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Changes in the Chemical Characteristics of Latosol Associated with the Application of Ash and Organic Compost in an Area under Cultivation of Sugarcane

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Abstract— *The aim of this study was to evaluate the transport of metals in three different depths of a vegetated soil with cane sugar, organic compost as fertilizer using and bagasse ash. The experiment was conducted in areas of a sugarcane mill in the central state of Goiás, Brazil. Six areas were sampled at five points each and at different depths (0-60 cm). Were evaluated the concentrations of metals in the soil, such as P, K, Ca, Mg, Cu, Mn and Cr, beyond the parameters of soil fertility, P, organic matter, pH, H + Al, K, Ca, Mg, CEC, sum of bases (SB), base saturation (V) and aluminum saturation (m Al). At the end of these analyzes, the data were subjected to analysis of variance and regression. The results for the fertility of the soils indicated that in general nutrient levels were higher for the topsoil. The application of gray promoted significant (Pr < 0,05) in total concentrations of Cu, Mn and Cr in soil at three depths studied and Mg at intermediate depth (20-40cm). Different years of application of organic compost influenced only the total concentrations of P and Cu in the topsoil. While in subsequent layers, there are significant differences only for K and Ca in layers 20-40cm and 40-60cm, respectively.*

I. INTRODUCTION

According to Conab (2020), the area cultivated with sugarcane in the Brazilian crop 2020/2021 is estimated at approximately 9.87 million hectares and is expected to grind 630.71 million tons of sugarcane, distributed in all producing states. For each ton of sugarcane are generated about 260 kilos of bagasse which, when burned in boilers, produces approximately 6 kilos of ash, which contains about 77% of quartz sand and coal powder. Thus, there are approximately 3.78 million tons of ash available in the sugar and alcohol industry of the country.

Several studies report that sugarcane ash is rich in macro and micronutrients such as K, Ca, Mg, P, S, Fe, Mn, Zn and Cu (ANGUISSOLA *et al*., 1999; OLANDERS & STEENARI, 1995; OLIVEIRA et al., 2010; FARINELLI, MUSSI, MANCINI, 2017). In this context, ash can replace all or part of mineral fertilization and liming, depending on the nutritional balance of the soil and the need for a given crop, according to its level of productivity (SALEQUE *et al*., 2004; LEE et al., 2006; FERREIRA et al., 2012).

However, this agro-industrial waste can also cause environmental problems related to its inadequate disposal in the soil. Elements such as Zn, Cu, Cd, Cr and Pb, when applied to the soil, can become potential sources of contamination of terrestrial and aquatic ecosystems. Therefore, in recent years, several studies on the leaching of metals from soil and ash mixtures have been carried out(EDIL *et al*., 1992;CREEK e SHACKELFORD, 1992; BILISKI e ALVA, 1995; ZHAN *et al*., 1996; GUSTIN e THOMES, 1997; GHOSH e SUBBARAO, 1998; KAMON e KATSUMI, 1999; HEEBINK e HASSETT, 2001; NISTI, 2016; MARTINS *et al*., 2019).

The hypothesis of this work is that the concentration of metals from the application of ash and compost decreases with the time of application in soil cultivated with sugarcane. Following this line, the objective of the study was to evaluate the transport of metals at three different depths of a vegetated soil with sugarcane, using as fertilizer organic compostand bagasse ash.

II. MATERIAL AND METHODS

The experiment was carried out in commercial areas of a sugar-ethanol plant in the central region of the state of Goiás.The soil of the studied areas is classified as RED LATOSOL (EMBRAPA, 2018).According to Köppen's climate classification, the climate in the place is classified as Aw, rainy tropical, savannah, having sub-humid character, with two well-defined seasons: a drought, lasting four to five months, and another rainy, usually occurring between late September and April.The maximum temperature is between 34°C and 36°C, and the minimum between 0°C and 4°C. Annual isotherm ranges from 20°C to 22°C, with average annual rainfall ranging from 1,500 to 2,000 mm.

The experimental design used was randomized complete blocks, with six treatments and five replicates. The treatments consisted of different years of consecutive applications of organic compost based on filter and ash cake, and one year of ash application, in areas cultivated with sugarcane, as described in Table 1. Areas of native forest adjacent to the areas fertilized with compost or ash were also studied, as well as sampling performed in forest area, to serve as a control area.

