academicJournals

Vol. 10(9), pp. 975-982, 26 February, 2015
DOI: 10.5897/AJAR2014.9351
Article Number: B063B1F51054
ISSN 1991-637X

http://www.academicjournals.org/AJAR

African Journal of Agricultural Research

Full Length Research Paper

Emission of CO_2 and soil microbial activity in sugarcane management systems

Rose Luiza Moraes Tavares[1], Camila Viana Vieira Farhate[1], Zigomar Menezes de Souza[1], Newton La Scala Júnior[2], José Luiz Rodrigues Torres[3] and Milton César Costa Campos[4]*

[1]School of Agricultural Engineering, University of Campinas, Av. Cândido Rondon, 501, Barão Geraldo, CEP 13083-875 Campinas, São Paulo, Brazil.
[2]Department of Exact Sciences, School of Agricultural and Veterinary Sciences of Jaboticabal, São Paulo State University, s/n, Santa Luzia CEP 14884900 Jaboticabal, São Paulo, Brazil.
[3]Department of Soils, Federal Institute of the Triângulo Mineiro, Uberaba Campus, Rua João Batista Ribeiro, 4000, CEP: 38064-790, Uberaba, State of Minas Gerais, Brazil.
[4]Department of Agronomy, Federal University Amazonas. Rua 29 de Agosto, 786, Centro, CEP.: 69.800-000, State of Amazonas, Brazil.

Received 11 November, 2014; Accepted 21 February, 2015

Because of the great importance of sugarcane in the Brazilian agricultural sector, this study was developed in order to evaluate the soil CO_2 flux and the soil microbial activity in the systems of burned sugarcane and green sugarcane. For this end, three areas were evaluated with different histories of sugarcane management: (1) burned sugarcane BS); (2) green sugarcane for 5 years (GS-5); (3) green sugarcane for 10 years (GS-10), considering that both areas of green sugarcane were converted from a scenario of prior burning before harvest. The soil CO_2 flux (FCO_2), basal respiration (BR), carbon of the microbial biomass (CMB), metabolic quotient (qCO_2) and microbial quotient (qMIC) were evaluated in 30 points in a 100 × 100 m sampling grid, amounting to 1 ha. The results indicated higher FCO_2 and CBM in the GS-10 area, and lower in the BS area, whose CO_2 emission and microbial activity were higher in summer. The metabolic and microbial quotients showed a greater balance of the soil microbial activity in the area of green sugarcane for 10 years, fostered mainly by the higher amount of mulch on the soil.

Key words: *Saccharum officinarum*, soil respiration, microorganisms, mulch.

INTRODUCTION

The cycle of sugarcane cultivation has been the subject of studies because of the impacts caused in the soil and atmosphere, related mainly to the sugarcane burning system, which is a common practice in Brazil and whose main objective is to facilitate the manual cutting. To replace the burning system, the green sugarcane system was implemented, in which sugarcane is harvested mechanically, without prior burning, and the waste is deposited on the soil, on an average of 10 to 30 Mg ha^{-1} of mulch (Souza et al., 2005), which benefits the soil (Mendonza et al., 2000; Souza et al., 2005) and provides a favorable microclimate environment for the

*Corresponding author. E-mail: mcesarsolos@gmail.com

development of biological communities that will act in the subsequent process of decomposition of organic residues (Xu and Qi, 2001; Franchini et al., 2007; Matias et al., 2009).

The green sugarcane system can function as carbon mitigation for the environment, because despite the of CO_2 release during the microbial decomposition of the carbon that would be lost if the sugarcane was burned is incorporated into the soil (Panosso et al., 2008). The CO_2 release is due to the action of microorganisms in the process of decomposition of organic matter stimulated by the greater amount of substrate that the green sugarcane system provides. These organisms are widely used as indicators of soil quality as they are very sensitive to changes in soil management in the short time (Galdos et al., 2009), since physical or chemical attributes are not always sufficient to explain the variations that occur in the soil from the actions of its use and handling.

The influence of temperature and soil moisture on CO_2 emissions has already been reported in several studies (Kosugi et al., 2007; Panosso et al., 2008; Siqueira Neto et al., 2011; Lenka and Lal, 2013; Song et al., 2013); thus, research studies for new factors that have a relationship with CO_2 are of the utmost importance to try to understand the dynamics of this gas in the soil, as well as its stabilization and carbon buildup. Soil microorganisms can clarify many questions on CO_2 emissions, as the microbial activity is primarily responsible for the decomposition of organic residues, nutrient recycling and energy flow in the soil, this way exerting influence on the carbon storage, availability of nutrients for plants and CO_2 emissions (Jenkinson and Ladd, 1981).

The carbon of the microbial biomass and the basal respiration are the most used attributes in studies on the biological indicators of the soil, and microbial biomass is the most active living part of the soil organic matter, formed mainly by fungi and bacteria (Kaschuk et al., 2009), while soil respiration indicates the degree of activity of the biomass. These attributes are considered easy indicators of soil quality because of their high sensitivity to changes in management or climate; however, some attributes show difficulties when being interpreted if evaluated individually (Lopes et al., 2013), such as, for example the basal respiration, since high respiration values do not always indicate desirable conditions in the short term, as a high respiration rate can mean release of nutrients into the soil, and in the long term, loss of organic carbon to the atmosphere.

