Carbon and chemical fractionation of soil organic matter in irrigated banana plantation subjected to conservation practice

Carbono e fracionamento químico da matéria orgânica do solo em bananal irrigado submetido à prática conservacionista

ABSTRACT
Irrigation and the use of cover crops are management practices that contribute to agriculture in regions with edaphoclimatic restrictions. The mentioned practices might affect the soil organic matter (SOM). In this context, the objective of this study were to evaluate the levels of total organic carbon (TOC), as well as the carbon in the chemical fractions of the SOM in an irrigated banana plantation submitted to soil conservation practice. The study was
conducted at the experimental farm of the Federal University of Ceará, in the municipality of Pentecoste (Ceará, Brazil). The design was in randomized blocks, with split-split plot and four replicates. In the plots, four irrigation levels were evaluated; in the subplots, four soil coverings and in the sub-subplots two soil depths were evaluated. The superficial layer of soil associated with both legume *Pueraria phaseoloides* as cover crop and smaller irrigation level, showed higher TOC content (19.2 g kg⁻¹). The highest amount of C was found in the fulvic acid fraction of SOM (3.8 to 6.2 g kg⁻¹) regardless of the irrigation level and soil cover. The irrigation level that provided up to 75% of the evapotranspiration of the banana, combined with the legume *Pueraria phaseoloides* as cover crop provided higher contents of TOC, most of which were concentrated in the fulvic acid fraction of SOM.

**Keywords:** soil management, organic residues, humic substances.

**RESUMO**
A irrigação e o uso de plantas de cobertura são práticas de manejo que contribuem com a agricultura em regiões que apresentam limitações edafoclimáticas. As práticas mencionadas devem afetar a matéria orgânica do solo (MOS). Nesse contexto, objetivou-se avaliar os teores de carbono orgânico total (COT) bem como o teor de carbono nas frações químicas da MOS em bananal irrigado e submetido a prática conservacionista. O estudo foi realizado na fazenda experimental da Universidade Federal do Ceará, no município de Pentecoste (Ceará, Brasil). O delineamento foi em blocos casualizados, com parcelas subsubdivididas e quatro repetições. Nas parcelas foram avaliadas quatro lâminas de irrigação, nas subparcelas quatro coberturas do solo e nas sub-subparcelas duas profundidades de solo. A camada superficial de solo associada à cobertura com a leguminosa *Pueraria phaseoloides* e à menor lâmina de irrigação apresentou maior teor de COT (19,2 g kg⁻¹). A maior quantidade de C foi encontrada na fração ácido fúlvico (3,8 a 6,2 g kg⁻¹) independente da lâmina de irrigação e cobertura do solo. A lâmina de irrigação que forneceu até 75% da evapotranspiração da bananeira e a utilização da leguminosa *Pueraria phaseoloides* como cobertura do solo proporcionaram maiores teores de COT cuja maior parte concentrou-se na fração ácido fúlvico da MOS.

**Palavras-chave:** manejo do solo, resíduos orgânicos, substâncias húmicas.

**1 INTRODUÇÃO**
Among the constituents of soil organic matter (SOM) carbon (C) is present in a greater proportion, so that SOM is considered as the largest reservoir of C on the earth's surface (Freixo et al., 2002). The permanence of organic matter in the soil is directly related to management factors (Faccin et al., 2016). Unlike texture and mineralogy, the use and management of soil is controlled by man and, depending on his decisions, the C stock can be increased or decreased, promoting the condition of improvement or deterioration of soil quality (Dick et al., 2009).

Vegetation is the main responsible for adding organic compounds to the soil which are synthesized during the photosynthesis process (Faria et al., 2008). According to D’Andréia et al. (2004) in soils with natural vegetation cover, organic C is in dynamic equilibrium, with
levels practically constant over time. This condition is altered when the soil is submitted to cultivation and a new balance is reached at a level that varies due to the characteristics of the adopted management system (Stevenson, 1994). The changes in the C stock can be more expressive in soils of semi-arid regions since the content of organic C in the areas of native vegetation is lower. According to Giongo et al. (2011) stocks of organic C in native forest soils in a semi-arid climate are lower when compared to stocks of soils under non-arid climate.