The organic compost was obtained by the composting process and consisted of the mechanical mixing of horizontal cells, using a tractorized "mixer" periodically with control of the temperature and humidity of the mixture. The composting process lasted approximately 30 days.The area of the plots studied ranged from thirty to forty hectares.Ten tons per hectare of ash or organic compost were applied each year, both using a tractorized cultivator after sugarcane regrowth/cutting/planting.

Table 1. Treatments performed in the experiment.

Treatments	Description
1	Control Area (forest area)
2	Area with 1 year of application of organic compost
3	Area with 2 years of application of organic compost
4	Area with 3 years of application of organic compost
5	Area with 4 years of application of organic compost
6	Area with 1 year of ash application

Soil samples were collected using Dutch auger, at depths of 0 to 20, 20 to 40 and 40 to 60 cm deep.Samples were randomly collected in each plot.For each sample, five distinct points were collected, and after homogenized by depth in a plastic container. Subsequently, the soil samples were air-dry and sieved in a 2 mm sieve.

The total concentrations available to the plants of P, K, Ca, Mg, Cu, Mn, and Cr were determined, following the methodologies described by USEPA (2012) and Nurmesniemi*et al*. (2008), respectively. Soil fertility parameters such as pH, H^{+}+Al^{3+}, sum of bases (SB), cation exchange capacity (CEC), organic matter content, base saturation (V) and aluminum (m(Al)), as well as available concentrations of P, K, Ca and Mg, were also determined, according to the methodology described by Embrapa (2009).

The results obtained were submitted to variance analysis and when the F test was significant, the means of treatments were compared by the Tukey test to 5% probability of error.

III. RESULTS AND DISCUSSION

4.1 Fertility

Non-significant differences in fertility parameters were found only for the variables Mg, Al, OM, and m% for the depth of 0-20cm (Table 2).The results indicated that in general the nutrient contents were higher for the soil surface layer and that the application time did not interfere in the concentration of some nutrients for the different depths.

Table 2. Soil nutrient contents at depths of 0-20, 20-40 and 40-60cm after application of treatments, at depths of 0-20, 20-40 and 40-60cm.

Treatment	P		MO		pH		H+Al		Al		K	
	m g dm^{-3}		g dm^{-3}		$CaCl_2$				cmolc dm^{-3}			
0 to 20 cm												
Ash	18,31	b	0,37	b	4,17	a	1,97	a	0,00	a	25,43	a
1year compost	73,24	b	0,48	b	2,60	ab	1,88	a	0,03	a	20,23	a
2 years compost	15,12	b	0,71	ab	2,23	b	1,42	a	0,10	a	15,13	a
3 years compost	264,60	a	1,16	ab	4,13	ab	1,56	a	0,00	a	21,05	a
4 years compost	98,47	ab	0,58	ab	3,88	ab	2,00	a	0,05	a	18,68	a
Control area	4,12	b	0,57	ab	3,08	ab	1,18	a	0,15	a	22,21	a
20 to 40 cm												
Ash	9,94	a	0,20	b	4,64	a	1,86	a	0,02	b	14,69	a
1 year compost	21,41	a	0,20	b	1,80	b	1,01	a	0,55	a	15,72	a
2 years compost	48,08	a	0,33	b	2,43	b	1,28	a	0,31	ab	11,48	a
3 years compost	117,80	a	0,89	a	3,31	ab	1,45	a	0,00	b	10,26	a
4 years compost	27,52	a	0,46	b	3,34	ab	1,59	a	0,17	ab	12,3	a
Control area	2,53	a	0,39	b	3,05	ab	1,24	a	0,25	ab	19,14	a
40 to 60 cm												
Ash	1,84	a	0,11	b	3,00	a	1,16		0,23	b	7,18	c
1 year compost	17,66	a	0,09	b	0,64	b	0,38		87,00	a	11,28	abc
2 yearscompost	26,09	a	0,53	ab	1,55	b	0,71		0,81	ab	10,39	abc
3 yearscompost	14,73	a	0,81	a	1,42	b	0,84		0,00	ab	19,43	a
4 yearscompost	2,15	a	0,43	ab	1,22	b	0,75		0,08	ab	8,66	bc
Control area	1,99	a	0,39	ab	1,47	b	0,74		0,50	ab	18,05	ab

Average followed by the same letter in the column do not differ statistically by the Tukey test at 5% probability.