The short- and long-term temporal monitoring aids in the interpretation of the soil microbiological quality; moreover, Anderson and Domsch (1990) proposed relationships between the attributes aiming at a more interpretative approach and to establish dynamic relationships between biomass and microbial activity, such as metabolic quotient (qCO_2), which calculates the release of CO_2 per unit of biomass for a certain time, and microbial quotient (qMIC), which evaluates the availability of organic carbon for microbial activity. Thus, an ecosystem out of balance will present high values of qCO_2 and low values of qMIC, which indicates greater energy consumption and higher level of stress of the biomass (Anderson and Domsch, 1990; Evangelista et al., 2013; Kuwano et al., 2014).

Biological indicators of the soil have been used in studies on the efficiency of management systems, such as conventional and no-tillage (Martinéz et al., 2013; Alves et al., 2011), of different ecosystems, such as pasture and shrubs (Loureiro et al., 2010), of forestry and agroforestry systems (Silva et al., 2012) and on the comparison of the management systems of green sugarcane and burned sugarcane (Mendonza et al., 2000). In these studies, the soil microbial activity showed sensitivity to management efforts, thus strengthening the use of these attributes in the understanding of the stability of soil carbon. This way, this study aimed to evaluate the soil CO_2 flux and the soil microbial activity in the systems of burned sugarcane and green sugarcane.

MATERIALS AND METHODS

The study was conducted in the northeast of the State of São Paulo, near the coordinates 21°19'8" South and 48°7'24" West. The climate in the region is classified as $B_2rB'4a'$ by the Thornthwaite climate classification criterion. The soil of the area was classified as eutroferric Oxisol, clayey texture, with flat and undulating topography.

The areas evaluated were implanted in three sugarcane management systems: burned sugarcane (BS), green sugarcane implemented for five years (GS-5), one cycle with this system, and green sugarcane implemented for ten years (GS-10), two cycles with this system, being that both green sugarcane areas were converted from the scenario of prior burning before harvest.

We performed a chemical characterization of the soil in the areas before the start of the evaluations (Table 1), whose data showed increased base saturation (SB) in BS, which may be related to the large amount of ash deposited on the soil surface from the prior burning of the sugarcane, thus contributing with the immediate addition of mineral nutrients, such as K, Ca and Mg.

The burned sugarcane area was managed with the burning system since the ‘80s and in 2011-2012. The area of green sugarcane implemented for five years began to be harvested by the mechanized system from 2006, and the system of mechanized harvesting began in 2001 in the area of green sugarcane implemented for ten years. On the reform of the sugarcane plantation, which occurred in the areas of burned sugarcane (every 6 ratoons) and green sugarcane for ten years (in 2007), there was the mechanical elimination of the ratoon of the previous crop and subsoiling at the depth of 0.45 m in the planting furrows. Soon after, 2 t ha^{-1} of dolomitic limestone were applied. For the planting fertilization, 480 kg ha^{-1} of NPK in the 10-25-20 formulation were used. Over the years, on average, 100 m^{-3} ha^{-1} of vinasse and 300 kg ha^{-1} of urea or 200 kg ha^{-1} of ammonium nitrate were applied in the areas.

The evaluations of the soil CO_2 flux (FCO_2) and soil collection at the 0.00 to 0.10 m layer for biological analyses were performed in 30 points on a sampling mesh at the regular intervals of 1, 2 and 10 m (1 ha), whose points were georeferenced with the aid of a total station (model TC 305 Leica ®) and DGPS (L1/L2 Hiper Lite Plus) (Figure 1). The evaluation of CO_2 was performed simultaneously in the three areas of study in the dry period of 2011 and wet period of

Table 1. Chemical characterization of the soil in the management areas of burned sugarcane, green sugarcane for five years and green sugarcane for ten years, in Pradópolis, São Paulo, Brazil, 2011-2012.

Chemical attributes	Burned sugarcane	Green sugarcane for five years	Green sugarcane for ten years
OM[(1)] (g kg^{-1})	3.93	4.31	3.37
SB[(2)] ($cmol_c$ dm^{-3})	11.44	6.08	5.02
CEC[(3)] ($cmol_c$ dm^{-3})	15.06	10.29	8.43
V%[(4)]	75.93	59.05	58.76
pH	5.22	4.80	4.91
Phosphorus (mg dm^{-3})	16.66	36.30	35.55
Sulfur (mg dm^{-3})	0.81	8.17	0.51
Potassium ($cmol_c$ dm^{-3})	6.08	0.60	6.94
Calcium ($cmol_c$ dm^{-3})	9.00	4.21	3.44
Magnesium ($cmol_c$ dm^{-3})	1.63	1.27	1.06

[(1)]OM = organic matter; [(2)]SB = sum of bases; [(3)]CEC = cation exchange capacity; [(4)]V% = base saturation.

