SOLUBLE CARBON IN OXISOL UNDER THE EFFECT OF ORGANIC RESIDUE RATES[1]

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SUMMARY

The application of organic residues to the soil can increase soluble organic carbon (SOC) and affect the pH and electrolytic conductivity (EC) of the soil. However, the magnitude of these changes depends on the type of residue and the applied dose. This study aimed to evaluate the effect of increasing C rates contained in organic residue on the pH, EC, water-extractable total carbon (WETC), water-extractable organic carbon (WEOC), and water-extractable inorganic carbon (WEIC) in soil treated with manure (chicken, swine, and quail), sawdust, coffee husk, and sewage sludge. The levels of total C (TC- KH_2PO_4), organic carbon (OC- KH_2PO_4), and inorganic C (IC- KH_2PO_4) extractable by a 0.1 mol L^{-1} KH_2PO_4 solution were also quantified in soil under the effect of increasing rates of chicken and quail manures. The following rates of organic residue C were applied to a dystrophic Red Latosol (Oxisol) sample: 0, 2,000, 5,000, 10,000, and 20,000 mg kg^{-1}. The addition of organic residues to the soil increased pH, except in the case of sewage sludge, which acidified the soil. The acidity correction potential of chicken and quail manure was highest, dependent on the manure rate applied; regardless of the dose used, sawdust barely alters the soil pH. At all tested rates, the EC of the soil treated with swine manure, coffee husk, and sawdust remained below 2.0 dS m^{-1}, which is a critical level for salinity-sensitive crops. However, the application of chicken or quail manure and sewage sludge at certain rates increased the EC to values above this threshold level. Highest levels of WETC, WEOC, and WEIC were obtained when chicken and quail manure and coffee husk were applied to the Oxisol. The quantities of SOC extracted by KH_2PO_4 were higher than the quantities extracted by water, demonstrating the ability of soil to adsorb C into its colloids.

Index terms: soluble organic carbon, manure, electrolytic conductivity, soil acidity, crop residues, carbon adsorption.

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RESUMO: *CARBONO SOLÚVEL EM LATOSSOLO SOB EFEITO DE DOSES DE RESÍDUOS ORGÂNICOS*

A adição de resíduos orgânicos pode aumentar o carbono orgânico solúvel (COS) e alterar o pH e a condutividade elétrolítica (CE) do solo, mas a magnitude dessas variações depende do resíduo e de sua dose aplicada. Objetivou-se avaliar o efeito de doses de carbono pela adição de resíduos orgânicos sobre o pH, a CE, o carbono total extraível por água (CTEA), o carbono orgânico extraível por água (COEA) e o carbono inorgânico extraível por água (CIEA), em solo tratado com estercos (galinha, suíno e codorna), serragem, casca de café e lodo de esgoto. Os teores de C total (CT- KH_2PO_4), C orgânico (CO- KH_2PO_4) e C inorgânico (CI- KH_2PO_4) extraível por solução de KH_2PO_4 0,1 mol L^{-1} também foram quantificados em solo sob efeito de doses crescentes de estercos de galinha e de codorna. O solo utilizado foi o Latossolo Vermelho distroférrico (LVdf) e as doses de C-resíduo orgânico constituíram-se de 0, 2.000, 5.000, 10.000 e 20.000 mg kg^{-1}. A adição de resíduos orgânicos ao solo promoveu aumento do pH, exceto no caso do lodo de esgoto, que acidificou o solo. Os estercos de galinha e de codorna apresentaram os maiores potenciais de correção da acidez do solo, cuja magnitude é dependente da dose de esterco aplicada; independentemente da dose utilizada, a serragem pouco altera o pH do solo. A CE do solo tratado com esterco de suíno, casca de café e serragem, em todas as doses avaliadas, manteve-se abaixo de 2,0 dS m^{-1}, nível crítico para culturas sensíveis à salinidade. Entretanto, a aplicação de estercos de galinha e de codorna e de lodo de esgoto, para algumas doses, elevou a CE para valores acima desse nível crítico. Os maiores teores de CTEA, COEA e CIEA foram obtidos quando se adicionaram ao Latossolo os estercos de galinha e de codorna e a casca de café. As quantidades de COS extraídas por KH_2PO_4 foram maiores que as extraídas por água, evidenciando a capacidade de o solo adsorver C em seus coloides.

Termos de indexação: carbono orgânico solúvel, estercos, condutividade eletrolítica, acidez do solo, resíduos vegetais, adsorção de carbono.

