

Effect of Cultivation and Soil Tillage Systems on the Microbial Biomass in Castor Bean Crop at the Irecê Plateau, Bahia

Camila Brasil Dias¹, Eduardo Gross², Arlicélio de Queiroz Paiva², Luciano da Silva Souza³,
Carlos Alberto da Silva Ledo⁴ & Francisco Alisson da Silva Xavier⁴

¹ Postgraduate Program in Crop Production, Universidade Estadual de Santa Cruz, Bahia, Brazil

² Departamento de Ciências Agrárias e Ambientais, Universidade Estadual de Santa Cruz, Bahia, Brazil

³ Universidade Federal do Recôncavo da Bahia, Bahia, Brazil

⁴ Embrapa Mandioca e Fruticultura, Bahia, Brazil

Correspondence: Eduardo Gross, Departamento de Ciências Agrárias e Ambientais, Universidade Estadual de Santa Cruz, Rod. Jorge Amado, Km 16 Ilhéus, BA, 45662-900, Brazil. Tel: 55-733-680-5191; Fax: 55-733-680-5254. E-mail: egross@uesc.br

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Abstract

Inadequate soil management alters the microbiological attributes of the soil, causing reduction in microbial biomass and activity. Microbial biomass is the living and active part of the soil and can serve as an indicator of changes in the quantity of due to changes in land use. This study aimed to evaluate the effect of intercropping and soil tillage systems on the microbial biomass in castor bean-based crop in the Irecê Plateau, Bahia, Brazil. The experiment was carried out on an eutrophic Haplic Cambisol with clay texture in the Mata Verde Farm of Alto do Quindinho, municipality of São Gabriel, Irecê Plateau, Bahia, Brazil. Six intercropping systems were evaluated including solely castor bean (control) and castor bean intercropped with each of the castor bean cake, common bean, pigeon pea, corn, and gliricidia. Plowing + harrowing and subsoiling were the two soil tillage techniques associated to the intercropping systems. C and N contents in microbial biomass (C_{mic} and N_{mic}), soil basal respiration and metabolic quotient were determined in soil samples collected from the 0-10 and 10-30 cm layers. The different soil management systems influenced microbial biomass and activity, and the most suitable conditions for soil microbiota occurred in the soil tillage system with subsoiling. In the semi - arid condition, at 0-10 cm depth, the castor bean + castor bean cake crop system promoted an increase of C_{mic} content, and the castor + gliricidia system increased N_{mic} content, both under soil tillage with subsoiling.

Keywords: microbiota, semi-arid region, management

1. Introduction

The region of Irecê is located in Northwestern Bahia, Brazil, and is considered as one of the country largest producer of castor bean. Its soils have high natural chemical fertility, but inadequate soil management, associated with water deficit, high temperatures and low physical quality of soils, contribute to low agricultural production in the region.

In Brazil, the Bahia state is the largest castor bean producer, with about 51,487 ha cultivated and a production of 33,541 tons in 2014, which corresponded to 89% of the national production and 95% of the production in the Northeast region (IBGE, 2016). However, yields in Bahia are lower than the national mean, a situation that has led research institutions to conduct studies to increase the production potential of castor bean in the mesoregion of Irecê, which is the main center of castor bean production in the country.

Agriculture modernization is closely related to the mechanization of field operations. One of most important and negative impacts of mechanization in agricultural systems is the increase of soil compaction due to machinery traffic (Roboredo et al., 2010). Mechanical soil tillage directly influences the physical and biological properties of the soil. The turning of the soil for the establishment of an agricultural crop causes imbalance in the microbiota, which affects nutrient cycling in the soil (Lisboa et al., 2012). Microbial biomass is considered as a good indicator to express the level of soil quality (Islam & Weil, 2000). Analysis of C and N contents in the microbial biomass in combination to soil basal respiration measurements are normally used for this purpose.

Joint analysis of these parameters generates an index called metabolic quotient (qCO_2). This index relates microbial respiration with the magnitude of its biomass, providing an analysis of the efficiency of microorganisms at transforming soil organic C into microbial-C (Anderson & Domsch, 1993; Alves et al., 2011).

The amounts of N immobilized in the biomass can reach very high values, above 100 kg ha⁻¹ (Anderson & Domsch, 1980). The N retained in the biomass is released as the microorganisms die and are mineralized by the remaining population, which is the reason why in soils subjected to environmental stresses most of the N mineralized can be of microbial origin (Marumoto et al., 1982). Therefore, microbial biomass acts as a N buffer of the soil, since it controls its availability through processes of mineralization and immobilization. In different soil management systems, the microbiota undergoes different stimuli due to the composition of the residues of plant species and to soil tillage methods. This results in differences in microbial activity, N immobilization-mineralization ratio and residue decomposition rates.