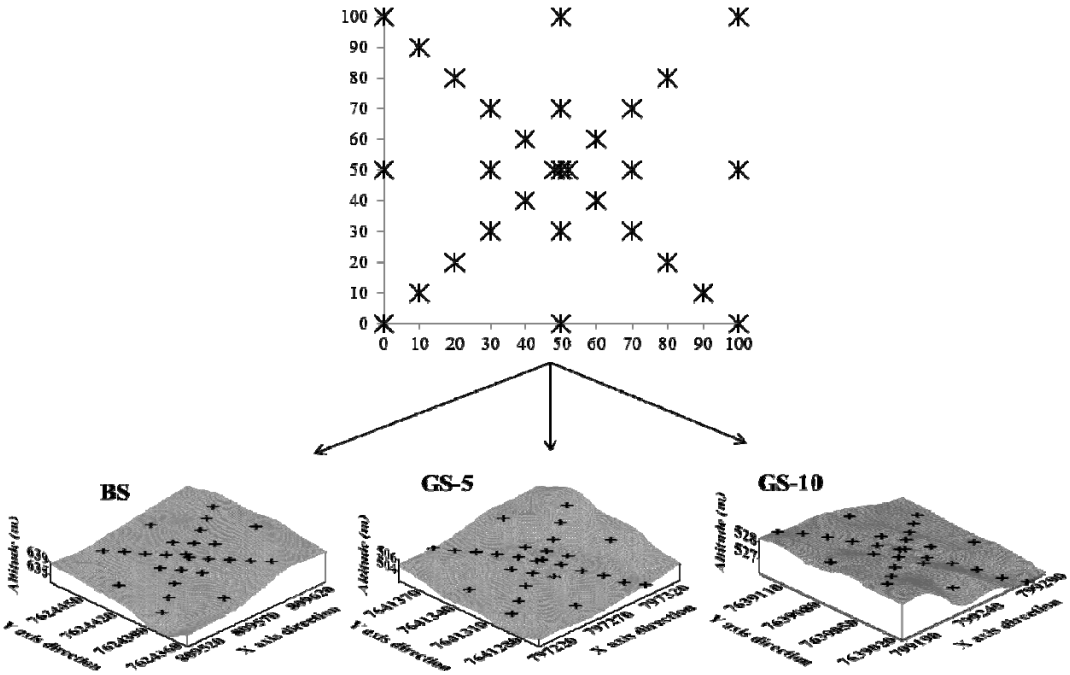

Figure 1. Sampling grid and relief maps of the areas evaluated in Pradópolis, São Paulo, Brazil, 2011-2012. BS = burned sugarcane; GS-5 = green sugarcane for 5 years; GS-10 = green sugarcane for 10 years.

2012 in the mornings (07:00 to 10:00 am). The evaluation was conducted with the aid of ground chambers, of the model LI-8100 (LICOR). The equipment is a closed system with internal volume of 991 cm^3, with contact area with the soil of 71.6 cm^2 and placed on PVC collars previously inserted into the soil at a depth of 3 cm. Soil moisture was measured simultaneously with the measurement of the CO_2 concentration with the aid of a portable TDR (Campbell®).

The CO_2 emission by basal respiration in laboratory was evaluated for comparative purposes with the CO_2 emission evaluated in field, named in this paper as soil CO_2 flux (FCO_2), and the main difference is that the basal respiration calculates the CO_2 from soil microorganisms, whereas the FCO_2 calculates the CO2 from microorganisms and roots.

Sampling for microbiological analysis was performed on the 0.00-0.10 m layer in two days of collection in each period (winter and summer) and area, amounting to 360 samples, which were kept under cooling until the analyses within a maximum of 30 days. The analysis for the carbon of the microbial biomass was carried out according to the fumigation-extraction method proposed by Vance et al.(1987) and the basal respiration according to the respirometry-titration method of Alef and NanniPieri (1995). The metabolic quotient (qCO2) and microbial quotient were determined according to the relation proposed by Anderson and Domsch (1990).

Data on air temperature, rainfall, air humidity (Figure 2A) and soil temperature (Figure 2B) on the days of evaluation are presented below and show variations between the periods analyzed (winter

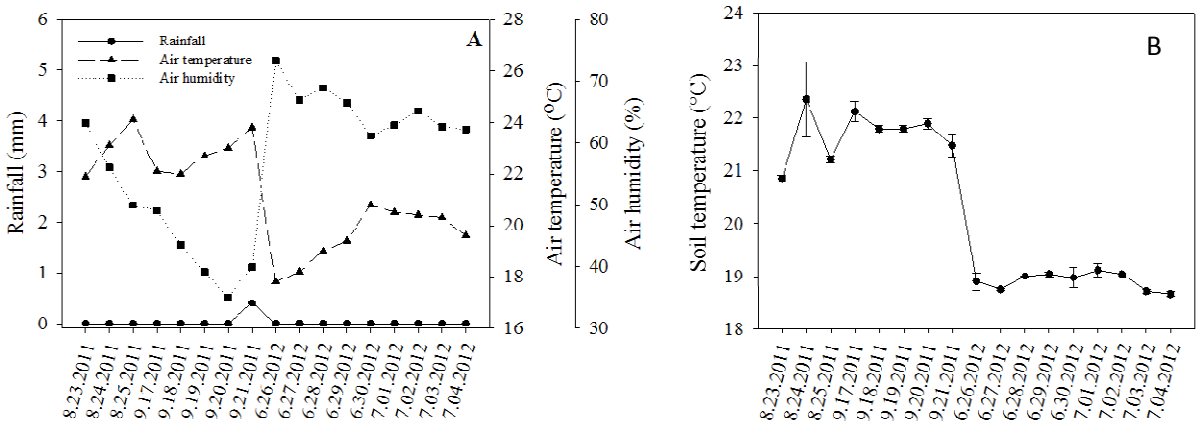

Figure 2. Rainfall, temperature, air humidity (A) and soil temperature (B) on the days of evaluation of soil CO_2 flux in winter and summer.

and summer), with the exception of rainfall, without the occurrence of rain.

Data analysis was performed by descriptive statistics, in which means, standard deviation, maximum and minimum values and coefficient of variation were calculated. To compare the means, the Student's t-test was used at 5% probability. The analysis of variance (repeated measurements over time) and linear regression were used for analysis of the temporal variability with graphical representation made in the software SigmaPlot, version 11.0.

