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Chemical soil attributes of Cerrado areas under different recovery managements or conservation levels

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The aquatic macrophytes removed from hydroelectric power plants, as well as boiler ash derived from burning sugarcane bagasse can provide nutrients and recover degraded soils more quickly. Thus, this study aimed to evaluate the chemical attributes of a degraded soil in recovery process with mechanical preparation, with or without addition of organic residue (aquatic macrophytes) or agroindustrial residue (ash from sugarcane bagasse), compared to a degraded area without interference in the time of soil removal and in a conserved Cerrado area. The experimental design was a randomized block with four replications. The treatments were: conserved Cerrado soil (T1), area of degraded soil without human intervention since their degradation (T2), soil with mechanized preparation without addition of residue (T3), soil with mechanized preparation and addition of 32 Mg ha^{-1} of organic residue (T4), soil with mechanical preparation and addition of 45 Mg ha^{-1} of agroindustrial residue (T5). The orthogonal contrasts analyzed were C1 [(T2+T3+T4+T5)/4 -T1], C2 [(T2+T3) - (T4+T5)], C3 [(T2) -(T3)] and C4 [(T4) - (T5)]. In general, the chemical attributes of degraded soil increased after the incorporation of organic and agroindustrial residue, which is higher than the soil of the conserved Cerrado area. The boiler ash contributed most, to increase the nutrient content and fertility of the degraded soil.

Key words: Aquatic macrophytes, ash from sugarcane bagasse, degraded soil, fertility, soil tillage.

INTRODUCTION

The Cerrado, Latin America's second largest biome, is known as the world's richest savanna. A great diversity of habitats, high species richness and an elevated level of threats lead to the inclusion of the Cerrado in the list of the world's critical areas for the conservation of biodiversity, the hotspots (Myers et al., 2000; Sloan et al., 2014).

In 1960s, the hydroelectric power plant of Ilha Solteira

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Table 1. Mean values for P, OM, pH, K, Ca, M Mg, H+Al, Al, B, Cu, Fe, Mn and Zn in the soil before application of treatments.

P	OM	pH	K	Ca	Mg	H+Al	Al	B	Cu	Fe	Mn	Zn
(mg dm^{-3})	(g dm^{-3})	($CaCl_2$)	- - - - - - (mmol$_c$ dm^{-3}) - - - - - - -					- - - - - - - (mg dm^{-3}) - - - - - - -				
3	10	4.5	0.5	1	1	27	5	0.11	0.6	2	12	0.06

(UHE/ISA-CESP) was established in the northeast of São Paulo state, Brazil, creating huge degraded areas, called "borrowing areas". Upper soil layers were removed and used for the construction of dam and foundations, exposing subsoil with high density. In the long run this result is negligible in natural regeneration (Rodrigues et al., 2007).

In these conditions of degradation, the Cerrado presents medium to slow natural regeneration potential (Viani et al., 2010). An exposition of subsoil as described in the borrowing areas resembles the destruction observed in mining areas, as reported by Pedrol et al. (2010), who, besides physical and chemical damage, also highlight landscape esthetics.

The planting of seedlings, the facilitation of natural regeneration processes or a combination of both are methods used for recovering of degraded or perturbed environments (Durigan et al., 2011; Pinto et al., 2011). In revegetation processes, the use of native species is recommended (Marques et al., 2014), especially with conditions of low nutrient availability and high aluminium concentrations and acidity, as common in Cerrado soils (Rodrigues et al., 2007).

The physical and chemical suitability of the soil, as well as the selection of proper species for revegetation are very important and depend on each situation. The adequate level of fertilization also depends on the used species and the specificity of the situation. In emergency situations fertilization enables fast establishment of vegetation, which helps to reduce erosion by consequent stabilization of the surface and the majority of soil properties (Duboc and Guerrini, 2007), often allowing the emergence of another species.

