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Organic residue inputs influence soil biological properties in organic farming systems

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ABSTRACT: The objective of this study was to evaluate the effect of organic residue inputs on microbial biomass carbon (MBC), microbial biomass nitrogen (MBN), enzyme activities (FDA and DHA), and soil organic carbon (SOC) in plots in an organic farming system. Soil samples were collected from experimental plots under a randomized block design using organic (ORG) and conventional (CNV) farming systems to grow acerola (*Malpighia glaba* L.). A native vegetation (NV) site was used as reference. The highest values of SOC (19.9 and 8.7 g kg^{-1}), were obtained in ORG sites, at depths of 0–10 and 10–20 cm, respectively, while the lowest values were found in CNV (5.5 and 4.1 g kg^{-1}), and NV (9.7 and 4.5 g kg^{-1}) sites measured at similar depths. MBC and MBN measurements were both higher in ORG soils with MBC measurements of 308 and 122 mg kg^{-1} in ORG and CNV soil respectively, and MBN values of 72 and 47 mg kg^{-1} in ORG and CNV soils, respectively. Total enzyme activity was highest in ORG soils with FDA values at 15.2, 6.2, and 8.5 mg kg^{-1} in ORG, CNV, and NV soils, respectively. DHA values were 5.7, 2.4, 3.2 mg kg^{-1}, in ORG, CNV, and NV soils, respectively. However, the specific activity of enzymes did not vary between systems. The results confirm that inputs of organic residues increase the content of organic C, microbial biomass, and total enzyme activity in soils under the organic farming system.

Key words: agricultural system; enzyme activities; soil microbial properties

Adições de resíduos orgânicos influenciam as propriedades biológicas do solo em sistema de agricultura orgânica

RESUMO: O objetivo deste estudo foi avaliar o efeito de adições de resíduos orgânicos sobre o C (MBC) e o N (MBN) da biomassa microbiana, atividade das enzimas (FDA e DHA) e o C orgânico do solo (SOC) em áreas sob sistema de agricultura orgânica. Amostras de solo foram coletadas em área experimental, sob desenho de blocos casualizados, com sistemas orgânico (ORG) e convencional (CNV) com acerola (*Malpighia glaba* L.). Uma área nativa (NV) foi usada como referencia. Os maiores valores de SOC (19,9 e 8,7 g kg^{-1}), a 0-10 e 10-20 cm, foram encontrados em ORG, enquanto os menores valores foram observados na CNV (5,5 e 4,1 g kg^{-1}), e NV (9,7 e 4,5 g kg^{-1}). MBC e MBN foram maiores em ORG (308 e 72 mg kg^{-1}, respectivamente) do que em CNV (112 e 47 mg kg^{-1}, respectivamente). A atividade total das enzimas foi maior em ORG (15,2 e 5,7 mg kg^{-1}, FDA e DHA, respectivamente) do que em CNV (6,2 e 2,4 mg kg^{-1}, FDA e DHA, respectivamente) e NV (8,5 e 3,2 mg kg^{-1}, FDA e DHA, respectivamente), enquanto a atividade especifica das enzimas não variou entre os sistemas. Os resultados confirmam que adições de resíduos orgânicos aumentam os conteúdos de C orgânico, biomassa microbiana e enzimas totais em solos sob sistema de agricultura orgânica.

Palavras-chave: sistema agrícola; atividades enzimáticas; propriedades microbianas do solo

Introduction

Organic farming improves soil health and productivity through use of sustainable methods, such as the organic residue inputs. These organic residues can stimulate the soil microorganisms and promote the accumulation of soil organic carbon (SOC) (Wang et al., 2015). Organic residues are composed of a mixture of carbon (C) sources and proteins, and the variation in C content influences their degradability. Carbohydrates and proteins are abundant in plant biomass and are excellent substrates for microbial growth, although most deplete quickly during decomposition; however, some plant biomass components such as cellulose and lignin degrade more gradually (Talbot & Treseder, 2012). Therefore, the quality, quantity, and composition of organic residue affect SOC content and the biological properties of soil differently.

This practice of using organic residues in an organic farming system focuses on enhancing the biological processes using soil microbial biomass (SMB), which leads to an increase in decomposition of organic residues and SOC content over time (Wang et al., 2015). An additional benefit of increased SMB is the synthesis of enzymes that play important roles in soil health, such as the decomposition of organic matter, and controlling the supply of nutrients to plants and microbes (Burns et al*.,* 2013).