Much of SOM consists of a series of non-humified acid compounds and humic macromolecules. The first group is represented by organic compounds and constitute 10 to 15% of the SOM; the second and main group is represented by humic substances (fulvic acids, humic acids and humine), which make up 85 to 90% of the SOM (Pinheiro et al., 2004). Humic substances are the most reactive organic matter compartment, which is why they are involved in most soil chemical reactions (Rosa et al., 2017). Through the content of C in humic substances it is possible to infer about the degree of humification of the SOM. Soil management has an influence on the C content of humic substances, according to results found by Loss et al. (2010).

Agricultural systems located in the Brazilian semi-arid region face difficulties in maintaining and/or increasing stocks of SOC (Pegoraro et al., 2018). However, the search for a sustainable agriculture in semi-arid environments demands the adoption of both conservation practices and appropriate management of irrigation. Among the conservation practices, the soil cover with vegetal residues stands out for corroborating for the increase in the SOC content (Boer et al., 2008).

By other hand, irrigation can have a dualistic action. Normally, it increases vegetation biomass, which may be an indicative of greater input of plant residues in irrigated compared with non-irrigated areas. However, by increasing water content in the soil, irrigation can intensify the rate of microbial decomposition of organic material by reducing the content of SOC (Bona et al., 2006). Information regarding the implications of irrigation in the processes that control the decomposition and accumulation of SOM in semi-arid regions is scarce.

Based on what has been exposed, it is assumed that both irrigation depths and soil cover in a banana plantation at Brazilian semi-arid region influence total organic carbon (TOC) contents, as well as the humification of SOM. In this sense, the present study aimed to evaluate the TOC content in the soil, as well as the C in the soil organic matter chemical fractions in an irrigated banana plantation subjected to conservation practice with cover crops.
2 MATERIAL AND METHODS

The study was developed in a field experiment with banana plants installed in the Curu Valley Experimental Farm (Pentecoste, CE – Brazil), belonging to the Federal University of Ceará. According to Köppen’s classification system the climate of the region is BSW’h’, which is semi-arid with irregular rains, average annual rainfall of 797 mm, concentrated between January and April, and maximum and minimum annual temperature averages of 33.4 ºC and 22.4 ºC, respectively (Araújo et al., 2012). The soil of the experimental area was classified as Neossolo Flúvico (Santos et al., 2018). The C organic content in the soil before the installation of the experiment was 8.0 g kg⁻¹.

The experimental design was in randomized blocks and split-split plot scheme with four replicates. In the plots were evaluated four irrigation levels corresponding to 50, 75, 100 and 125% of banana plants evapotranspiration. The plots (12 x 40 m) were constituted by four rows of banana (Musa spp) tree cv. Prata Anã, planted in a simple row system with spacing of 3 x 2 m, consisting of 80 plants. In the subplots, four soil cover were evaluated: the leguminous Pueraria phaseoloides and Calopogonium muconoides L., spontaneous vegetation composed mainly by grasses Panicum maximum Jacq, and banana plant residues (conventional management used in this study as a control), totalizing 64 experimental units. Each plot was divided in four subplots (12 x 10 m) with twenty plants, the six central plants being considered to be harvested. In the sub-subplots were evaluated two soil layers (0-5 cm and 5-10 cm).

Evaluations related to this study were done after the first harvest of banana plants and three cuts of cover plants. After cover plant cuts, the vegetal residues were placed between the banana rows without incorporation into the soil.

The collect of plant material to determine the production of dry matter was done randomly in the harvested area of each subplot using a PVC quadrat frame presenting 0.25 m². The aboveground biomass of plants contained in the area of the quadrat frame was cut close to the ground, packed in paper bags and sent to the laboratory to obtain the wet weight. After drying in an oven with air flow at 65ºC, until they reach constant weight, the biomass dry matter was obtained.

The soil samples were collected seventy days after the cut of cover plants at two depths directing the sampling to the banana planting lines, approximately 20 cm away from the stalk. The TOC and the carbon in the chemical fractions of SOM were determined according to the methods described in Mendonça & Matos (2005) and Teixeira et al. (2017) respectively. The variables were statistically analyzed using the software ASSISTAT (Silva & Azevedo 2002),
which allowed the variance analysis by the F test, and then Tukey test was performed to compare means.