In degraded Cerrado, soils with low natural fertility and definite pluvial regime chemical and organic inputs are crucial to precipitate the process of revegetation (Pedrol et al., 2010). This requires the quest for organic inputs that enhance the chemical, physical and biological conditions of degraded soil.

In this context, the use of organic and agroindustrial residues is a possibility for the reduction of costs for mineral fertilizers, removal of aquatic macrophytes from hydroelectric power plants (Gunnarsson and Petersen, 2007), or of ash from boilers after burning of sugar cane bagasse (Balakrishnan and Batra, 2011; Eggleston and Lima, 2015). These can be added to the soil in order to provide nutrients, enhance biological and physical soil conditions, and therefore recover degraded soil faster.

The objective of this work was to evaluate the chemical attributes of a degraded soil in the recovery process with mechanical treatment of the soil, with and without addition of organic (aquatic macrophytes) and agroindustrial (ash from burning of sugar cane bagasse) residues, in comparison to a degraded area without any interference since soil removal and a conserved Cerrado area, contribute to the rapid recovery of degraded soils.

MATERIALS AND METHODS

The experimental area was established in 2011 at the UNESP/Ilha Solteira campus Experimental Farm, located in Selvíria/MS. The area was degraded in the 1060s for the construction of the hydroelectric power plant "Ilha Solteira" – SP. Native Cerrado vegetation as well as the upper soil layers were removed, exposing clayey subsoil (clay = 450, silt = 128, sand = 422 g kg^{-1}) which remained uncovered until 2011, presenting low nutrient contents determined according to Raij et al. (2001) (Table 1).

The average altitude of the region is 335 m, the climate classification as Aw, according to Köppen, with an average annual temperature and precipitation of 23.7°C and 1300 mm, respectively (Figure 1). The predominant soil type of the region is a Typic Hapludox. The experimental area design was a randomized block with agroindustrial residue levels (AR) applied in bands, in a factorial 3 x 4, 3 doses (0, 16 and 32 Mg ha^{-1}) of organic residue (OR) - macrophytes and 4 doses (0, 15, 30 and 45 Mg ha^{-1}) of agroindustrial residue (RA) - ash from sugarcane bagasse. Together they complete 12 treatments with 3 repetitions, established in 36 blocks of 600 m^2 each, separated trough 0.5 m belts (Figure 2).

The experimental area soil was grided (0.40 m deep), to rupture the sealing superficial, and scarified (0.37 m depth). The organic residue (OR) was a compound of aquatic macrophytes, consisting *Egeria densa* Planch., *Egeria najas* Planch., *Ceratophyllum demersum* L., *Eichhornia azura* Kunth, *Eichhornia crassipes* (Martius) Solms-Laubach, *Pistia stratiotes* L. and *Typha latifolia* L., according to Thomaz et al. (2008). They were removed from the reservoir of the hydroelectric power plant of Jupiá, dried in the sun for 120 days and nutritionally analyzed according to the methodology of Malavolta et al. (1997) (Table 2). The agroindustrial residue (AR) was ash from burning sugar cane bagasse remaining from the production of sugar and alcohol in the Alcoolvale factory in Aparecida do Taboado/MS. It was fully dried in the sun for 30 days and chemically analyzed according to Raij et al. (2001) (Table 3).

Both residues were distributed with a limestone distributor and incorporated in the degraded soil with the medium grid. The area remained uncultivated for three months. In February 2012 seedlings of 10 Cerrado tree species were introduced in a randomized way, planted in 40 cm deep holes with a distance of 4.0 x 5.0 m, demanding 1080 plants.

