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Biochar, farmyard manure and poultry litter on chemical attributes of a Distrophic Cambissol and soybean crop

Alexandre Martins Abdao dos Passos[1], Pedro Milanez de Rezende[2], Everson Reis Carvalho[3], Fabrício William de Ávila[4]

[1] Empresa Brasileira de Pesquisa Agropecuária, Rondônia, BR 364 km 5,5, Zona Rural, CEP 76815-800, Porto Velho-RO, Brasil. E-mail: alexandre.abdao@embrapa.br
[2] Universidade Federal de Lavras, Departamento de Agricultura, Campus Universitário, CEP 37200-000, Lavras-MG, Brasil. Caixa Postal 37. E-mail: pmrezend@dag.ufla.br
[3] Universidade Federal de Uberlândia, Instituto de Ciências Agrarias, Av. Goiás, 2000, Vila Nova, CEP 38500-000, Monte Carmelo-MG, Brasil. E-mail: eversonreiscarvalho@hotmail.com
[4] Universidade Estadual do Centro-Oeste, Departamento de Agronomia, Rua Simeão Varela de Sá, 3, Vila Carli, CEP 85040-080, Guarapuava-PR, Brasil. E-mail: fwavila@unicentro.br

ABSTRACT

The use of organic wastes, as an alternative to inorganic fertilizer, can be an important strategy for Brazilian agriculture. The objective was to evaluate the residual effects and the agronomic efficiency of organic amendments use on chemical attributes of a Haplic Cambisol and to soybean crop. A field experiment was carried out in a completely randomized split-plot design with three replications in Minas Gerais, Brazil, 2008/09. In the plots, the sources of organic amendments were evaluated (poultry litter, farmyard manure, and biochar) using three application rates (3, 6 and 9 Mg ha^{-1}) into the subplots, and control treatment without amendments. Agronomic efficiency of the wastes linearly increased with the doses, independent of the organic source. Poultry litter, a nutrient-rich organic amendment, increased the soybean grain yield. The biochar use boosted the availability of calcium and magnesium levels in the soil, and a consequent increase in the sum of bases, base saturation, pH and effective cation exchange capacity of the soil. The poultry litter utilization enhances the soil acidity and availability of potassium, sulfur and zinc, over the time. The use of organic amendments increases the levels of phosphorus, potassium and zinc in the soil, after soybean cropping.

Key words: agronomic efficiency index, *Glycine max*, organic amendments, sustainability

Pó de carvão, esterco de curral e cama de frango no cultivo da soja e atributos químicos de um Cambissolo distrófico

RESUMO

A utilização de resíduos orgânicos, como alternativa ao uso de fertilizantes minerais inorgânicos, pode representar uma importante estratégia para a agricultura brasileira. Objetivou-se, nesse trabalho, avaliar a eficiência agronômica e os efeitos residuais da utilização dos resíduos orgânicos, cama de frango, esterco de curral e pó de carvão nos atributos químicos de um Cambissolo Háplico cultivado convencionalmente com a cultura da soja. O experimento de campo foi realizado em esquema de parcelas subdivididas, utilizando o delineamento em blocos casualizados com três repetições. Nas parcelas foram avaliadas as fontes dos resíduos orgânicos e, nas subparcelas, as doses dos resíduos (3, 6 e 9 Mg ha^{-1}), mais o tratamento controle sem resíduos, na safra 2008/09, em Itutinga, MG, Brasil. Verificou-se que a eficiência agronômica dos resíduos aumentou com a elevação das doses, independente da fonte utilizada. A cama de frango, um resíduo orgânico rico em nutrientes, apresentou eficiência agronômica para elevar a produção de grãos de soja, sendo este resíduo orgânico mais eficiente agronomicamente que esterco de curral e pó de carvão. O uso do pó de carvão proporciona aumentos nos níveis de cálcio e magnésio do solo, com consequente elevação da soma de bases, saturação por base, pH e CTC efetiva do solo. Por sua vez, a utilização de cama de frango eleva a acidez e a disponibilidade de potássio, enxofre e zinco no solo, em curto prazo. Em geral, a aplicação de resíduos orgânicos proporciona incrementos nos níveis residuais de fósforo, potássio e zinco, após o cultivo da soja.

