Soil carbon and nitrogen mineralization caused by pig slurry application under different soil tillage systems

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Abstract – The objective of this work was to evaluate the change in soil C and N mineralization due to successive pig slurry application under conventional tillage (CT) and no tillage (NT) systems. The experiment was carried out in a clayey Latossolo Vermelho eutrófico (Rhodic Eutrudox) in Palotina, PR, Brazil. Increasing doses of pig slurry (0, 30, 60 and 120 m^3 ha^{-1} per year) were applied in both tillage systems, with three replicates. Half of the pig slurry was applied before summer soil preparation, and the other half before the winter crop season. The areas were cultivated with soybean (*Glycine max* L.) and maize (*Zea mays* L.) in the summers of 1998 and 1999, respectively, and with wheat (*Triticum sativum* Lam.) in the winters of both years. Soil samples were collected at 0–5, 5–10, and 10–20 cm depths. Under both CT and NT systems, pig slurry application increased C and N mineralization. However, increasing pig slurry additions decreased the C to N mineralization ratio. Under the NT system, C and N mineralization was greater than in CT system.

Index terms: conventional tillage, no tillage, nutrient cycling, potential mineralization, swine manure.

Mineralização de C e N causada pela adição de dejetos líquidos de suínos em diferentes preparos do solo

Resumo – O objetivo deste trabalho foi avaliar as alterações na mineralização de C e N do solo resultantes da aplicação de dejetos líquidos de suínos (DLS) em sistemas de preparo do solo convencional (CT) e plantio direto (NT). O experimento foi conduzido em um Latossolo Vermelho eutrófico, de textura argilosa, em Palotina, PR, Brasil. Doses crescentes de DLS (0, 30, 60 e 120 m^3 ha^{-1} por ano) foram aplicadas nos dois sistemas de preparo do solo, com três repetições. Metade das dosagens de DLS foi aplicada antes do preparo do solo da cultura de verão e a outra metade antes do da cultura de inverno. As áreas foram cultivadas com soja (*Glycine max* L.) e milho (*Zea mays* L.) nos verões de 1998 e 1999, respectivamente, e trigo (*Triticum sativum* Lam.) nos invernos de ambos os anos. As amostras de solos foram coletadas nas profundidades de 0–5, 5–10 e 10–20 cm. A aplicação de DLS aumentou a mineralização de C e de N, tanto no sistema CT como no NT. Contudo, o aumento da dose de DLS diminuiu a razão de mineralização entre C e N. No sistema de NT, a mineralização de C e de N foi maior que no CT.

Termos para indexação: plantio convencional, plantio direto, ciclagem de nutrientes, potencial de mineralização, resíduos de suínos.

Introduction

Brazil is the fourth largest producer of swine worldwide, with more than 37 million heads slaughtered annually (Miranda, 2007), and nearly 300 million liters of liquid swine dejections produced each day (Scherer et al., 1996). Pig slurry is a mixture that includes swine urine and feces, ration remains, excess of drinking water and water used to clean the facilities. The production of high volumes of swine waste is related to intense swine production, characterized by the confinement of animals and the use of large volumes of water for the removal of swine dejections from production units to storage tanks. Swine dejections are stored in tanks for at least 120 days to reduce environmental risk prior to soil application (Seganfredo, 2007).

In Southern Brazil, there are many swine farms, and their waste is often used as an agricultural fertilizer. This practice is an easy, inexpensive solution for the disposal of swine residue on agricultural property. Although pig manure enhances plant growth and reduce application of mineral fertilizer, it is an environmentally risky activity (Seganfredo, 2007). In many regions, the amount of pig slurry exceeds the quantity that can be safely accommodated by the available agricultural land, and repeated annual applications of large amounts of pig manure can cause soil nutritional side effects and environmental damage. Giacomini et al. (2009a) observed that half of the pig slurry nitrogen is lost from soil-plant systems, regardless of soil management system. For this reasons, the design of safe pig slurry applications in agriculture is necessary.