In March 2015, three years after the implementation of the

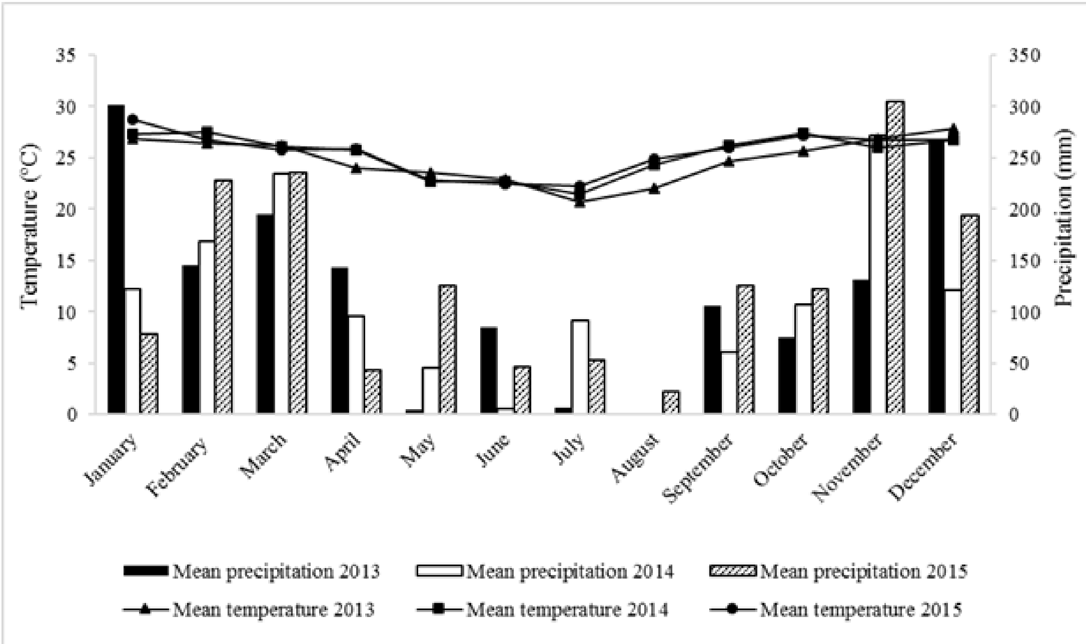

Figure 1. Mean Temperature and Precipitation for 2013, 2014 and 2015. (Source: http://clima.feis.unesp.br.).

Figure 2. Localization of the sampling sites in the area of Conserved Cerrado. This experimental area is in a natural recuperation process after being exposed to degradation (without any intervention).

experiment, six soil samples per plot were collected, in a depth of 0.0 to 0.2 m. For comparison purposes, samples were also collected in conserved Cerrado and degraded area without intervention. To collect samples in the conserved Cerrado area (without human intervention after degradation in the 1960s) plots of similar size as in the experiment were located. Georeferences and the sampling were made in the same manner. The experimental setup was in randomized blocks with four repetitions. The treatments were as follows: Soil from conserved Cerrado near the experimental area (T1), Soil from degraded area without human intervention after degradation (T2), Soil with mechanical treatment without addition of residues (T3), Soil with mechanical treatment and addition of 32 Mg ha^{-1} dry organic residues (T4), Soil with mechanical treatment and addition of 45 Mg ha^{-1} dry agroindustrial residues (T5).

The collected soil samples were air dried, sieved and submit to analysis of the following chemical attributes: content of phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg) through an

Table 2. Nutrient content of the organic residue of aquatic macrophytes.

N	P	K	Ca	Mg	S	B	Cu	Fe	Mn	Zn
($g\ kg^{-1}$)						($mg\ kg^{-1}$)				
17.6	1.7	6.5	11.6	2.4	6.7	27	57	2000	194	34

Table 3. Chemical characteristics of the agroindustrial residue (ash from sugar cane bagasse).

P	OM	pH	K	Ca	Mg	H+Al	Al	SB	CEC	V	Ca/ CEC	Mg/ CEC	m
($mg\ dm^{-3}$)	($g\ dm^{-3}$)	$CaCl_2$	($mmol_c\ dm^{-3}$)							(%)			
167	28	8.9	36.6	242	23	8	0	301.6	309.6	97	78	7	0

Table 4. Values for P, OM, pH, K, Ca, Mg, H+Al, Al, SB and S for different contrasts according to the treaments.