Palavras-chave: eficiência agronômica, *Glycine max*, resíduos orgânicos, sustentabilidade

Introduction

The low fertility of agricultural soils in Brazil and other tropical countries is one of the main factors limiting crop yields. Therefore, use of lime and fertilizers is essential to improve yields and maintain the soil fertility (Moterle et al., 2009).

In Brazil, the major consumption of fertilizers is limited to few crops, being soybean crops responsible for more than a third of the national demand (ANDA, 2013). The importation of mineral fertilizers contribute to a significant share of chemical product trade deficit in Brazil. The dependence on external fertilizer supplies could lead to a fertilizer crisis in near future. In this context, the use of organic wastes, as an alternative to inorganic fertilizer, has shown to be an important strategy for Brazilian agriculture.

Furthermore, the use of organic residues provides environmental benefits transforming potentially polluting wastes into valuable inputs as the organic fertilizers (Bonini et al., 2015).

In long term experiments, combination of organic and inorganic nutrient sources providing synergic effects in the soil, increasing the availability of nutrients to the plants have being demonstrated (Sainju et al., 2010). Appropriate soil fertility management has a direct positive consequence on the crop yields. Bhattacharyya et al. (2008) observed reduced annual yield of a soybean-wheat rotation system when only mineral fertilizers were applied, in comparison with the bovine farmyard manure use. In spite of the lower contribution of nutrients per volume, organic amendments, such as bovine manure and poultry litter might even be superior to the mineral fertilizers, improving the biological, physical and chemical attributes of the soil (Bhattacharyya et al., 2010). Evaluating the effects of several applications of organic wastes, such as the turkey litter, over the years, Pinto et al. (2012) found improving on soil fertility, increasing the pH, N, P, K, and base saturation rates, as well as organic carbon, and decreasing aluminum saturation.

The incorporation of biochar into the agricultural soils has received growing interest on the part of current science. Because it is known this amendment input is akin to a process, which occurred thousands of years ago in the Amazon, where fertile soils called *Terra Preta de índio* ("dark earth") were created through a process similar to pyrolysis (Morris, 2006). Therefore, through the pyrolysis of biomass residues, the resulting of biochar might provide unique co-benefits to increase agricultural productivity and agroecosystem sustainability, mainly in low natural fertility and degraded soils (Woolf et al., 2010).

For soybean crop, applying on-farm wastes can be a sustainable strategy to increase its productivity. The objective of this study is to evaluate the agronomic efficiency and residual effect of poultry litter, farmyard manure and biochar use on the soybean crop and chemical attributes of a dystrophic Haplic Cambissol.

Material and Methods

The experiment was carried out in Itutinga, Brazil, located at 21º 23' S latitude and 44º 39' W longitude at an average elevation of 958 m. The area presents a dry winter and rainy summer, with the most precipitation in December and January, and an average annual precipitation of 1,460 mm. According to the international classification of Köppen, the climate is Cwa type, with average temperatures of 20.7 ºC. The precipitation and the average daily temperatures observed in the area during the experiment are presented in Figure 1.

A randomized block design was used, with three replications in a split-plot scheme. The organic amendments sources were applied on the plots: poultry litter (PL), farmyard manure (FM) and biochar (BC). In the subplots, the rates of 3; 6 and 9 Mg ha^{-1} of the organic amendment were used (Bhattacharyya et al., 2008), plus the control treatment with no residues (0 Mg ha^{-1}). The organic amendments were evenly incorporated in the area, one day before sowing. The subplots comprehend four soybean rows, five meters long (10 m^2 per subplot).

The physiochemical composition of the amendments is presented in Table 1. The method used in the analysis was reported by Silva (2009). The poultry litter was constituted of rice straw, feces, feathers and diet remains. The farmyard manure used, originating from semi-confined dairy cattle, was on-farm produced, cured and dried. The biochar, an industrial residue, by-product of the steel industry, originating from charcoal under partial combustion of eucalyptus wood planted for such finality.