The effects of pig slurry application on the soil environment depend on soil management practices and tillage systems, and may affect soil organic matter content, microbial activity and nutrient turnover. The addition of pig slurry to the soil can favor the soil mineralization process, due to high N content in swine dejections (Giacomini & Aita, 2008), mainly under no tillage system, in which pig slurry is applied on previous crop plant residues (Aita et al., 2006). The mineralization of soil C and N is an important process that regulate the functioning of natural and managed ecosystems. Studies about the soil mineralizable C and N pools are essential to understand how C storage responds to changes in soil management, mainly due to pig slurry application under different tillage systems (Ahn et al., 2009).

The objective of this work was to evaluate the change in soil C and N mineralization due to successive pig slurry application under conventional and no tillage systems.

Materials and Methods

The experiment was established in 1996 at the experimental station of Instituto Agronômico do Paraná, in Palotina, west of Paraná state (24°17'S, 53°50'W), Brazil, under a clayey Oxisol classified as a Latossolo Vermelho eutrófico (Rhodic Eutrudox), according to Brazilian system of soil classification (Bhering & Santos, 2008). The soil had in its surface (0–20 cm) 600 g kg^{-1} clay, 160 g kg^{-1} silt, 240 g kg^{-1} sand, pH 5.2 ($CaCl_2$), 14.8 mg kg^{-1} P (Mehlich) and 20.0 g kg^{-1} organic carbon (Walkley-Black). The climate, according Köppen classification, is Cfa, Subtropical, characterized by humid and warm summers and dry and cold winter.

A complete block experimental design with a split plot arrangement and three replicates was used, with tillage systems in the main plot (100x5 m) and pig slurry application rates in the subplot (20x5 m), separated by 2.0-m lateral borders. Tillage treatments included: no tillage system (NT); and conventional tillage system (CT), with one-disc plow tillage at 20-cm depth and two light harrowings for seedbed preparation. Pig slurry was added at four doses (0, 30, 60 and 120 m^3 ha^{-1} per year), half was applied in summer, and half in winter crop season, prior to soil preparation. Average composition of pig slurry on a dry weight basis was: N, 30.7 g kg^{-1}; P, 27.6 g kg^{-1}; K, 61.4 g kg^{-1}; Ca, 31.2 g kg^{-1}; Mg, 12.0 g kg^{-1}; Cu, 634 mg kg^{-1}; Zn, 951 mg kg^{-1}; Bo, 92 mg kg^{-1}; Mn, 455 mg kg^{-1}; dry matter, 20.9; C/N 4.8; pH 7.8. The area was cultivated with soybean (*Glycine max* L.) and maize (*Zea mays* L.) in the summers of 1998 and 1999, respectively, and wheat (*Triticum sativum* Lam.) in the winters of both years. Crop stubbles were retained on the surface in the NT system, or they were tilled conventionally in the CT system (plowed at 20-cm depth) following fall and spring harvest.

Five soil subsamples were taken randomly from each replicate at 0–5, 5–10 and 10–20 cm depths using a 55-mm diameter core, in March and October of 1998 and 1999. Samples collected at the end of summer and winter crop seasons were sieved through a 4-mm screen to remove large plant material, and stored at 4°C until analysis.

Carbon mineralization was determined by incubating 30 g of moist soil in a 350 mL sealed jar, in the presence of NaOH trap, with a separate vessel of water to maintain humidity for 3, 6, 10, 17 and 24 days at 30°C, in a dark chamber. Sodium hydroxide was collected and replaced for each sample, and the released CO_2 concentration was determined by flow injection analysis (Kawazaki et al., 2000). Nitrogen mineralization was determined by incubating 5 g of moist soil for 24 days at 30°C. Nitrogen extraction was done with 20 mL of K_2SO_4 solution (0.25 mol L^{-1}) by shaking them for 50 min at 220 rpm, followed by centrifugation at 600 g for 10 min and filtering. Nitrate concentration was determined according to Miyazawa et al. (1985). The determination consisted of measuring NO_3^- in soil extracts without chemical reduction, using ultraviolet spectrophotometry at 210 nm (NO_3^- + interfering ions), and at longer wavelengths (239 nm). The difference between absorbance values obtained at 239 nm (NO_3^- plus dissolved organics) and 210 nm (dissolved organics) gave nitrate concentration. The mineralized N was calculated from the difference in nitrate concentration in soil samples before and after incubation (24 days). All determinations were performed in triplicate and were expressed on a dry weight basis.