RESULTS AND DISCUSSION

The average FCO_2 flux in the evaluated periods (winter and summer) was significantly higher in the GS-10 area, with 2.37 µmol m^{-2} s^{-1}, compared to the other areas, with 1.69 µmol m^{-2} s^{-1} for BS and 1.10 µmol m^{-2} s^{-1} for GS-5 (Table 2).

We believe that the higher FCO_2 on the GS-10 area is related to the greater amount of plant residue on the soil, which is a result of the mechanized harvesting. The presence of mulch on the soil provides a habitat for microorganisms (Franchini et al., 2007) and serves as substrate for the microbial activity during the process of decomposition of the organic matter, thus reflecting in increased CO_2 emissions (Evanylo and Mcguinn, 2009). In addition, the minimum soil tillage provides favorable conditions for the development of microorganisms in the surface layer of the soil, which increases the microbial biomass and the FCO_2 (Matias et al., 2009).

The evaluation periods influenced the FCO_2 in the green sugarcane areas, being 51 and 18% higher in summer than in winter for the GS-5 and GS-10 areas, respectively, while for the burned sugarcane area, the variation of FCO_2 between periods was less expressive (Figure 3A and B). Studies have shown higher FCO_2 on the wettest period of the year (Xu and Qi, 2001; Kosugi et al., 2007; Song et al., 2013), which may be related to the greater microbial activity stimulated by the soil moisture and/or by the activity of the roots that are in the period of growth and development. Siqueira et al. (2011) verified that the maximum CO_2 emission occurred in the Brazilian Cerrado area in the rainy season (October-March), which was 14 times higher than the minimum emission obtained in the dry season (April-September).

The basal respiration (BR), in winter, was higher in the burned sugarcane with 109.67 µg CO_2 g^{-1} day-1 and, in summer, it was higher in the GS-5 area with 96.05 µg CO_2 g^{-1} day^{-1}, while in the GS-10 area it was lower both in winter and in summer with 50.94 and 40.67 µg CO_2 g^{-1} day^{-1}, respectively (Table 2 and Figure 3C and D). According to Lopes et al. (2013), balanced ecosystems tend to have lower rates of BR, as the vegetation cover on the soil, which is characteristic of these areas, provides material at different levels of decomposition and complexity of plant residues, thus resulting in lower levels of soil respiration.

The analysis of BR, in which the CO_2 emission from the soil was calculated by incubation process in laboratory, presented a divergent trend from the FCO_2 obtained in field (Table 2). It is worth mentioning that the FCO_2 calculates the resulting gas flux resulting from the soil microbial activity and plant roots, while BR takes into account only the respiration of microorganisms, which is one of the reasons for the difference of patterns between FCO_2 and BR. In addition, in the literature, the isolated evaluation of the BR can lead to misunderstandings, since it can be interpreted both in the beneficial sense to the soil, with an accelerated organic matter decomposition process reflecting on nutrient availability to plants, and in the unfavorable sense, with large CO_2 emission, which shows more losses than gains in carbon in the soil (Alves et al., 2011; Evangelista et al., 2013; Lopes et al., 2013).

The carbon of the microbial biomass (CMB) in winter showed no significant differences when compared between the three areas of sugarcane management, with the values of 184, 186 and 197 µg C g^{-1} day^{-1} for BS, GS-

Table 2. Microbiological attributes and soil moisture evaluated in the winter and summer periods on the sugarcane management systems (burned sugarcane, green sugarcane implemented for 5 years and green sugarcane implemented for 10 years) in Pradópolis, São Paulo, Brazil, 2011-2012.

Variablees	Winter					Summer				
	Mean	SD	Min	Max	CV	Mean	SD	Min	Max	CV
					Burned sugarcane					
FCO_2	1.69^{Ba}	0.63	0.51	2.95	37.1	1.65^{bA}	0.46	0.56	2.45	29.6
BR	109.6^{Aa}	50.4	47.0	226	45.9	57.6^{bB}	16.3	26.7	116.3	28.4
CMB	184.2^{aB}	42.9	114.0	253.2	23.2	220.6^{bA}	65.9	55.2	346.0	29.8
qCO_2	0.63^{a}	0.31	0.19	2.35	49.9	0.33^{a}	0.22	0.15	0.97	65.9
qMIC	6.93^{a}	1.38	4.26	10.7	17.5	7.57c	1.96	2.94	10.9	25.9
Sm	11.09^{Ab}	1.27	10.2	14.2	9.8	21.35^{bA}	0.65	19.2	31.9	15.1
					Green sugarcane-5 years					
FCO_2	1.10c^{B}	0.77	0.02	2.40	40.6	2.28^{aA}	0.72	2.34	5.52	31.8
BR	53.4^{bB}	17.4	24.3	92.1	32.6	96.0^{aA}	41.5	36.5	188.3	43.2
CMB	186.7^{aB}	62.3	89.9	424.9	33.4	282.8^{bA}	69.2	171.4	300.6	34.4
qCO_2	0.32^{b}	0.14	0.15	0.75	44.4	0.33^{a}	0.13	0.11	0.73	40.0
qMIC	5.08^{b}	2.02	1.68	9.41	37.3	9.82^{b}	3.14	5.40	16.01	32.0
Sm	11.16^{aB}	1.85	9.00	17	16.6	38.41^{aA}	2.46	32.33	44.78	6.40
					Green sugarcane-10 years					
FCO_2	2.37^{aB}	0.76	1.50	4.2	31.9	2.91^{aA}	1.50	0.92	7.0	41.8
BR	50.9^{bA}	17.0	27.2	96.5	33.4	40.6c^{B}	15.4	14.8	76.5	37.9
CMB	197.6^{aB}	68.5	90.0	348.3	44.6	321.3^{aA}	65.8	266.7	474.0	30.4
qCO_2	0.32^{b}	0.19	0.16	1.11	60.6	0.10^{b}	0.03	0.04	0.17	35.0
qMIC	7.35^{a}	2.61	3.23	12.5	35.5	12.28^{a}	2.53	9.33	16.10	30.6
Sm	10.17^{aB}	1.42	8.00	14	13.9	29.71^{bA}	2.58	24	35	8.69

