Evolution and accumulation of $C\text{-}CO_2$ in different agroecological production systems

Evolução e acúmulo de $C\text{-}CO_2$ em diferentes sistemas de produção agroecológica

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Abstract

The $C\text{-}CO_2$ evolution via soil microbial activity can be used as a parameter to highlight differences in agroecological production systems. This work aimed to evaluate the microbial activity of soil through the evolution of $C\text{-}CO_2$ (mineralizable carbon) from the respiration of microorganisms under different production systems. Five areas were selected: cultivation of fig; passion fruit consortium – *Desmodium* sp.; cultivation of corn/beans, with conventional tillage (CT) of the soil, cultivation of eggplant/corn under no-tillage (NT) and agroforestry system (AFS). Soil samples were collected at depths of 0.0 - 0.05 and 0.05 - 0.10 m, microbial activity ($C\text{-}CO_2$ evolution in the laboratory) and the accumulation of $C\text{-}CO_2$ for 37 days was assessed. Soon after hatching, all systems evaluated showed peaks of $C\text{-}CO_2$, with variations of these peaks more pronounced until the 9th day of evaluation. At 21 days there is stabilization of microbial activity. Growing fig resulted in higher peaks of $C\text{-}CO_2$ evolution, and also higher accumulations at the end of the 37 day trial. The acreage under NT agroecological showed lower accumulation of $C\text{-}CO_2$. The conventional tillage resulted in lower peak $C\text{-}CO_2$ at a depth of 5-10 cm.

Key-words: Agroecology systems, microorganisms, mineralizable carbon, respiration.

Resumo

A evolução de $C\text{-}CO_2$ por meio da atividade microbiana do solo pode ser utilizada como parâmetro para evidenciar diferenças em sistemas de produção agroecológica. Este trabalho teve como objetivo avaliar a atividade microbiana do solo por meio da evolução de $C\text{-}CO_2$ (carbono mineralizável) oriundo da respiração dos microorganismos sob diferentes sistemas de produção. Foram selecionadas cinco áreas: cultivo de figo; consórcio maracujá – *Desmodium* sp.; cultivo de milho/feijão, com preparo convencional (PC) do solo; cultivo de berinjela/milho, em sistema plantio direto (PD) e um sistema agroflorestal (SAF). Foram coletadas amostras de solo nas profundidades de 0-0.05 m e 0.05 - 0.10 m, sendo avaliada a evolução de $C\text{-}CO_2$ em laboratório e o acúmulo de $C\text{-}CO_2$ durante 37 dias. Logo após a incubação, todos os sistemas avaliados apresentaram picos de $C\text{-}CO_2$, com variações desses picos mais acentuadas até o 9° dia. Aos 21 dias verificou-se a estabilização da atividade microbiana. O cultivo de figo acarretou em maiores picos de evolução de $C\text{-}CO_2$ e, também maiores acúmulos ao final dos 37 dias. A área cultivada sob PD manejado agroecologicamente apresentou menor acúmulo de $C\text{-}CO_2$. O PC do solo acarretou em menores picos de $C\text{-}CO_2$ em 0.05-0.10 m.

Palavras-chave: Carbono mineralizável, microorganismos, respiração, sistemas agroecológicos.

Introduction

An agro-ecological system presents characteristics which confer good development, both in production and in soil quality. These features are contents of organic soil matter (SOM) enough to favor the soil attributes such as aggregation and nutrient availability; plant biodiversity on which depends the diversity of life in the soil; the use of cover (dead or alive) of soil to reduce heating of the surface layer; Wind control the (windbreaks, corridors, hedges) to mitigate the loss of moisture; and minimal supply of external inputs for the productive unit. In General, agro-ecology encompasses the environment as a whole, including the social aspect, crop production and conservation of natural resources for the maintenance of the sustainability of the agro-ecosystem (Salmi *et al.*, 2006; Loss *et al.*, 2009; Loss *et al.*, 2011).

Human intervention in natural ecosystems for the implementation of agricultural activities reduces stocks and alters the chemical composition of SOM (Santos *et al.*, 2008; Pillon *et al.*, 2011). On the study of these impacts, the production systems with annual crops are the most investigated, because of its large size, historical use and economic importance. The results of these studies indicate that SOM losses amount to more than 50% of the initial levels in relatively short periods (less than 10 years), especially in sandy textured soils and where management practices are less conservationist (Mielniczuk *et al.*, 2003).

