	-0.3
Al^{+3}	**-0.92**	-0.36	T	-0.27	-0.94

[1] P, B, Cu, Fe, Mn, SB, $S\text{-}SO_4$, Zn and Na are expressed in mg dm^{-3} and K^+, Ca^{+2} and Mg^{+2} in $cmol_c\ dm^3$. Correlations in bold (absolute value >0.50) were considered highly significant in interpreting the principal component analysis.

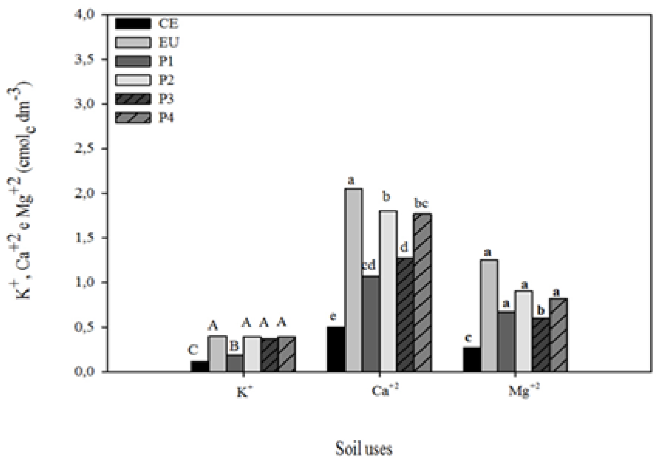

Fig 3. Potassium (K^+), calcium (Ca^{+2}) and magnesium (Mg^{+2}) availability under different soil use types in the Triangulo Mineiro region of Brazil: Native Cerrado (CE), *Eucalyptus* sp. (EU) and four *Brachiária decumbes* pasture areas (P1, P2, P3 and P4). Bars identified by capital letters compare K^+ (DMS: 0.009) availability under different soil use types. Bars with bold lowercase letters and bold lowercase letters compare Ca^{+2} (DMS: 0.200) and Mg^{+2}(DMS: 0.160), respectively. Distinct letters represent statistically different values (Tukey, p<0.05).

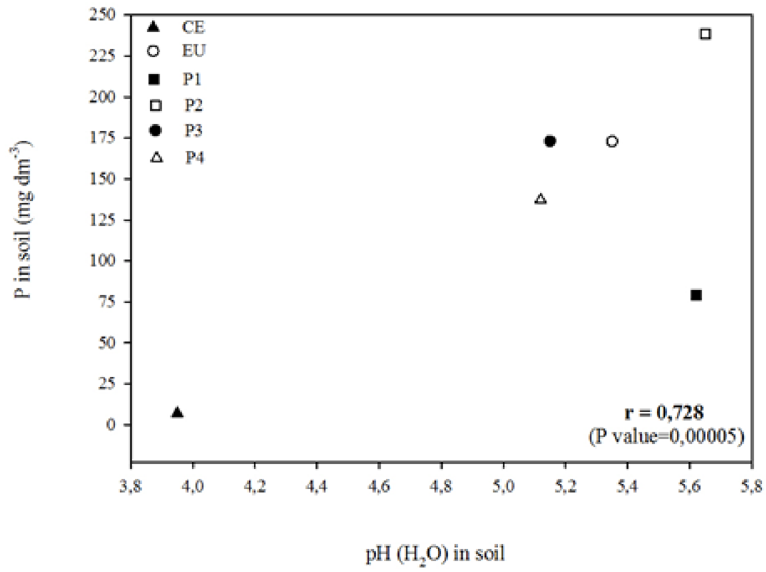

Fig 4. Available phosphorus - P (mg dm^{-3}) and pH (H_2O) of the soil under different types of soil use in the Triangulo Mineiro region of Brazil: Native cerrado (CE), *Eucalyptus* sp. (EU) and four *Brachiária decumbes* pasture areas (P1, P2, P3 and P4).

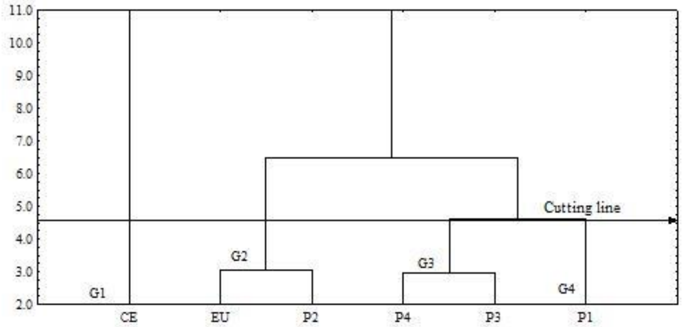

Fig 5. Dendrogram from hierarchical cluster analysis showing groupings based on soil-use types: Native Cerrado (CE), *Eucalyptus* sp. (EU) and four *Brachiária decumbes* pasture areas (P1, P2, P3 and P4).