The soil tillage was conducted through plowing and disking. The application of the organic wastes was done spreading on the plots, with subsequent incorporation. Previously to sowing, the soybean seeds of the cultivar "BRS Favorita" (Glyphosate-resistant, GR) were inoculated with *Bradyrhizobium japonica* (1,200,000 bacteria per seeds). Thinning was conducted in order to reach 15 plants per meter. The sowing was done in

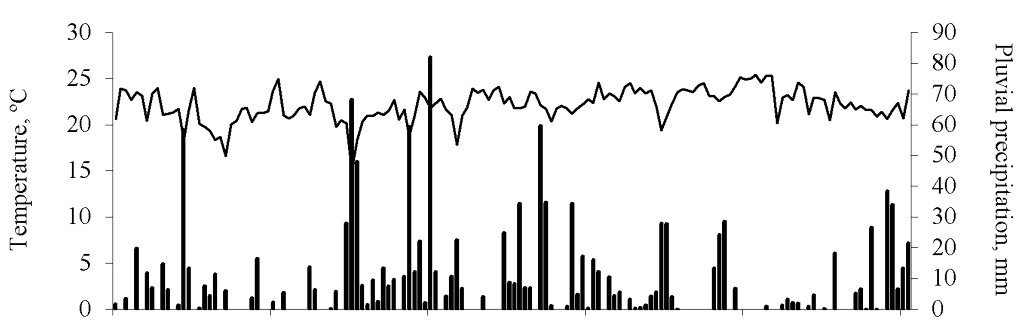


Figure 1. Average temperatures (°C) and rainfall (mm) between November 2008 and April 2009. Climatological Station, Federal University of Lavras (UFLA)

Table 1. Physiochemical analysis of the poultry litter (PL), farmyard manure (FM) and biochar (BC)

Parameters	Units	Results		
		PL	FM	BC
pH in water	-	7.40	7.60	7.30
Electrical conductivity (EC)	($dS\ m^{-1}$)	26.40	19.00	2.90
Water retention capacity	($ml\ g^{-1}$)	2.10	1.80	0.80
Apparent density	($g\ cm^{-3}$)	0.40	0.40	0.80
Total carbon	($g\ kg^{-1}$)	411.00	285.00	191.00
Organic matter (OM)	($g\ kg^{-1}$)	820.00	570.00	380.00
Total Nitrogen (N)	($g\ kg^{-1}$)	44.00	24.00	5.00
N-ammonium	($mg\ kg^{-1}$)	362.00	70.00	26.00
N-nitrate	($mg\ kg^{-1}$)	82.00	624.00	178.00
Total Phosphorus (P)	($g\ kg^{-1}$)	8.50	1.10	0.40
Total Potassium (K)	($g\ kg^{-1}$)	37.00	19.60	2.60
Sodium (Na)	($g\ kg^{-1}$)	4.50	0.90	0.40
Calcium (Ca)	($g\ kg^{-1}$)	31.00	9.50	13.00
Magnesium (Mg)	($g\ kg^{-1}$)	11.50	5.40	2.30
Sulfur (S)	($mg\ kg^{-1}$)	6.20	2.70	0.00
Boron (B)	($mg\ kg^{-1}$)	46.70	13.00	0.00
Copper (Cu)	($mg\ kg^{-1}$)	119.00	30.00	19.00
Iron (Fe)	($mg\ kg^{-1}$)	2324.00	14.56	354.60
Manganese (Mn)	($mg\ kg^{-1}$)	691.00	232.00	1107.00
Zinc (Zn)	($mg\ kg^{-1}$)	624.00	82.00	371.00

*Analyses performed at the Soil Science Department of the Federal University of Lavras (UFLA).

November of 2008. The soil classified as dystrophic Haplic Cambisol (Embrapa, 2013). The physiochemical attributes from soil were analyzed according to Silva (2009) and interpreters according to Ribeiro et al. (1999) (Table 2).