The increase in the SMB and SOC content is considered critical for sustainable soil management and maintenance of soil productivity (Wang et al., 2015). High levels of SMB and SOC are found to be closely associated with organic farming systems compared with conventional farming (Scotti et al., 2015). Previously, Santos et al. (2012) observed that the input of organic residues in organic farming resulted in higher SMB and SOC. However, a consistent pattern of SOC and SMB after several years of inputs of organic residues has not been recognized. In addition, Piotrowska–Długosz & Wilczewski (2014) reported increase in total activity of enzymes in an organic farming system, but the specific activity of enzymes varied according to quality of the amendments (Bowles et al*.,* 2014).

Therefore, we evaluated the effect of eight years of inputs of organic residues in a sandy soil under organic farming as compared with conventional farming. We hypothesized that the inputs of organic residues rich in C, such as carnauba straw, would increase SMB and SOC considerably. However, the total and specific activity of enzymes could be affected differently in this practice in organic farming. Thus, the objective of this study was to evaluate the effect of inputs of organic residues on microbial biomass, enzyme activity, and organic C in soil under an organic farming system in Northeast Brazil.

Material and Methods

The long-term experiment, in a randomized block design, under conventional and organic farming is located in an area of 2.0 hectare at Parnaíba, Piauí state, Brazil (03º 01´ S; 41º 46´ W; 45 m). The climate is rather dry with a mean precipitation of 1000 mm year^{-1} and an annual mean temperature of 30º C. The soil type is an Arenosol with 970, 10 and 20 g kg^{-1} of sand, silt and clay, respectively.

For this study, the evaluation was done in March 2015 (the mean of temperature and precipitation were 27º C and 163.5 mm, respectively) in plots (1000 m^2), replicated four times, with ‘‘acerola’’ orchard (*Malpighia glaba* L.) under eight years of conventional farming (CNV) and organic farming (ORG). An adjacent native vegetation (NV) site was used as reference. NV consists of native vegetation from a transition between Cerrado and Caatinga. In the CNV and ORG plots, the plants are distanced 2.0 m long and 3.0 m wide. During eight years, plants were irrigated through conventional irrigation according to their water requirement. Thus, a mean of 1200 m^3 ha^{-1} per month was applied for plants. Conventional and organic plots are managed since 2006. The agricultural practices in CNV include annual inputs of 200 kg ha^{-1} of urea, 80 kg ha^{-1} of triple superphosphate and 80 kg ha^{-1} of potassium chloride. Annually, lime is applied at a rate of 1 t ha^{-1}. ORG plots received, at the first year (2006), inputs of green manure: “crotalaria” [*Crotalaria juncea* (L.)], cowpea [*Vigna unguiculata* (L.) Walp] and “mucuna preta” [*Cajanus cajan* (L.)], and 0.5 t ha^{-1} of rock phosphate. Annually, the agricultural practices in ORG include inputs of composted cow manure (20 t ha^{-1}), rock phosphate (0.5 t ha^{-1}), and ‘‘carnauba’’ straw (10 t ha^{-1}) applied in the soil surface under plant canopies. The chemical characteristics of composted cow manure and “carnauba” straw are shown in Table 1.

Soil samples were obtained in March 2015 at each plot (four plots per system) in a sampling area of 20 x 20 m. Soil samples were taken from randomly selected locations at 0-10 and 10-20 cm depth. Ten soil cores from each plot were combined to form one composite sample. All samples were immediately stored in sealed plastic bags in a cooler and transported to the Laboratory of Soil Quality (CCA/UFPI). The field-moist samples were sieved (2-mm mesh) and

Table 1. Chemical properties of composted cow manure and “carnauba” straw added to organic plots.

Component	Content
Composted cow manure	
Moisture (g kg^{-1})	201
pH (1:2.5)	6.5
Organic ma er (g kg^{-1})	302.5
Total N (g kg^{-1})	7.21
C/N ra o	21.5
P available (g kg^{-1})	4.1
K available (g kg^{-1})	2.9
Carnaúba straw	
Protein (%)	2.3
P (%)	0.41
Fibre (%)	80.3
Lignin (%)	21.5
C/N ra o	86.2

stored in sealed plastic bags at 4°C for microbial analyses. The remaining soil samples were air-dried. Soil samples were ground and passed through a 0.2-mm sieve before evaluating chemical properties (Table 2). Soil pH (water), exchangeable cations (Ca^{2+}, Mg^{2+} and K^{+}) and available phosphorus (P) were analyzed according to Donagema et al. (1997).

