

# ORGANIC MATTER FRACTIONS AND SOIL FERTILITY UNDER THE INFLUENCE OF LIMING, VERMICOMPOST AND CATTLE MANURE

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**ABSTRACT:** This work evaluates effects of cattle manure vermicompost in association with liming on soil fertility indexes. The experiment was carried out in greenhouse conditions, in pots containing samples of a Typic Hapludox, medium-textured soil. Five levels of vermicompost (equivalent to 0, 28, 42, 56, and 70 t ha<sup>-1</sup>, dry weight) and five liming levels (to raise base saturation to 20, 30, 40, 50, and 60%) were combined in a factorial scheme and samples were incubated for 180 days. Samples of the same soil received the equivalent to 70 t ha<sup>-1</sup> of the cattle manure used to produce the vermicompost, and the same lime rates. Cattle manure was better than vermicompost to supply K and Mg. Small differences in P supply were observed between the manures. The vermicompost increased the levels of Ca, pH, organic matter (OM) and CEC more than the manure. C-humic acids decreased and C-humin increased with vermicompost application. With liming, C-humic acids decreased, but the total content of OM was not affected.

**Key words:** manure, pH, fulvic acids, humic acids, humin

## FRAÇÕES ORGÂNICAS E FERTILIDADE DO SOLO SOB INFLUÊNCIA DE CALAGEM, VERMICOMPOSTO E ESTERCO DE CURRAL

**RESUMO:** Os efeitos do vermicomposto de esterco de curral associado à calagem em atributos da fertilidade do solo foram avaliados através de experimento em vasos empregando um Latossolo Vermelho, distrófico, textura média. Cinco doses do vermicomposto (equivalentes a 0; 28; 42; 56 e 70 t ha<sup>-1</sup>, peso seco) e cinco doses de calcário (visando elevar a saturação por bases a: 20; 30; 40; 50 e 60%) foram combinadas em esquema fatorial, sendo as amostras de solo incubadas por 180 dias. Para comparação entre o vermicomposto e o esterco de curral, amostras do mesmo solo receberam o equivalente a 70 t ha<sup>-1</sup> do esterco de curral que originou o vermicomposto e as cinco doses de calcário listadas anteriormente. Através do cálculo do Índice de Eficiência Agronômica, foi verificado que o potencial de fornecimento de K e de Mg pelo esterco é maior do que o do vermicomposto, e que o de P, é semelhante. O vermicomposto aumentou os teores de Ca<sup>2+</sup> e de matéria orgânica (MO), os valores de pH em CaCl<sub>2</sub> e a CTC a pH 7. Com o aumento das doses de vermicomposto houve diminuição do C-ácidos húmicos e aumento do C-humina e com a calagem o C-total não aumentou mas houve diminuição do C-ácidos húmicos.

**Palavras-chave:** adubos orgânicos, pH, ácidos fúlvicos, ácidos húmicos, humina

### INTRODUCTION

Soil organic matter (OM) contains two large groups of substances - the non-humic and the humic compounds. The first group is represented by substances with greater bioavailability and known chemical properties, such as polysaccharides and sugars, proteins and amino acids, lipids and fatty acids, waxes, pigments and other substances of low molecular weight (Schnitzer, 1991; Stevenson, 1994; Lobartini & Orioli, 1996). Humic substances (HS) constitute a heterogeneous, dark-colored and amorphous mixture of substances with high molecular weight (Stevenson, 1994). However, there has been in-

creasing evidence that HS consist of associations of relatively small, heterogeneous molecules, bound together by weak dispersive forces (Piccolo, 2001) and show greater chemical stability and lower bioavailability than non-humic substances (Lobartini & Orioli, 1996).

According to their solubility traits, HS are divided into humic acid (HA), soluble in alkaline medium; fulvic acid (FA), soluble in both alkaline and acid media; and humin (H), insoluble in both media (Schnitzer, 1991; Stevenson, 1994). The humin fraction represents the largest amount in humus, both in soils of tropical regions and soils under temperate climate conditions. This is a highly condensed fraction (more than 60% C), closely linked to

the soil's mineral fraction, and cannot be separated even in alkaline medium (Marschner & Wilczynski, 1991; Melo et al., 1994; Nascimento et al., 1988; Rosales et al., 1999; Stevenson, 1986; Yagi et al., 2000).

HS represent between 65% and 80% of the total OM and its active fraction (Schnitzer, 1991; Piccolo, 2001). The high cation exchange capacity (CEC) of these substances is attributed mainly to carboxylic and phenolic radicals, and increases as the pH increases (Hayes & Malcolm, 2001). According to Stevenson (1986), FA and HA present between 6,400 and 14,200 and between 5,600 and 8,900  $\text{mmol}_c \text{kg}^{-1}$  total acidity from phenolic and carboxylic radicals, respectively. Differences between amounts of radicals in the two fractions are related to the fact that FA has greater amounts of O and smaller amounts of C than HA, despite the lower molecular weight of the first. In addition, oxygen in FA is almost totally in the form of COOH, O-H and C=O groups, while in HA, substantial part of the O occurs as structural component (ether or ester bonds).