INTRODUCTION

Although the soluble organic carbon (SOC) fraction represents only a small portion of the total organic carbon (TOC) in the soil (Metting, 1993), it constitutes the most mobile and reactive C fraction (Marschner & Kalbitz, 2003) and is involved in several processes that occur in the soil (Chantigny, 2003). This fraction consists of the intermediate products of organic residue degradation, such as proteins, carbohydrates, hydrocarbons, and their derivatives, as well as of fractions of low-molecular-weight, humic substances and numerous other simpler organic compounds (Gonet & Debska, 2006). The SOC is often defined as a soluble fraction that passes through a membrane with 0.45-mm pore diameter (Solinger et al., 2001). However, other operational definitions have been proposed, according to the extraction procedure (Zsolnay, 1996). In this study, the term water-extractable organic carbon (WEOC) refers to the SOC fraction that includes all forms of water-soluble organic carbon (Chantigny, 2003).

Numerous organic residues have potential uses in agriculture, including manure, industrial residues, sewage sludge, vinasse, several effluents, and coffee husk. These residues have widely variable pH, electrolytic conductivity (EC), C content and nutrient levels; thus, some act as N sources, others as sources of K, some of P, and others act as soil conditioners, depending on the rate applied, increasing the cation exchange capacity (CEC) and improving the soil structure and, thus, the water retention capacity of the soil (Montemurro et al., 2004; Montemurro & Maiorana, 2008; Melo et al., 2008; Higashikawa et al., 2010). In addition to improved soil properties, the soil pH has been shown to increase as a result of the application of organic matter (Franchini et al., 1999; Zheljazkov & Warman, 2004; Mkhabela & Warman, 2005; Zhang et al., 2006). Likewise, EC has been shown to increase by the application of municipal waste compost (Abreu Junior et al., 2000; Oliveira, 2000), tannery sludge (Aquino Neto & Camargo, 2000), and sewage sludge (Fia et al., 2005; Teixeira et al., 2005). Chicken and quail manure can cause salinization due to their high EC values, depending on the rate and frequency with which they are added to soil (Melo et al., 2008). Therefore, residues should be applied to the soil obeying technical criteria as, in some cases, they may represent a potential environmental polluter due to changes in pH and increases in EC and salinity, which may compromise soil and water quality (Wright et al., 2005), especially when these materials are continually used at high rates.

There are already reports on soils used for vegetable cultivation in the Southern State of Minas Gerais, Brazil, where the continued use of manure can increase the pH to values above the recommended levels for the cultivation of most crops. Because manure, primarily chicken manure, is applied more than once annually to vegetable fields, the cumulative loads of manure may represent approximately 40 t ha^{-1} in less than four years of cultivation. These excessive loads of manure may also affect the EC, but the effects of manure on this property have not yet been evaluated. The treatments tested in this study are based on this history of continuous and high manure use and its possible adverse effects on soil and plants. The evaluations were restricted to the short term, given that excessive increases in pH and possibly EC may compromise plant growth during the initial days of growth for short-cycle vegetable crops. In addition, studies aiming to evaluate soluble C in Brazilian soils are scarce, especially studies to measure soluble organic C and C in the form of $CaCO_3$, which predominates in chicken and quail manure and in soil treated with these residues. The research actions proposed in this study are based on the fact that increased presence of soluble C in the soil may mitigate the adverse effects of excessive increases in pH and EC continuously fertilized with manure.

As previously mentioned, the agricultural use of organic residues can increase the SOC levels and affect nutrient and metal mobility in soils (Chantigny et al., 2002; Wright et al., 2005). Because increasing SOC is associated with increased TOC content (Ciotta et al., 2004), it is expected that systems that receive higher quantities of soil organic matter also have higher SOC levels (Inácio, 2009). The SOC concentration is also affected by the chemical composition of the organic residues added to the soil (Cerný et al., 2003; Xu et al., 2006), especially organic matter with a low degree of decomposition (Asmar et al., 1994) and/or organic residues with elevated soluble organic compound levels that promote immediate increases in SOC levels (Chantigny et al., 2002).

Several procedures used for extracting SOC are described in the scientific literature, which differ regarding the extractor used (Madhun et al., 1986; Kennedy et al., 1996), extraction time (Madhun et al., 1986; Zsolnay & Steindl, 1991), and soil:extraction solution ratio (Negrin et al., 1996; Gigliotti et al., 1997). Gonet & Debska (2006) found that the quantities of SOC extracted from soils depend on the extractor properties and that a borate buffer solution extracts more C than 0.004 mol L^{-1} $CaCl_2$. Bolan et al. (1994) and Baziramakenga et al. (1995) found that extraction solutions such as 0.1 mol L^{-1} HCl and 0.1 mol L^{-1} NaOH extract organic compounds more efficiently than water.