The effect of cover plants and tillage systems on the improvement of soil biological attributes should be quantified regionally and for each production system, because it depends on soil texture and mineralogy, relief and on the conditions of temperature and moisture (Cunha et al., 2011). Thus, this study aimed to evaluate the effect of intercropping systems and soil tillage techniques on microbial biomass in castor bean crop in the Irecê Plateau, Bahia, Brazil.

2. Materials and Methods

The experiment was carried out in an area of the Mata Verde farm, in Alto do Quindinho, municipality of São Gabriel, Irecê Plateau, Bahia. UTM 24 L 182102 E and 8764029 S at an elevation 784 m a.s.l. The climate was semi-arid. The average annual rainfall was 583 mm and the average temperature 23.3 °C. The soil was predominantly Tb eutrophic Haplic Cambisol (Embrapa, 2006).

Plots with 900 m² area (30 m × 30 m) were delimited and the spacing adopted for the castor bean crop was 3.0 m × 1.0 m, totaling 300 plants per plot. The cultivar 'BRS 149 Nordestina' was used, which has medium size, semi-dehiscent fruits and black seeds with 48.9% oil content. Its mean yield was 1,500 kg ha⁻¹ and its cycle lasts 250 days (Freire et al., 2007). Six castor bean intercropping systems were evaluated including (1) castor bean (control), (2) castor bean + castor bean cake, (3) castor bean + common bean, (4) castor bean + pigeon pea, (5) castor bean + corn, and (6) castor bean + *Gliricidia sepium* under two different soil tillage systems *i.e.* (1) conventional tillage with plowing + harrowing and (2) soil tillage with subsoiling before castor bean planting. Subsoiling was carried out with a subsoiler composed of three shanks spaced by 0.50 m and 0.05 m wide point, with 0.50 m working depth. The experiment was arranged in a split-plot design, in randomized blocks where soil tillage methods were the main plots and intercropping the subplots.

The soil presented the physicochemical characteristics contained in Table 1.

Table 1. Physic and chemical characteristics of the soils in the experimental area

Sand	Silt	Clay	H ₂ O PWP	Density	pH _{H₂O}	Avail P	Avail K	Al ³⁺	H+Al	CEC	BS	Organic matter
-----	g kg ⁻¹	-----	-- m ³ m ⁻³	-- kg dm ⁻³		-----	mg dm ⁻³	-----	cmol _c dm ⁻³	-----	%	dag kg ⁻¹
235	235	447	0.17	1.3	6.3	4.2	104	0.0	2.2	14.5	83	2.1

Note. H₂O PWP = moisture at permanent wilting point, Density = bulk density, Avail P = available P, Avail K = available K, CEC = cation exchange capacity, BS = base saturation

Soil temperature was monitored in each soil tillage treatment by copper-constantan thermocouples sensors (Alutal, Votorantim, São Paulo, Brazil) installed at 5, 10, and 20 cm depth. To monitor soil moisture, CS616 sensors (Campbell Scientific Inc., Utah, USA) were installed in each treatment, which recorded the moisture content integrated over the 0-30 cm layer. Soil temperature and soil moisture sensors were interconnected by a data logger (CR1000, Campbell Scientific Inc., Utah, USA), programmed to take readings every hour and store the data. Table 2 present mean values of soil temperature and volumetric moisture on the sampling days.

Table 2. Means of soil temperature (Temp) and volumetric moisture (θ) on the days of soil sampling from 2015 to 2017 in experimental field

Intercropping systems	Tillage systems			
	Plowing + harrowing		Subsoiling	
	Temp (°C)	θ ($\text{m}^3 \text{m}^{-3}$)	Temp (°C)	θ ($\text{m}^3 \text{m}^{-3}$)
Castor bean (control)	30.18	0.08	30.04	0.07
Castor bean + common bean	30.15	0.08	30.62	0.09
Castor bean + gliricidia	31.01	0.07	30.98	0.06
Castor bean + pigeon pea	32.43	0.07	31.12	0.06
Castor bean + corn	30.47	0.09	30.58	0.07
Castor bean + castor bean cake	30.45	0.09	30.65	0.10

Soil samples for microbiological analysis were collected using a Dutch auger at 0-10 cm and 10-30 cm depths. In each plot, nine soil cores were collected to form a composite sample for each depth. Immediately after collection, the composite samples were sieved through a 2-mm mesh, placed in plastic bags, identified and stored in cold chamber at 4 °C until analysis. Soil sampling was carried out on the days in which soil volumetric moisture contents were below the permanent wilting point ($\theta_{\text{PWP}} < 0.17 \text{ m}^3 \text{m}^{-3}$), precisely on November 15, 2015; March 30, 2016; November 05, 2016 and April 11, 2017.