Potassium varied in relation to the applications of compost and ash. In general, the highest values were obtained in the surface layer (0-20 cm), decreasing with depth, and were lower in the application of ash. Since ashes are largely susceptible to losses by leaching and/or erosion (PONS *et*al., 2016; MAGALHÃES *etal*., 2018). Or because the higher concentrations of K are related to natural organic matter or incorporated by the compost, since the k concentration value was lower for the soil under ash application.

This result can be partially explained by the characteristics of thecompost. According to Rossetto *et al*. (2008) the benefit of the presence of organic radicals in the decomposition filter cake can occupy phosphorus fixation sites, protecting this nutrient from the reaction with clay minerals and iron oxides and thus making it available and better used by the plant.In relation to the amount of P in the treatment with ash, this factor can be attributed to the amount of the same in its composition 25,175 g kg^{-1}.

Phosphorus is considered an essential element for plants and is in low quantity in Brazilian soils (BASTOS *et al*., 2008; NODARI & GUERRA, 2015).The main factors that affect the availability of P in the soil are the organic matter content, the content and type of clay, the capacity to change cations, the buffer power, the calcium, iron and aluminum contents and the humidity, consequently interfering in its absorption by plants (KORNDÖRFER & MELO, 2009).

In the present study, the amount of MO was probably not the relevant factor in phosphorus availability, but rather the quality of the materials of the compost and ash (Table 2). It is observed that availability increases with the applied number oftreatments with three and four years. Therefore, the application of ash with high P content leads to an increase in the concentration of this in the soil because a small amount will be available for consumption by the plant.Thus, explaining the high P values in such treatments. The phosphorus in the compost is organic and its release is gradually occurring by mineralization and attack of microorganisms in the soil.

For the nutrient calcium, there is a tendency to maintain the amount of the same with application of ash in depth, a fact that may have occurred by the migration of ash, being more significantly in depth (40-60) compared to the other treatments (Table 3).

Table 3. Soil nutrient contents at depths of 0-20, 20-40 and 40-60cm after application of treatments, at depths of 0-20, 20-40 and 40-60cm.

Treatment	Ca		Mg		SB		CTC		V		m(Al)	
	cmolc dm-3								%			
0 to 20 cm												
Ash	5,70	ab	4,55	abc	6,42	ab	12,10	a	61,48	ab	0,00	a
1 year compost	5,60	b	3,79	bc	5,14	ab	9,86	ab	60,54	ab	0,73	a
2 years compost	5,22	b	4,08	abc	4,36	b	8,04	b	48,31	b	2,76	a
3 years compost	6,44	a	2,93	c	6,85	a	9,78	ab	69,90	a	0,00	a
4 years compost	5,03	b	6,28	abc	6,47	ab	12,80	a	51,16	ab	0,91	a
Control area	5,04	b	5,33	ab	4,82	ab	10,40	ab	50,45	ab	3,64	a
20 to 40 cm												
Ash	5,50	ab	5,07	a	6,74	a	11,80	a	57,56	a	0,29	b
1 year compost	4,48	c	5,30	a	3,01	b	10,10	a	33,84	b	16,18	a
2 years compost	4,89	bc	5,00	a	4,42	ab	9,46	a	46,05	ab	10,85	ab
3 years compost	5,86	a	3,55	a	5,52	ab	9,07	a	60,75	a	0,00	b
4 years compost	5,25	ab	3,43	a	5,39	ab	8,82	a	59,35	a	3,87	ab
Control area	4,92	bc	4,80	a	4,67	ab	9,96	a	47,01	ab	5,67	ab
40 to 60 cm												
Ash	5,27	ab	5,14	a	4,55	ab	9,69	ab	47,57	a	6,09	bc
1 year compost	4,16	c	5,14	a	1,39	b	6,53	ab	20,04	a	40,67	a
2 years compost	4,59	bc	5,62	a	3,30	ab	9,60	ab	34,09	a	25,68	ab
3 years compost	5,86	a	3,65	a	3,47	ab	7,08	b	42,87	a	0,00	c
4 years compost	5,17	ab	3,97	a	2,40	ab	6,37	b	40,78	a	4,76	bc
Control area	4,66	bc	4,80	a	2,54	ab	22,1	a	52,12	a	12,59	bc

Average followed by the same letter in the column do not differ statistically by the Tukey test at 5%probability.