Considering the high adsorption of organic compounds by the mineral fraction of the soil used in this study, it is believed that the use of water as an extractor may underestimate the SOC levels and that KH_2PO_4 is more efficient in the extraction process, given that phosphate has a high affinity for adsorption sites occupied by organic ligands (Shen et al., 1996), which are released into the SOC solution. Furthermore, it is expected that the pH, EC and C levels extracted by water and KH_2PO_4 will be higher in soils incubated with higher rates of nutrient-rich organic residues and organic residues with a low degree of decomposition. In view of the foregoing, this study had the following objectives: evaluate the pH, EC, water-extractable total carbon (WETC), water-extractable organic carbon (WEOC), and water-extractable inorganic carbon (WEIC) in soil samples treated with increasing levels of C contained in organic residues; and quantify WETC, WEOC, and WEIC and the total C (TC- KH_2PO_4), organic C (OC- KH_2PO_4), and inorganic C (IC-KH_2PO_4) extractable by KH_2PO_4 solution in soil samples incubated with increasing rates of chicken and quail manure.

MATERIAL AND METHODS

A soil sample (0-5 cm layer) of a dystrophic Red Latosol (Oxisol) (LVdf, 66 % clay) was used in the study, chosen for its high C content (4.4 %). After sampling, the soil samples were air-dried, ground, and sieved (2-mm mesh) to obtain air-dried fine soil, and stored in a dry place. The main properties of the study soil were pH (H_2O) (1:2.5) = 4.2; P (Mehlich-1) = 2.0 mg dm^{-3}; K = 59 mg dm^{-3}; Ca = 0.2 $cmol_c$ dm^{-3}; Mg = 0.2 $cmol_c$ dm^{-3}; and V = 3.0 %. Before incubation with organic residues, 200 mg kg^{-1} P as $Ca(H_2PO_4)_2$ p.a., 3.37 g kg^{-1} as $CaCO_3$ and 0.94 g kg^{-1} of $MgCO_3$ were added to the soil to raise base saturation to 60 % (Raij, 1991). The soil moisture content was maintained close to field capacity and the temperature at approximately 20 °C, for 15 days. Next, the soil matter was dried in a forced circulation oven at 70 °C and fertility was analyzed. The main properties of the Oxisol sample after P application and acidity correction were pH (H_2O) (1:2.5) = 6.3; P (Mehlich-1) = 18.6 mg dm^{-3}; K = 299 mg dm^{-3}; Ca = 5.7 $cmol_c$ dm^{-3}; Mg = 1.6 $cmol_c$ dm^{-3}; and V = 61.5 %.

The organic residues used in this study consisted of chicken, swine, and quail manure, sawdust, coffee husk, and sewage sludge. Table 1 shows the main chemical and physicochemical properties of the organic material used in the study; these data were compiled by Pinheiro et al. (2013). The macronutrient and micronutrient levels of some of the residues were reported by Higashikawa et al. (2010).

Centrifugation tubes of 60 mL were filled with 20 g of soil sample, to which varying quantities of organic residues were added, containing 0, 2,000, 5,000, 10,000 and 20,000 mg kg^{-1} C. These rates simulate the residue loads applied in the cultivation of different crops, especially of vegetable crops, in nursery beds with continued use of manure. The experiment was arranged in a completely randomized design (CRD) with a (6 × 5) × 3 factorial scheme, i.e., six organic residues combined with five rates of organic residue C with three replicates for each treatment, for a total of 90 experimental units.

The incubation period of the soil with organic residues was 30 days; during this period, soil moisture was maintained adding water in order to reach

Table 1. Main chemical and physicochemical properties of the organic residues used in the study

Organic residue	C	WEOC	N	C/N	$pH(H_2O)$	EC
	dag kg^{-1}	mg kg^{-1}	%			dS m^{-1}
Chicken manure	22.7	31,80	4.8	4.7	7.1	6.6
Quail manure	25.5	32,10	2.4	10.6	7.1	7.4
Swine manure	26.3	13,10	2.0	13.1	7.7	2.8
Sawdust	44.6	3,58	0.3	131	4.4	1.5
Coffee husk	42.0	NA	3.0	14.0	4.7	6.3
Sewage sludge	19.8	3,23	2.2	9.0	3.4	3.3

WEOC, water-extractable organic carbon; C/N, C/N ratio; EC, electrolytic conductivity; NA, not analyzed.
Source: data compiled by Pinheiro et al. (2013).

contents in soil close to 70 % of field capacity. The initial volume of water required for wetting the soil samples incubated with different organic residue C rates was approximately 8 mL. The tubes containing soil combined with organic residue C rates were weighed every 5 days, and deionized water was added when necessary to maintain the weight established at the onset of the experiment.