Soil microbial biomass was determined by the irradiation-extraction method (Islam & Weil, 1998), using electromagnetic energy (microwaves) to cause cell lysis in the microorganisms. For each treatment, two subsamples (irradiated and non-irradiated) of 20 g of soil were used. Samples were irradiated using a microwave oven and the time of irradiation was 90 seconds. For C extraction, a $0.5 \text{ mol L}^{-1} \text{K}_2\text{SO}_4$ solution was used. The samples were shaken for one hour in horizontal shaker at 180 rpm and, after half an hour of decantation, the supernatant was filtered using slow quantitative filter paper. For the analysis of C and N contents, aliquots of 5 and 20 mL were collected, respectively. Carbon content on the extracts was determined by wet combustion (Yeomans & Bremner, 1988) and nitrogen by the Kjeldahl method (Tedesco et al., 1995).

Microbial biomass C and N (MB-C and MB-N) contents were calculated using Equations 1 and 2, respectively.

$$\text{MB-C} = (\text{Ci} - \text{Cni})/\text{Kc} \quad (1)$$

where,

MB-C = Carbon content of soil microbial biomass (mg kg^{-1}); Ci = Carbon content of the irradiated sample (mg kg^{-1}); Cni = Carbon content of the non-irradiated sample (mg kg^{-1}); Kc = correction factor for the method of irradiation-extraction of carbon from soil microbial biomass (Sparling & West, 1988), Kc = 0.33.

$$\text{MB-N} = (\text{Ni} - \text{Nni})/\text{Kn} \quad (2)$$

where,

MB-N = Nitrogen content of soil microbial biomass (mg kg^{-1}); Ni = Nitrogen content of the irradiated sample (mg kg^{-1}); Nni = Nitrogen content of the non-irradiated sample (mg kg^{-1}); Kn = correction factor for the method of irradiation-extraction of nitrogen from soil microbial biomass (Brookes et al., 1985) and Kn = 0.54.

Soil basal respiration (SBR) was determined by quantifying the carbon dioxide (CO_2) released in the process of microbial respiration after 10 days of incubation according to Mendonça and Matos (2005). Briefly, 100 g of each of the soil samples were incubated at 25 °C in hermetically sealed flasks in the presence of $0.5 \text{ mol L}^{-1} \text{NaOH}$ solution (30 mL). After incubation time, the container was opened and kept for 15 minutes at room temperature. Then, 10-mL aliquots were collected in the NaOH solution and mixed with 3 mL of $0.5 \text{ mol L}^{-1} \text{BaCl}_2$ solution. The solution was titrated with $0.25 \text{ mol L}^{-1} \text{HCl}$ after addition of phenolphthalein indicator. SBR was expressed in $\text{mg C-CO}_2 \text{ kg}^{-1} \text{ soil h}^{-1}$. The ratio between SBR and MB-C was used to determine the metabolic quotient ($q\text{CO}_2$), which expresses the efficiency of microbial biomass at converting soil organic C to microbial C (Anderson & Domsch, 1993). The $q\text{CO}_2$ was expressed in $\text{mg C-CO}_2 \text{ mg}^{-1} \text{MB-C h}^{-1}$.

Statistical Analysis

The data soil microbial biomass C (MB-C) and N (MB-N), soil basal respiration (SBR), and metabolic quotient ($q\text{CO}_2$) were subjected to an analysis of variance to evaluate the effect of soil tillage as well as the effect of the intercropping systems. The mean values of the soil tillage techniques were compared by Tukey test at 0.05 probability level to evaluate the effect of soil tillage and the mean values of the intercropping systems were separated using Scott-Knott test at 0.05 probability level.

3. Results

In both layers, the interaction between soil tillage and intercropping systems was significant for MB-C contents (Table 3). In general, soil tillage with subsoiling led to increase in MB-C in comparison to the tillage with plowing and harrowing. This response can be attributed to the greater turning of the soil by the plow and harrow, which accelerates the process of oxidation of soil organic matter causing stress on the microbial biomass.