Free aluminum increased relative to depth. This may be due to the effect of previous surface-made liming and, orhigher organic matter content in the layer (0-20 cm).In addition to the liming, organic matter originates organic ligands that are released during the mineralization process, which form complexes with aluminum or soluble complexes with phosphorus from the soil solution, preventing it from being adsorbed (IYAMUREMYE *et al.*, 1996; GONÇALVES, SILVA, OLIVEIRA, and STEINER, 2020). The reduction of Al toxicity after application of plant residues was also observed by Hue and Licudine (1999).

Regarding pH, there was a significant difference between the treatments. There is a variation in the values mainly with 3 years of compost, being higher. This fact can be explained by the formation of soluble acids at the beginning of composting, which are converted to carbon dioxide by microbial action (Iyengar & Bhave, 2005). Or because the nitrification process occurs in the other treatments, generating as a product H^+ molecules, explaining lower values in relation to the treatment with 3 years of application, especially with four years being observed an increase in H+Al in the soil.

For H+Al, there was a statistical difference, with the treatment with four years of compost being the highest value. As this treatment has a four-year history of compost application is likely a relative amount of nitrogen, it is initially transformed into ammonium ($NH4^+$) by the action of nitrosomonas, and then in $NO2^-$ by the predominant action of nitrobacteria, which quickly converts to nitrate, which is the final product of the degradation of organic N(SANCHEZ-MONEDERO*et al*., 2001; KIEHL, 2002; MORAES*et al*., 2020). It happens that when ammonia ($NH4^+$) is oxidized to $NO3^-$, there is net production of $2H^+$, justifying the high values.

4.2 Total and Available Nutrients

The different treatments interfered significantly (Pr<0,05) in the total concentrations of P, Ca, Cu, Mn, and Cr, in the 0 to 20 cm depth layer (Table 4). With the increase in the years of application of organic compost, the total concentrations of P were also increased, corroborating the results of Almeida Júnior (2010), where he observed a positive correlation between P content in the soil and amount of filter cake applied on the surface.However, this effect was not observed in subsequent layers (20-40 and 40-60 cm), due to the low natural mobility of this nutrient in the soil.

Table 4. Total concentration of elements in the soil after application of the treatments, at depths of 0-20, 20-40 and 40-60cm.

Treatment	P		K		Ca		Mg		Cu		Mn		Cr	
	mg L-1													
0 to 20 cm														
Ash	71,45	b	12,40	a	94,50	a	24,9	a	0,478	a	8,712	a	1,34	a
1 year compost	50,24	b	11,50	a	75,50	bc	17,9	a	0,158	b	0,860	bc	0,59	b
2 years compost	66,10	b	27,20	a	84,20	abc	25,2	a	0,202	b	0,546	c	0,40	b
3 years compost	85,45	b	26,20	a	91,10	ab	24,7	a	0,160	b	1,122	bc	0,49	b
4 years compost	137,10	a	15,83	a	70,33	c	21,7	a	0,360	a	1,157	bc	0,42	b
Control area	51,40	b	8,40	a	72,50	c	18,2	a	0,426	a	1,556	b	0,93	ab
20 to 40 cm														
Ash	65,50	a	8,40	ab	80,20	a	22,8	a	0,492	a	8,774	a	1,22	a
1 year compost	45,20	a	4,75	b	77,20	a	17,0	c	0,136	a	0,786	c	0,60	bc
2 years compost	41,44	a	22,62	a	80,40	a	22,2	bc	0,202	a	0,910	bc	0,46	c
3 years compost	54,17	a	12,50	ab	75,80	a	20,6	c	0,133	a	0,864	bc	0,53	c
4 years compost	63,34	a	14,50	ab	68,50	a	21,7	bc	0,263	a	0,900	bc	0,28	c
Control area	48,67	a	7,60	ab	72,80	a	16,0	a	0,400	a	1,870	b	1,10	ab
40 to 60 cm														
Ash	47,40	a	10,50	a	83,70	ab	22,8	a	0,470	a	8,870	a	1,13	a
1 year compost	42,22	a	6,88	a	74,00	ab	16,7	a	0,134	b	0,628	b	0,49	b
2 years compost	61,94	a	21,17	a	90,20	a	22,9	a	0,220	b	0,728	b	0,37	b
3 years compost	35,94	a	13,62	a	80,90	ab	17,1	a	0,138	b	0,734	b	0,60	b
4 years compost	42,56	a	16,00	a	71,33	b	18,3	a	0,190	b	0,623	b	0,42	b