3 RESULTS AND DISCUSSION

To assess the benefits of plants used as soil cover, dry matter production is the most widely used agronomic property (Teodoro et al., 2011), since it is related to the supply of nutrients and soil cover and varies mainly due to management practices. Irrigation did not influence the production of dry matter (Table 1), so it is possible to affirm that the differences observed have occurred due to the morphophysiological characteristics of the plant species in each treatment. Among these characteristics are aspects related to the plant size as well as the tolerance to shading and successive cuts. With the exception of banana plant residues, the other soil cover evaluated suffered restrictions of light incidence. In addition, the samplings were made when soil cover plants had already suffered three previous cuts, reducing its biomass.

| Soil cover treatments | Irrigation levels | 1    | 2    | 3    | 4    | Average |
|-----------------------|-------------------|------|------|------|------|---------|
| *Pueraria phaseoloides* |                   | 12.8 | 11.2 | 10.2 | 10.1 | 11.1 b  |
| *Calopogonium muconoides* L. |            | 2.6  | 2.5  | 2.5  | 4.3  | 3.0 c   |
| Spontaneous vegetation |                   | 9.2  | 8.1  | 7.1  | 6.3  | 7.7 b   |
| Banana plant residues  |                   | 37.4 | 32.4 | 35.3 | 38.96| 36.0 a  |
| Average               |                   | 15.5 | 13.6 | 13.8 | 14.9 | ns      |

1, 2, 3 and 4 irrigation levels with 50, 75, 100 and 125% of the evapotranspiration of the banana crop. Averages followed by the same letter do not differ statistically at the 1% of probability level. ns: not significant at the 1% of probability level. Author (2013).

The TOC presented significative differences in response to the evaluated treatments (P<0.001). Agricultural soils have TOC levels ranging from 2 to 50 g kg⁻¹ (Mendonça & Matos, 2005), the results found in this study are within this range. The TOC values in response to the interaction between irrigation levels and cover crops are shown in Table 2. The highest averages for this interaction were observed in the subplots with *Pueraria phaseoloides*, mainly when submitted to the lowest levels of irrigation. It is assumed that the largest irrigation levels have accelerated the decomposition process of the SOM, since the higher soil moisture may have improved the conditions for microorganisms activity. Bona et al. (2006) observed that irrigation increased the decomposition rate of organic matter by 19% in the soil under
conventional tillage and 15% in the soil under no-tillage. According with the mentioned authors, this increase was due to the greater availability of water for the heterotrophic microorganisms. Bloem et al. (1992) observed that relatively small increases in water potential were accompanied by an increase in microbial activity. Diogenes et al. (2011) found an increase in microbial activity in areas that received greatest amount of water through irrigation.

Table 2. Total organic carbon (TOC) contents (g kg\(^{-1}\)) in response to the interaction between irrigation levels and soil cover.

| Irrigation levels | Soil cover | PP       | CM       | SV       | BR       |
|------------------|------------|----------|----------|----------|----------|
| 1                | 19.2 aA    | 12.8 aC  | 18.2 aB  | 12.5 aD  |
| 2                | 19.1 aA    | 12.8 aC  | 18.2 aB  | 12.5 aD  |
| 3                | 17.9 bA    | 11.8 bC  | 17.5 bB  | 11.6 bC  |
| 4                | 17.6 cA    | 11.5 cC  | 17.0 cB  | 11.3 cC  |

1, 2, 3 and 4 irrigation levels with 50, 75, 100 and 125% of the evapotranspiration of the banana crop. PP: leguminous *Pueraria phaseoloides*; CM: leguminous *Calopogonium mucunoides* L; SV: Spontaneous vegetation; BR: Banana plant residues. Averages followed the same lowercase letter in the columns and the same uppercase letter in the lines do not differ statistically from each other at the level of 1% probability according to the F and Tukey test. Author (2013).