Table 3. Analysis of variance of data soil microbial biomass (MB-C) and N (N-MB), the basal soil respiration (SBR) and metabolic quotient (qCO_2)

FV (MB-C)	GL	SQ	QM	FC	Pr > Fc
A	5	139587.83	27917.567	20.397	0.0011
Error 1	6	8212.44	1368.7412		
B	1	174823.57	174823.578	163.320	0.0000
A*B	5	48988.077	9797.6154	9.153	0.0009
Error 2	12	12845.2129	1070.4344		
C	1	62173.6931	62173.693	86.751	0.0000
A*C	5	33904.696	6780.939	9.461	0.0000
B*C	1	6727.591	6727.59	9.387	0.0053
A*B*C	5	3492.9578	6984.19	9.745	0.0000
Error 3	24	17200.544	716.68		
Total	65	507956.6			
FV (MB-N)	GL	SQ	QM	FC	Pr > Fc
A	5	180.277	36.055	76.657	0.0000
Error 1	6	2.8220	0.470		
B	1	0.348715	0.348	0.817	0.3838
A*B	5	94.040323	18.8080	44.066	0.0000
Error 2	12	5.1121	0.4268		
C	1	306.5081	306.5081	366.103	0.0000
A*C	5	36.5842	7.3168	8.739	0.0001
B*C	1	4.2533	4.253329	5.080	0.0336
A*B*C	5	21.677344	4.3354	5.178	0.0023
Error 3	24	20.093217	0.8372		
Total	65	671.7163			
FV (RBS)	GL	SQ	QM	FC	Pr > Fc
A	5	0.003287	0.000657	4.307	0.0520
Error 1	6	0.000916	0.000153		
B	1	0.002153	0.002153	18.951	0.0009
A*B	5	0.006543	0.001309	11.520	0.0003
Error 2	12	0.001363	0.000114		
C	1	0.046075	0.046075	527.512	0.0000
A*C	5	0.008600	0.001720	19.691	0.0000
B*C	1	0.000061	0.000061	0.702	0.4104
A*B*C	5	0.009481	0.001896	21.709	0.0000
Error 3	24	0.002096	0.000087		
Total	65	0.080575			
FV (qCO_2)	GL	SQ	QM	FC	Pr > Fc
A	5	2.1087	0.421745	3.501	0.0795
Error 1	6	0.722723	0.120454		
B	1	2.514283	2.514283	23.044	0.0004
A*B	5	1.999335	0.399867	3.665	0.0303
Error 2	12	1.309294	0.109108		
C	1	4.097170	4.097170	52.603	0.0000
A*C	5	0.333413	0.066683	0.856	0.5243
B*C	1	0.172009	0.172009	2.208	0.1503
A*B*C	5	0.787321	0.157464	2.022	0.1117
Error 3	24	1.869331	0.077889		
Total	65	15.91358			

Note. A: vegetal cover; B: Soil preparation factor; C: Soil depth; FV: variation factor; V.A.: variable analyzed; GL: degree of freedom; SQ: sum of square; QM: middle square; Fc: Fvalue.

Table 4. Soil microbial biomass C (MB-C) and N (MB-N), soil basal respiration (SBR), and metabolic quotient (qCO_2) in the 0-10 and 10-30 cm layers as a function of different intercropping systems and soil tillage methods in castor bean crop of 2015-2017