Control area	38,45 a	6,13 a	70,30 b	17,3 a	0,400 a	1,352 b	1,07 a

Average followed by the same letter in the column do not differ statistically by the Tukey test at 5% probability.

There were no significant increases in K and Mg concentrations in the soil under ash application.On the other hand, Ferreira et al. (2012) observed significant differences in K and P concentrations in the soil after the application of different types of sugarcane bagasse ash in varied doses, as well as the interaction of these factors, confronting the results of the present study.Research conducted in tropical soils has studied the behavior of heavy metals in these soils.Among these, Oliveira & Mattiazzo (2001)highlight that heavy metals were retained in the surface layer of a Latosol where it received sewage sludge and cultivated with sugarcane.

The highest concentrations of Ca, Cu, Mn and Cr in the surface layer were observed when pure ash was applied. Probably due to the higher concentration of nutrients that this treatment has, compared to the organic compound (ash+filter cake), according to Table 4. On the other hand, Ferreira *et al*. (2012)did not observe significant differences in the contents of these chemical elements after the application of sugarcane bagasse ash.It is noteworthy that for some chemical elements (Cu and Cr), the control did not differ statistically from the ash, possibly since there is no sugarcane crop in the area and, therefore, the non-removal of these from the soil, via root absorption.Research conducted by Chaudhuri *et al*. (2003)it allowed to conclude that the application of ash in the soil proportionally increased the concentrations of Cu in the 0-20cm layer in an acid soil, corroborating the results of the present study.

Among the micronutrients, Cu is the least mobile in the soil thanks to its strong adsorption in organic and inorganic soil colloids. In organic matter, Cu is retained mainly by humic and fulvic acids, forming stable complexes. Therefore, cu organic complexes play an important role both in mobility and availability of Cu for plants (ABREU*et al*., 2007). The areas where they received organic compound, Cu concentrations in the surface layer were lower than the ash (Table 4), confirming the effect of organic matter on the formation of complexes with this metal. Some of these complexes are so stable that most Cu deficiencies have been associated with organic soils(ABREU*et al*., 2007; SATTOLO, MARIANO, BOSCHIERO, OTTO, 2017; AFFERTÉ *et al*., 2018).

In the 20 to 40 cm layer, significant differences were found between treatments for the total concentrations of K, Mg, Mn, and Cr (Table 4). For K, the highest average was observed in the area where two years of compost application was received, but it differed statistically only from the treatment which received one year of compost application. For Mg, Mn and Cr, the highest concentrations were observed when pure ash was applied.

Studies conducted by Oliveira et al. (2002), state that Latosols where they received surface application of organic residues, even in tropical conditions, where highly weathered soils dominate, no movement of heavy metals such as Cu and Cr in the soil profile was observed.However, in the present study, it is possible to observe higher concentrations of thesemetals in the layers of 20-40 and 40-60cm (Table 4), where organic compost was received, mainly, in the areas where it received pure ash, demonstrating movement in the soil profile.

In the 40 to 60 cm layer, the total levels of Ca, Cu, Mn, Cr were significantly influenced (Table 4). The highest concentrations of Cu, Mn and Cr were observed where pure ash was received, while for Ca the highest average was observed in the area where compost was applied for two consecutive years.