After the incubation period, SOC was extracted according to the method proposed by Scaglia & Adani (2009), with the following modifications: approximately 7.5 mL of deionized water was added to each tube containing soil combined with organic residue C rates, which were homogenized by hand and then mechanical agitation (125 rpm for 40 min); subsequently, the samples were centrifuged at 9,000 rpm for 15 min, after which the pH and EC readings were taken. After these steps, the samples were centrifuged again at 9,000 rpm for 15 min and filtered through a 0.45-µm pore membrane. The WETC, WEOC, and WEIC levels were determined using an Elementar Vario Cube TOC automatic analyzer in the liquid module.

Organic C was extracted from soil samples treated with increasing rates of quail and chicken manure using KH_2PO_4. Thus, after the extraction with water, a further extraction with 0.1 mol L^{-1} KH_2PO_4 was performed by adding approximately 5 mL of extraction solution to the tubes containing soil combined with organic residue C rates. After this step, the samples were agitated (125 rpm for 40 min), centrifuged (9,000 rpm for 15 min), and filtered through a membrane with a 0.45-µm pore diameter. The TC-KH_2PO_4, OC-KH_2PO_4, and IC-KH_2PO_4 contents were quantified using the aforementioned TOC automatic analyzer. The study was conducted at the Laboratory of Soil Organic Matter Study (*LEMOS*) - DCS/UFLA.

The data obtained were subjected to analysis of variance (ANOVA) and regression analysis using the SISVAR statistical program (Ferreira, 2003), with significance set at 5. Linear correlation analyses were also performed for the soil WETC levels, C/N ratio, and N content of the residues, as well as with the soil pH levels, where the degree of association between the variables was evaluated based on the correlation coefficients and their degrees of significance.

RESULTS AND DISCUSSION

The pH and electrolytic conductivity

Increasing the residue C rates increased the pH of the soil samples treated with organic residues, with the exception of sewage sludge, which acidified the soil with increasing residue C rates (Figure 1a). Adding 20,000 mg kg^{-1} of sewage sludge-C decreased the soil pH by one unit compared to the treatment without applying the sludge (0 mg kg^{-1} residue C). Soil acidification occurs due to the low pH (3.4) of the non-limed sludge. Similar effects were observed by other researchers (Epstein et al., 1976; Nascimento et al., 2004; Singh & Agrawal, 2010), although Oliveira et al. (2002) found that applying sewage sludge at rates of 33, 66, and 99 t ha^{-1} (dry basis) caused immediate increases in the soil pH, due to the alkalinity of the material used.

Among the residues used, the chicken and quail manure provided the highest increases in soil pH (Figure 1a). At the highest rates of chicken and quail manure, the soil samples exhibited pH values of 7.3 and 7.4 in water, respectively, which lie above the optimal pH range (5.5 to 6.5) recommended for most crops (Duarte, 2010). However, according to Ernani & Gianello (1983), the increase in pH occurs immediately after adding the residues and tends to return to its initial value over time.

The quantity of chicken manure added to obtain residue C rates equivalent to the rates of quail manure was higher because chicken manure has a lower C content (Table 1). Thus, adding 11,350 mg kg^{-1} of residue C is equivalent to 100 t ha^{-1} of chicken manure and to 89 t ha^{-1} of quail manure in the 0-20 cm soil layer. Adding these quantities of chicken and quail manure to the soil increases the pH from 6.0 to 6.6 and 7.0, respectively. This result shows that the liming potential of quail manure is higher than that of chicken manure, given that adding lower quantities