Within each treatment, data were averaged over the four seasons and two years and subjected to analysis of variance using the Statistical Analysis System (SAS) (SAS Institute, 1998). Soil organic matter mineralization, for each tillage system and depth, were submitted to regression analysis. The significant equation by F test at 5% probability was chosen and showed the highest correlation coefficient.

Results and Discussion

The three years of pig slurry application did not change pH or soil contents of Ca, Mg, or K, in none of the evaluated tillage systems (Table 1). It also did not affect the soil cation exchange capacity or base saturation. Phosphorus contents increased due to the application of pig slurry both in CT and NT. At 0–5-cm depth, soil P increase under NT was, generally, three fold higher than under CT; however at 5–15-cm depth, soil P increased twice under CT compared to NT. Conventional tillage system disturbs soil in its upper 20 cm, while under NT there is an accumulation in the surface layer. However, even without soil disturbance there is still movement of P to the subsurface layers. These results agree with Hountin et al. (2000), who observed that P moved to 100-cm depth, after 14 years of pig slurry application. These authors concluded that P (from manure) moved from soil surface to subsurface layers in its organic form.

Average values of C and N mineralization (C_{min} and N_{min}), obtained from the four sampling seasons, indicated that they were affected by soil tillage system. Increasing doses of pig slurry had a positive effect on C_{min} and N_{min} (Figure 1).

Carbon mineralization after 24 days of incubation varied from 59 to 180 μg C-CO_2 g^{-1} under CT and from 93 to 332 μg C-CO_2 g^{-1} under NT (Figure 1). It increased linearly in relation to pig slurry doses both in CT and NT systems at 0–5-cm depth. At 5–10 cm, C_{min} followed a linear model in the NT system and a quadratic model in the CT system. At 10–20-cm depth, the increase in C_{min} followed a quadratic model both for CT and NT systems. The NT system had higher C_{min} at 0–5 and 5–10 cm depths. The increase in C_{min} due to pig slurry doses under NT was more than twice of that observed under the CT system at 0–5-cm depth. Generally, C_{min} in the NT system was 52% higher than in the CT system.

Carbon mineralization rates observed in this study are consistent with other studies, which reported variations between 5 and 30 μg C-CO_2 g^{-1} per day, in soil that received sludge (Martines et al., 2006), and from 1.5 μg C-CO_2 g^{-1} per day (Balota et al., 2004) to 19.2 μg C-CO_2 g^{-1} per day (Marques et al., 2000) in managed soil. Other works under field conditions in Southern Brazil have reported the effect of pig slurry application on in situ C_{min} (Marques, 2005; Aita et al., 2006). The majority of these studies have shown

Table 1. Soil chemical properties under conventional (CT) or no tillage (NT) systems after three years of pig slurry application(1).