However, it is still recent the generation of scientific knowledge with regard to the changes promoted in soil properties resulting from organic cultivation with fruit and oleraceae (Loss *et al.*, 2009; Loss *et al.*, 2010ab; 2011). Moreover, there are few studies which assessed the impact of the cultivation of perennial and annual species in organic systems, in relation to microbial activity. Thus, these assessments are important because nutrient cycling occurs as a consequence of microbial activity and it is especially important in ecosystems of low fertility such as those that occur in tropical soils.

Through the evolution of $C\text{-}CO_2$ originating from microbial respiration it can be evidenced the changes resulting from different land use systems (Peña *et al.*, 2005; Loss *et al.*, 2013), thus characterizing it as a good edaphic indicator. Therefore, high respiration rates (mineralizable carbon) may mean greater cycling of carbon and nutrients to plants (D'Andrea *et al.*, 2002).

One way to quantify the labile compartment is the determination of mineralizable C which originates from the breakdown of organic molecules by the degradation of substrates incorporated into the soil, converted into energy and biomass by the process of respiration (Rose *et al.*, 2003). The mineralized carbon is measured from the evolution of CO_2 (Mendonça and Matos, 2005; Loss *et al.*, 2013) which reflects the microbial activity in the decomposition of SOM (Bossuyt *et al.*, 2002). This study evaluated the soil microbial activity through the evolution of $C\text{-}CO_2$ (mineralizable carbon) coming from the respiration of microorganisms under different agro-ecological production systems.

Materials and methods

The study was conducted in the Integrated Agroecological Production System (SIPA), implemented in 1993 in and area of 59 ha. The SIPA is located at Embrapa Agrobiology, Seropédica, RJ (22 45'S, 43°41'O, at 33 masl). The climate is Aw, according to the classification of Köppen. The soil is an Ultisol (Loss *et al.*, 2011) with sandy loam texture in the surface horizon, with 784, 168 and 48 g / kg (0-5 cm) and 770, 168 and 62 g / kg (5-10 cm) for sand, clay and silt, respectively. In SIPA several experiments with oleraceae and fruit are conducted, and five areas were selected (0.12 ha):

1. A fig crop (*Ficus carica*) of 7 years old and grass (*Paspalum notatum*) between the rows. At planting of the fruit (1999) Siratro (*Macroptillium artropurpureum*) was used as the cover crop, which remained in the area through 2002 (Merlin *et al.*, 2005). The amount of dry matter (DM) from leaves of natural siratro dehiscence reached 2 t/ha, resulting in a stock of 50 kg/ha of N (Almeida and War, 2008). The organic fertilizer used in fig planting consisted of 30 l of cattle manure per pit, 1/3 placed in the bottom of the pit and 2/3 homogenized with the soil removed from the pit. In the coverage for the initial orchard formation, 4.5 kg of poultry litter was used, within 50 cm apart from each plant. At the time of collection of the soil samples for this study (2005), the area with fig was found only covered with vegetable waste from the cut of Bahia grass (*Paspalum notatum*), not being checked the influence of legume cover.
2. Cultivation of corn/beans in an area that has been used for conducting experiments with crop rotation such as maize (*Zea mays*), beans (*Phaseolus vulgaris*), okra (*Abelmoschus esculentus*), cabbage (*Brassica oleracea*), eggplant (*Solanum melogena*) for the last 8 years, and conventional tillage (CT) of the soil (plowing and harrowing) was used. This area is used for sunn hemp (*Crotalaria juncea* and *C. spectabilis*) in both interpcropped andor in the form of pre-cultivation. In an experiment with the okra crop, intercropped with *C. juncea*, with two treatments, one with mowed and other with pruned legumes; Ribas *et al.* (2003) observed that the sunn hemp produced 4.4 and 3.9 t/ha in the first cut, respectively, for the treatments mowing and pruned, accumulating 130 and 116.5 kg/ha of N in these treatments.
3. Cultivation of eggplant/maize with the same sequence of crop rotation and usage time as the maize area (CT), however with no-tillage (NT). This area makes use of the legumes gray velvet bean (Mucuna pruriens), dwarf velvet bean (Mucuna deeringiana), C. spectabilis and C. juncea, intercropped with the main crop. For the production of DM, stands out its use in intercropping with cabbage, promoting DM contribution of 1.6 t / ha from C. spectabilis and 1.8 t / ha from dwarf mucuna in 2003; 2.8 t / ha from Crotalaria juncea and 5.5 t / ha from gray velvet bean in intercropping with maize in the period 2003 - 04; 1.4 t / ha from C. spectabilis and 1.5 t / ha from dwarf mucuna in 2004 (Silva *et al.*, 2009). At the time of collection of the soil samples, the areas with eggplant/corn (NT) and corn/beans (CT) had no cover crops covering the soil.
4. Passion fruit (*Passiflora edulis*) - *Desmodium* sp. intercropping, this was being cultivated with passion fruit since 1996. This area has always performed intercropping with legumes, from 1996 to 2000 utilized *Arachis pintoi*. Then the fruit was intercropped with *Desmodium* sp. The organic fertilization used for the passion fruit plantation consisted of 30 l of cattle manure per pit, with two coverage fertilizations with poultry litter per year, at a rate of 100 kg/ha from N.
5. Agroforestry system (AFS) with 5 years and is composed of banana (*Musa sapientum*), açaí (*Euterpe oleracea*), cocoa (*Thebroma cacao*), papaya (*Carica papaya*) and guapuruvu (*Schizolobium parahyba*), among others. The AFS did not received any kind of supplementary fertilization, meaning that the supply of nutrients is due to the