To evaluate the effects of the organic waste supply, it was used the grain yield, corrected to 13% moisture (wet basis), to calculate agronomic efficiency index (AEI) (Sharma et al., 2013). The AEI of treatments was measured through the formula: AEI = (GYi-GYo)/(GYp-GYo)*100, in which GYi is the observed grain yield of the treatment, GYo is the yield of the control plot without organic amendment inputs and without mineral fertilizer, GYp is the yield reference, which was added only 400 kg ha^{-1} of NPK mineral fertilizer (04-30-16, with 6.10 of Ca, 2.97 of S, 0.06 of B, 0.97 of Mn and 0.31% of Zn) following the recommendation of Ribeiro et al. (1999). Three additional plots were planted only with NPK mineral fertilizer to calculate the AEI.

Table 2. Results and interpretations of chemical and physical attributes of the 0.00-0.20 m in a Cambissol soil layer

Parameter	Unit	Results
pH in water	(1:2.5)	5.4 (average acidity)
Phosphorus (P) (Mehlich 1)	$mg\ dm^{-3}$	2.0 (very low)
Potassium	$mg\ dm^{-3}$	98.0 (good)
Calcium (Ca^{2+})	$cmol_c\ dm^{-3}$	1.5 (average)
Magnesium (Mg^{2+})	$cmol_c\ dm^{-3}$	0.4 (low)
Aluminum (Al^{3+})	$cmol_c\ dm^{-3}$	0.2 (very low)
Potential acidity (H + Al)	$cmol_c\ dm^{-3}$	4.0 (average)
Sum of bases (SB)	$cmol_c\ dm^{-3}$	2.2 (average)
Effective CEC (t)	$cmol_c\ dm^{-3}$	2.4 (average)
CEC at pH 7.0 (T)	$cmol_c\ dm^{-3}$	6.2 (average)
Saturation by bases (V)	%	35.0 (low)
Saturation by Al^{3+} (m)	%	9.0 (very low)
Organic matter (OM)	$g\ kg^{-1}$	40.0 (good)
Equilibrium phosphorus (PEq)	$mg\ L^{-1}$	14.0
Sulfur (S)	$mg\ dm^{-3}$	14.9 (very good)
Zinc (Zn)	$mg\ dm^{-3}$	0.5 (low)
Iron (Fe)	$mg\ dm^{-3}$	32.6 (good)
Manganese (Mn)	$mg\ dm^{-3}$	4.8 (low)
Copper (Cu)	$mg\ dm^{-3}$	1.5 (good)
Boron (B)	$mg\ dm^{-3}$	0.4 (average)
Sand	$g\ kg^{-1}$	310
Silt	$g\ kg^{-1}$	290
Clay	$g\ kg^{-1}$	400

After the grain harvest, soil samplings were collected in subplots, with the intention of verifying the influence of the organic amendment sources and doses on the chemical attributes from dry soil (sampling depth of 0.00 - 0.20 m): P $_{(Mehlich\ 1)}$, K $_{(Mehlich\ 1)}$, Ca^{2+} $_{(KCl\ -\ 1\ mol\ L^{-1})}$, Mg^{2+} $_{(KCl\ -\ 1\ mol\ L^{-1})}$, S $_{(monocalcic\ phosphate\ in\ acetic\ acid)}$, Zn $_{(Mehlich\ 1)}$, Fe $_{(Mehlich\ 1)}$, Mn $_{(Mehlich\ 1)}$, Cu $_{(Mehlich\ 1)}$, B $_{(hot\ water)}$, Al^{3+} $_{(KCl\ -\ 1\ mol\ L^{-1})}$, H +Al $_{(H\ by\ SMP)}$, P $_{(equilibrium\ )}$, Saturation by bases, Organic Matter ($_{4N\ of\ Na_2Cr_2O_7\ +\ 10N\ of\ H_2SO_4}$), and pH in water (Silva, 2009).

The data were submitted to analysis of variance (F test), using the Sisvar® software (Ferreira, 2011). When significant, at 1 or 5% probability, the means of the two factors were compared using the Scott Knott test (organic amendments sources) or polynomial regression analysis (rates).

Results and Discussion

All the variables were affected by the single treatments (simply effects), except the levels of organic matter (OM), boron (B), manganese (Mn), copper (Cu), iron (Fe) and the potential cationic exchange capacity in pH 7 (T). As a result, any observed interactive effect of the treatments (sources x rates) was reported (interaction between rate and amendment was not significant) (Table 3).