Pig slurry doses (m^3 ha^{-1} per year)	P (mg kg^{-1})		Organic C (mg kg^{-1})		pH		CEC ($cmol_c$ kg^{-1})		Base saturation (%)	
	CT	NT	CT	NT	CT	NT	CT	NT	CT	NT
					0–5-cm depth					
0	14.8cB	30.0dA	16.4bB	24.5abA	4.9	5.1	13.7	15.0	60.7	64.1
30	21.7bcB	62.5cA	18.4abB	23.1abA	5.1	5.1	13.8	16.0	63.4	65.6
60	26.9bB	89.7bA	16.8bB	21.9bA	4.9	5.1	12.4	14.8	56.9	63.7
120	55.8aB	121.3aA	20.5aB	25.9aA	5.2	5.1	15.0	16.3	66.9	64.5
					5–10-cm depth					
0	13.3cA	19.0cA	17.1bA	19.8abA	5.0	5.0	13.6	14.5	60.7	62.1
30	20.0bcB	29.6bA	18.4abA	20.2abA	5.1	5.1	14.1	15.2	64.0	65.4
60	26.3bA	27.6bA	17.0bA	17.9bA	4.9	5.0	13.7	13.4	60.0	58.6
120	51.3aA	49.5aA	20.4aA	22.0aA	5.2	5.2	15.1	15.9	66.3	66.9
					10–15-cm depth					
0	12.5dA	11.6bcA	16.8abA	17.1bcA	5.0	5.0	13.7	13.6	62.1	59.6
30	24.9cA	16.8abA	19.2aA	18.7abA	5.2	5.3	14.6	15.3	66.8	67.9
60	33.6bA	8.7cB	15.5bA	14.9cA	5.0	5.0	13.3	13.3	61.8	60.5
120	44.5aA	23.9aB	19.4aA	20.4aA	5.2	5.4	14.3	15.2	65.2	69.7

(1)Means followed by equal letters, uppercase between tillage systems and lowercase within pig slurry doses, do not differ by Tukey test at 5% probability.

a significant CO_2 flux after pig slurry application. Sixty-two days after the application of 44 m^3 ha^{-1} of pig slurry, 147 kg ha^{-1} of C-CO_2 were released (Marques, 2005), and 180 kg ha^{-1} of C-CO_2 were released by the application of 40 m^3 ha^{-1} (Aita et al., 2006). In these reports, the release of CO_2 in the control treatment was subtracted from the amount of CO_2 released from pig slurry application. Thus, CO_2 measured was due solely to the application of pig slurry. Studies in Canada have also shown that a large amount of CO_2 was released after pig slurry application (Rochette et al., 2000a; Chantigny et al., 2001). According to Rochette et al. (2000a), the majority of C loss occurred during the first week following the application of pig slurry. The release of CO_2 immediately after pig slurry application is due to the metabolism of sugars and amino acids, which are readily available to soil microorganisms. However, the increase in CO_2 flux following pig slurry application is not only due to microbial activity, but also to C-CO_2 liberated from the dissociation of carbonates and to the rapid release of C-CO_2 when alkaline slurry (pH, 7.5) is applied to an acidic soil (pH, 5.5) (Sommer & Sherlock, 1996).

The values of C_{min} (normalized to the control treatment) obtained under different doses of pig slurry were 62, 59 and 124 kg ha^{-1} of C-CO_2, respectively, for 30, 60 and 120 m^3 ha^{-1} of pig slurry applied to CT plots, and 21, 83 and 186 kg ha^{-1} of C-CO_2, respectively, for 30, 60 and 120 m^3 ha^{-1} applied to NT plots. These results are comparable to those obtained by Marques (2005)