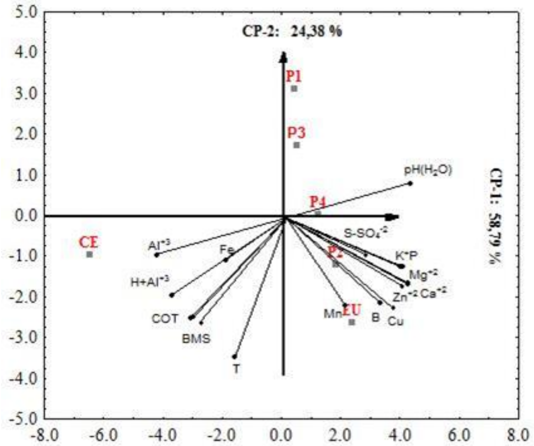

Fig 6. Principal component analysis (PCA) of: Total organic carbon (TOC), microbial biomass carbon (C-SMB), pH (H_2O), phosphorus (P), potassium (K^+), calcium (Ca^{+2}), magnesium (Mg^{+2}), aluminum (Al^{+3}), hydrogen plus aluminum (H+Al), sulfur ($S\text{-}SO_4^{-2}$), boron (B), copper (Cu), iron (Fe), manganese (Mn), zinc (Zn) and cation exchange capacity (T) in the soil under different uses in the Triangulo Mineiro region of Brazil.

Since their vectors were shorter than those of the other variables with very low correlation coefficients (less than |0.70|) (Table 3). The Cerrado was distinguished from other soil-use types by its higher concentrations of H+Al, TOC, SMB and Al^{+3}, that were highly correlated and had points that were close to the values of the coefficient of correlations, respectively -0.77; -0.60; -0.54 and -0.92, from CP1 (Table 3). TOC and SMB were the most highly correlated variables given their significant and similar vectors. The high correlation between SMB and TOC is due to the relationship between SMB and organic material, nutrient cycling and energy flow (De-Polli; Guerra, 1999). Given these characteristics, it is highly recommended to measure SMB for C activity in the soil. Martins et al. (2010) used multivariate analysis to show the correlation of SMB, TOC and H+Al and recommend these as the most sensitive attributes and indicators of soil degradation levels. Eucalyptus and Pasture 2 (unlike Pasture 3, 4 and 1) are associated with higher concentrations of macro and micronutrients. Fig.6 shows the formation of a group that is highly correlated with all macro and micronutrients. High correlation between Ca^{+2} and Mg^{+2} in the soil may decrease or increase absorption through the process of antagonism, potential competitive inhibition and synergy among some elements (e.g. B, Cu and Zn) (Malavolta et al., 1997). The variable pH (H_2O) is correlated with nutrient availability in CP2. This confirms the influence of pH on nutrient availability in the soil and its inverse relationship with Al^{+3} availability (opposite vectors), in which higher pH decreases Al^{+3} availability in the soil. Raising soil pH through liming reduces the availability of all micronutrients except Mo (Malavolta, 1980).

Materials and Methods

Study area characterization

Our study area was located on the Fazenda da Tenda farm in the municipality of Uberlandia, Triangulo Mineiro region, Minas Gerais, Brazil. The altitude of the region averages 830 meters and the climate is predominately classified as Aw (Köppen) –tropical wet with dry winters (Antunes, 1986). Analysis and interpretation were based on completely randomized characterization conditions for the six soil-use types (Cerrado, Eucalyptus and Pasture 1, 2, 3 and 4), soil depth (0-0.2m) and four repetitions. The four pasture types were distinguished by terrain and identified as P1, P2, P3 and P4 (Fig. 1). The native Cerrado area (18º53´24,46"S, 48º10´13,53"W and 891 m) is a preserved area located between the pasture and Eucalyptus sites. Soil at this site was darker due to the accumulation of organic material. The soil at the Eucalyptus site (18º53´23,14"S, 48º10´17,10"W and 886 m) was darker and similar to that of the native Cerrado site, with litter accumulation and low vegetation. Nevertheless, litter accumulation at Eucalyptus sites can be low depending on region and species. Pulrolnik et al. (2009) studied 20-year-old Eucalyptus urophylla, spaced at 3 x 2 m and found litter deposition on the soil surface of 13.8 Mg ha-