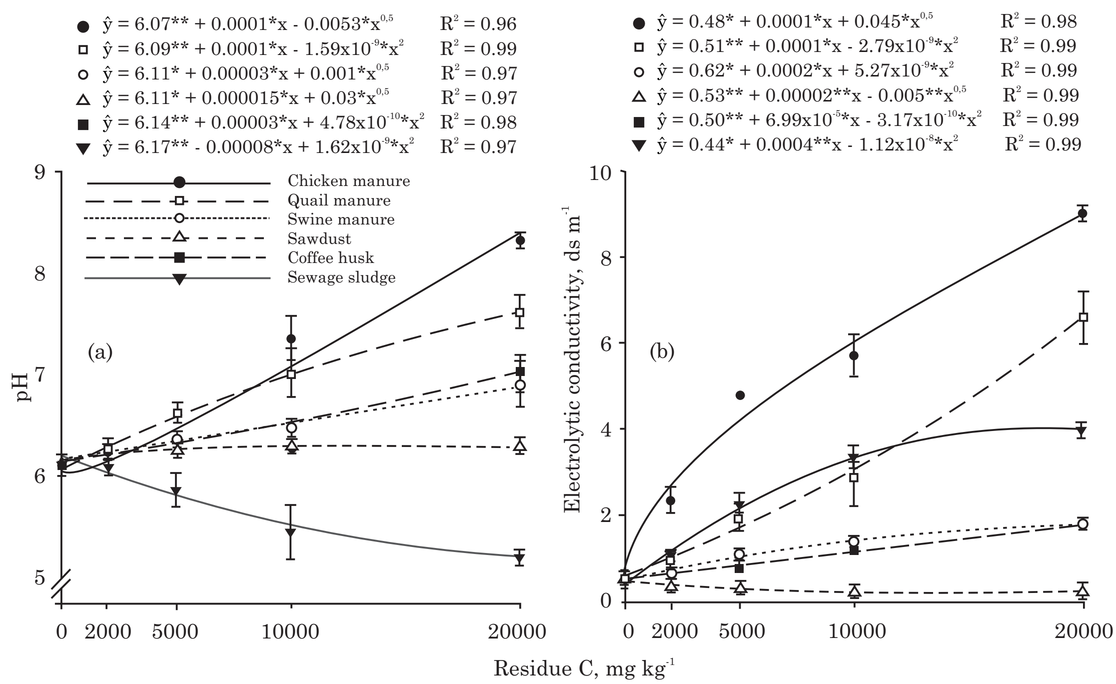

Figure 1. Soil pH (a) and EC (b) in response to increasing C levels in organic residues.

of quail manure results in higher soil pH. Both chicken and quail manure have similar pH values (Table 1), which means that, in addition to the rate applied, constituents of these manure types other than hydrogen concentration regulate the increases in soil pH reported in this study.

In fact, the changes in soil pH that result from adding organic residues may be related to, among other factors, the cations levels present in the materials and consequently to soluble organic anions (Marschner & Noble, 2000; Miyazawa et al., 2000).

Applying increasing residue C levels increased the EC of the soil samples treated with chicken and quail manure (Figure 1b). In contrast to the other residues, EC was not increased by sawdust. Based on the square-root regression model ($\hat{y} = 0.53^{**} + 0.00002^{**}\ x - 0.005^{**}\ x^{0.5}\ R^2 = 0.99$), an EC of 0.2 dS cm^{-1} was obtained by applying 16,997 mg kg^{-1} residue C from sawdust. In the treatment without application of this material (0 mg kg^{-1}), the EC was 0.5 dS cm^{-1}. Applying sewage sludge at a 9,000 mg kg^{-1} C dose increased the EC of the soil samples. From this concentration further, however, the increases in conductivity were not proportional to the quantity of residue added. The agricultural use of sewage sludge can increase soil EC (Logan et al., 1997) and cause seasonal salinization effects, thereby compromising plant growth and development depending on climate, soil type, and the application rate and frequency (Bevacqua & Mellano, 1994).

A quadratic increase in EC was obtained when applying rates of coffee husk and swine manure. The maximum EC obtained when applying swine manure was 1.4 dS m^{-1} at a concentration of 17,921 mg kg^{-1} residue C. A similar EC value was only obtained by adding 400 mg kg^{-1} C-chicken manure. This result reflects the effect of adding higher quantities of chicken manure, due to its lower C content, in addition to the higher EC value of this residue compared to swine manure (Table 1).

The EC values of soil treated with swine manure, coffee husk, and sawdust remained below 2.0 dS m^{-1} (considered a good condition, though some crops are sensitive to salts at EC <2.0 dS m^{-1}) at all rates evaluated (Alberta Environmental Protection, 2010). It is however noteworthy, that when determining this property, the soil:water ratio was 1:0.8, i.e., more diluted than the reference value in the saturation extract reported by Jones Junior (1983). Values above 2.0 dS m^{-1} were obtained by adding chicken manure, sewage sludge and quail manure at the following rates of organic residue C: 1,143, 4,500, and 6,000 mg kg^{-1}, respectively. However, under field conditions, it is believed that the EC values may be lower than the values found under the conditions evaluated in this study, because ion uptake by plants, for example, contributes to reducing soil EC (Caovilla et al., 2005). Furthermore, ion leaching minimizes the possible effects associated with salinity in open farming systems and in regions with regular rainfall during the plant growth cycle.