The simply effects of the organic amendment sources on the variables (the results are the average of all rates) are presented in Table 4. Appropriate agronomic efficiency index (values equal to or above 100%) was only observed on the poultry litter use. AEI is a parameter representing the ability of the plant to increase yield in response to organic amendment applied related to the yield of the soybean crop with 400 kg ha^{-1} of the mineral fertilizer. The use of the poultry litter provided higher agronomic efficiency compared to the farmyard manure and the biochar (Table 4).

The poultry litter increased the residual potassium levels by 7.44 mg dm^{-3} compared to the original level in the soil (98.0 mg dm^{-3}) after cropping (Table 2). The residual increase of potassium, by the poultry litter use, can be related to the concentrations of this nutrient, 1.9 and 14.2 times higher in relation to the farmyard manure and biochar, respectively (Table 1). Pinto et al. (2012) also found increments of potassium levels into soil, through sequential application of turkey litter in a rotational grazing system in the Brazilian Savanna.

That fact demonstrates the potential use of the poultry litter as an alternative and low cost source of potassium. In 2009, Brazilian farmers spent about US$ 2 billion with importation of potassium chloride, the main source of K to crops (ANDA, 2013). Regarding the increase of shortage of that nutrient in the world, with the consequent price elevation of the K mineral fertilizers, it becomes mandatory to intensify research related to the substituting and or enhance the use efficiency of the existent K sources.

The residual levels of calcium and magnesium were significantly higher in the biochar treatments compared to the other organic amendments. Hence, the highest levels of Ca and Mg cations significantly influenced the values of the sum of bases (SB) and base saturation (V). Base saturation is a direct result of the maintenance of exchangeable base

Table 3. Results of analysis de variance of Agronomic efficiency index (AEI), pH (pH), levels of phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg) e sulfur (S), aluminum (Al), total acidity (H+Al), sum of bases (SB), saturation by bases (V), saturation by Al^{3+} (m), Organic matter (OM) and effective cation exchange capacity (CEC)

Source of variance	DF	AEI	pH	P	K	Ca	Mg	S
Block	2	13151.76	0.10	0.64	183.32	0.21	0.030	21.50
Source (S)	2	48335.10**	0.08**	0.74	4643.41**	0.89**	0.027*	64.69*
Error 1	4	984.58	0.01	0.20	232.634	0.05	0.003	8.03
Rates (R)	3	12573.66**	0.01	0.43 §	933.98**	0.14	0.010	7.43
S x R	6	1888.46	0.04	0.25	296.26	0.29	0.012	13.70
Error 2	18	1561.30	0.03	0.14	120.63	0.18	0.011	5.95
CV 1 (%)		23.89	1.08	24.47	18.24	14.13	13.55	28.42
CV 2 (%)		25.26	2.84	20.09	13.13	27.56	26.30	24.47
		Al	**H+Al**	**SB**	**V**	**m**	**OM**	**CEC**
Block	2	0.0019	1.2519	0.3286	160.5219	3.8611	0.1163	0.3419
Source (S)	2	0.0119**	0.9786*	0.9169**	268.3611*	48.0278*	0.0663	0.7353**
Error 1	4	0.0007	0.0974	0.0436	15.8019	4.3611	0.0362	0.0386
Rates (R)	3	0.0003	0.0203	0.2847	37.9222	1.0648	0.0190	0.3003
S x R	6	0.0019	0.2463	0.3814	82.7211	4.8426	0.0351	0.3608
Error 2	18	0.0033	0.4130	0.2664	91.5968	14.1944	0.0264	0.2290
CV 1 (%)		23.14	8.63	9.65	10.61	38.16	6.94	8.62
CV 2 (%)		50.69	17.78	23.85	25.55	68.85	5.93	20.98

*Significant at 0.05 level by test F (p≤0,05). ** Significant at 0.01 level by test F (p≤0,01). § Significant at 0.10 level by test F (p≤0,10). NS: not significant.