Intercropping system	Tillage systems							
	Plowing + harrowing				Subsoiling			
	MB-C	MB-N	SBR	qCO_2	MB-C	MB-N	SBR	qCO_2
----- mg kg ⁻¹ -----		mg C-CO ₂ kg ⁻¹ soil h ⁻¹	mg C-CO ₂ g Cmic ⁻¹ h ⁻¹	----- mg kg ⁻¹ -----		mg C-CO ₂ kg ⁻¹ soil h ⁻¹	mg C-CO ₂ g Cmic ⁻¹ h ⁻¹	
<i>0-10 cm</i>								
Castor bean (control)	239 bA	9 cB	0.12 cA	0.50 bA	247 cA	12 cB	0.11 cB	0.44 aA
Castor bean + castor bean cake	272 aB	14 aA	0.13 bA	0.48 bA	349 aA	12 cB	0.09 dB	0.26 aB
Castor bean + common bean	236 bB	14 aA	0.11 dB	0.46 bA	263 cA	12 cB	0.13 bA	0.49 aA
Castor bean + pigeon pea	286 aA	14 aA	0.12 cB	0.42 bA	300 bA	13 bA	0.14 aA	0.46 aA
Castor bean + corn	172 cB	12 bA	0.14 aA	0.81 aA	292 bA	11 cA	0.13 bB	0.44 aB
Castor bean + gliricidia	270 aB	13 aB	0.11 dA	0.41 bA	317 bA	15 aA	0.11 cA	0.35 aA
<i>10-30 cm</i>								
Castor bean (control)	163 cB	7 bB	0.14 bA	0.86 aA	259 bA	9 bA	0.15 aA	0.58 aA
Castor bean + castor bean cake	274 aB	11 aA	0.15 bA	0.55 aA	321 aA	11 aA	0.16 aA	0.50 aA
Castor bean + common bean	181 cB	11 aA	0.15 bA	0.83 aA	295 aA	10 aA	0.14 bA	0.47 aB
Castor bean + pigeon pea	217 bA	10 aA	0.14 bA	0.64aA	202 cA	9 bA	0.14 bA	0.69 aA
Castor bean + corn	169 cB	10 aA	0.17 aA	1.00 aA	261 bA	11 aA	0.13 bB	0.50aB
Castor bean + gliricidia	184 cB	11 aA	0.17 aA	0.92 aA	284 aA	12 aA	0.15 aB	0.53 aB

Note. Means followed by the same letter, lowercase in columns (Scott-Knott test) comparing intercropping systems and uppercase in rows (Tukey test) comparing tillage systems, for each variable and layer separately, do not differ significantly at 5% probability.

In the 0-10 cm layer, for soil tillage with subsoiling, the highest MB-C contents were found in the intercropping system with castor bean + castor bean cake. In the 10-30 cm layer, highest MB-C values were found in the intercropping systems with castor bean + castor bean cake, castor bean + common bean and castor bean + gliricidia.

The interaction between soil tillage and intercropping systems was significant for the MB-N contents in the 0-0.10 and 10-30 cm layers (Table 3). The intercropping system with castor bean under monoculture and soil tillage with plowing and harrowing (control) led to the lowest MB-N at the studied depths. Soil tillage with subsoiling, at the 0-10 cm, resulted in highest MB-N in the systems with castor bean + gliricidia and castor bean + pigeon pea.

All intercropping systems showed higher MB-N contents than the control (castor bean in monoculture and soil tillage with plowing and harrowing) at the studied depths, which can be due to the effect of management, because of the greater supply of organic residues. The effects were more pronounced in the systems with castor bean + gliricidia for soil tillage with subsoiling in the layers of 0-10 cm and 10-30 cm, where MB-N contents were 15 and 12 mg kg⁻¹, respectively.

Microbial activity, measured as evolved CO₂, varied from 0.11 mg C-CO₂ kg⁻¹ for castor bean + common bean and castor bean + gliricidia at 0-10 cm depth to 0.17 mg C-CO₂ kg⁻¹ for castor bean + corn and castor bean + gliricidia at 10-30 cm depth for soil tillage with plowing + harrowing (Table 4).

In spite of statistical differences, amounts of released CO₂-C between plowing harrowing and subsoiling systems regarding to the different intercropping systems were quite similar, especially in the 10-30 cm layer (Table 3). In turn, the lowest values of SBR occurred in the castor bean + gliricidia, castor bean and castor bean + castor bean cake systems.

The intercropping castor bean + corn under soil tillage with plowing + harrowing led to the highest qCO_2 in the 0.0-10 cm layer (Table 4). There was no significant effect of the intercropping systems on the qCO_2 for both soil layers when subsoiling was adopted (Table 3). In the 0-10 cm layer, the intercropping systems with castor bean + corn and castor + castor bean cake led to higher values of qCO_2 when soil tillage was performed with plowing +

harrowing compared to the tillage with subsoiling. Higher values of $q\text{CO}_2$ were also observed in the 10-30 cm layer for the systems with castor bean + common bean, castor bean + gliricidia, and castor bean + corn (Table 4).

4. Discussion

In the present study, soil tillage with plow and harrow decreased MB-C contents indicating that this practice contributes to reducing the magnitude (and possibly the diversity) of soil microbial biomass, with large impact on the edaphic microbiota. Similar trend was observed by Cunha et al. (2011) who found that conventional soil tillage with plowing + harrowing led to lower microbial-C content compared to no-tillage system in the Brazilian Cerrado, indicating that soil turning damages microbial cells and consequently reduces the C content of the microbial biomass. On the other hand, subsoiling management because of less soil disturbance led to increase of MB-C and decrease SBR and $q\text{CO}_2$, suggesting higher sustainability of the agricultural system.