Water extractable carbon and phosphate

Except for sewage sludge, water-extractable C levels were observed to increase with increasing C levels in organic residues (Figure 2a,b,c). Since WEOC

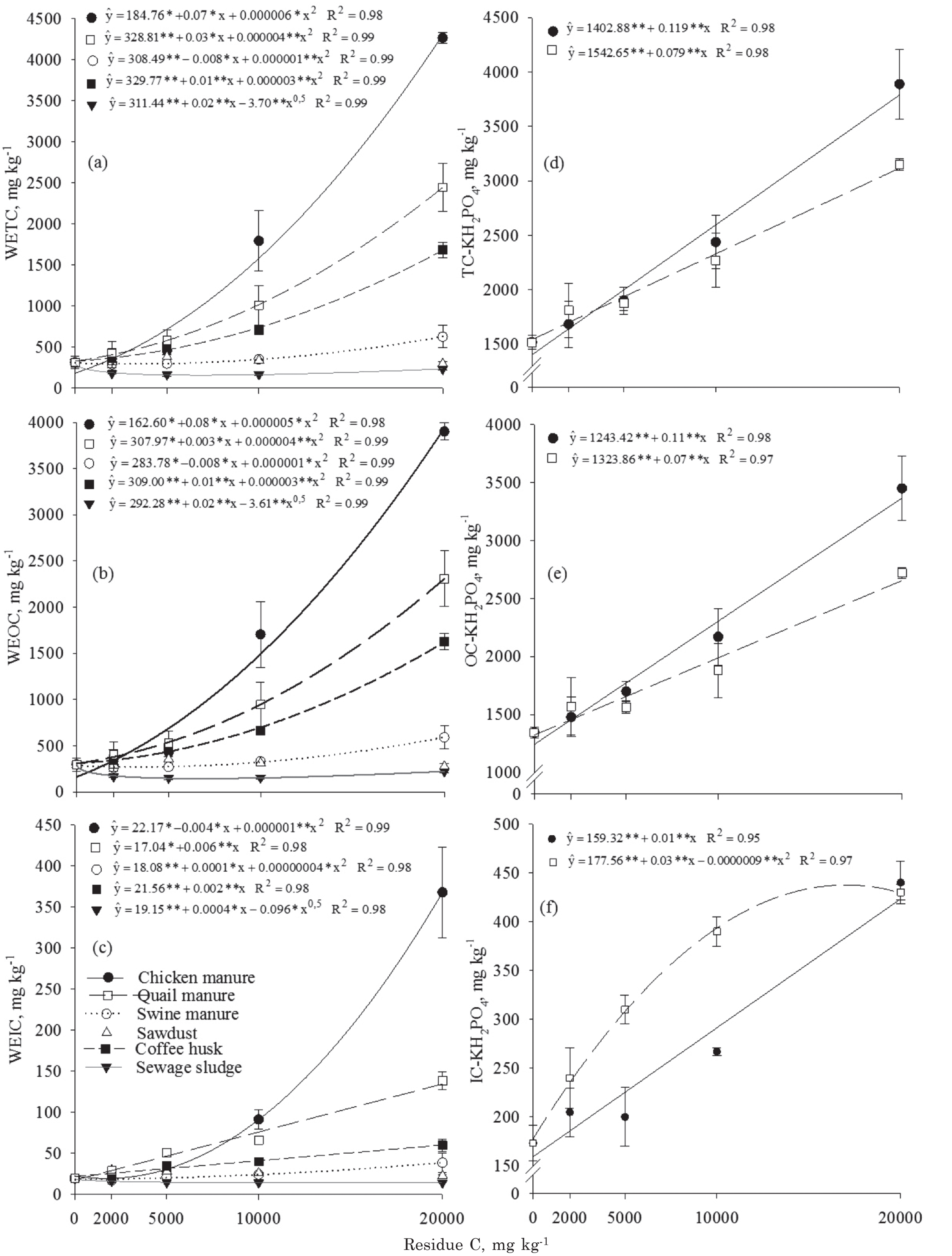

Figure 2. Levels of water-extractable total carbon (WETC), water-extractable organic carbon (WEOC), water-extractable inorganic carbon (WEIC), total carbon ($TC-KH_2PO_4$), organic carbon ($OC-KH_2PO_4$), and inorganic carbon ($IC-KH_2PO_4$) extracted by KH_2PO_4 in response to increasing residue C levels.

constituted the largest total C fraction (approximately 94 %), this portion will be more emphasized. However, in studies addressing soil C dynamics in the system in more detail, knowledge about the inorganic C levels is important (Wang & Alva, 1999).