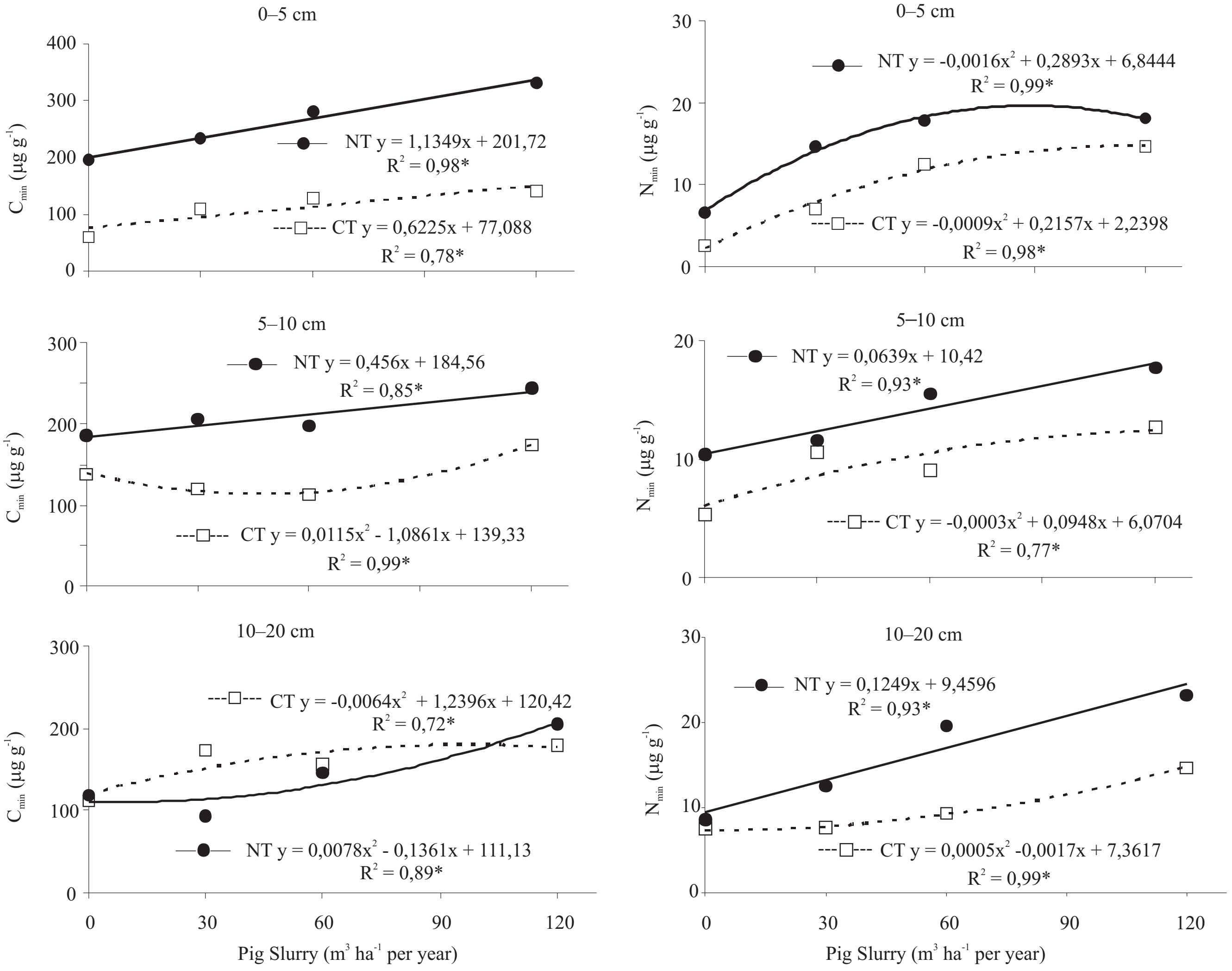

Figure 1. Soil carbon (C_{min}) and nitrogen (N_{min}) mineralization, according to varying doses of pig slurry application on soils under different tillage systems. *Significant at 5% probability.

and Aita et al. (2006), despite large methodological differences between the studies. The aforementioned works focused on in situ C mineralization following pig slurry application, whereas the present study focused on potential mineralization under laboratory conditions, approximately 90 days after pig slurry application. In this study, the pig slurry was applied before soil preparation, and the soil samples were collected at harvest. The C_{min} obtained from in situ studies was the result of biological processes affected by the addition of readily available compounds. In contrast, the C_{min} obtained in this study resulted, probably in its majority, from microbial biomass mineralization, which is a more labile C pool.