contribution and decomposition of plant material contributed by the species present in the system.

The areas eggplant/corn, passion fruit/*Desmodium* and corn/beans were separated by rows 1.5 m width, where jussara palm plants were used (*Euterpe oleracea*). In the areas with fig and AFS, the row was formed by trees of carambola (*Averrhoa carambola*) and which were amongst the first three areas, separated by a carrier 4 m wide.

The management of soil fertility in the areas began with the acidity correction by dolomite lime incorporation, being first performed in 1993, during the implementation of SIPA, in an amount based on the results from the soil analysis of each plot. Organic fertilizers used in the SIPA had on average the following nutrient content (g / kg): C = 37.25, Ca = 50.03, Mg = 6.23, P = 2.68 2, K = 23.93 (poultry manure) and N = 15:20, Ca = 9.68, Mg = 3:43, P = 2.24, K = 5.80 (manure). This characterization of the fertilizers (avian and bovine manure) used results from a history of existing analyzes through various works developed on site (Loss *et al.* 2009).

In each area were collected (June/2006) ten simple samples mixed to compose a composite sample, with five repetitions. The samples were collected between the rows, close to the root system of each culture at depths of 0-5 cm and 5-10 cm. After this step the samples were transported and processed for obtaining the air-dried soil (TFSA). The chemical characterization of the soil from the different systems was done according to Loss *et al.* (2009; 2010a, b), an average of the major attributes is shown in Table 1.

The incubation experiment was performed in the laboratory. TFSA samples were placed on newspaper and moistened again (Goncalves *et al.*, 2002) by spraying with water, twice a day (morning and evening) for 2 weeks. Then the field capacity (CC) was determined according to the funnel method. To this end, 30 g TFSA were weighed and placed in a plastic funnel of 10 cm diameter, sealed with glass wool at the bottom, to avoid loss of material. Subsequently, the TFSA was saturated with deionized water. The funnels were covered with plastic wrap to minimize evaporative water loss and remained so for 4-6 hours to drain the excess water. Then about 5 g of each sample was dried at 105 ° C until constant mass was attained. CC was determined using the equation: WC = P1-P2 / P2; where CC = field capacity; P1 = weight of the moistened soil sample (g); P2 = dry weight of soil sample (g).

For the evaluation of the C-CO_2 in the laboratory, under controlled temperature (average 25 °C), the method proposed by Mendonca and Matos was used (2005). 50g TFSA was weighed and packed in 500 cm3 containers with airtight closure, with soil moisture adjusted to 65% CC. To each container a flask containing 30 ml of NaOH 0.5 mol/l was added to capture the C-CO_2 and another containing 30 ml of H2O (to keep moisture).

Sampling was made at 24 h intervals for the first 7 days, 48 h between the 8th and 17th day and 96 h between 18th and 37th day. When opening the containers, the vial containing NaOH was withdarwn, taking care to leave each container holding the soil, open for 15 min to for the the exchange of air to occur (keeping this time uniform for all samples). After the time, another flask containing 30 ml of NaOH 0.5 mol/l, was added and the container was hermetically closed for further incubation. While waiting for the air exchange, 10 ml of NaOH (preincubated with the ground) were pipetted to a 125 ml Erlenmeyer flas k and then 10 ml of $BaCl_2$ 0.05/mol and three drops of 1% phenolphthalein were added and immediately titrated with HCl 0.25/mol.