The residues that induced the highest levels of WETC, WEOC, and WEIC were chicken and quail manure and coffee husk; soil WEOC levels of 3,700, 2,468, and 1,749 mg kg^{-1} were obtained when adding the highest dose of these residues, respectively. The higher pH observed mainly in the soil samples treated with chicken and quail manure (Figure 1a), among other factors, may explain the higher WEOC levels obtained. Although the C/N ratio is an index to predict the decomposition rate of organic matter (the higher the C/N ratio of a substrate, the lower the decomposition rate) (Melillo et al., 1982), according to Taylor et al. (1991), the lignin content, nutrient (especially N) and phenol concentrations and the SOC content of the residues are also considered main reduction factors of the decomposition speed. In this study, there was a significant positive correlation at 1 % probability between the soil pH and WETC and between the residue N content and the soil WETC content, but there was no correlation between the C/N ratio of the residues and the soil WETC content (Table 2).

Unlike in the treatments with coffee husk, the WEOC levels do not reflect the C/N ratio of this residue. For example, sewage sludge has a lower C/N ratio but did not increase the soil WEOC content. Coffee husk applications to the soil increased the pH (Figure 1a), which may have increased the mineralization rate of organic matter, thus inhibiting the effect of the chemical composition of the residue on the mineralization process (Khalil et al., 2005). In addition to the C/N ratio, the soluble forms of C in the residue are also properties that can predict their decomposition rates (Trinsoutrot et al., 2000). Significant increases in SOC after adding manure and compounds to the soil were found by Chantigny et al. (2002), and these changes were attributed to soluble molecules present in the residues.

An important issue related to the agricultural use of chicken and quail manure are the relatively higher N levels of these manure types and, therefore, lower C/N ratios than of other residues, indicating that these material may constitute immediate C sources for plants. The application of residues with high N levels and low chemical stability to the soil must be performed carefully, observing the rates, soil type, and application method, to avoid nitrate leaching. The continued use of high manure rates may result in adverse effects on soil properties, with probable negative consequences for the plants, as has been shown here for pH and EC. Thus, it is recommended that manure applications should be based on previously established agronomic and technical aspects, in the nutritional requirement of the crop (mainly N), the moisture content and chemical composition of the residue, and in the current legislation on agricultural use and the maximum loads of pollutants to be added to the soil (Silva, 2008).

Table 2. Matrix of linear correlation for WETC, soil pH, N content, and C/N ratio of the residues

Variable	Soil WETC
Soil pH	0.86**
N content of the residues	0.81**
C/N ratio of the residues	0.38
WETC of the residues	0.92**

WETC, water-extractable total carbon. ** Significant at 1 %.

There was a positive significant correlation between the residue WETC content and the soil WETC content (Table 2). The organic C in the residues is composed of two fractions with different degrees of biodegradability, and their biological degradation depends on the degradation rate of a wide variety of C compounds present in the sample (e.g., carbohydrates, amino acids, fatty acids, lignin) and their nutrient content (Bernal et al., 1998). The chicken and quail manure are rapidly mineralized by microorganisms because they have higher WETC levels (Table 1) and therefore release more SOC into the soil.

Based on the regression equation ($\hat{y} = 311.44^{**} + 0.02^{**}\ x - 3.70^{**}\ x^{0.5}\ R^2 = 0.99$), decreases in the WETC levels were observed up to a concentration of 8,550 mg kg^{-1} C (sewage sludge). At higher concentrations, the WETC levels increased, but not to values above the dose of 311 mg kg^{-1} (value of the treatment without addition of residue C) (Figure 2a). The pH of the soil treated with sewage sludge was lower than when treated with residue C rates (Figure 1a), which may explain the C decreases (Figure 2a,b,c). According to Michalzik & Matzner (1999), the release of dissolved organic C from organic matter increases at higher temperature and higher pH and decreases at higher C/N ratio of the residue.

With regard to sawdust, no model was obtained to explain the initial behavior of the increase followed by a decrease (from 2,000 mg kg^{-1}) in the C concentrations evaluated in this study. Significant increases in the WETC, WEOC, and WEIC (23.6, 21.7, and 52.6 %, respectively) were obtained at the dose of 2,000 mg kg^{-1} residue C compared to the lowest dose (0 mg kg^{-1} residue C). The C/N ratio of sawdust is high (Table 1), which hinders the release of labile C that contributes to increase the SOC levels.