^{1}. Kolm and Poggiani (2003) and Martins et al., (1995) found average litter accumulations of 18.1 Mg ha^{-1} under other conditions. The Eucalyptus site had been cut at the time of soil collection. Pig manure had been applied during planting and between rows after crop establishment. The Brachiaria pastures had lighter colored soil and had been used for beef cattle grazing. The pasture site was divided into four sub areas based on altitude: P1: near a highway (18º53´26,39"S, 48º10´00,09"W), P2 (18º53´26,30"S, 48º10´02,90"W) and P4 (18º53´25,32"S, 48º10´10,27"W) at 891m and P3 (18º53´25,51"S, 48º10´07,61"W) at 890m. Liquid pig manure was applied to the soil of the Eucalyptus and pasture sites at 30-day intervals using a fertigation propulsion system with three-inch pipes and a flow rate of 180 – 200 m^3 ha^{-1}. This application was only partial because it involved separating out the solids and only applying the resulting liquid. The farm raises most of its 15,000 pigs through a complete cycle (breeding, maternity, nursery and finishing). Pig manure is a byproduct of raising pigs for slaughter. Average daily waste production under these conditions ranged from approximately 0.016 m^{-3}, 0.0014 m^{-3} and 0.007 m^{-3} during the breeding, piglet and finishing stages.

Variables analyzed

Mixed soil samples were collected for nutrient characterization using a motorized post hole digger with a 40 cm twist bit (120 mm circumference) connected to a plastic reservoir. After collection, the samples were identified and sent to a laboratory. Macronutrient (phosphorus-P, potassium - K^+, Calcium - Ca^{+2} and sulphur - S-SO_4), micronutrient (boron – B, copper - Cu, iron – Fe, manganese - Mn and zinc -Zn), aluminum (Al^{+3}), hydrogen plus aluminum (H+Al) and pH-H_2O levels were determined by the methodologies recommended by Embrapa (1997). Total organic carbon (TOC) was determined by wet oxidation of potassium dichromate with external heating (Yeomans and Bremner, 1988). Microbial biomass C (C-SMB) was determined by an irradiation and extraction method (Vance et al.,1987) that uses a microwave oven as a radiation source (Islam and Weil, 1998). Subsequently, a factor of 0.33 was used to determine conversion (Kc) of C for C-SMB (Sparling and West, 1998).

Univariate statistical analysis

Variable variability was calculated by first determining descriptive statistics such as mean, standard deviation, minimum, maximum and median. Normality assumptions were evaluated by the Shapiro-Wilk test (SPSS Inc., USA) and variance homogeneity by the Bartlett test (SPSS Inc., USA). Based on these, the H0 hypothesis was accepted without data transformation. Next, the data was tested by the F-test. When the H0 hypothesis was rejected and H1 accepted, the means were compared by the Tukey test at 5% probability (Sisvar Inc., Brasil).

Multivariate Statistical Analysis

Various multivariate methods were used including hierarchical grouping, which was used to simultaneously analyze different variables within each soil-use (Cerrado, Eucalyptus and pasture (1, 2, 3 and 4) at depth (0- 0.2 m) and four repetitions. Thus, the data were standardized to obtain a zero mean and constant variance (Sneath and Sokal, 1973). Afterwards, the Euclidean distance between data points was calculated.

The Ward algorithm, among others, was used to group similar data points. This method defines the distance between two groups as the sum of squares between the two groups for all variables (Hair et al., 2005). The results of the analysis were graphed (dendrogram) to help identify and interpret groupings of data points. Principal component analysis (PCA) was carried out by classifying variables according to their characteristics to better visualize the relationships between variables. These new axes are considered orthogonal (new variables) and identified as principal components and the values of these new variables are considered scores of the principal components or principal coordinates (Piovesan, 2008). We selected components with eigenvalues greater than 1 (Kaiser, 1958) because these components provide relevant information from the original variables. The results were displayed in a biplot to show the relationships between the variables and soil use types.

Conclusion

Topography and seepage rates should be considered when using pig manure as a soil fertilizer. Applications of pig manure increase macro and micronutrient availability in the soil. Applications in the Cerrado are related to higher concentrations of Al, Al+H, TOC and SMB, whereas applications to pasture and Eucalyptus sites lead to higher nutrient concentrations. None of the soil-use types examined in the study have characteristics similar to natural Cerrado. Pasture 1 was the most dissimilar to Cerrado, followed by Pasture 3,4 and 2 and Eucalyptus.