Soil microbial biomass C (MBC) and N (MBN) were determined according to Vance et al. (1987) with extraction of C and N from fumigated and unfumigated soils by K_2SO_4. An extraction efficiency coefficient of 0.38 and 0.45 were used to convert the difference in C and N between fumigated and unfumigated soil in MBC and MBN, respectively. Soil organic carbon (SOC) in the extracts was measured by wet combustion (Yeomans & Bremner, 1988). The ratio between MBC and SOC was calculated as a measure for carbon availability and the ratio between MBC and MBN provided information on soil microbial stoichiometry. The soil respiration was monitored through daily measurement of CO_2 evolution under aerobic incubation at 25°C for 7 days (Alef & Nannipieri, 1995). Hydrolysis of fluorescein diacetate (FDA) and dehydrogenase activity were determined according to the methods described by Alef & Nannipieri (1995).

The results are expressed on the basis of oven-dry soil. All data were analyzed using the SAS 9.3 (SAS Institute, 2011). Means and standard deviations were calculated. One-way analysis of variance was used for comparing the differences between the sites. Least significant difference (LSD) analysis was performed to test significant differences between means, and all differences reported in the text were tested and considered significant at $p < 0.05$.

Table 2. Chemical properties of soil under conventional (CNV), organic (ORG) and native vegetation (NV).

Plot	pH	P	K	Ca	Mg
	water	mg kg^{-1}	cmol$_c$ kg^{-1}		
			0-10 cm		
ORG	7.0	9.7	0.11	2.1	0.6
CNV	7.1	10.4	0.30	1.8	0.5
NV	5.9	5.1	0.06	0.9	0.2
			10-20 cm		
ORG	6.8	8.9	0.13	2.0	0.7
CNV	7.0	9.6	0.19	2.2	0.9
NV	5.7	4.7	0.05	0.8	0.3

Results and Discussion

The highest SOC content ($p < 0.05$) was found in ORG at two observed soil depths. At 0–10 cm deep, the lowest SOC content was found in CNV, while SOC content was similar between CNV and NV (Figure 1A). At 0–10 cm deep, MBC was highest ($p < 0.05$) in ORG compared with that in CNV and NV. However, at 10–20 cm deep, MBC was similar between ORG and NV, while it was lower in CNV (Figure 1B). The values of MBN were higher ($p < 0.05$) in ORG compared with those in NV and CNV measured at both depths (Figure 1C). The results demonstrate that MBC and MBN increased approximately 210% and 60% from CNV to ORG, respectively.

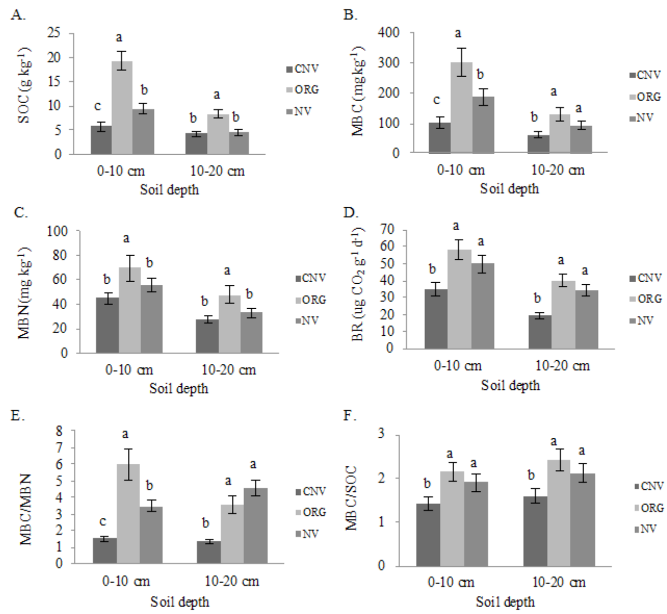

Figure 1. Soil organic C (A.), microbial biomass C (B.) and N (C.), basal respiration (D), ratio MBC:MBN (E), and MBC:SOC (F.) under conventional (CNV), organic (ORG) and native vegetation (NV). Bars indicate standard deviation and when present the same letter are not significantly different between plots within each soil depth ($p \geq 0.05$).