Applying organic fertilizers elicit increasing OM and positively change other chemical characteristics associated with soil fertility, such as CEC, pH and nutrient availability (Mazur et al., 1983; Ferreira & Cruz, 1992; Alves et al., 1999). In addition, the increase in pH can affect the dynamics of soil organic matter fractions, leading to a depolymerization of HA and to a small increase in FA (Araujo et al., 1995).

Significant increases in OM and C contents in all OM fractions were observed by Rosales et al. (1999) with the application of 40  $\text{m}^3$  compost, either combined or not with mineral fertilizers. Eleven years later, the OM contents increased between 15.3 and 19.8  $\text{g kg}^{-1}$ , reaching 20.8  $\text{g kg}^{-1}$  when compost and mineral fertilization were combined. The application of compost accompanied by mineral fertilization supplied greater amounts of HA and FA to the surface layer.

In Brazil, cattle manure is the most frequently utilized organic fertilizer. In recent years, supplying cattle manure vermicompost has become a profitable activity for many producers. However, no available research results would allow a conclusion as to whether using this product is more advantageous than using manure. This work was therefore developed to compare the effects of cattle manure and vermicompost, together with liming, on soil fertility, especially regarding the quality of the generated organic matter.

## MATERIAL AND METHODS

The experiment was conducted in a greenhouse on samples from the layer 0 - 0.20 m of a medium-textured, Typic Hapludox, collected in a forested area in Jaboticabal, SP, Brazil (21°15'17"S and 48°19'20"W). The soil's preliminary chemical analysis (Raij et al., 1987)

presented: P resin = 3  $\text{mg dm}^{-3}$ ; OM = 21  $\text{g dm}^{-3}$ ; pH in  $\text{CaCl}_2$  0.01  $\text{mol L}^{-1}$  = 4.0; K = 0.5  $\text{mmol}_c \text{dm}^{-3}$ ; Ca = 3  $\text{mmol}_c \text{dm}^{-3}$ ; Mg = 1  $\text{mmol}_c \text{dm}^{-3}$ ; Al = 6  $\text{mmol}_c \text{dm}^{-3}$ ; H+Al = 47  $\text{mmol}_c \text{dm}^{-3}$ ; CEC at pH 7.0 = 52  $\text{mmol}_c \text{dm}^{-3}$ ; and base saturation = 9%.

Trials were set up in a completely randomized design, in a 5x5 factorial scheme (five vermicompost rates x five liming rates), with two replicates. The vermicompost utilized was obtained from dairy cattle manure under confinement. The lime rate factor, obtained by using  $\text{CaCO}_3$  and magnesium hydroxycarbonate (Ca:Mg ratio of 3:1), corresponded to rates necessary to obtain base saturation indexes equal to 20; 30; 40; 50 and 60%. The vermicompost factor utilized rates of 0; 28; 42; 56 and 70  $\text{t ha}^{-1}$ . The cattle manure 70  $\text{t ha}^{-1}$  rate (same manure utilized to produce the vermicompost), combined with the same lime rates (V% = 20; 30; 40; 50; and 60), was used in comparison with the 70  $\text{t ha}^{-1}$  vermicompost rate.

The organic fertilizers were air-dried, ground, passed through a 2 mm sieve and chemically characterized (C, N, P, K, Ca, Mg, Cu, Fe, Mn, and Zn), according to Kiehl (1985). The products (organic fertilizers and lime) were mixed with 1  $\text{dm}^3$  soil and transferred to aluminum pots covered with newspaper sheets. The experiment was conducted for 180 days, and the soil was watered to 60% of its water retention capacity.

At the end of the incubation period the soil was sampled to evaluate its chemical attributes, and to perform soil OM fractioning (Raij et al., 1987; Stevenson, 1986). CEC at pH 7.0 was determined by the direct method (Glória et al., 1965), as a replacement for the sum of exchangeable  $\text{K}^+$ ,  $\text{Ca}^{2+}$  and  $\text{Mg}^{2+}$  contents, and potential acidity (H+Al) (Raij et al., 1987). This procedure was adopted because the experiment was carried out in a closed system, without water percolation, and salt accumulation occurred because of mineralization of the organic fertilizers and OM, which could lead to an overestimation of the calculated CEC values.

The scheme proposed by Stevenson (1986) was followed for OM fractioning, except with regard to the water soluble carbon fraction extraction, previously done by treating the sample with a NaOH 0.1  $\text{mol L}^{-1}$  solution. Extraction procedure was based on Dabin (1976), and a mass equivalent to 10  $\text{cm}^3$  of soil was used. Laboratory procedures are described ahead:

**Water-soluble organic matter:** Fifty mL deionized water were added to a centrifuge tube (250 mL) containing 10  $\text{cm}^3$  of the sample; suspension was shaken for 30 min at 150 rpm, in horizontal shaker. Samples were centrifuged for 15 min at 10,000 rpm, and the supernatant was filtered through Whatman n.1 filter paper.

**Humic substances:** The sediment in the centrifuge tube was resuspended with 100 mL of a NaOH 0.1  $\text{mol L}^{-1}$  so-

lution. The suspension was shaken for 60 min at 150 rpm and centrifuged for 10 min at 8,000 rpm. The supernatant was transferred to a 200 mL volumetric flask. The procedure was repeated with 50 mL of a NaOH 0.1 mol L<sup>-1</sup> solution, followed by 30 min shaking. The supernatant was transferred to the same volumetric flask and the volume was completed with deionized water. Part of the volume obtained was utilized (100 mL) for FA and HA separation, and the rest was used to determine carbon content in the humic fractions.