FCO_2 = Soil CO_2 flux evaluated in field (µmol m^{-2} s^{-1}); BR = basal respiration – CO_2 emissions evaluated in the Laboratory (µg CO_2 $g^{-1}day^{-1}$); CMB = Carbon of the Microbial Biomass (µg C $g^{-1}day^{-1}$); qCO_2 = metabolic quotient (µg CO_2 µg C-SMB day^{-1}); qMIC = microbial quotient (µg Corg µg C-SMB day^{-1}); Sm = Soil moisture (%). Means followed by the same lowercase letter in the column (management systems) and uppercase letter in the row (evaluation periods) do not differ by the Student's t-test at 5% probability.

5 and GS-10, respectively (Table 2 and Figure 4). However, in summer, the CMB was 6.5 and 5.6% higher in the GS-10 area when compared with the BS and GS-5 areas, respectively. Similar trend was found in the study of Mendonza et al. (2000), who detected values of CMB of 152.1 and 195.6 µg C g^{-1} day^{-1} in the 00-0.05 m soil layer for the areas of burned sugarcane and green sugarcane, respectively, and Galdos et al. (2009) verified that the CMB was 2.5 times higher in the area of green sugarcane compared to the burned sugarcane.

The values of CMB corroborate with the values of FCO_2 evaluated in field, in which the GS-10 area showed the highest amount of microbial biomass, which reflects into a greater soil CO_2 flux (Table 2). Thus, a direct relation between these two attributes can be observed as the CO_2 emitted by the soil is essentially produced by the decomposition of organic matter from the action of microorganisms and the respiration of plant roots (Panosso et al., 2008). The study of Xu and Qi (2001) in soil with pine plantation proved the direct relationship between FCO_2 and CMB during the monitoring of both attributes in the period from J une to October, 1998. The evaluation of the CMB between the periods of evaluation was significant, being greater in summer than winter in the three sugarcane areas evaluated (Table 2 and Figure 4), as the wet period is characterized by conditions of temperature and soil moisture that are more favorable to the soil microbial activity (Mendonza et al., 2000; Zornoza et al., 2007). The optimum humidity is approximately 60 to 80% and the optimum temperature is 30°C. However, the activity decreases as the soil temperature exceeds the optimum temperature (Evanylo and Mcguinn, 2009).

Soil moisture data ranged from 10 to 11% in winter and from 21 to 38% in summer (Table 2), and the soil temperature ranged from 20 to 22°C in winter and from 18 to 19°C in summer (Figure 2B), being the attributes suboptimal, which boosts the mulch factor in the stimulation of the soil microbial activity, mainly in the GS-10 area, which showed the highest CMB. A similar result was obtained by Mendonza et al. (2000), who verified higher CMB in the green sugarcane system than in the burned sugarcane, especially during the rainy season in study under yellow Argisol, which, according to the

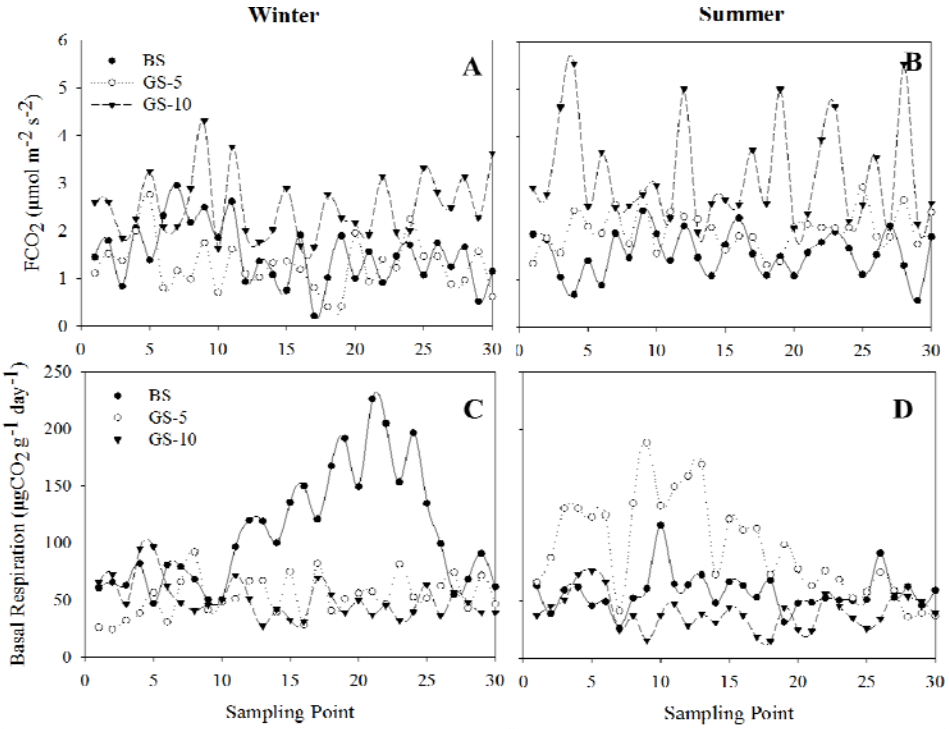

Figure 3. Soil CO_2 flux - FCO_2 (A and B), basal respiration - BR (C and D) of the soil evaluated in winter and summer in the management systems of burned sugarcane (BS), green sugarcane implemented for 5 years (GS-5) and green sugarcane implemented for 10 years (GS-10) in Pradópolis, São Paulo, Brazil, 2011-2012.

authors, together with the favorable climatic factors in the green sugarcane system, would have allowed the microbial biomass to find plenty of substrate for its development in the remaining mulch from the previous year.