Contrast	P	OM	pH	K	Ca	Mg	H+Al	Al	SB	S
	($mg\ dm^{-3}$)	($g\ dm^{-3}$)	$CaCl_2$	($mmol_c\ dm^{-3}$)						($mg\ dm^{-3}$)
C1	3.25**	12.5**	-0.21**	0.01ns	2.38**	4.31**	32.63**	24.63*	6.71**	-1.44**
C2	0.00ns	0.00ns	-0.26**	-0.33**	-3.5**	-2.38**	6.75**	3.75**	-5.21**	-1.63**
C3	0.00ns	0.00ns	0.05ns	0.00ns	0.75ns	0.5ns	1.5ns	0.5ns	1.28ns	0.25ns
C4	0.00ns	0.00ns	-0.18**	-0.35*	-2.75ns	-0.75ns	0.00ns	0.00ns	-3.85ns	0.00ns

** significant for 1%, * significant for 5%, ns = not significant for Scheffé test, T1= Soil from conserved Cerrado near the experimental area; T2= Soil from degraded area without human intervention after degradation; T3= Soil with mechanical treatment without addition of residues; T4= Soil with mechanical treatment and addition of 32 Mg ha^{-1} dry organic residues; T5= Soil with mechanical treatment and addition of 45 Mg ha^{-1} dry agroindustrial residues. C1 [(T2+T3+T4+T5)/4-T1]; C2 [(T2+T3)-(T4+T5)]; C3 [(T2)-(T3)]; C4 [(T4)-(T5)].

extraction method with ion exchange resins. The content of organic matter (OM) was determined by a colorimetric method and the pH in calcium chloride ($CaCl_2$), besides the acidic potential (H+Al) pH 7.0 and aluminium content (Al). The sum of bases (SB = Ca+Mg+K), cation exchange capacity (Communications Engineering Company (CEC) = SB + (H+Al)), base saturation (V% = (100 x SB)/CEC) and aluminum saturation (m% = (100 x Al)/CEC = (100 x Al)/Ca+Mg+K+Na+Al), were calculated according to Raij et al. (2001).

Obtained data was submit to analysis of orthogonal contrasts by Scheffé test ($p<0.05$), using statistic software SISVAR (Ferreira, 2011). The analyzed orthogonal contrasts were C1 [(T2+T3+T4+T5)/4-T1], C2 [(T2+T3)-(T4+T5)], C3 [(T2)-(T3)] e C4 [(T4)-(T5)].

RESULTS AND DISCUSSION

Contrary to expectations C1 showed the highest content of P, OM, Ca, Mg, Al as well as H+Al, SB, CEC, Mg/CEC, B, Cu, Fe, Mn and Zn in the soils of the degraded area in recuperation. The area of conserved Cerrado soil has higher values for pH and content of S (Tables 4 and 5). These results can lead back to the application of organic (OR) or agroindustrial residues (AR) which contain high amounts of nutrients (Tables 2 and 3).

According to Najar et al. (2015) the addition of OR can influence the physical, biological and chemical properties of soils which consequently alter the soil dynamics and finally the fertility of the same. Feitosa et al. (2009) mentioned that, the boiler ash derived from burning sugarcane bagasse is sources for macro and micronutrients. The application of this ash enables a higher retention of water which correlates with the acidity of soils because of the application of one ton of ash which corresponds to 0.5 tons of limestone. For a secure use of this material, studies should be realized to improve the knowledge of its composition and consequently the quantities needed to achieve best results.

Galindo et al. (2015) verifies that, the aquatic macrophyte species *E. densa* has the potential to be used as an organic fertilizer, because the nutrients can be retained in the macrophyte biomass (Câmara et al., 2015). This could also explain the obtained results. In the contrast C2, where no residues were applied, a higher potential acidity could be recorded as well as higher content of Al and m% in the soil samples (Tables 4 and 5). This undesired attributes affect in a negative form the soil quality and consequently the development of vegetation.