Table 1. Soil chemical characteristics in the various systems tested

Evaluated systems	Evaluated properties /depth					
	pH	**Ca+Mg**	**K**	**P**	**TOC^a**	**N**
		cmol$_c$/kg		**mg/kg**	**g/kg**	
			0 - 5 cm			
Eggplant/corn (PD)	6.85	5.20	0.40	98.75	12.10	1.61
Corn/beans (PC)	6.85	5.90	0.30	124.65	11.41	0.96
Fig	6.70	5.85	0.75	289.30	17.70	1.93
Passion fruit	6.30	5.30	0.40	74.80	12.38	1.18
SAF	6.60	4.80	0.20	80.95	13.05	0.85
			5 - 10 cm			
Eggplant/corn (PD)	6.65	4.65	0.20	90.50	9.82	0.96
Corn/beans (PC)	6.95	5.85	0.35	102.70	12.48	0.86
Fig	6.70	5.40	0.60	159.50	13.25	1.28
Passion fruit	5.85	4.65	0.20	43.60	10.97	1.07
SAF	6.15	4.45	0.10	61.40	9.04	0.75

a. TOC = Total organic carbon.

The calculation of C-CO_2 evolved is presented in mg C-CO_2/100 cm^3 of soil, during the interval utilized for sample monitoring. The formula for this value is:

$$C - CO_2\ (mg) = (B-V) \times M \times 6 \times (V_1/V_2);$$

where: B = HCl volume used in the control titration; V = volume of HCl used in sample titration (ml) 6 = carbon atomic mass (12) divided by the number of moles of CO_2 that react with NaOH, V1 = total volumen of NaOH used in CO_2 capture V2 = volume of NaOH used for titration (ml).

Through the TOC and N data (Table 1) the C/N ratio was calculated, and at the end of 37 days, the accumulation of C-CO_2 was quantified, each assessment made being presented as graphs. The design used was completely randomized, with five agro-ecological production systems and five repetitions. For the data of each analyzed variable, in each of the depths, tests for normality of the data and homogeneity of the variance of the errors was made. Subsequently, the results were subjected to analysis of variance with application of the F test and the mean values compared to each other by the LSD-student test at 5%, with the aid of the statistical program SAEG 5.0 (Statistical Analysis and Genetics System - Federal University of Viçosa).

Results and discussion

The area with fig presented the larger amounts of C-CO_2 after incubation, followed by the areas with AFS (0-5 and 5-10 cm) and corn/beans (CT) (5-10 cm) (Figures 1 and 2). Microbial activity quickly responds to changing soil conditions after long periods of low activity. So, as soon as moisture was restored (soil rewetting) there was an increase in respiration and mineralization of TOC and of N from SOM (Gonçalves *et al.*, 2002; Loss *et al.*, 2013). Drying the soil to obtain the TFSA could make the SOM more accessible to decomposition, besides the fact of the dead microorganisms after drying being perhaps readily attacked by the remaining ones after rewetting (Gonçalves *et al.*, 2002; Carvalho *et al.*, 2008) yielding microbial activity pulses observed through the evolution of C-CO_2 in the first 24 h after the start of incubation.

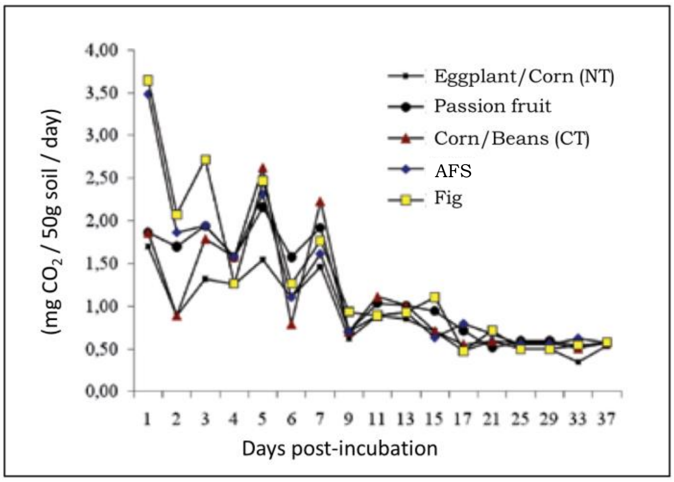

Figure 1. Daily evolution of C-CO_2 in TFSA samples (0-5 cm) incubated during 37 days of evaluation.