The cover with *Pueraria phaseoloides* provided higher TOC values (17.6 to 19.2 g kg\(^{-1}\)) and this may be associated with its production of low C/N ratio biomass that causes greater speed in the decomposition of the residues to form SOM. Under the same climate and soil conditions, the speed of decomposition of residue is directly influenced by chemical characteristics, such as N content and C/N ratio (Espíndola et al., 2006). According to Perin et al. (2002), the lower C/N ratio in soil cover biomass contributes to the increase of TOC, especially when handling the cover with mowing and maintaining plant residues in the area, enhancing the supply of organic material to the soil surface. Although *Pueraria phaseoloides* did not present a higher production of dry matter when compared to banana plant residues, it increases TOC in the soil probably because its biomass presented higher decomposition speed in the evaluated period increasing SOM. Leguminous biomass has a faster decomposition rate when compared to non-leguminous species (Borges et al., 2015).

*Calopogonium mucunoides* L. did not provide high increments of TOC; this may be a consequence of its lower intake of dry matter, which, in turn, may be due to the lower tolerance to both shading by the main crop and to successive plant cuts. The spontaneous vegetation, composed predominantly by the grass *Panicum maximum* Jacq, despite having produced dry matter statistically similar to the *Pueraria phaseoloides*, did not show a similar behavior.
regarding the increase in TOC, possibly due to the longer time required for decomposition of its plant biomass. Grasses have a higher C/N ratio than leguminous and this causes their decomposition to be slower, splitting the release of nutrients into the soil. According to Borghi et al. (2006), when grasses are used as cover crops they provide high production of biomass with high C/N ratio, which decreases their rates of decomposition and release of nutrients. Espíndola et al. (2006) observed a C/N ratio of 79.3 for spontaneous vegetation also composed by the grass *Panicum maximum* Jacq. and 23.5 for *Pueraria phaseoloides*.

The TOC levels in response to the interactions between the irrigation levels and depth and between soil covers and depth, respectively, are presented in Table 3.

**Table 3. Total organic carbon (TOC) (g kg$^{-1}$) in response to irrigation levels, soil cover and soil depth.**

| Soil Depth | Irrigation levels 1 | 2 | 3 | 4 | Soil covers PP | CM | SV | BR |
|------------|---------------------|---|---|---|---------------|----|----|----|
| 1          | 16.4 aA             | 16.4 aA | 15.5 bA | 15.1 cA | 19.2 aA     | 13.0 cA | 18.5 bA | 12.7 dA |
| 2          | 14.9 aB             | 14.9 aB | 13.9 bB | 13.6 cB | 17.8 aB     | 11.4 cB | 16.9 bB | 11.2 dB |

Soil depth 1 and 2: samples collected at soil depths of 0-5 and 5-10 cm, respectively. 1, 2, 3 and 4 irrigation level with 50, 75, 100 and 125% of the evapotranspiration of the banana crop. PP: leguminous *Pueraria phaseoloides*; CM: leguminous *Calopogonium mucunoides* L; SV: Spontaneous vegetation; BR: Banana plant residues. Averages followed by the same lowercase letter in the rows and the same uppercase letter in the columns (for irrigation levels and soil covers alone) do not differ statistically from each other at the level of 1% probability according to the F and Tukey tests. Author (2013).

The soil surface presented higher TOC contents regardless of the irrigation levels and soil cover used (Table 3). This is a consequence of the management adopted, since there was no incorporation of plant residues, contributing to the higher TOC content in the superficial layer that was directly in contact with the decomposing biomass. This result was consistent with that found by Guareschi et al. (2012) who observed a higher TOC content in the surface layer in areas without soil disturbance. Other research has also observed higher levels of TOC in the superficial layers of the soils under different uses (Diógenes et al., 2011; Iwata et al., 2012; Matoso et al., 2012).

For the organic C contents in the SOM fractions, there was no significant interaction between irrigation levels, cover and soil depth (P>0.05); therefore, double interactions between treatment factors were observed (P<0.05). In the Table 4 are presented the averages of the organic C levels present in the chemical fractions of the SOM as a function of the interaction between irrigation levels and soil cover. For the fractions of fulvic acids (AF), humic acids (HA) and humine (HUM) the highest values of organic C (4.1 to 6.2 g kg$^{-1}$) were
observed in the subplots covered with *Pueraria phaseoloides* regardless of the irrigation levels used. This result was expected as this leguminous provided higher levels of TOC as previously discussed.