Furthermore, when carbon mineralization in soils under different tillage systems is compared in the laboratory, the results do not reflect field conditions, because the NT treatment has a minimal soil disturbance. The laboratory samples are disturbed upon sampling and processing, which can expose protected soil organic matter to microorganisms. Additionally, the incubation conditions, including temperature and moisture are ideal for mineralization in laboratory. These factors stimulate C and N mineralization. When crop residues are incorporated into the soil, they decompose faster than when they remain on soil surface. In this experiment, plant residues remained on the soil surface in NT plots, which may have produced slower decomposition rates than in the CT plots. Another important aspect that should be mentioned is the high total dry matter mass produced by crops in the experiment: 9.7 Mg ha^{-1} per year for maize, 5.5 Mg ha^{-1} per year, for soybean, and 3.3 Mg ha^{-1} per year, for wheat.

The ratio between mineralized C and organic C over 24 days (C_{min}/C_{org}), at 0–20 cm depth, ranged from 0.61 to 0.82% under CT, and from 0.81 to 1.13% under NT. In the literature, the C_{min}/C_{org} ratio varies widely, from 0.30% (Marques et al., 2000) to 1.99% (Martines et al., 2006). However, under temperate climate, the ratio varies from 2.1 to 4.5, according to land use (Ahn et al., 2009). Mineralization patterns of pig slurry often show large initial releases of CO_2 during the first week of incubation, due to the mineralization of readily available compounds. Following pig slurry application, Luz (2007) observed that approximately 20 and 32% of the C added from pig slurry is mineralized within 15 days when incorporated into soil or applied to the soil surface, respectively. The amount of C mineralized may vary considerably. According to Marques (2005), approximately 30% of C from slurry additions is mineralized in the first 25 days. Giacomini (2005), working in laboratory conditions, observed that 45% of C was mineralized within 25 days, when slurry was applied to the soil surface. Mineralization of approximately one-third of C added as pig slurry was observed within three months (Aita et al., 2006), providing evidence that C is retained in the soil. Soil retention of C is related to the presence of recalcitrant compounds or to the immobilization of C by microbial biomass. However, the amount of C mineralized may be overestimated, due to the initial non-biological emission of CO_2 by the dissociation of carbonates in swine dejections (Aita et al., 2006).

The organic C consumed by microbes is partitioned between microbial cell biomass production, metabolite excretion and respiration. For this reason, the evolution of C-CO_2 cannot be considered as a direct measure of soil decomposition, because only two-thirds of the decomposed C is released as CO_2, while one-third is assimilated by microbes (Paul & Clark, 1996). Nitrogen mineralization over 24 days varied from 2.5 to 14.7 μg N-NO_3^- g^{-1}, under CT, and from 6.6 to 23.3 μg N-NO_3^- g^{-1} under NT (Figure 1). The N_{min} increased significantly with increasing pig slurry doses, both for CT and NT plots, at all studied depths. Under NT, the increase in N_{min} was quadratic at 0–5 cm and linear at 5–10 and 10–20-cm depths. Under CT system, the increase of N_{min} due to pig slurry additions was quadratic at all studied depths. The NT system presented a higher N_{min} than the CT system at all studied doses. The increase of N_{min} due to pig slurry doses in NT was around 50% higher than in CT system. Nitrogen mineralization rates observed in this study are consistent with other works. Boeira et al. (2002) reported N_{min} from 30 μg N g^{-1} to 210 μg N g^{-1}, in 112-day incubation in soil that received sludge, and Balota et al. (2004) reported 1.2 to 5.2 μg N-NO_3^- g^{-1} in 24-day incubation in soil under different management systems. Giacomini (2005) observed that N_{min} 80 days after pig slurry application was 16.1 mg kg^{-1} N, when dejections were incorporated, and 27 mg kg^{-1} N, when dejections were applied to the soil surface. These values represent a potential mineralization of organic N at 26 and 44%, respectively.