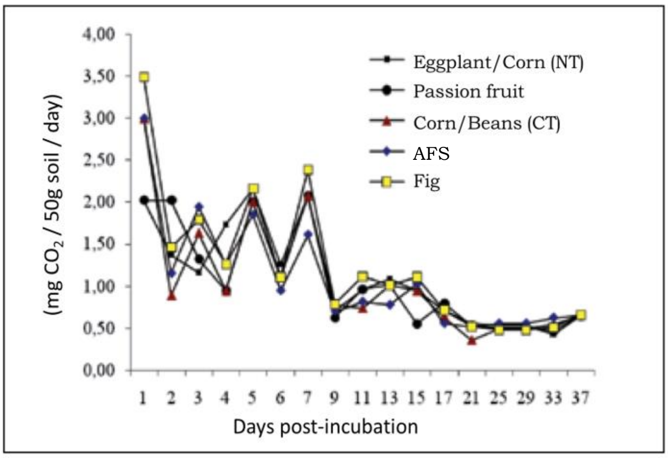

Figure 2. Daily evolution of C-CO_2 in TFSA samples (5-10 cm) incubated during 37 days of evaluation.

Table 2. C-CO_2 accumulation and C/N ratio in soil for the different soil use systems tested.

	Evaluated properties/Depth	
Evaluated systems	**C-CO_2 (mg/50 g soil)**	**C/N**
	0 - 5 cm	
Eggplant/corn (PD)	78.70 b*	7.51 c
Corn/beans (PC)	88.61 ab	11.88 b
Fig	94.94 a	9.17 bc
Passion fruit	96.35 a	10.49 b
AFS	88.69 ab	15,29 a
	5 - 10 cm	
Eggplant/corn (PD)	82.19 d	10.22 b
Corn/beans (PC)	92.28 bc	14.51 a
Fig	99.39 a	10.35 b
Passion fruit	89.47 c	10.25 b
AFS	92.35 b	12.05 ab

* Means followed by the same letter in the column do not significantly differ between the different soil use systems by the LSD-Student test at 5 %.

The peak release of C-CO_2 occurred in the area with fig after soil rewetting may be due to the higher content of N and TOC (Table 1) (Loss *et al.*, 2010 a, b), and low C/N ration of the soil evaluated in this area (Table 2). The SOM with smaller C/N relation is more labile and is readily available for mineralization by soil biota, being the Fig area confirmed for higher contents for N (Loss *et al.*, 2010a) associated with the fertilization with cattle manure and legumes in previous years (Merlin *et al.*, 2005; Almeida and War, 2008). Assessing the microbial activity in Latosol aggregates incubated in the laboratory, Loss *et al.* (2013) also observed higher C-CO_2 peaks in NT areas that had low C/N ratio and higher contents of TOC and N, after the restoration of moisture and of the aggregates and subsequent incubation.

These C-CO_2 peaks are known as 'priming' effect, in the which stimulation of microbial activity by the addition of organic residues and/or increased availability of readily decomposable SOM (lower C/N ratio) promotes the acceleration of decomposition of SOM (Kuzyakov *et al.*, 2000) enhancing the evolution of C-CO_2.

Important aspects in the evolution of potentially mineralizable carbon contents are also related to the soil management history. Among these is of importance the addition of easily decomposable biomass, which induces the priming effect (Buso and Kliemann, 2003). The high levels of C-CO_2 found in the AFS shortly after the restoration of moisture may be due to the quality of SOM, because this area has greater plant diversity. Therefore there is a plant contribution from fruit and tree species with different root systems, culminating in differentiated SOM formation, stimulating the activity of different types of bacteria.

The C-CO_2 peaks found in the area of corn/beans (CT) were higher at the depth of 5-10 cm as compared to those found in 0-5 cm. This trend may be due to soil tillage that through the practices of plowing and harrowing, allocate crop residues that were on the surface (0-5 cm) to the depth of 5-10 cm. With increased availability of crop residues, associated with their fragmentation through the practices of plowing and harrowing, there is greater microbial activity. Therefore, we have higher SOM mineralization, by microbial activity, resulting in increased evolution of C-CO_2.