ORG and NV showed the highest values ($p < 0.05$) of basal respiration than CNV at both depths (Figure 1D). The MBC/MBN ratio was highest ($p < 0.05$) in ORG compared with that in CNV and NV at a depth of 0–10 cm, while no significant difference was observed at 10–20 cm between ORG and NV (Figure 1E). There were no differences between ORG and NV for the MBC/SOC ratio in the evaluated soil depths, while CNV presented the lowest values (Figure 1F).

The total FDA hydrolysis and DHA activity were highest ($p < 0.05$) in ORG compared with those in CNV and NV, at both soil depths (Figures 2A, C). The specific FDA hydrolysis and DHA activity were not different between ORG and CNV at both soil depths (Figures 2B, D).

The results found for SOC content indicate that permanent inputs of organic residue in an organic farming system, such as organic compost and carnauba straw, have contributed to the increase in soil organic matter content. Interestingly, at 0–10 cm depth, the values of SOC found in ORG were about 210% and 340% higher compared with those found in NV and CNV, respectively. The results agree with previous studies on organic farming systems that demonstrate an increase in the SOC content compared with conventional farming (Gattinger et al., 2012; Scotti et al., 2015; Alvaro-Fuentes et al., 2013). Specifically, in organic plots the addition of carnauba straw presents a large C:N ratio and lignin content, which could have contributed to organic matter accumulation in soil. This result corroborates those of Tu et al. (2006) who compared, in an organic farming system, organic residues with high (composted cotton gin trash) and low (animal manure) C:N ratios and found that the highest SOC accumulation was a result of input of residues with higher a C:N ratio.

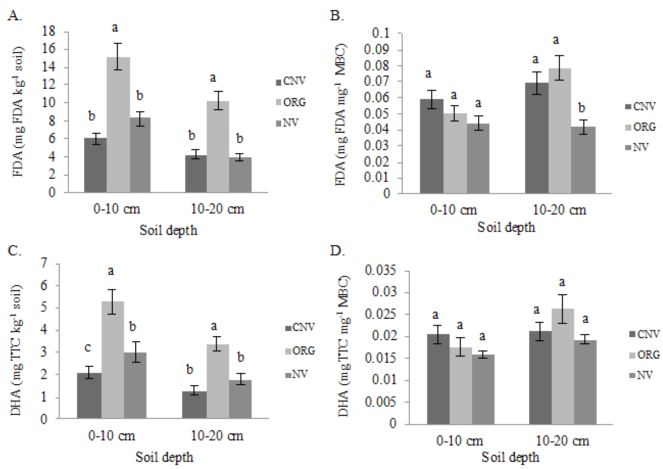

Figure 2. Activity of FDA total (A.) and specific (B.), and dehydrogenase total (C.) and specific (D.) under conventional (CNV), organic (ORG) and native vegetation (NV). Bars indicate standard deviation and when present the same letter are not significantly different between plots within each soil depth ($p \geq 0.05$).

The inputs of organic compost and carnauba straw also increased SMB in an organic farming system. Annually, organic plots receive about 8 t C ha^{-1} (from organic residues) and it has contributed to the significant increase in MBC. Compared with NV, MBC increased 70% in ORG and it corroborates the results of the study of Gattinger et al. (2012) that found a 100% increase in MBC from organic plots that received 10 t C ha^{-1}. This indicates that, in sandy soil with low cation exchange capacity, organic practices can positively influence the microbial biomass and, consequently, increase the pool of nutrients available for plants. On the contrary, there was a lower increase of MBN in ORG compared with that in CNV, which may be attributed to a low concentration of N in the organic residues applied in ORG and the application of inorganic N in CNV. It is possible that the application of inorganic N may have positively influenced the microbial biomass N in CNV, or that N fertilization may have accelerated the mineralization and resulted in a decrease in the SMB N in ORG.