In intensive soil tillage management, macro-aggregates are rapidly broken, making the occluded soil organic matter (initially physically protected) more vulnerable to decomposition and mineralization (Simansky et al., 2013). This factor temporarily stimulate the microbiota to degrade soil organic matter, however, MB-C contents decrease rapidly with further depletion of the soil organic C (Lisboa et al., 2012).

To obtain reference values for the microbiological quality of the agricultural field, Lopes et al. (2013) elaborated different levels of interpretation of bioindicators for clayey Red Latosols of the Cerrado region, in the 0-10 cm layer, based on the organic matter content of the soil. Considering the minimum value of 205 mg C kg⁻¹ of soil based on the organic matter content proposed by these authors, the values of Cmic in the present study were considered as low in the system with castor bean + corn under tillage with plowing and harrowing, and classified as moderate (Cmic 206-405 mg of C kg⁻¹ of soil) in the other systems. For Lopes et al. (2013), this “low” value of microbial indicators can be a sign that inadequate management practices are being used

The results of the present study provide evidence that interaction between soil tillage with subsoiling and intercropping system with castor bean + castor bean cake has higher potential for microbial-C accumulation than the other evaluated systems. Ferreira et al. (2011) stated that management systems which promote less disturbance to soil microbial biomass have great stability, contributing to increase sustainability of the agricultural system. Lopes et al. (2012) evaluated a Tb eutrophic Haplic Cambisol in the Caatinga biome and observed that microbial-C increased in the superficial soil layers regardless of the years of intercropping because of the greater availability of organic matter, water and nutrients.

During prolonged drought periods, very common in the Irecê Plateau, *Gliricidia sepium* was the only specie that remained green after a water deficit period lasting from 2014 to 2017. However, we found that spacing of planting used in the present study, one row planted in the interrows of castor bean with 1.20 m between plants, seems not to be adequate to intercrop gliricidia with castor bean in the semi-arid region. New studies should be conducted to test the most adequate spacing for this intercropping, since this leguminous species, besides its resistance to drought and N fixation symbiotically, provides shade for animals, reducing stress and promoting thermal comfort, and serves as feed for cattle due to its high protein content.

The results of MB-N should be carefully interpreted, since a high biological activity may result from consumption of labile C and N pools, or due to oxidation of organic matter from the breakdown of aggregates by anthropic action, or even from the momentary addition of organic residues. Thus, high MB-N contents may indicate both a situation of disturbance and high productivity of the ecosystem (Islam & Weil, 2000).

Higher SBR values in the intercropping of castor bean + corn under soil tillage with plowing + harrowing can be related to the disturbances caused on soil microbial biomass. The results of $q\text{CO}_2$ evaluating this system showed that microbial biomass was less efficient at using organic compounds, releasing more C in the form of CO₂ and incorporating less C to microbial tissues, especially in the 0-10 cm layer.

In general, plowing and harrowing treatments presented higher values of $q\text{CO}_2$ and SBR, which suggests greater loss of soil organic carbon compared to subsoiling management. This fact can be attributed to soil turning, which favors the oxidation of soil organic matter, increasing the release of CO₂ to the atmosphere.

According to Islam and Weil (2000), SBR rates *per se* may not reflect an effect of soil disturbance. Instead, this variable should be preferentially related to $q\text{CO}_2$ values in order to obtain a more realistic diagnostic of soil environment. When $q\text{CO}_2$ is high, microorganisms are converting less soil organic C into microbial-C, which indicates a stress condition. According to Cunha et al. (2011), when microbial biomass becomes more efficient, less CO₂ is lost to the atmosphere and higher C rate is incorporated to microbial biomass, resulting in lower values of $q\text{CO}_2$.

Management systems in which soil microbial community is less disturbed there is great stability, contributing to higher sustainability (Ferreria et al., 2011). Based on the results observed for the attributes of the microbial biomass, it can be inferred that, compared to soil tillage with plowing + harrowing, soil tillage with subsoiling caused lower disturbance in soil microbial biomass, leading to higher values of Cmic, which possibly results in greater sustainability of the agricultural activity.

5. Conclusions

The different soil management systems influenced microbial biomass and activity, and the most favorable conditions for soil microbiota occurred in the soil tillage system with subsoiling.

In the semi - arid condition, at 0-10 cm depth, the castor bean + castor bean crop system promoted an increase in the Cmic content, and the castor + gliricicide system increased in the Nmic content, both under soil preparation with subsoiling

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