Also, in relation to the area of corn/beans (CT), in particular 5 - 10 cm the smallest values of C-CO_2 were observed at 2, 4, 11 and 21 days (Figure 2). This pattern may result from the breakdown of soil aggregates through the practice of plowing and harrowing. Thus, the SOM which was previously protected from the attack of soil microorganisms within aggregates now becomes exposed to the action of these microorganisms.

The areas of eggplant/corn (NT) and passion fruit showed the lowest values of C-CO_2 shortly after rewetting. The passion fruit area was covered by *Desmodium* sp., a type of legume that provides high levels of aggregation to the ground. In addition, the area eggplant/corn is handled with a NT system, resulting in increased plant input to the soil surface and also high levels of aggregation. These systems increase the stability of soil aggregates (Loss *et al.*, 2009) resulting in greater physical protection of SOM inside the aggregates, hindering the access of microbial activity. Thus, in these areas were the smallest C-CO_2 flows after rewetting of the soil.

Among the agroecological systems evaluated, there was an alternation of C-CO_2 peaks (decrease followed by increase) after rewetting of the soil until the 9th day, after which the stabilization the evolution of C-CO_2 was observed. This pattern is caused by the consumption of SOM by microbiota (Carvalho *et al.*, 2008). These microorganisms, while feeding the available SOM, release C-CO_2, resulting in the observed peaks. However, when they die due to lack of substrate, particularly N, the evolution of C-CO_2 decreases. These organisms that die will be used as an energy source by the remaining, which will multiply generating new peak CO_2 evolution (Carvalho *et al.*, 2008; French *et al.*, 2009). A similar pattern was observed by Cruz *et al.* (2004) when studying the evolution of C-CO_2 of litter from different vegetation covers. Another probable cause of this pattern is that microorganisms adapted to decompose certain type of substrate present in the soil at the initial moment, decompose this substrate, and when this ends, these microorganisms die due to lack of appropriate substrate and different types of microorganisms adapted to new conditions start to multiply again increasing the rate of C-CO_2, thereby observing the alternation of C-CO_2 peaks in the first 9 days. These results are corroborated by Loss *et al.* (2013) where the authors evaluated the microbial activity in Latosol aggregates in different land use systems incubated in the laboratory and found this same pattern of alternating C-CO_2 peaks.

Observing the dynamics of the evolution of the C-CO_2 incubation time it was found that up to 7 days, in all systems studied, an alternation of the C-CO_2 peaks in larger proportions, and from the 25th day the stabilization of microbial respiration occurred (Figures 1 and 2). These results are corroborated by Farias *et al.* (2005) who evaluated the evolution of the C-CO_2 in Oxisol up to 65 days. The authors found that the stabilization of microbial activity occured between the 25th and 30th day.

The areas cultivated with fig (0-5 and 5-10 cm) and passion fruit (5-10 cm) showed higher accumulation of C-CO_2 after 37 days (Table 2). These results may be due to the high contents of TOC, N and P (Fig area, Table 1) and also due to the presence of larger contents of labile carbon (Loss *et al.*, 2010b) observed in these areas, particularly in 0- 5 cm. The greater availability of SOM with higher lability, the greater the microbial activity, hence the greater the C-CO_2 fluxes.

For the area of eggplant/corn (NT) the lower accumulation of C-CO_2 could be due to better chemical balance found between fractions of oxidizable carbon (Loss *et al.*, 2010b). According to these authors, the oxidized fractionation of TOC of the areas under study showed that for the eggplant/corn area there is a predominance of larger proportions of organic matter in the soil of greater lability (F1 fraction) and more recalcitrant organic matter (F4 fraction). By means of this result it is possible to inferr that the lower accumulation of C-CO_2 in the eggplant/maize area were due to the better compartmentalization of the carbon forms, providing a milder microbial activity in this area when compared with the areas which have higher proportions of more labile carbon.

Conclusions

- Fig crop in an agro-ecological system resulted in larger peaks of C-CO_2 evolution and also in highest accumulation at the end of the 37 days of evaluation.
- The area cultivated under no-tillage system agroecologically managed presented lower accumulation of C-CO_2.
- The conventional tillage resulted in smaller C-CO_2 peaks at a of depth 5-10 cm.

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