Acknowledgements

The authors would like to thank the following Brazilian institutions for financial support: Fundação de Amparo à Pesquisa do Estado de Minas Gerais (FAPEMIG), Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES), Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq).

References

Abipecs-Associação Brasileira da Indústria Produtora e Exportadora de Carne Suína (2014) Disponível em: < http://www.abipecs.org.br/pt/estatisticas.html>. Acessado: junh/2014

Almeida RF, Silveira CH, Mikhael JER, Franco FO, Ribeiro BT, Ferreira AS, Mendonça ES, Wendling B (2014a) CO2 emissions from soil incubated with sugarcane straw and nitrogen fertilizer. Afr J Biotechnol. 13:3376-3384.

Almeida RF, Machado HA, Martins FP, Queiroz IDS, Teixeira WG, Mikhael JER, Borges EN (2014b) Correlação do tamanho e distribuição dos agregados em Latossolos amarelo da região do triângulo mineiro em diferentes ambientes. Biosci J. 30:1325-1334.

Antunes FZ (1986) Caracterização climática do Estado de Minas Gerais. Informe Agropecuário. 138:9-13

Bernal MP, Alburquerque JA, Moral R (2009) Composting of animal manures and chemical criteria for compost maturity assessment A review. Bioresour Technol. 100:5444–5453.

Cang L, Wang YJ, Zhou DM, Dong YH (2004) Heavy metals pollution in poultry and livestock feeds and manures under intensive farming in Jiangsu Province China. J Environ Sci.16:371–374.

Cobo JG, Barros E, Kass DCL, Thomas RJ (2002) Nitrogen mineralization and crop uptake from surfasse applies leaves