**Table 4.** Total organic carbon (TOC) in the soil (g kg\(^{-1}\)), carbon (C) contents (g kg\(^{-1}\)) in the fulvic acids (FA), humic acids (HA) and humine (HUM) fractions of the soil organic matter, and percentage of organic carbon in each soil organic matter chemical fraction in response to irrigation levels and soil cover.

| Irrigation levels | Soil cover          | *Pueraria phaseoloides* |          |          |          |          |          |          |          |          |
|------------------|---------------------|-------------------------|----------|----------|----------|----------|----------|----------|----------|----------|
|                  |                     | TOC (g Kg\(^{-1}\))    | C-FA     | C-HA     | C-HUM    | FA        | HA       | HUM      | HA/FA    |
| 1                |                     | 19.2                    | 6.2 aA   | 5.6 aA   | 4.1 aA   | 32.3      | 29.4     | 21.4     | 0.9      |
| 2                |                     | 19.1                    | 6.2 aA   | 5.6 aA   | 4.1 aA   | 32.2      | 29.3     | 21.3     | 0.9      |
| 3                |                     | 18.0                    | 6.2 aA   | 5.6 aA   | 4.1 aA   | 34.3      | 31.0     | 22.7     | 0.9      |
| 4                |                     | 17.6                    | 6.2 aA   | 5.6 aA   | 4.1 aA   | 35.2      | 33.4     | 23.3     | 0.9      |
| Average          |                     |                         |          |          |          |          |          |          |          | 0.9 a    |

| Spontaneous vegetation |          |          |          |          |          |          |          |          |          |          |
|------------------------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|
| TOC (g Kg\(^{-1}\))    | C-FA     | C-HA     | C-HUM    | FA        | HA       | HUM      | HA/FA    |
| 1                      | 12.8     | 4.2 aC   | 3.5 aC   | 2.3 aC   | 32.7      | 27.4     | 17.7     | 0.8      |
| 2                      | 12.8     | 4.2 aC   | 3.5 aC   | 2.2 aC   | 32.8      | 27.1     | 17.3     | 0.8      |
| 3                      | 11.8     | 4.2 aC   | 3.5 aC   | 2.3 aC   | 35.6      | 29.4     | 19.4     | 0.8      |
| 4                      | 11.5     | 4.2 aC   | 3.5 aC   | 2.2 aC   | 36.4      | 30.3     | 19.6     | 0.8      |
| Average                |          |          |          |          |          |          |          |          | 0.8 b    |

1, 2, 3 and 4 irrigation level with 50, 75, 100 and 125% of the evapotranspiration of the banana crop. AF: fulvic acid; AH: humic acid; HUM: humine. Averages followed by the same lower case letter in the columns within the ground cover and the same upper case letter between the ground cover does not differ statistically from each other at the level of 5% probability according to the F and Tukey test. And averages followed by the same lower case letter in the AH /
AF ratio between the soil coverings do not differ statistically from each other at the level of 1% probability according to the F and Tukey tests. Author (2013).

The fractions of SOM have different characteristics and it distribution in the soil may indicate changes resulting from the management adopted (Pinto et al., 2020). Among the chemical fractions of SOM in this study, the FA was the one containing the higher amount of organic C (Table 4). The percentage of the TOC in this fraction varied from 30.5 to 36.4% (Table 4).

The AF fraction is more reactive than other fractions because it contains greater amount of carboxylic and phenolic groups (Primo et al., 2011). However, it has greater solubility and mobility in the soil and can be carried to deeper layers. In addition, FA fraction contains easily degradable compounds, being the first to suffer microbial attack, thus presenting low recalcitrance (Silva et al., 2009). According to Melo et al. (2008) the highest proportion of FA indicates that the organic matter is not completely humified. The highest C content in FA fraction found in this study means SOM still will suffer humification, and it is similar with other studies on which higher C content was found in FA fraction of SOM (Melo et al., 2008, Miranda et al., 2007 and Ruivo et al., 2002).