**Fulvic acids fraction:** One hundred mL of the HS fraction were pipetted to a centrifuge tube. Concentrated H<sub>2</sub>SO<sub>4</sub> was added to lower the pH to 2.0, manually shaken. The suspension was submitted to centrifugation for 10 min at 5,000 rpm. The supernatant contained the FA fraction, and the precipitate contained the HA fraction. Carbon was determined in the HS and HA fractions; C in the FA fraction was obtained by difference between those two fractions.

**Humic acids fraction:** After fraction FA was obtained, 25 mL of a NaOH 0.1 mol L<sup>-1</sup> solution were added to the precipitate in the centrifuge tube; the precipitate was solubilized by manual shaking. The fraction was quantitatively transferred to a 50-mL volumetric flask with deionized water and the volume was completed to capacity.

**Humins:** The sediment that remained in the centrifuge tube after HS was fully transferred to a Petri dish and oven dried at 65°C. After drying, the residue mass was obtained and the material was ground with mortar for later determination of carbon content.

The colorimetric method was utilized for carbon quantification in the OM fractions. Two linear calibration graphs were prepared: one using a glucose solution to convert the absorbance data into carbon in the water soluble, HS and HA fractions, and the other by adapting the procedure utilized in the South Dakota modified method (Quaggio & Raij, 1979), to convert the humin fraction data.

Solutions with 0 to 600 mg L<sup>-1</sup> C were used to prepare the glucose linear calibration graph. Four-mL aliquots of each standard and a 10-mL aliquot of a Na<sub>2</sub>Cr<sub>2</sub>O<sub>7</sub> 0.667 mol L<sup>-1</sup> + H<sub>2</sub>SO<sub>4</sub> 5 mol L<sup>-1</sup> solution were transferred to a 250-mL Erlenmeyer flask. The flask, with a test tube containing water attached to its neck, was heated on a plate at 100°C for 7 min. After cooling, the reading of extract's absorbance was obtained in a colorimeter at 650 nm. The absorbance for organic matter fractions was obtained in 4 mL aliquots of the extract, which received the same treatment as the glucose standards.

To obtain the linear calibration graph for humins, the humic substances fraction were extracted and discarded, from 12 standard soils in use at the laboratory,

and the residue-containing humin was obtained. Carbon in the humin fraction was determined by the Walkley & Black method. In a different series of the same residues, the absorbance was determined from extracts obtained by the modified South Dakota method (Quaggio & Raij, 1979). Based on the C-humin contents data obtained by the Walkley & Black method, and on the measured absorbance values, the regression equation utilized to convert absorbance values of the samples into carbon concentration of the humin fraction was calculated. For C-humin determination, 1 cm<sup>3</sup> of soil was utilized. Based on the mass of 1 cm<sup>3</sup> humin, from the total humin mass obtained from each sample and on the mass of 10 cm<sup>3</sup> of soil used to extract the fractions, it was possible to express C-humin as g dm<sup>-3</sup>.

The effects of vermicompost and liming on the soil's chemical attributes were evaluated through analysis of variance by the F test and, when significance occurred, the effects were partitioned by polynomial regression. The agronomic efficiency index (AEI) was determined for P, K, Ca, Mg, OM and CEC data by the following equation, adapted from Raij (1991):

$$AEI = \frac{Y_{\text{verm}} - Y_{\text{ctrl}}}{Y_{\text{mnre}} - Y_{\text{ctrl}}} \times 100$$

Y = soil fertility attribute (OM, CEC at pH 7.0, resin-extracted P, etc.); verm = Y values in the treatment that received 70 t ha<sup>-1</sup> vermicompost; ctrl = Y values in the control; mnre = Y values in the treatment that received 70 t ha<sup>-1</sup> cattle manure. The evaluation of liming and vermicompost effects on the C content in the OM fractions was made in compliance with the same statistical procedure described for the soil's chemical attributes; comparison between manure and vermicompost was done by Tukey test ( $P < 0.05$ ).

## RESULTS AND DISCUSSION

### Effects of organic fertilization and liming on soil fertility

Characterization of the organic fertilizers utilized revealed that the vermicompost became poorer in K and richer in Cu, Fe, Mn and Zn, in comparison to cattle manure (Table 1). Losses by leaching justify the decrease in K and, in the case of micronutrients, enriching is explained mainly by contamination by soil from the place where the vermicomposting was done, and by the relative concentration that occurred as a consequence of volume reduction at the vermicomposting stage. With the application of 70 t ha<sup>-1</sup> manure, the amounts incorporated to the soil would be, in kg ha<sup>-1</sup>, 1,890 N; 840 P; 1,190 K; 1,190 Ca and 560 Mg; with the application of 70 t ha<sup>-1</sup> vermicompost, those amounts would be 1,680; 910; 350; 1,750 and 420 kg ha<sup>-1</sup> respectively.