The values of qCO_2 ranged from 0.10 to 0.63 µg CO_2 µg C-SMB day^{-1} (Table 2). The low value of qCO_2 indicated economy on energy usage, which reflects a more stable environment or closer to its equilibrium (Anderson and Domsch, 1990). The results show that the cultivation system significantly affected the qCO_2 of the BS and GS-10 areas, with lower qCO_2 in GS-10 (Figure 4), which, according to Partelli et al. (2012), is the evidence of the lower consumption of oxidizable carbon for the maintenance of microorganisms, thus configuring the equilibrium situation of the soil microbial activity.

In a study by Evangelista et al. (2013), the qCO_2 was 49.07% higher in the burned sugarcane area that in the green sugarcane, and, according to the authors, as the microbial biomass becomes more efficient in the use of the ecosystem resources, less CO_2 is lost by the respiration and a higher proportion of carbon is incorporated into the microbial tissues, which results in decreased qCO_2. Kuwano et al. (2014), working with soils under different uses in Northern Paraná, observed that the sugarcane areas under the burning system presented the highest qCO_2, probably as a result of the burning before harvest, which decreases soil carbon inputs; moreover, the disturbance of the soil through heavy tillage on the renovation of the sugarcane plantation disrupts the microbial community not only by the breakdown of soil aggregates, but also by the loss of water from the soil.

The qMIC, obtained by the relationship between CMB and OC, was similar in winter in the BS and GS-10 areas, with 6.93 and 7.35 µg CO_2 day^{-1} µg OC, respectively, which may be related to the similar levels of organic carbon present in these areas, with 2.94 and 2.59 g kg^{-1} for BS and GS-10, respectively (Table 2). In summer, the qMIC was higher in the GS-10 area, with 12.28 µg CO_2 day^{-1} µg OC, and lower in the burned sugarcane area, with 7.57 µg CO_2 day^{-1} µg OC (Figure 4), and a higher qMIC is an evidence of organic matter of better quality, more active and less recalcitrant, with greater availability of organic carbon to the soil microbial activity (Jenkinson, Ladd, 1981).

In some studies, FCO_2 was positively correlated with organic carbon (La Scala et al., 2000; Medeiros et al., 2011; Lenka, Lal, 2013). However, in this study, the GS-10 area showed lower organic carbon content and greater FCO_2. It is possible that the high microbial activity in the GS-10 area has reduced the organic carbon content, as the increase of cycles of decomposition of soil organic matter by microorganisms will result in a low