Ferreira et al. (2012) pointed that a reduction of acidity after ash application facilitates plant growth. This material

Table 5. Values for CEC, V%, Ca/CEC Mg/CEC, m%, B, Cu, Fe, Mn and Zn for different contrasts according to the treaments.

Contrast	CEC	V%	Ca/CEC	Mg/CEC	m%	B	Cu	Fe	Mn	Zn
	(mmol$_c$ dm^{-3})	- - - - - - - - - - - % - - - - - - - - - -				- - - - - - - - - (mg dm^{-3}) - - - - - - - -				
C1	39,33**	0,75^{ns}	-1,63^{ns}	2,94**	3,75^{ns}	0,19**	2,89**	34,19**	24,98**	0,38**
C2	1,54^{ns}	-15,5**	-10**	-4,13**	41,5**	0,01^{ns}	-0,13**	-1,13**	-0,58^{ns}	0,00^{ns}
C3	2,78^{ns}	3,0^{ns}	1,75^{ns}	1,0^{ns}	-6,5^{ns}	0,02^{ns}	0,00^{ns}	-0,5^{ns}	-0,08^{ns}	0,00^{ns}
C4	-0,85^{ns}	-11,0*	-7,75*	-2,25*	30,0**	-0,04**	0,15*	0,25^{ns}	1,08^{ns}	0,00^{ns}

** significant for 1%, * significant for 5%, ns = not significant for Scheffé test, T1= Soil from conserved Cerrado near the experimental area; T2= Soil from degraded area without human intervention after degradation; T3= Soil with mechanical treatment without addition of residues; T4= Soil with mechanical treatment and addition of 32 Mg ha^{-1} dry organic residues; T5= Soil with mechanical treatment and addition of 45 Mg ha^{-1} dry agroindustrial residues. C1 [(T2+T3+T4+T5)/4-T1]; C2 [(T2+T3)-(T4+T5)]; C3 [(T2)-(T3)]; C4 [(T4)-(T5)].

contains high amounts of alkaline substances which reduces the potential acidity. In the contrast C2, when OR and AR were applied, higher contents of K, Ca, Mg, S, Cu and Fe as well as higher values of Ca/CEC, Mg/CEC, pH, SB and V%, could be observed, which are directly related to the content of nutrients and chemical characteristics (pH) of the residues (Tables 2 and 3).

Application of plant ash has been the subject of many studies showing an increase in the amount of K in tropical soils (Augusto et al., 2008; Ferreira et al., 2012). The high content of K in AR (36, 6 mmolc dm^{-3} in this study) can be justified by the high content of this macronutrient in sugar cane. The result of the high application rate of K, being this nutrient is the most used for sugarcane cultivations (Oliveira et al., 2010). Lima (2011) also verified that the application of different organic fertilizer reduces the P-fixation in soils and contributes to an increase of its availability to vegetation. Ram and Masto (2014) also observed a rise in soil quality and a significant rise in soil pH after ash application, while Nayak et al. (2014) ascribes to the influence of this material on microbial populations, reducing their diversity in soils.

This study also corroborates the positive effect of application of macrophytes in soils. Masto et al. (2013) observed higher pH values, microbial activity and vigorousness of seedlings, which are the result of an application of biochar from *E. crassipes* in soils, or contains a mixture of aquatic macrophytes with variation in its nutritional composition. Sakadevan and Bavor (1999) as well as Henry-Silva and Camargo (2008) acknowledge that the variation in nutrient absorption of macrophytes is caused by different characteristics of the water body and the time spent in the efflux. The structure of the water body influences the process of nutrient uptake and sedimentation of particles, giving a positive correlation between effectivity of nutrient uptake and residence period in the efflux.