Effects of vermicompost and liming on soil fertility attributes are depicted in Table 2. The contents of available P and exchangeable K, Ca and Mg increased linearly as the vermicompost rates increased, regardless of liming (Figure 1a, b, c, d). The agronomic efficiency index (AEI) was calculated to compare the highest vermicompost rate to the application of the same rate of manure. Vermicompost was more efficient than cattle manure in supplying exchangeable calcium (AEI = 139%) and less efficient in increasing the exchangeable potassium (AEI = 22%) and magnesium (AEI = 68%) contents, reflecting the tendency of the original content concentrations of these elements in the utilized materials. The contribution of manure and vermicompost to available P in the soil was similar (AEI = 108%).

Organic fertilization, in association or not with liming, provided increases in soil pH (Figure 2). By using the isoline chart, it is possible to estimate the rate of substitution of lime by vermicompost to obtain equivalent pH values. As an example, a pH value around 5.6 can be obtained by applying 2 t ha<sup>-1</sup> lime (rate necessary to obtain V% = 47% under the conditions of the experiment) and 60 t ha<sup>-1</sup> vermicompost, or 2.4 t ha<sup>-1</sup> lime (V% = 55%) with 50 t ha<sup>-1</sup> vermicompost. Abreu Jr. et al. (2000) observed a 30 to 50% decrease in potential acidity in a group of 20 acid soils and a substitution rate of 2 t ha<sup>-1</sup> lime or higher, for 60 t ha<sup>-1</sup> urban waste compost.

Organic fertilization increases soil pH supplying bases, forming alkaline humates during the process of decomposition and synthesis of these residues, and by Al complexing through organic molecules, such as FA (Mazur et al., 1983; Ferreira & Cruz, 1992) and other low molecular weight acids (Hue et al., 1986). With the equivalent to 70 t ha<sup>-1</sup> vermicompost and cattle manure, the pH value in the treatment with liming to raise V to 20%, which was 4.1, increased to 5.3 and 4.9, respectively (pH values that

would be obtained with liming for V = 60%, without organic fertilization). In addition, the highest pH (5.8) was observed in association with liming for V equal to 50 or 60% and 70 t ha<sup>-1</sup> vermicompost (Figure 3).

OM contents were only affected by the application of vermicompost (Table 2), increasing linearly (Figure 1e). In addition, the AEI for vermicompost, as compared to cattle manure, was 180%, indicating that the vermicompost was 80% more efficient to increase OM than manure. Therefore, 70 t ha<sup>-1</sup> of cattle manure would be necessary to produce the same amount of OM generated by 39 t ha<sup>-1</sup> of vermicompost. Manure is a material in decomposition. Therefore, when manure is applied to the soil, it continues losing CO<sub>2</sub> to the atmosphere until the more labile OM is decomposed. So when equivalent amounts of compost and manure are applied to the soil, it is expected that the compost will incorporate more OM to the soil, because of the greater OM stability in the compost.

There was interaction ( $P < 0.01$ ) between fertilization with vermicompost and liming, with respect to the effect of these treatments on CEC values (Table 2). The increase in CEC with the vermicompost rates was linear for V = 20; 30; 50 and 60%, and quadratic for V = 40% (Figure 4). Notwithstanding, when the effect of liming was partitioned within each vermicompost rate, regressions were non-significant. Vermicompost and manure rates of 70 t ha<sup>-1</sup> modified the CEC values from 44 mmol<sub>c</sub> dm<sup>-3</sup> to 62 and 57 mmol<sub>c</sub> dm<sup>-3</sup>, respectively. Significant increases in CEC at pH 7.0 were obtained by Melo et al. (1994) with the application of sewage sludge in a soil planted with sugarcane. The comparison of the effect of vermicompost on CEC, in relation to manure, was done by the AEI, which reached 145%, indicating that the vermicompost was 45% more efficient than manure in increasing the soil's CEC. This greater efficiency is associated with the greater production of functional groups during the vermicomposting process, which are

Table 1 - Chemical characterization of organic fertilizers utilized.

Organic fertilizer	C	N	P	K	Ca	Mg	Fe	Cu	Mn	Zn
Cattle manure	330	27	12	17	17	8	8	46	337	105
Vermicompost	158	24	13	5	25	6	28	107	649	197

Table 2 - Analysis of variance of the effects of vermicompost rates and liming levels on soil attributes.

Factor	P	OM	pH	K	Ca	Mg	CEC
Liming (C)	0.8 <sup>ns</sup>	0.8 <sup>ns</sup>	310.0**	1.3 <sup>ns</sup>	25.3**	21.3**	4.4**
Vermicompost (V)	209.9**	21.1**	841.5**	853.9**	132.6**	149.9**	118.5**
C x V interaction	0.8 <sup>ns</sup>	0.8 <sup>ns</sup>	4.5**	1.1 <sup>ns</sup>	0.8 <sup>ns</sup>	0.8 <sup>ns</sup>	3.3**
CV%	15.7	10.9	0.9	4.3	10.8	11.3	6.4

<sup>ns</sup>and \*\* non significant and significant at 1%, respectively.

responsible for the production of surface charges, as verified by Jiménez & Garcia (1992) during the composting process of urban residues.