Applying increasing residue C rates of quail manure and coffee husk linearly increased the WEIC levels (Figure 2c). A quadratic increase was observed in the treatments with rates of swine and chicken manure, with maximum values of 38 and 367 mg kg^{-1} of WEIC, respectively. The materials with the highest increases in the WEIC values were as follows, in ascending order: chicken manure > quail manure >

coffee husk > swine manure > sawdust. The properties of the residues are related to factors including their production process, animal age, feed type, and degree of composting (Abad et al., 2002; Abreu Junior et al., 2005; Silva, 2008). The feed type animals are fed with influences the manure quality; many poultry farmers use lime in feeds, which explains the higher WEIC values found in the soil treated with rates of quail and chicken manure.

With KH_2PO_4, high C quantities could be extracted from the soil treated with chicken and quail manure. Linear increases (in the studied range) in the levels of TC-KH_2PO_4, OC-KH_2PO_4, and IC-KH_2PO_4 with increasing residue C levels were observed (Figure 2d, e, f), except for IC-KH_2PO_4, where there was a quadratic increase in relation to increasing residue C levels in quail manure (Figure 2f). The C quantities extracted by KH_2PO_4 were higher than the quantities extracted by water for all concentrations of residue C applied in chicken and quail manure; the mean levels of TC-KH_2PO_4 were 1.6 and 2.2 times as high, respectively, than WETC in the treatments with chicken and quail manure. According to Zsolnay (1996), highly water-soluble molecules, such as glucose and amino acids, may be distributed between desorbed and sorbed forms. Considering the equilibrium of adsorption and desorption of soil SOC, it is possible to find a portion of C stored in the soil, even after extraction with water (Tao & Lin, 2000), as observed in the present study. The remaining quantity of SOC in the solid phase of the soil depends on the soil properties and SOC itself (Tao & Lin, 2000). Soil can adsorb organic acids with high energy (Haynes, 1984), and Oxisols, especially the dystrophic Red Latosol used in this study, which is an oxidic soil, have a greater ability to adsorb anions than less weathered soil (Novais & Smyth, 1999).

In a study that aimed to evaluate the effect of the extractor on the quantities of SOC extracted from samples of mineral soils under forests, Rennert et al. (2007) found that the mean quantities of SOC extracted were higher using 0.5 mol L^{-1} K_2SO_4, followed by water and then by 0.01 mol L^{-1} $CaCl_2$. The quantities of SOC extracted by water and by 0.5 mol L^{-1} K_2SO_4 reached maximum values of 164 and 126 mg kg^{-1}, respectively. For the treatment without chicken manure application (0 mg kg^{-1} C), the quantities of SOC extracted by water and by 0.1 mol L^{-1} KH_2PO_4 were 295 and 1,345 mg kg^{-1}, respectively, i.e., higher than the values reported by Rennert et al. (2007), who considered mainly the fraction extracted with KH_2PO_4.

Standardizing a method for extracting SOC is important for comparing the results from different studies. In addition to the concentration and type of extractor, it is believed that the following other factors influence the results obtained, even for the same soil sample:extraction time, sample moisture, soil:extraction solution ratio, sample storage type, and the method used to quantify the C levels in the extracts (Zsolnay & Gorlitz, 1994). Although there is no universal procedure for SOC extraction from soils (Chantigny, 2003), water, $CaCl_2$, and K_2SO_4 are the most commonly used extractors (Rennert et al., 2007); therefore, the results presented here indicate the need to test KH_2PO_4 under varied conditions.

CONCLUSIONS

1. Adding organic residue C rates increases the soil pH, except in the case of sewage sludge, which acidifies the soil. Chicken and quail manure increase the soil pH to values above the recommended for cultivation of most crops.

2. The soil electrolytic conductivity increases with increasing rates of manure (chicken, quail, and swine), coffee husk and sludge. Values above the critical level of EC are obtained by adding chicken manure, sewage sludge and quail manure at rates of 1,143, 4,500, and 6,000 mg kg^{-1} of organic residue C, respectively.

3. Except for sewage sludge, adding organic residues to the soil increases the water-extractable carbon levels, especially at the highest application rates of less decomposed nutrient-rich manure, such as chicken and quail manure.

4. The SOC quantities extracted by potassium phosphate are 1.6 to 2.2 times higher, respectively, in treatments with chicken and quail manure, than those extracted by water, showing that a portion of the SOC is adsorbed by the colloids of the Oxisol studied.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the funding of this research by the Research Foundation of the State of Minas Gerais - Fapemig (Process CAG APQ-5362-3. 08/07); and are indebted to the Brazilian Federal Agency for Support and Evaluation of Graduate Education - CAPES, for granting the doctoral/postdoctoral scholarship to the first author of this study; and to Brazilian Council for Scientific and Technological Development - CNPq (Process 308592011-5), for granting research scholarships.

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