Table 4. Agronomic efficiency and chemical analysis of a Cambissol after organic residues application (0 to 0.2 m)

Attributes	Organic sources (average of rates)*			
	Poultry litter	Farmyard manure	Biochar	Averages of the organics sources
Agronomic efficiency index	148.42 A	51.04 B	15.04 B	71.49
pH in water	5.53 B	5.58 B	5.68 A	5.59
P (mg dm^{-3})	2.13 A	1.67 A	1.74 A	1.85
K (mg dm^{-3})	105.44 A	78.17 B	67.25 B	83.62
Ca^{2+} ($cmol_c$ dm^{-3})	1.29 B	1.52 B	1.83 A	1.55
Mg^{2+} ($cmol_c$ dm^{-3})	0.35 B	0.38 B	0.44 A	0.39
Al^{3+} ($cmol_c$ dm^{-3})	0.15 A	0.10 B	0.09 B	0.11
H +Al ($cmol_c$ dm^{-3})	3.86 A	3.68 A	3.30 B	3.61
Sum of bases ($cmol_c$ dm^{-3})	1.93 B	2.10 B	2.47 A	2.16
Effective CEC (t) ($cmol_c$ dm^{-3})	2.08 B	2.20 B	2.56 A	2.28
CEC at pH 7 (T) ($cmol_c$ dm^{-3})	5.78 A	5.78 A	5.77 A	5.78
Saturation by Al (%)	7.75 A	4.67 B	4.00 B	5.47
Saturation by bases (%)	33.40 B	36.32 B	42.65 A	37.46
O.M. (g kg^{-1})	27.30 A	28.20 A	26.70 A	27.40
P-equi (mg L^{-1})	16.53 A	16.46 A	16.73 A	16.58
S (mg dm^{-3})	12.59 A	9.14 B	8.18 B	9.97
Zn (mg dm^{-3})	1.54 A	1.08 B	1.16 B	1.26
Fe (mg dm^{-3})	31.57 A	31.96 A	34.56 A	32.69
Mn (mg dm^{-3})	6.54 A	5.81 A	7.16 A	6.41
Cu (mg dm^{-3})	1.53 A	1.47 A	1.44 A	1.47
B (mg dm^{-3})	0.28 A	0.19 A	0.18 A	0.20

*Means followed by the same letter in the rows do not differ by Knott-Scott test at 5% probability

cations (contents of exchangeable Ca, Mg, K and Na) in the cultivated layer from soil, which depends of negative charges on the surfaces of the soil clays and organic matter (Zhang et al., 2015). In biochar treatment, on average of all rates, the values were 28 and 17% superior to those presented by the poultry litter and farmyard manure use, respectively (Table 4). This might occur due the lower export of bases by the grains because of the lower grain yield, which can be observed by the lowest agronomic efficiency value provided by the biochar (Table 4).

The use of the poultry litter increased the values of the exchangeable acidity (Al^{3+}) and sulfur in the soil, possibly by the presence of additives in this residue. To enhance the productivity and to reduce the cost, the modern aviculture has used additives to mitigate the volatilization of ammonia from poultry litter. In this case, aluminum sulfate is being highly applied for its high efficiency (Medeiros et al., 2008). The higher value of soil aluminum saturation (m) observed with application of poultry litter, in relation to the other sources, demonstrates higher participation of the exchangeable aluminum in the effective CEC (t), than the base levels (K, Ca, Mg and Na).

The treatments did not affect the levels of micronutrients Mn, Cu, Fe and B, however, residual effects of the sources were observed on Zn levels. The highest concentrations of Zn were obtained by the poultry litter use (Table 4). The absence of treatment effects on copper levels might be associated to the significant increase of zinc levels, because the two elements compete for the complexing site in soil (Wang et al., 2010). The use of organic amendments should be backed by research that evaluates their effect on the levels of the elements in soil, and their dynamics in agroecosystem. A reason is that the frequent application, over time, can cause contamination by nitrates or heavy metals, such as zinc and copper, in the soil, vegetation and water bodies (Wang et al., 2010).