of green manure on a tropical volcanic-sah soil. Biol Fer Soil. 36:87-92.
Coutinho RP, Urquiaga S, Boddey RM, Alves BJR, Torres AQA, Jantalia CP (2010) Estoque de carbono e nitrogênio e emissão de N2O em diferentes usos do solo na Mata Atlântica. Pesquisa Agropecuária Brasileira. 45:195-203.
De-Polli H, Guerra JGM (1999) C, N e P na biomassa microbiana do solo. In: Santos GA, Camargo FAO (eds) Fundamentos da matéria orgânica do solo: ecossistemas tropicais e subtropicais, Gênesis, Porto Alegre.
Embrapa-Empresa Brasileira de Pesquisa Agropecuária (1997) Manual de Métodos de Análise de Solo, 2rd edn. Embrapa, Rio de Janeiro.
Espindola JAA, Almeida DL, Guerra JGM, Da Silva EMR (2001) Flutuação sazonal da biomassa microbiana e teores de nitrato e amônio de solo coberto com paspalum notatum em um agroecossistema. Revista Floresta e Ambiente. 8:104-113.
Girotto E (2007) Cobre e zinco no solo sob uso intensivo de dejeto líquido de suínos 2007 121f (Dissertação de Mestrado) - Universidade Federal de Santa Maria, Santa Maria.
Hair Jr JF, Anderson RE, Tatham RL, Black WC (2005) Análise multivariada de dados, 5rd edn. Bookman, Porto Alegre.
Islam KR, Weil RR (1998) Microwave irradiation of soil for routine measurement of microbial biomass carbon. Biol Fertil Soils. 27:408-416.
Kaiser HF (1958) The varimax criterion for analytic rotation in factor analysis. Psychometrika. 23:187-200.
Kolm L, Poggiani F. (2003) Ciclagem de nutrients em plantações de E. grandis submetidas à prática de desbastes progressivos. Science Forest. 63:79-93.
Konzen EA, Pereira Filho IA, Bahia Filho AFC, Pereira FA (1998) Manejo do esterco líquido de suínos e sua utilização na adubação do milho, 2rd edn. Circular Técnica nº 25 Embrapa/CNPSA, Sete Lagoas.
Konzen EA (2003) Fertilização de lavoura e pastagem com dejetos de suinos e cama de aves. Paper presented at the Seminário Técnico da Cultura de Milho, Videira, 1-13 2003.
Lima AMN, Silva IR, Neves JCL, Novais RF, Barros NF, Mendonça ES, Demolinari MSM, Leite FP (2008) Frações da Matéria orgânica do solo após três décadas de cultivo de eucalipto no Vale do Rio Doce–MG. Revista Brasileira de Ciência do Solo. 32:1053-1063.
Losinger WC, Sampath RK (2000) Economies of scale in the production of swine manure. Arq Bras Med Vet Zootec. 52:1-3.
Lu D, Wang L, Yan B, Ou Y, Guan J, Bian Y, Zhang Y (2014) Speciation of Cu and Zn during composting of pig manure amended with rock phosphate. Waste Management. 34:1529–1536.
Malavolta E (1980) Elementos de nutrição mineral de plantas, 1rd edn Agronomia Ceres, Piracicaba.
Malavolta E, Vitti GC, Oliveira SA (1997) Avaliação do estado nutricional das plantas: Princípios e aplicações, 1rd edn. Associação Brasileira para Pesquisa Potassa e do Fosfato, Piracicaba.
Malavolta E (2006) Manual de nutrição mineral de plantas, 1rd edn Ceres, São Paulo.
Martins SV, Barros NF, Sampaio OB, Gomes RT (1995) Liberação e lixiviação de nutrientes pela queima da manta orgânica de três coberturas vegetais. R Árvore. 19:149-156.
Martins CM, Galindo ICL, Souza ER, Poroca HA (2010) Atributos químicos e microbianos do solo de áreas em processo de desertificação no semiárido de Pernambuco. Revista Brasileira Ciência do Solo. 34:1883-1890.
Piovesan P, Araújo LB, Deanddias CTS (2009) Validação cruzada com correção de autovalores e regressão isotônica nos modelos de efeitos principais aditivos e interação multiplicativa. Ciência Rural. 39:1018-1023.
Pulrolnik K, Barros NF, Silva IR, Novais RF, Brandani CB (2009) Estoques de carbono e nitrogênio em frações lábeis e estáveis da matéria orgânica de solos sob eucalipto, pastagem e Cerrado no Vale do Jequitinhonha – MG. Revista Brasileira Ciência do Solo. 33:1125-1136.
Raij BV, Cantarella H, Quaggio JA, Furlani AMC (1997) Recomendações de adubação e calagem para o Estado de São Paulo, 2rd edn. Instituto Agronômico/Fundação IAC (Boletim Técnico, 100), Campinas.
Roscoe R, Machado PL (2002) Fracionamento físico do solo em etudos da matéria ogânica. Embrapa Agropecuária–Embrapa Solos, Rio de Janeiro.
Rotkittikhun P, Chaiyarat R, Kruatrachue M, Pokethitiyook P, Baker AJM (2007) Growth and lead accumulation by the grasses Vetiveria zizanioides and Thysanolaena maxima in lead-contaminated soil amended with pig manure and fertilizer: A glasshouse study. Chemosphere. 66:45–53.
Seganfredo MA (2000) A questão ambiental na utilização de dejetos de suínos como fertilizante do solo, nº 22 Circular TécnicaEmbrapa/CNPSA, Concórdia.
Silva RA (2011) Impactos ambientais causados pela criação de suínos. Disponível em: <http://www.webartigos.com/articles/57975/1/IMPACTOS-AMBIENTAIS-CAUSADOS-PELA-CRIACAO-DE-SUINOS/pagina1.html#ixzz1Rr019sVr>
Sneath PH, Sokal RR (1973) Numerical taxonomy: the principles and practice of numerical classification. 1 rd edn W.H. Freeman, San Francisco.
Sparling GP, West AW (1998) A direct extration method to estimate soil microbial C: calibration in situ using microbial respiration and 14C labeled cells. Soil Biol Biochem. 20:337-343.
Toth JD, Feng Y (2011) Veterinary antibiotics at environmental relevant concentrations inhibit soil iron reduction and nitrification. Soil Biol Biochem. 43:2470–2472.
Vance ED, Brookes PC, Jenkinson DS (1987) An extraction method for measuring soil microbial biomass-C. Soil Biology and Biochemistry. 19:703-707.
Yin D, Liu W, Zhai N, Yang G, Wang X, Feng Y, Ren G (2014) Anaerobic digestion of pig and dairy manure under photo-dark fermentation condition. Bioresource Technol. 166:373–380.
Yeomans J, Bremner JM (1988) A rapid and precise method four routine determination of organic carbon in soil. Communications Soil Sci Plant Anal. 19: 1467-1476.
Wang H, Dong YH, Yang YY, Toor GS, Zhang XM (2013) Changes in heavy metal contents in animal feeds and manures in an intensive animal production region of China. J Environ Sci. 25: 2435–2442.