The used pig slurry had approximately 3.1% N on dry weight basis. The application of pig slurry at 30, 60 and 120 m^3 ha^{-1} per year is equal to the addition of 92, 184, and 368 kg ha^{-1} of ammonium sulfate, respectively. Despite the large amount of ammoniacal N in pig slurry (40–70%), its N can undergo several transformations in soil, resulting in substantial losses of N due to the volatilization of ammonia, nitrate leaching and denitrification (N_2O). However, after application of pig slurry to soil, a significant amount of ammoniacal N is transformed to nitrate N (Giacomini et al., 2009b). Besides, approximately 50% of the total nitrogen in pig slurry is readily available to plants or microorganisms (Giacomini, 2005; Aita et al., 2006). Giacomini et al. (2009b) observed that approximately 18% of ammoniacal N, applied as pig slurry, was immobilized by microbial biomass after five days of incubation. Therefore, pig slurry is considered to be a great source of nitrogen. In spite of that, Giacomini et al. (2009a) observed that the contribution of ammoniacal N to the available N for corn is relatively low, since more than 50% of it is lost from the soil-plant system.

Large differences in potential mineralization between treatments (greater than 450% for C_{min} and 800% for N_{min}) showed that pig slurry additions change the amount of labile organic C and N accumulated in soil. The results of the present study agree with others (Rochette et al., 2000a, 2000b; Giacomini, 2005; Marques, 2005; Aita et al., 2006, 2007; Giacomini et al., 2009), which demonstrated the responsiveness of potential mineralization to pig slurry application and soil tillage systems. Variation in C and N mineralization clearly shows that pig slurry additions cause different rates of organic matter decomposition and affect microbial biomass and activity.

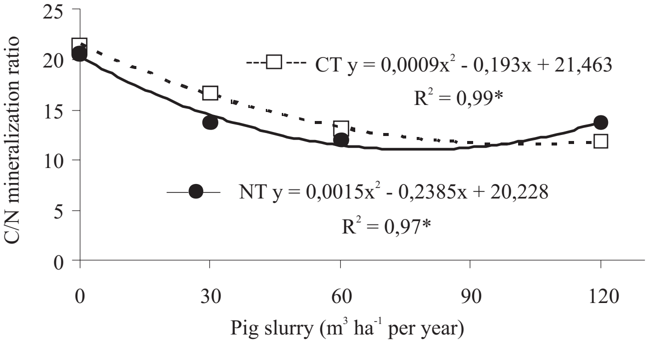

Figure 2. Carbon to nitrogen mineralization ratio at 0–20 cm depth in soils under different tillage systems according to pig slurry doses. *Significant at 5% probability.

The C to N mineralization ratio at 0–20 cm depths varied from 11.9 to 21.4, under CT, and from 12.0 to 20.5 under NT (Figure 2). Differences in the C to N mineralization ratio shows the effects of soil management. On average, a decrease in the C/N mineralization ratio was related to increases in pig slurry doses, according to a quadratic model both for CT and NT systems. Carbon to nitrogen mineralization ratios may indicate the C/N ratio of organic matter used by microbial populations. Although our results showed a low carbon to nitrogen mineralization ratio, there was an increase of organic C content up to 14% with a pig slurry application of 120 m^3 ha^{-1} per year.

The carbon to nitrogen mineralization ratio can be used as an index of labile substrate availability. For instance, carbon to nitrogen mineralization ratios greater than 25 indicate that crop residue and soil organic matter have low concentrations of N (Franzluebbers & Arshad, 1996). Wider carbon to nitrogen mineralization ratios may indicate that N is limited for heterotrophic microbes, and a greater potential for N immobilization exists. The range of carbon to nitrogen mineralization ratios obtained in the present study varied from 7.9 to 29.8, reflecting the low C/N ratio of pig slurry (4.8).

There were strong correlations between C_{min} and N_{min} ($R^2 = 0.86^*$) throughout the treatments, as well as between C_{min} and organic C ($R^2 = 0.61^*$). Correlations between mineralized C and N confirms that cycles of these two elements are closely associated.

Conclusions

1. Pig slurry applications increase soil C and N mineralization rates both in CT and NT systems.
2. Higher pig slurry doses decrease C to N mineralization ratio.

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