The MBC:MBN ratio indicates the relative availability of C and N to soil microorganisms and also reflects changes in the microbial community structure. The results showed that the MBC:MBN ratio significantly increased in ORG, reflecting the higher content of SMB C and low levels of microbial biomass N found in organic plots. It confirms that the practices in the organic farming system favored MBC with a high input C source instead of MBN with low inputs of a nitrogen source. The results of soil respiration show that, similarly with microbial biomass, the inputs of organic residue stimulated the soil microbial activity. The increase in soil microbial activity is an indicator of decomposition of organic residues and, thus, promotes a release of nutrients available for plant growth (Silva et al., 2014). Previous studies have shown an increase in soil microbial activity under an organic farming system, as measured by basal respiration (Sudhakaran et al., 2013; Silva et al., 2014).

The MBC:TOC ratio is used to evaluate the availability of organic C and its turnover. High values of MBC:TOC ratio indicate more availability of C to soil microorganisms whereas lower values indicate more C stability (Chandra et al., 2016). Therefore, the higher MBC:TOC ratio found in ORG reflects the high content of SMB and indicates more C available for turnover in the soil.

The total and specific activity of enzymes demonstrated different patterns at different sites. Activity of soil enzymes can be used as a sensitive indicator of soil microbial activity in response to agricultural practices (Bowles et al., 2014). The higher total activity of enzymes found in ORG may confirm the positive impact of permanent inputs of organic residues on soil biological activity as compared with conventional farming system.

The results showed that specific FDA hydrolysis and DHA activity did not vary between ORG and CNV, (Bowles et al., 2014), showing that the agricultural system affected the size of microbial biomass without affecting its ability to produce enzymes. Interestingly, the results suggest that application of compost and organic residues did not stimulate soil microbes to produce more enzymes. According to Vinhal-Freitas et al. (2010), organic compost presents high stability and provides carbon compounds that are hydrolyzed more slowly by enzymes. Therefore, the results indicate that the microbial communities of both ORG and CNV soils present similar metabolic activity as observed by the specific activity of enzymes (Lagomarsino et al., 2011).

Conclusions

Organic residue inputs, such as those of organic compost and carnauba straw, increased the content of organic C, microbial biomass, and total enzyme activity in soils in the organic farming system.

The specific activity of enzymes is not affected by the inputs of organic residues, indicating that these residues increase the size of microbial biomass but not its metabolic activity.

Literature Cited

Alef, K.; Nannipieri, P. Methods in soil microbiology and biochemistry. New York: Academic Press, 1995. 608p.

Alvaro-Fuentes, J.; Morell, F. J.; Madejón, E.; Lampurlanés, J.; Arrúe, J. L.; Cantero-Martínez, C. Soil biochemical properties in a semiarid Mediterranean agroecosystem as affected by long-term tillage and N fertilization. Soil and Tillage Research, v. 129, p. 69-74, 2013. https://doi.org/10.1016/j.still.2013.01.005.

Bowles, T. M.; Acosta-Martínez, V.; Calderón, F.; Jackson, L. E. Soil enzyme activities, microbial communities, and carbon and nitrogen availability in organic agroecosystems across an intensively-managed agricultural landscape. Soil Biology and Biochemistry, v. 68, p. 252-262, 2014. https://doi.org/10.1016/j.soilbio.2013.10.004.

Burns, R. G.; DeForest, J. L.; Marxsen, J.; Sinsabaugh, R. L.; Stromberger, M. E.; Wallenstein, M. D.; Weintraub, M. N.; Zoppini, A. Soil enzymes in a changing environment: current knowledge and future directions. Soil Biology and Biochemistry, v. 58, p.216-234, 2013. https://doi.org/10.1016/j.soilbio.2012.11.009.

Chandra, L. R.; Gupta, S.; Pande, V.; Singh, N. Impact of forest vegetation on soil characteristics: a correlation between soil biological and physico-chemical properties. 3 Biotech, v. 6, n. 2, article188, 2016. https://doi.org/10.1007/s13205-016-0510-y.

Donagema, G.K., Campos, D.V.B., Calderano, S.B., Teixeira, W.G., Viana, J.H.M. Manual de métodos de análise de solo. Embrapa: Rio de Janeiro, 2011. 230p.