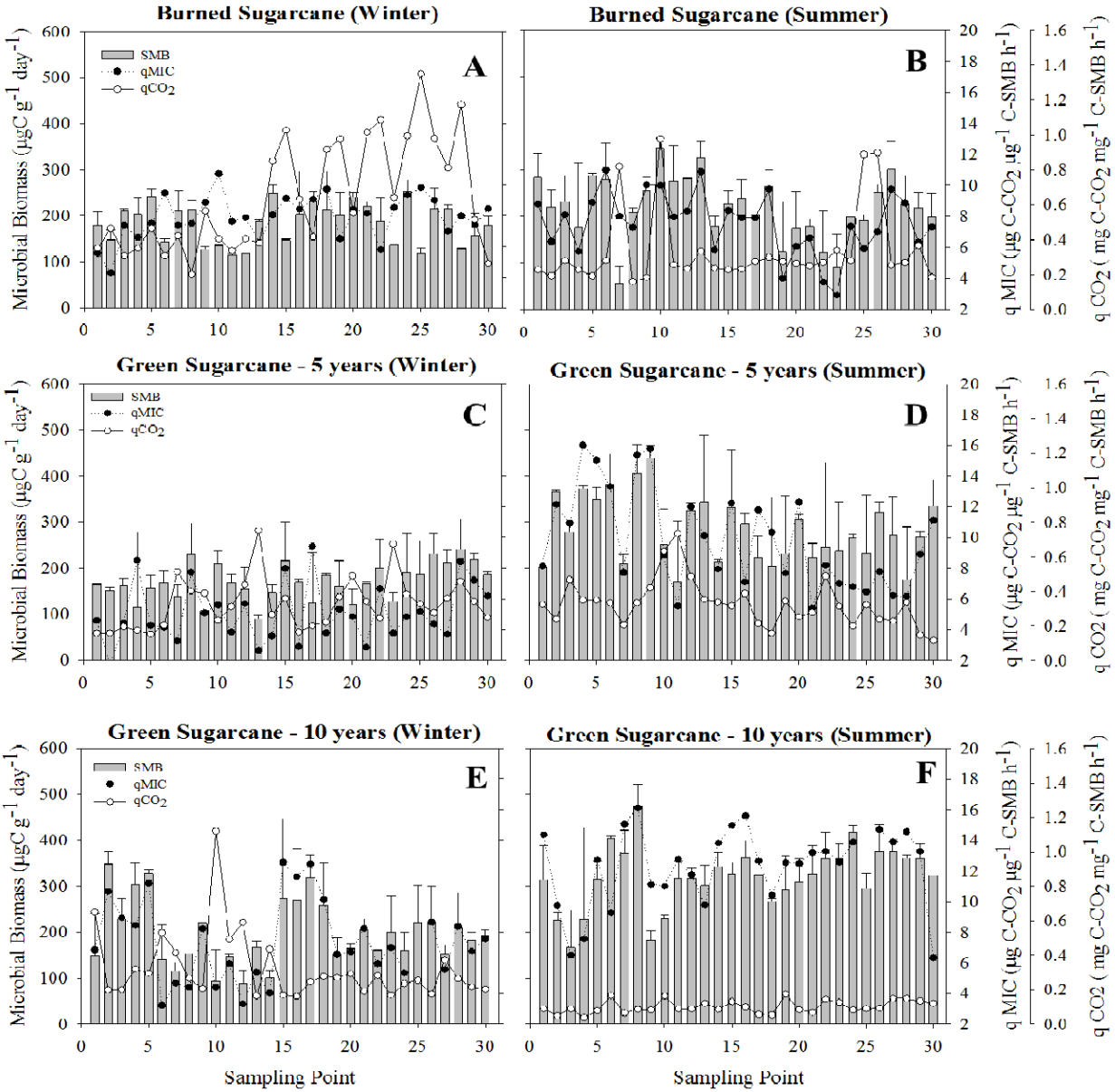

Figure 4. Effect of different sugarcane management systems (burned sugarcane, green sugarcane implemented for 5 years and green sugarcane implemented for 10 years) in the metabolic quotient (qCO_2) and microbial quotient (qMIC) in the summer and winter periods in Pradópolis, São Paulo, Brazil, 2011-2012.

organic carbon content, which is more protected and stabilized within microaggregates (Lenka and Lal, 2013). Corroborating with the result of this study, Fang et al. (1998) detected higher CO_2 emission in regions with lower organic carbon content in soil under pine plantation.

Conclusion

1. Soil CO_2 flux was higher in the area of green sugarcane implemented for 10 years.
2. Soil CO_2 flux and microbial activity were higher in the wet period.
3. The metabolic and microbial quotients showed a greater balance of the soil microbial activity in the area of green sugarcane implemented for 10 years.
4. The presence of mulch on the soil stimulates the microbial activity and increases the soil CO_2 flux.

Conflict of Interest

The authors have not declared any conflict of interest.

ACKNOWLEDGEMENTS

The authors expressed their gratitude to The São Paulo Research Foundation (FAPESP) for financing the project of study and to the São Martinho Plant for providing the experimental area.

REFERENCES

Alef K, Nannipieri P (1995). Estimation of microbial activities. In: Alef K, Nannipieri P. (ed.). Methods in applied soil microbiology and biochemistry. London: Academic Press. pp. 193-270. http://dx.doi.org/10.1016/B978-012513840-6/50021-5

Alves TS, Campos LL, Elias Neto N, Matsuoka M, Loureiro MF (2011). Biomassa e atividade microbiana de solo sob vegetação nativa e diferentes sistemas de manejos. Acta Sci. Agro. 33:341-347.

Anderson TH, Domsch KH (1990). Application of eco-physiological quotients (qCO2 and qMIC) on microbial biomasses from soils of different cropping histories. Soil Biol. Biochem. 22:251-255. http://dx.doi.org/10.1016/0038-0717(90)90094-G

Evangelista CR, Partelli FL, Ferreira EPB, Pires FR (2013). Atributos microbiológicos do solo na cultura da cana-de-açúcar sob manejo orgânico e convencional. Semina: Ci. Agra. 34:1549-1562.

Evanylo GE, Mcguinn R (2009). Agricultural management practices and soil quality: measuring, assessing, and comparing laboratory and field test kit indicators of soil quality attributes. Virginia: Polytechnic Institute and State University. P. 12.

Fang C, Moncrieff JB, Gholz HL, Clark KL (1998). Soil CO2 efflux and its spatial variation in a Florida slash pine plantation. Plant Soil. 205:135-146. http://dx.doi.org/10.1023/A:1004304309827

Franchini JC, Crispino CC, Souza RA, Torres E, Hungria M (2007). Microbiological parameters as indicators of soil quality under various soil management and crop rotation systems in Southern Brazil. Soil Till. Res. 92:18-29. http://dx.doi.org/10.1016/j.still.2005.12.010

Galdos MV, Cerri CC, Cerri CEP (2009). Soil carbon stocks under burned and unburned sugarcane in Brazil. Geoderma. 153:347-352. http://dx.doi.org/10.1016/j.geoderma.2009.08.025

Jenkinson DS, Ladd JN (1981). Microbial biomass in soil: Measurement and turnover. Soil Biol. Biochem. 5:415-471.