The HUM fraction showed the lowest organic C content regardless of soil cover and irrigation levels applied (Table 4). The organic C content in this fraction varied from 2.2 to 4.1 g kg\(^{-1}\) (Table 4). The HUM fraction is the one remaining after HA and FA extraction and has high insolubility and recalcitrance characteristics; thus this fraction is considered the most stable of the SOM (Schiavo et al., 2007). The percentage HUM fraction in the soil TOC of this study varied from 17.2 to 23.3% (Table 4). According to Canellas et al. (2003), the percentage of C in the HUM fraction in relation to TOC below 45% suggests the presence of poorly evolved humus. It is possible that the time period between cover crops cut and soil sampling in this study was not enough to completely humification of the SOM, resulting in low C values in the HUM fraction. It was observed that under long term experiment in semi-arid conditions the proportion of organic C in the HUM fraction is higher than in the other fractions (Pegoraro et al., 2018).

The HA fraction showed intermediate levels of organic C independent of soil cover and irrigation levels, ranging from 3.2 to 5.6 g Kg\(^{-1}\) (Table 4). The percentage of C in this fraction in relation to TOC varied from 25.9 to 33.4% (Table 4). Represents the intermediate fraction between the stabilization of compounds by interaction with mineral matter and the occurrence of free oxidized organic acids in the soil solution (Canellas et al., 2003). Therefore,
it is considered as natural markers of the maturation process of SOM. In the present study, most organic C was associated with the FA and HA fractions and it is indicates C amount in fractions of less stability (Rosset et al. 2016).

The HA/FA ratio is used as an indicator of the humification process and represents the level of evolution of SOM (Pfleger et al., 2017). Ratios greater than 1.0 are indicative of greater transformation in SOM. In this study HA/FA ratios close to 1.0 were observed in the treatments with *Pueraria phaseoloides* and spontaneous vegetation, with no statistical difference between them (p <0.01) (Table 4). In soils of tropical regions, the HA/FA ratio is usually less than one due to the high rate of decomposition of plant residues (Barros et al., 2012). It is assumed that in semi-arid soils the behavior is similar. The low HA/FA ratio, associated with a lower percentage of organic C in the HUM fraction in relation to TOC (<45%), indicates weak humification of the organic material added on the soil (Canellas et al., 2003).

The contents of organic C in the chemical fractions of the SOM as a function of the interaction between soil cover and sampling depth are presented in Table 5. The organic C content of the SOM chemical fractions decreased with soil depth (Table 5). This may be a consequence of the management, since plant residues were not incorporated into the soil. Canellas et al. (2003) and Loss et al. (2007) also found a reduction in the organic C content of SOM chemical fractions with increasing depth, corroborating the result found in the present study. There was no significant effect (p <0.05) of the interaction between irrigation levels and soil depth.

Table 5. Organic carbon (g kg\(^{-1}\)) in the chemical fractions of SOM in response to the interaction between soil cover and soil depth.

| Soil cover | Soil Depth | FA     | HA     | HUM    | FA     | HA     | HUM    |
|------------|------------|--------|--------|--------|--------|--------|--------|
|            | 1          |        |        |        |        |        |        |
| PP         |            | 6.54 aA| 5.83 aA| 4.64 aA| 5.83 aB| 5.42 aB| 3.54 aB|
| CM         |            | 4.51 cA| 3.78 cA| 2.49 cA| 3.85 cB| 3.17 cB| 2.01 cB|
| SV         |            | 6.19 bA| 5.48 bA| 4.10 bA| 5.30 bB| 4.93 bB| 3.09 bB|
| BR         |            | 4.34 dA| 3.61 dA| 2.34 dA| 3.38 dB| 2.93 dB| 2.06 dB|

Soil depth 1 and 2: samples collected at depths of 0-5 and 5-10 cm, respectively. PP: leguminous *Pueraria phaseoloides*; CM: leguminous *Calopogonium mucunoides* L.; SV: Spontaneous vegetation; BR: Banana plant residues. FA: fulvic acid; HA: humic acid; HUM: humine. Averages followed by the same lowercase letter in the lines and the same uppercase letter in the columns do not differ statistically from each other at the level of 1% probability according to the F and Tukey test. Author (2013).
4 CONCLUSIONS

The smallest irrigation depths associated with soil cover with *Pueraria phaseoloides* provided higher content of TOC in the soil, with most of the organic C concentrated in the less stable fractions. The *Pueraria phaseoloides* and spontaneous vegetation provided organic matter with a higher degree of humification, with values closed to 1.0.

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