**Liming effect on the soil's organic matter fractions**

The water-soluble C fraction (C-WS) represented less than 1% of the total C in the soil. The carbon content in this fraction was only affected by liming (Table 3),

and no statistical significance was obtained for the linear and quadratic regression models. Kreutzer (1995) obtained an increase in organic carbon content dissolved with liming in a spruce stand with 80 years of age, in Norway. The carbon content in the humic substances (C-HS) was affected by liming and fertilization with vermicompost (Table 3). Through regression analysis, a significant and negative correlation between the C content in this frac-

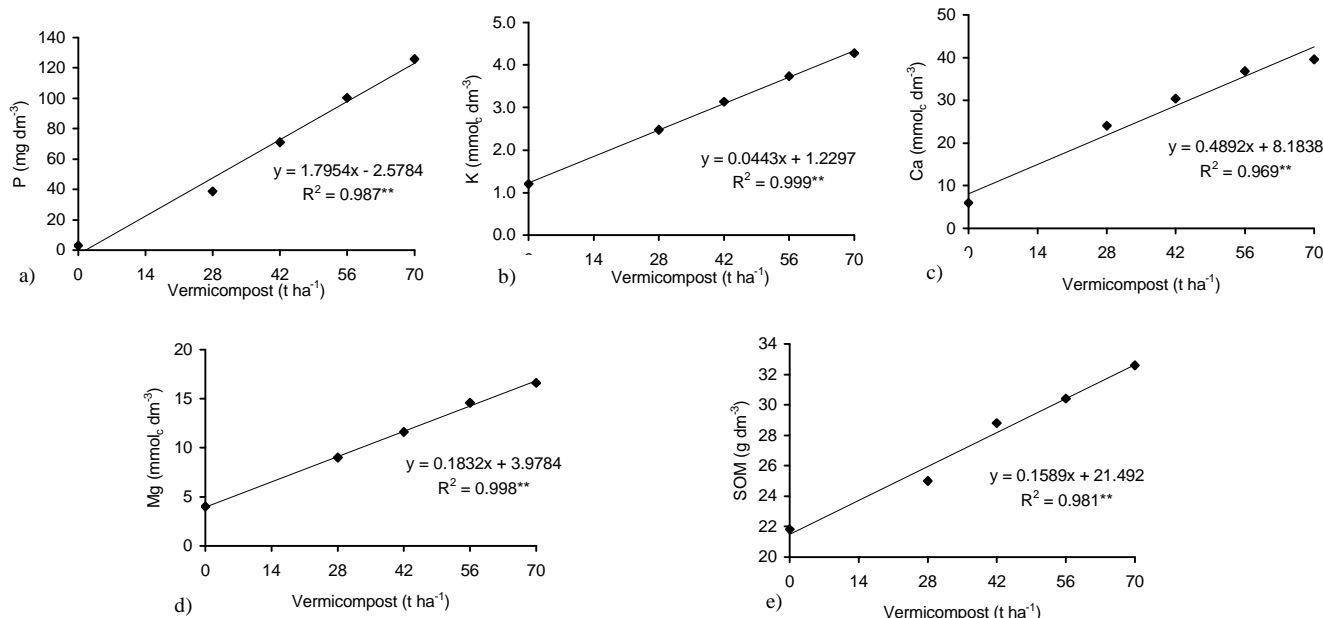


Figure 1 - Soil fertility attributes as a function of vermicompost rates. \*\*significant at 1%.

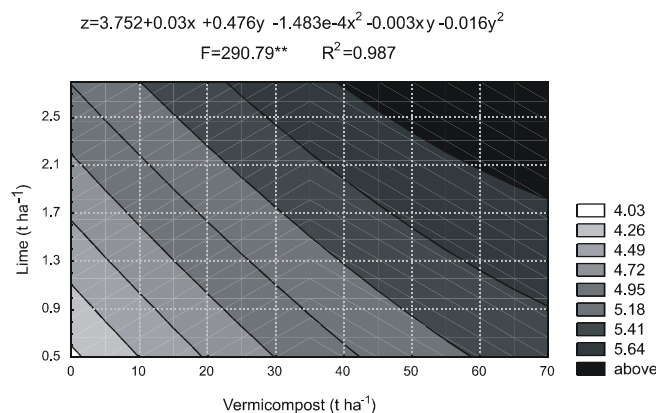


Figure 2 - Isolines for pH in CaCl<sub>2</sub> as a function of vermicompost and lime rates. \*\*significant at 1%.

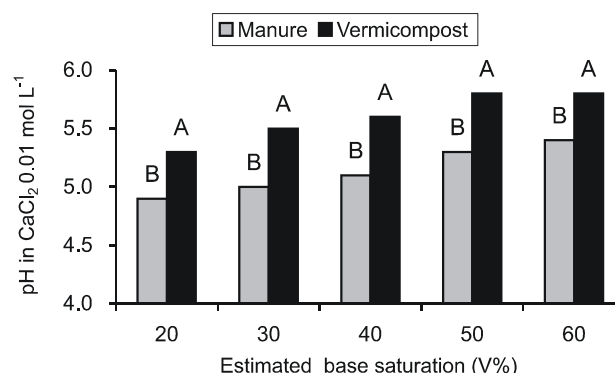


Figure 3 - Comparison between effects of application of 70 t ha<sup>-1</sup> vermicompost and manure, on soil pH, in all liming levels. Distinct letters indicate significant effect by Tukey test (P < 0.05).