The application of organic amendments might affect the properties of the soil, but the effects are usually not visible in a short term experiment (Miller & Miller, 2000). Likewise, the short-term effect of the organic amendment applications did not increase the organic matter level of the soil. A decrease on organic matter, of 12.7 dag kg^{-1} soil, was observed in relation to the analysis done before the experiment (Tables 2 and 4). We must point out that those losses can occur from the intense soil tillage, when the turning over of the arable layer exposes considerable amounts of organic matter, previously protected, to the oxidative effects from environment (Cerri et al., 2010).

The soil tillage is one of the main greenhouse gas generation factors, among these CO_2, originating from the organic matter of the soil (Cerri et al., 2010). As much as possible, the best management practices should be used, such as no-tillage practice, seeking to preserve and increase the sustainability of the cropping systems through the increase of the organic matter of the soil. In addition, the reintegration of the organic residues to the agroecosystem, like the manures, that are important sources of greenhouse effect gases when inappropriately managed (Cerri et al., 2010). One should considered that the studied soil, a Cambissol, is highly susceptible to soil, nutrient and organic matter losses by water erosion under conventional tillage cropping system.

A linear relationship was verified among the doses of the three amendments applied and the increase of the agronomic efficiency index (Figure 2). The amendments presented values equal to or above 100% of the agronomic efficiency index by the application of 7 Mg ha^{-1} or more, equaling the grain yield obtained by the reference fertilization used (400 kg ha^{-1} of the mineral fertilizer). The curve was better adjusted to the linear model, indicating the need to study higher doses seeking to obtain of the point of maximum technical yield.

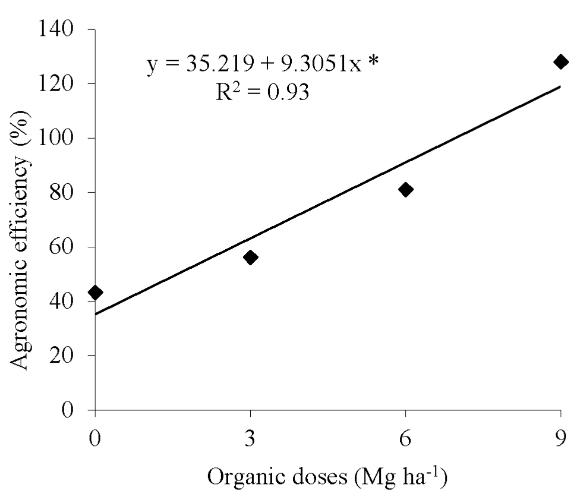
Increases in the grain yield by doses above 7 Mg ha^{-1} (AE > 100%) demonstrate the high productive potential provided by the organic wastes. The organic amendments have high capacity to improve the soil fertility quality by the supply of nutrients. Organic amendments provides lower phosphorus fixation, increasing the mineralization of several nutrients such as nitrogen (Sainju et al., 2010); the liberation of potassium (Yu et al., 2009) and the availability of micronutrients by the complexing with organic radicals (Wang et al., 2010). Furthermore, it increases the pH, N, P, K, base saturation levels, organic carbon and decreasing aluminum saturation, among others beneficial effects that positively influence the grain yield increase (Pinto et al., 2012).

The increasing doses of amendments influenced positively and linearly the phosphorus levels in the soil (Figure 3). Demonstrating that the doses might be considered low for the characteristic, because the curve adjusted to the data having been a linear line and the maximum point was not reached.

Increasing the doses of the organic amendments, P adsorption sites in the soil can have been blocked by the strong bonding of carboxylic and phenolic functional groups of the organic matter to the hydroxyls of the Fe and Al oxides, competing with P adsorption sites and increasing the availability of that nutrient for the plants (Guo & Song, 2010). The organic amendments can be a phosphorus sources for agriculture, mainly those originating from monogastric animal excrements, such as poultry, that have low feed use efficiency (Szogi et al., 2010). Those sources might present adequate agronomic efficiency and low cost inputs (Table 3), depending of the local availability, increasing the profitability of farmers.