Calgaro et al. (2008) observed an increase in chemical attributes (OM, P, pH, K, SB, CEC, and V %) when *E. crassipes* was applied. The use of this or other residues have been reported to be beneficial for degraded areas as organic or microbial fertilizers supporting revegetation (Trlica and Brown, 2013). Pavinato and Rosolem (2008) noticed that residues from vegetation improve the Ca, Mg and K content. This causes a complexation of hydrogen and aluminium with bonds of residues before the process of humification gets started, rising SB as could be observed in this study.

Colodro and Espindola (2006), Alves et al. (2007), Kitamura et al. (2008), Modesto et al. (2009), Costa et al. (2014) and Bonini et al. (2015) also studied the soil recuperation of degraded areas after constructions and could verify an improve of chemical properties of soils, which can also be seen in this study, after application of sewage sludge, organic residues or green manure.

Analyzing the contrast C3, the characteristics of the degraded area doesn´t show any difference in chemical properties in treatments with or without mechanization and addition of residues (Tables 4 and 5). The systems of use and manage of Cerrado soils correlate directly with the chemical, biological and physical properties, although machining work has the biggest impact on soils (Carneiro et al., 2009). Acceleration in the decomposition process of organic material, cause a reduction in CEC and an increase in leaching of exchangeable bases which consequently reduce water retention, in soils.

Only mechanization doesn't improve chemical properties in soils in an advanced degradation process. Therefore, to the treatment of mechanization up to a depth of 15 cm, material with high nutrient content has to be added. The content of organic matter (OM) was also very low, probably because of a very low initial OM content. Bronick and Lal (2005) describe that, the mechanization techniques used change the structure in soils and accelerate decomposition of organic material, resulting in decrease of productivity and exposure of soil. Pavan and Chaves (1998) explain that to reduce the process of decomposition of organic matter, the superficial machining work also has to be minimized as well as de loss of soil, water or nutrients. The reuse of residues, maintenance of soil nutrients, improvement of

CO_2 fixation and its incorporation into the soil or cultivation rotation with cultivars with high biomass production are other aspects that can decrease the decomposition of organic matter.

In observing contrast C4, it can be noticed that the application of OR and mechanization of the soil, increases m% and the content of Cu in comparison of application of AR and mechanization (Tables 4 and 5). Sampaio and Oliveira (2005) mention that, the application of biomass from *E. densa* which grow in turbines of water bodies, are viable and can be recommended as an organic fertilizer for maize plantations. On one hand the problem of destination of residue from turbines can be solved and on the other hand the application of nutrients and a rise of agricultural production can be achieved.

The application of AR in a mechanized soil, raised the pH and K, Ca, Mg and B contents with amount of SB, CEC V% and Ca/CEC in the soil, in comparison with OR and an addition on mechanized soil. The increase in soil properties can lead back to the application of nutrients trough AR (Carrier et al., 2012; Ram and Masto, 2014). The research of Machado et al. (2014) compared treatments with and without application of organic residues (aquatic macrophytes) and phosphorus (triple superphosphate) as fertilizers for degraded soils. Results showed a positive influence on soil fertility whereby organic residues can be used as fertilizers.

The obtained results of this study show that the application of agroindustrial and aquatic macrophytes residues can be used as a sustainable form to restore fertility of degraded soils. A possible increase of this material can be traced back to anthropogenic eutrophication of water bodies. Using this material as a proposal to minimize the anthropogenic impact on environment originated many decades ago, these can be an alternative to traditional methods that uses large amounts of commercial fertilizers in recovering of degraded soils.

Conclusion

The chemical attributes of the degraded soil increased after the introduction of organic and agroindustrial residues, being even higher in relation to Cerrado soil. The ash from sugar cane bagasse was the residue that contributed most to increasing nutrient content and fertility of the degraded soil.

CONFLICT OF INTERESTS

The authors declare that there is no conflict of interests regarding the publication of this paper.

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