Gattinger, A.; Muller, A.; Haeni, M.; Skinner, C.; Fliessbach, A.; Buchmann, N.; Mäder, P.; Stolze, M.; Smith, P.; Scialabba, N. E.; Niggli, U. Enhanced top soil carbon stocks under organic farming. Proceedings of the National Academy of Sciences, v. 109, n. 44, p. 18226-18231, 2012. https://doi.org/10.1073/pnas.1209429109.

Lagomarsino, A.; Benedetti, A.; Marinari, S.; Pompili, L.; Moscatelli, M. C.; Roggero, P. P.; Lai, R.; Ledda, L.; Grego, S. Soil organic C variability and microbial functions in a Mediterranean agro-forest ecosystem. Biology and Fertility of Soils, v. 47, n. 3, p.283–291, 2011. https://doi.org/10.1007/s00374-010-0530-4.

Piotrowska-Długosz, A.; Wilczewski, E. Assessment of soil nitrogen and related enzymes as influenced by the incorporation time of field pea cultivated as a catch crop in Alfisol. Environmental Monitoring and Assessment, v. 186, n. 12, p. 8425–8441, 2014. https://doi.org/10.1007/s10661-014-4014-0.

Santos, V. B.; Araújo, A. S. F.; Leite, L. F. C.; Nunes, L. A. P. L.; Melo, W. J. Soil microbial biomass and organic matter fractions during transition from conventional to organic farming systems. Geoderma, v. 170, p.227-231, 2012. https://doi.org/10.1016/j.geoderma.2011.11.007.

SAS Institute. Statistical Analysis System user's guide. Version 9.3. Cary: Statistical Analysis System Institute, 2011. 513p.

Scotti, R.; Bonanomi, G.; Scelza, R.; Zoina, A.; Rao, M. A. Organic amendments as sustainable tool to recovery fertility in intensive agricultural systems. Journal of soil science and plant nutrition, v. 15, n. 2, p. 333-352, 2015. https://doi.org/10.4067/S0718-95162015005000031.

Silva, I. F.; Araujo Neto, S. E.; Kusdra, J. F. Biological activity of organic farming, agroforestry and pasture in the Amazon. Revista Ciência Agronômica, v. 45, n. 3, p. 427-432, 2014. https://doi.org/10.1590/S1806-66902014000300001.

Sudhakaran, M.; Ramamoorthy, D.; Rajesh, K. S. Impacts of conventional, sustainable and organic farming system on soil microbial population and soil biochemical properties, Puducherry, India. International Journal of Environmental Science and Technology, v. 4, n. 1, p.28-41, 2013. https://doi.org/10.6088/ijes.2013040100004.

Talbot, J. M.; Treseder, K. K. Interactions among lignin, cellulose, and nitrogen drive litter chemistry–decay relationships. Ecology, v. 93, n.2, p. 345–354, 2012. https://doi.org/10.1890/11-0843.1.

Tu, C.; Louws, F. J.; Creamer, N. G.; Mueller, J. P.; Brownie, C.; Fager, K.; Bell, M.; Hu, S. Responses of soil microbial biomass and N availability to transition strategies from conventional to organic farming systems. Agriculture, Ecosystems & Environment, n. 1-4, v. 113, p.206-215, 2006. https://doi.org/10.1016/j.agee.2005.09.013.

Vance, E. D.; Brookes, P. C.; Jenkinson, D. D. An extraction method for measuring soil microbial biomass. Soil Biology and Biochemistry, v. 19, n. 6, p. 703-707, 1987. https://doi.org/10.1016/0038-0717(87)90052-6.

Vinhal-Freitas, I. C.; Wangen, D. R. B.; Ferreira, A. S.; Corrêa, G. F.; Wendling, B. Microbial and enzymatic activity in soil after organic composting. Revista Brasileira de Ciência do Solo, v. 34, n. 3, p. 757-764, 2010. https://doi.org/10.1590/S0100-06832010000300017.

Wang, J.; Wang, X.; Xu, M.; Feng, G.; Zhang, W.; Yang, X.; Huang, S. Contributions of wheat and maize residues to soil organic carbon under long-term rotation in north China. Scientific Reports, v. 5, article number 11409, 2015. https://doi.org/10.1038/srep11409.

Yeomans, J.C.; Bremner, J.M. A rapid and precise method for routine determination of organic carbon in soil. Communication in Soil Science & Plant Analysis, v.19, n. 13, p.1467-1476, 1988. https://doi.org/10.1080/00103628809368027.