Table 3 - Analysis of variance of effects of vermicompost rates and liming levels on soil's organic matter fractions.

Factor	C-WS	C-HS	C-HA	C-FA	C-H	C total
----- F -----						
Liming (C)	2.8*	5.1**	8.3**	1.5 <sup>ns</sup>	1.2 <sup>ns</sup>	1.5 <sup>ns</sup>
Vermicompost (V)	0.93 <sup>ns</sup>	2.9*	4.9**	0.9 <sup>ns</sup>	53.3**	37.8**
C x V interaction	1.6 <sup>ns</sup>	1.1 <sup>ns</sup>	1.8 <sup>ns</sup>	0.9 <sup>ns</sup>	0.7 <sup>ns</sup>	1.6 <sup>ns</sup>
CV%	2.4	18.0	14.4	57.0	10.2	7.5

<sup>ns</sup>, \* and \*\* non significant and significant at 5 and 1%, respectively. C: carbon; WS: water soluble; HS: humic substances; HA: humic acids; FA: fulvic acids; H: humin; total: total carbon content.

tion and the liming levels was observed, and the best fit was obtained with the linear regression model (Figure 5a).

When the effects of pH on the humic acids (C-HA) and fulvic acids (C-FA) fractions are disregarded, the proportion of carbon relative to the total ranged from 26 to 17% and from 17 to 12%, respectively. The highest values for each fraction were obtained with treatments that did not receive vermicompost, and the smallest values were observed in treatments which received the equivalent to 70 t ha<sup>-1</sup> vermicompost.

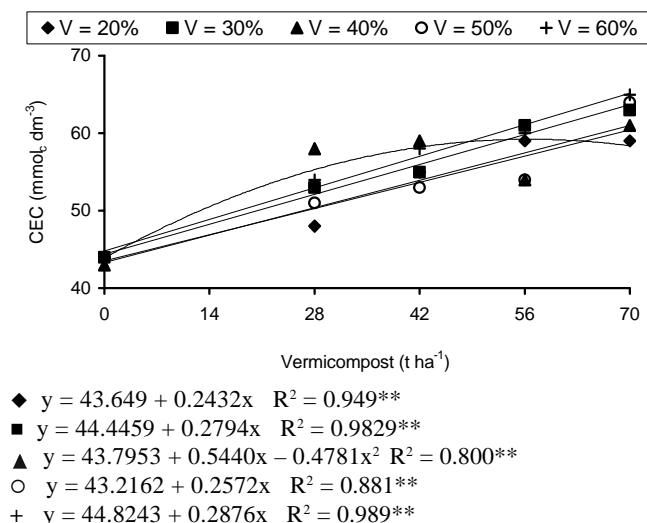


Figure 4 - CEC as a function of vermicompost rates, in each liming level. \*\*significant at 1%.

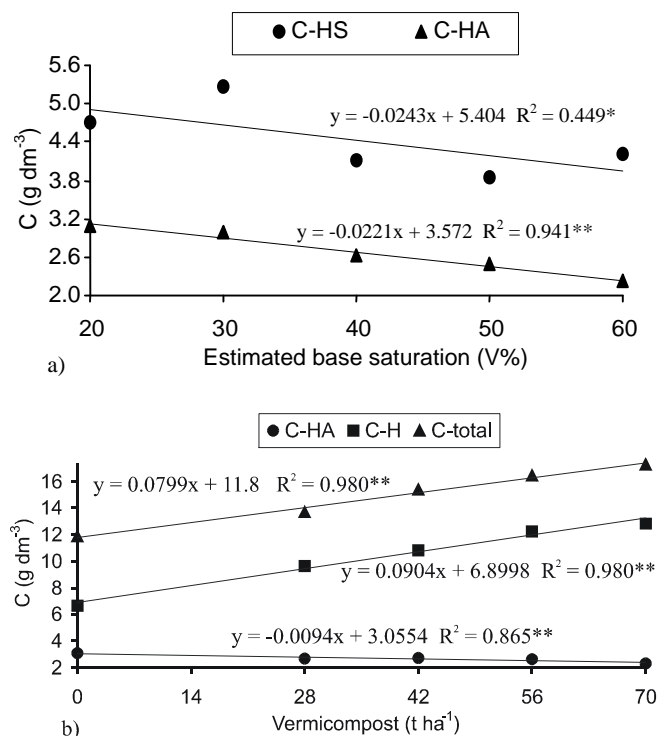


Figure 5 - Carbon in the organic matter fractions as a function of liming a) and vermicompost b). \* and \*\*significant at 5% and 1%, respectively.

Liming decreased the C content in the HA fraction (Figure 5a), but did not affect the C contents in the FA fraction, probably because of interconversions between the less polymerized fractions, resulting in high variability of the results (Melo et al., 1994). Silva et al. (2000) observed an increase in total C content and a reduction in C in the FA and HA fractions in a Red Latosol under a citrus grove, resulting from liming. The decrease in C-HA contents might be related to the presence of oxides which, however not determined in that study, are usually abundant in latosols. In oxide and kaolinite-rich tropical soils, the C-HA fraction can be more easily decomposed than the C-FA fraction, giving rise to more reactive fractions, easily consumed by microorganisms (Mendonça, 1995), since the adsorption of OM to oxides is influenced by carboxylic groups, more abundant in the FAs (Greenland, 1971; Varadachari et al., 1995; Lobartini & Orioli, 1996).