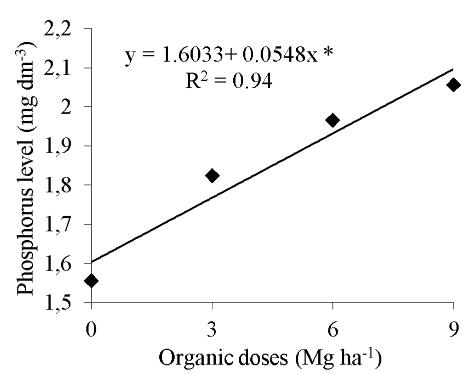
The levels of potassium in the soil presented a linear behavior in function of the doses of the amendments used. The highest dose increased 33.7% of the edaphic levels in relation to their non-use (Figure 4). The use of fertilizers to supply the nutritional demands of the soybean plants regarding the potassium is an essential condition to obtain grain yield increases in Brazil (Oliveira et al., 2001). Potassium is the second most absorbed nutrient by the soybean plant. In addition, it is the second most exported, and should be replaced, at least to maintain the soil fertility (Moterle et al., 2009). Yu et al. (2009) observed that the application of manure associated with mineral fertilizer is the best fertilization strategy seeking to improve the K balance level in a soybean-corn production system in China.

A positive and linear effect of the doses of the organic amendments on the soil zinc levels was observed (Figure 5). The dose of 6 Mg ha^{-1} incresed Zn by 35.7% (0.39 mg dm^{-3}) in relation to the absence of amendment use. The increase of the zinc levels by organic amendments use is described in the literature (Smanhotto et al., 2010). This is relevant because the



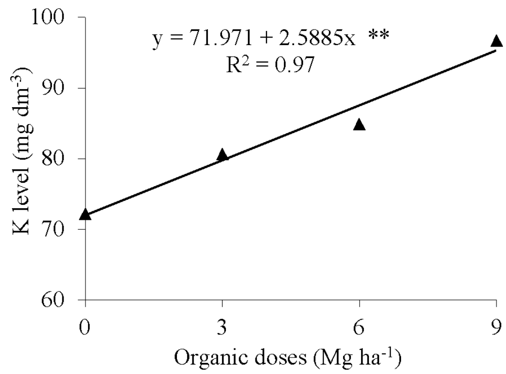
* Significant at 5% probability

Figure 2. Regression equation for the agronomic efficiency index in function of the doses of organic amendment, Itutinga Brazil



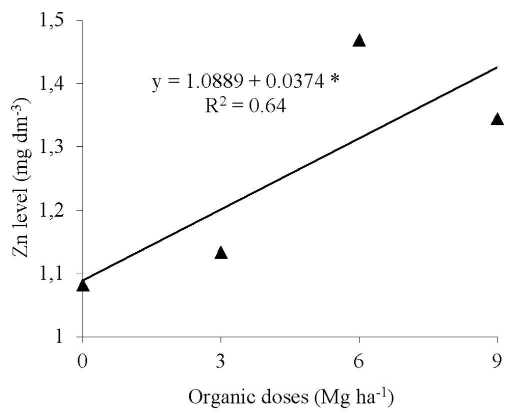
* Significant at 10% probability ($p \leq 0.0523$).

Figure 3. Regression equation for phosphorus (P) in soil in function of the doses of organic amendment. Itutinga, Brazil



**Significant at 1% probability (p≤0.01).

Figure 4. Regression equation for potassium (K) in soil in function of the doses of organic amendment. Itutinga, Brazil



*Significant, at 5% probability (p ≤ 0.05).

Figure 5. Regression equation for zinc (Zn) in soil in function of the doses of organic amendment. Itutinga, Brazil

zinc deficiency is a limiting factor of agricultural production worldwide. About 50% of the soils used for grain worldwide has little available Zn, this reduces the production as well as the nutritional quality of the grains (Fageria, 2002). This is very important in Brazil because of prevalence of Zn deficiencies observed in the soils throughout country.

Conclusions

Nutrient-rich organic amendments, such as poultry litter, are agronomically effective to increase of soybean grain yield. The use of biochar provides increases in the levels of calcium and magnesium, sum of bases, base saturation, pH and effective CEC of the soil. Organic amendments application provides beneficial increases of phosphorus, potassium and zinc levels in the soil, after a soybean cropping.

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