Mn concentrations were higher when pure ash was applied in the three layers studied, demonstrating that this effect is mainly due to ash, because in the areas where compost was applied, no significant differences were found. Cr concentrations also followed the same tendency.

In the soil surface layer (0 to 20 cm), except for phosphorus, the concentrations of all nutrients studied were influenced by the application of ash or organic compost (Table 5). The highest concentrations of Mg, Cu and Mn were observed in the plots that received pure ash.

Table 5.Concentration of nutrients available to plants in the soil after application of treatments, at depths of 0-20, 20-40 and 40-60cm.

Treatment	P		K		Ca		Mg		Cu		Mn		Cr	
	mg L-1													
0 to 20 cm														
Ash	11,25	a	20,12	b	160,80	a	31,50	a	0,526	a	9,730	a	0,070	a
1 year compost	21,58	a	16,88	b	83,75	bc	19,31	ab	0,188	b	0,880	cd	0,022	ab
2 years compost	2,82	a	15,62	b	77,00	c	17,75	b	0,113	b	0,785	d	0,018	ab
3 years compost	78,60	a	32,80	ab	138,10	ab	25,80	ab	0,118	b	3,102	bc	0,006	b
4 years compost	18,08	a	44,50	a	160,70	a	26,00	ab	0,257	b	1,760	cd	0,023	ab
Control area	2,25	a	33,62	ab	95,38	bc	13,62	b	0,284	b	4,168	b	0,008	b
20 to 40 cm														
Ash	10,05	a	16,38	a	138,90	a	24,50	a	0,448	a	9,360	a	0,032	a
1 year compost	2,96	a	22,12	a	60,50	b	11,90	b	0,148	c	1,132	c	0,030	a
2 years compost	29,01	a	9,50	a	101,00	ab	14,60	ab	0,092	c	0,813	c	0,000	a
3 years compost	9,87	a	30,25	a	99,62	ab	16,80	ab	0,108	c	2,394	c	0,010	a
4 years compost	3,68	a	29,00	a	119,80	ab	21,50	ab	0,163	c	1,430	c	0,000	a
Control area	3,48	a	25,17	a	84,83	ab	15,88	ab	0,308	b	5,390	b	0,000	a
40 to 60 cm														
Ash	2,96	a	14,40	abc	99,10	a	14,62	a	0,272	a	9,544	a	0,066	a
1 year compost	5,30	a	9,50	bc	43,62	c	4,88	c	0,082	b	0,370	d	0,018	a
2 years compost	5,66	a	6,00	c	55,62	bc	7,50	bc	0,062	b	0,474	d	0,014	a
3 years compost	8,06	a	27,75	a	76,30	ab	10,38	abc	0,084	b	1,476	c	0,006	a
4 years compost	1,14	a	21,50	ab	60,17	bc	9,50	abc	0,070	b	1,473	c	0,003	a
Control area	4,46	a	20,88	ab	60,00	bc	12,00	ab	0,274	a	3,756	b	0,008	a

Average followed by the same letter in the column did not differ statistically by the Tukey test at 5% probability.

In the layer of 20 to 40 cm depth in the soil, only the concentrations of Ca, Mg, Cu and Mn were influenced by the application of compost or ash. In the 40 to 60 cm depth layer, in addition to these elements mentioned, the K concentration was also influenced, which is corroborated by Ramos, Lana, Korndörfer and Silva (2017).

The application of compost in consecutive years favored only the levels of K and Ca.On the other hand, in the deepest soil layer (40 to60),higher concentrations of K were observed.Potassium has low adsorption capacity by soil colloids (SHARMA *et*al., 2016; AQUINO *et al*., 2018; YILMAZ, WZOREK, AKÇAY, 2018), being quite susceptible to percolation along the soil profile. In this sense, possibly due to this process, higher Concentrations of K were observed in the areas that received composed for three or four years.

IV. CONCLUSIONS

1. The application of ash in the soil promoted an increase in the total concentrations of heavy metals in the soil such as Cu, Mn, and Cr up to 60 cm deep.
2. Application of organic compost in different years favors the increase in total nutrient concentrations in the soil surface layer and thereby improving the potential for their availability for sugarcane crop.

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