Therefore, in very clayey latosols, a great part of the reactive FA sites would be blocked by kaolinite as well as Fe and Al oxides and hydroxides, by the ligand exchange reactions, thus forming strong bonds with their negative charges, making them more resistant to decomposition than HAs (Greenland, 1971; Varadachari et al., 1995). On the other hand, Tombácz (1999) mentions that the aggregation between HA molecules and the surface of mineral particles depends upon an increase in pH, and that dissociation in such molecules is diffculted when they are aggregated, because of their hydrophobic traits.

The decrease in exchangeable Al<sup>3+</sup> with liming may also be associated to a decrease in C-HA. In the soil under study, the exchangeable Al<sup>3+</sup> in treatments without liming and without organic fertilization was 6 mmolc dm<sup>-3</sup>, a mean level (Ribeiro et al., 1999). Liming decreases the forms of exchangeable aluminum and those associated with organic molecules, and increases the calcium content associated with the OM (Mendonça & Rowell, 1994). For this reason, it promotes destabilization of the organic molecules, making them more susceptible to microbial attacks, since the complexes of Ca with the OM are more unstable than those of OM with Al (Canellas et al., 1999).

It is expected that liming will bring an increase in microbial activity and a decrease in the OM content in the soil (Curtin et al., 1998). Marschner & Wilczynsky (1991) reported that, while the carbon content in a soil under a *Pinus* forest remained unchanged in a treatment without acidity correction, in areas where liming had been performed there was a 10% decrease in the content of C after four years of evaluation. However, the effect of liming may vary with time and environment conditions, such as soil temperature and moisture (Kreutzer, 1995), which might justify the sustained total C contents, obtained both by direct determination and by sum of fractions.

The C-H fraction was responsible for about 70 to 75% of total C, except in the treatment that did not receive organic fertilizer, in which this percentage decreased to

56%. C-H was not affected by soil pH, and because it represents the major part of total C, the same effect was observed for total C obtained by sum of fractions (Table 3).

### Organic fertilization effect on soil's organic matter fractions

Organic fertilization with vermicompost led to a linear decrease in C content in the HA fraction and to a linear increase in total C and in the C-H fraction (Figure 5b). In addition to being related to the increase in pH caused by liming and by the addition of vermicompost, the decrease in C-HA content could also be associated with the increase in C-H content. The increase in C-H contents was correlated ( $P < 0.01$ ) with the decrease in the contents of C-HA ( $y = 17.064 - 2.463x$ ,  $r = -0.536$ ).

The humification rate (C-HS/C-total), when liming is disregarded, was 0.25 for vermicompost treatments and 0.30 for manure treatments, indicating a greater proportion of less polymerized carbon compounds when manure is utilized. Extrapolating the results to a layer between 0 and 20 cm in one hectare, the difference between fertilizers would be an additional 1.08 t ha<sup>-1</sup> C-HS when manure is applied, and an additional 2.88 t ha<sup>-1</sup> C-H when vermicompost is applied. These results support assertion by Lal (2001), that the humification efficiency is usually greater for composted material as compared to a fresh one.

Relations between the soil's OM fractions (C-FA and C-HA) and CEC at pH 7.0 are presented in Figure 6. Results obtained with the application of vermicompost were utilized for the calculations. Since there was a decrease in C-HA with organic fertilization and liming, the relationship between this form of carbon and CEC at pH 7.0 was negative. Because of the variability in the C-FA fraction, no correlation was obtained between it and CEC at pH 7.0, even though this form of carbon shows greater concentration of radicals responsible for the exchange capacity (Greenland, 1971; Stevenson, 1994). On the other hand, the soil's CEC increased linearly with the increase in C-H. In most treatments, as already mentioned, the organic C associated with this fraction represented about 70% of the total, and an increase in C-H was observed under organic fertilization. These data agree with those presented by Melo et al. (1994), who observed that among the OM fractions, humin was the fraction most strongly correlated with CEC ( $r = 0.59$ ).

There was no difference between the application of 70 t ha<sup>-1</sup> manure or vermicompost, in each liming condition, as to the contents of C-HS and C-H (Figure 7a) and C-FA and C-HA (Figure 7b). Because of the more advanced degree of stabilization in the material obtained by vermicomposting, this result was unexpected, since the action of worms alters qualitative and quantitatively the organic matter present in manures; these changes are more