Kaschuk G, Alberton O, Hungria M (2009). Three decades of soil microbial biomass studies in Brazilian ecosystems: Lessons learned about soil quality and indications for improving sustainability. Soil Biol. Biochem. 42:1-13. http://dx.doi.org/10.1016/j.soilbio.2009.08.020

Kosugi Y, Mitani T, Itoh M, Noguchi S, Tani M, Matsuo N, Takanashi S, Ohkubo S, Nik AR (2007). Spatial and temporal variation in soil respiration in a Southeast Asian tropical rainforest. Agric. Forest Meteorol. 147:35-47. http://dx.doi.org/10.1016/j.agrformet.2007.06.005

Kuwano BH, Knob A, Fagotti DSL, Melém Júnior NJ, Godoy L, Diehl RC, Krawulski CC, Andrade Filho G, Zangaro Filho, W, Tavares-Filho J, Nogueira MA (2014). Soil quality indicators in a rhodic kandiudult under different uses in northern Parana, Brazil. R. Bras. Ci. Solo. 38:50-59.http://dx.doi.org/10.1590/S0100-06832014000100005

La Scala Júnior N, Marques Júnior J, Pereira GT, Corá JE (2000). Carbon dioxide emission related to chemical properties of a tropical bare soil. Soil Biol. Biochem. 32:1469-1473. http://dx.doi.org/10.1016/S0038-0717(00)00053-5

Lenka NK, Lal R (2013). Soil aggregation and greenhouse gas flux after 15 years of wheat straw and fertilizer management in a no-till system. Soil Till. Res. 126:78-89. http://dx.doi.org/10.1016/j.still.2012.08.011

Lopes AAC, Sousa DMG, Chaer G, Reis Júnior FB, Goedert WJ, Mendes IC (2013). Interpretation of microbial soil indicators as a function of crop yield and organic carbon. Soil Sci. Soc. Am. J. 25:461-472. http://dx.doi.org/10.2136/sssaj2012.0191

Loureiro DC, Polli H, Ceddia MB, Aquino MA (2010). Spatial variability of microbial biomass and organic matter labile pools in a haplic planosol soil. Bragantia. 69:85-95. http://dx.doi.org/10.1590/S0006-87052010000500010

Martinéz E, Fuentes JP, Pino V, Silva P, Acevedo E (2013). Chemical and biological properties as affected by no-tillage and conventional tillage systems in an irrigated Haploxeroll of Central Chile. Soil Till. Res.126:238-245. http://dx.doi.org/10.1016/j.still.2012.07.014

Matias MCBS, Salviano AAC, Leite FD, Araujo SF (2009). Biomassa microbiana e estoques de C e N do solo em diferentes sistemas de manejo, no Cerrado do Estado do Piaui. Acta Sci. Agro. 31:517-521.

Medeiros JC, Silva AP, Cerri CEP, Fracetto FJC (2011). Linking physical quality and CO2 emission under long-term no-till and conventional-till in a subtropical soil in Brazil. Plant Soil, 338:5-15. http://dx.doi.org/10.1007/s11104-010-0420-4

Mendonza HNS, Lima E, Anjos LHC, Silva LA, Ceddia MB, Antunes, MVM (2000). Propriedades químicas e biológicas de solo de tabuleiro cultivado com cana-de-açúcar com e sem queima da palhada. R. Bras. Ci. Solo. 24:201-207. http://dx.doi.org/10.1590/S0100-06832000000100022

Panosso AR, Pereira GT, Marques Junior J, La Scala Junior N (2008). Variabilidade espacial da emissão de CO2 em Latossolos sob cultivo de cana-de-açúcar em diferentes sistemas de manejo. Eng. Agric. 28:227-236.

Partelli FL, Vieira HD, Ferreira EPB, Viana AP, Martins MA, Urquiaga S (2012). Chemical and microbiological soil characteristics under conventional and organic coffee production systems. Commun. Soil Sci. Plant Anal. 43:847-864. http://dx.doi.org/10.1080/00103624.2012.648470

Silva MSC, Silva EMR, Pereira MG, Silva CF (2012). Estoque de serapilheira e atividade microbiana em solo sob sistemas agroflorestais. Floresta Ambient. 19:431-441. http://dx.doi.org/10.4322/floram.2012.058

Siqueira Neto M, Piccolo MDC, Costa Junior C, Cerri CC, Bernoux M (2011). Emissão de gases do efeito estufa em diferentes usos da terra no bioma Cerrado. R. Bras. Ci. Solo. 35:63-76.

Song Z, Yuan H, Kimberley MO, Jiang H, Zhou G, Wang H (2013). Soil CO2 flux dynamics in the two main plantation forest types in subtropical China. Sci. Total. Environ. 444:363-368. http://dx.doi.org/10.1016/j.scitotenv.2012.12.006 PMid:23280294

Souza ZM, Prado RM, Paixão ACS, Cesarin LG (2005). Sistemas de colheita e manejo da palhada de cana-de-açúcar. Pesq. Agropec. Bras. 40:271-278. http://dx.doi.org/10.1590/S0100-204X2005000300011

Vance ED, Brookes PC, Jenkinson, DS (1987) An extraction method for measuring soil microbial biomass C. Biol. Biochem. 19:703-707. http://dx.doi.org/10.1016/0038-0717(87)90052-6

Xu M, Qi Y (2001). Soil-surface CO2 efflux and its spatial and temporal variations in a young ponderosa pine plantation in northern California. Glob Chang Biol. 7:667-677. http://dx.doi.org/10.1046/j.1354-1013.2001.00435.x

Zornoza R, Guerrero C, Mataix-Solera J, Arcenegui V, García-Orenes F, Mataix-Beneyto J (2007). Assessing the effects of air-drying and rewetting pre-treatment on soil microbial biomass, basal respiration, metabolic quotient and soluble carbon under Mediterranean conditions. Eur. J. Soil Biol. 43:120-129. http://dx.doi.org/10.1016/j.ejsobi.2006.11.004