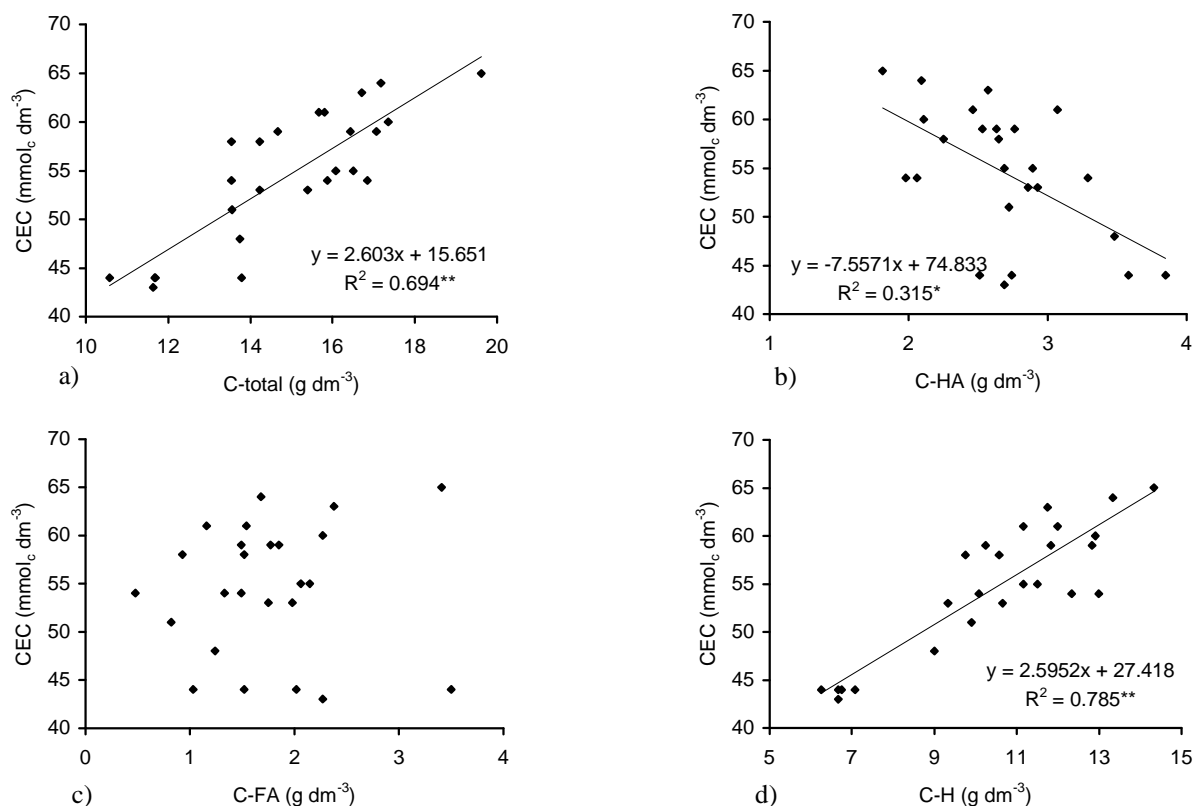


Figure 6 - Correlation between soil CEC at pH 7.0 and total carbon content a) and C in the humic acids b), fulvic acids c) and humin d) fractions. \* and \*\*significant at 5% and 1%, respectively.

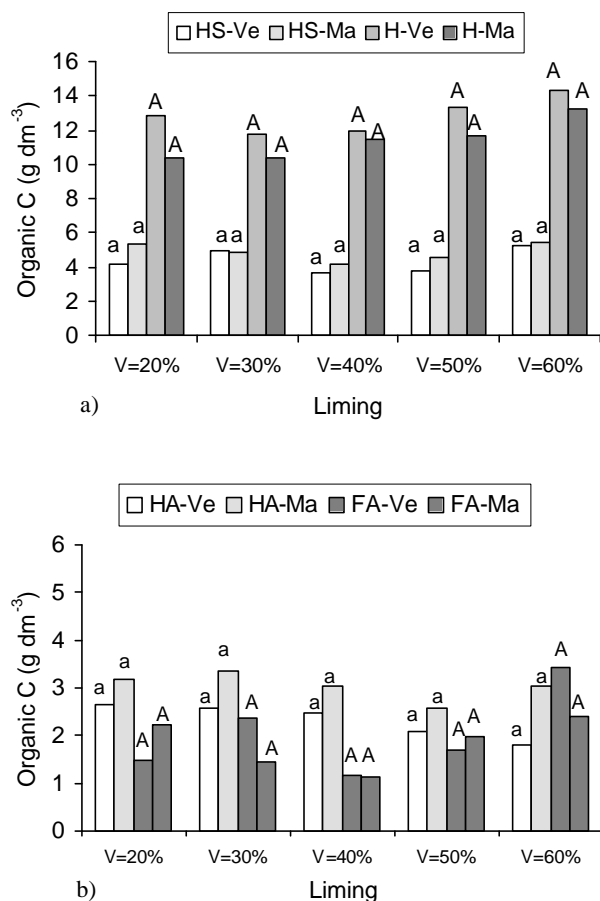


Figure 7 - Comparison of effects of application of vermicompost (Ve) and manure (Ma) on fractions C-HS and C-H (a) and C-HA and C-FA (b). Common upper or lower case letters indicate the absence of significant effect by Tukey test ( $P < 0.05$ ). C: carbon; HS: humic substances; HA: humic acids; FA: fulvic acids; H: humin.

evident when the source of material is not very humified (Petrucci et al., 1988). On the other hand, the mean C-HA contents in the soil, regardless of liming level, were smaller with the use of vermicompost (data not presented). As commented before, vermicompost and manure caused an increase in soil pH, but the effect of the first was greater (Figure 3). Therefore, the smallest C-HA contents obtained with the use of vermicompost may be related to greater depolymerization of smaller-chain compounds in the HA with the greater increase in pH (Ghosh & Schnitzer, 1980).

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