IMPACT OF SUGARCANE CULTIVATION ON THE BIOLOGICAL ATTRIBUTES OF AN OXISOL IN THE BRAZILIAN SAVANNAH

IMPACTO DO CULTIVO DA CANA-DE-AÇÚCAR NOS ATRIBUTOS BIOLÓGICOS EM LATOSSOLO NO CERRADO BRASILEIRO

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ABSTRACT: Sugarcane is fundamental for the energy matrix in Brazil. The evaluation of biochemical attributes in different sugarcane production systems provides information on their environmental sustainability. Altogether, soil biochemical attributes are considered very sensitive indicators of changes in soil properties and of alterations caused by soil management and land-use systems. The aim of this work was to study the effect of organic and conventional sugarcane cultivation systems on microbial soil properties. Changes in carbon (C) and nitrogen (N) microbial and microbial activity were evaluated in a Cerrado Oxisol in the state of Goiás, Brazil, cultivated with sugarcane in three different production systems: organic (Organic Cane - OC), conventional with burning (Burned Cane - BC), and conventional without burning (Raw Cane - RC). The native Cerrado (NC) and other cultivated pasture (PT) were used as references. The soil samples were collected during the dry and rainy seasons from two depths: 0-10 and 10-20 cm. The chronological order of the implementation of the land-use (NC, PT and sugarcane) and cultivation (RC, BC, OC) systems were: NC, PT, RC/BC, OC. The microbial biomass C (C_{SMB}), microbial biomass N (N_{SMB}), basal respiration (Br), metabolic quotient (qCO_2) and the C_{SMB}/C_{org}, N_{SMB}/N_{total} and C_{SMB}/N_{SMB} ratios were determined. The different land-use and cultivation systems influenced microbial biomass and activity. The replacement of conventional tillage for organic system recovered C_{SMB} and N_{SMB} levels and improved recycling of nutrients in the microbial biomass (N_{SMB}/N_{total}). The conventional tillage system with burning (BC) was less efficient in use of energy and carbon (high qCO_2), resulting in a loss of C-CO_2 to the atmosphere.

KEYWORDS: Cerrado. Organic farming. Soil microbial biomass. qCO_2. Microbial C. Microbial N.

INTRODUCTION

Brazil is the largest sugarcane producer in the world, and 8,434,300 hectares were cultivated with this crop during the 2011/2012 season. The extensive Brazilian sugarcane cultivation has increased mainly in the savannah (Cerrado) in the Midwestern region. During the latest crop year, this region recorded the highest increase (27.9%) in cultivated areas in Brazil (CONAB, 2011). The expansion of sugarcane crop in this region has sparkled discussions regarding the production of environmentally sustainable food and energy while conserving the Cerrado ecosystem. Cerrado covers 24% of Brazil's territory and constitutes the second-largest biodiversity in South America (MUELLER; MARTHA-JUNIOR, 2008). The Brazilian savannah constitutes one third of the national biodiversity, and biologically, it is considered the richest tropical savannah in the world (FALEIRO et al., 2008).

Depending on the cultivation system, sugarcane exerts a heavy environmental impact. Blair et al. (1998) measured appreciable decrease in soil organic matter (SOM) contents under long term sugarcane production. Sugarcane burning has profound impacts as it destroys the soil organic matter, leaving it exposed to erosion, impacting microorganisms and causing significant pollution by GEE emission, specially CO_2 (SOUZA et al., 2012). Organic sugarcane cultivation, using mainly vinasse, filter cake and green manure for soil fertility management, is operationally feasible and is accepted by organizations that certify organic production. This cultivation system, aiming for economic and ecological sustainability, may be an alternative for sustainable sugarcane cultivation in the Cerrado because it minimizes the dependence on non-renewable energy (MAPA, 2010).

Soil management alters soil microbial properties (PEREZ et al., 2005) and quantifying the change of soil attributes due to the intensity of land-

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use and soil management has been a key tool for monitoring soil quality (NEVES et al., 2007). Biochemical attributes, such as the amount of microbial carbon (C_{SMB}) and microbial nitrogen (N_{SMB}), in addition to basal respiration (Br), C_{SMB}/C_{org} and N_{SMB}/N_{Total} ratios, are very sensitive to changes in the soil because they are easily affected by chemical and physical disturbances caused by cultivation and the application of fertilizers and pesticides (KIMPE; WARKENTIN, 1998). Changes in these parameters can be used to identify early alterations of soil organic matter.

The microbial biomass performs important function in the soil (JENKINSON; LADD, 1981; JENKINSON et al., 2004), such as nutrient cycling and immobilizing nutrients for a given period, thus preventing losses. In addition, the microbial biomass catalyzes biochemical transformations in the soil and represents a labile compartment in which the nutrients are recycled in the short-term (DUXBURY et al., 1989). Under transformation in the soil, carbon is greatly influenced by biotic and abiotic factors, and it is initially destined for the microbial biomass and functions as stored energy for microbial processes. Carbon may be used as an identifier for early alterations to organic matter (RICE et al., 1996) and is an indicator of soil quality (DICK et al., 1996).

The C_{SMB}/C_{org} ratio reflects key processes related to additions and transformations in organic matter and is an indication of the efficiency of converting organic matter carbon into microbial carbon (SPARLING, 1992). The Br can be assessed by measuring the CO_2-C release in samples collected from the field; the amount of carbon released indicates if the carbon is labile or readily metabolized in the soil (DORAN; PARKIN, 1996). However, the interpretation of biological activity data should be performed with caution because high microbial activity does not necessarily ensure better soil quality. Indeed, high microbial activity can even be considered a negative factor because it accelerates the decomposition of organic residues, which decreases the carbon residence time in the soil (ARAÚJO et al., 2007). Because it is a sensitive indicator for estimating the potential for organic matter decomposition (GAMA-RODRIGUES et al., 1997), the qCO_2 (ratio between Br and C_{SMB}) is a key tool for evaluating environmental and anthropogenic effects on soil microbial activity (ANDERSON; DOMSCH, 1993).

There is little information available regarding the effect of organic and conventional sugarcane cultivation on soil microbial attributes in the Cerrado. Souza et al. (2012) studied the influence of sugarcane harvesting systems, with and without burning, on the biological properties of an Oxisol and observed that cane cultivation altered the original soil properties, and the largest modifications occurred in the burned cane areas. On the other hand, Sant'anna et al. (2009) reported no significant differences among areas under cultivation of organic, raw and burned sugarcane under a Typic Fragiudults soil (Argissolo Amarelo in Brazilian soil taxonomy). Sugarcane production employing the organic cultivation system is gaining economic importance, especially for the production and export of organic sugar. In the organic sugarcane production, thousands of tons of vinasse and filter cake are added increasing soil organic C and nutrients. Thus, in addition to the benefits of organic products to human health and society, assessing the effects of the organic cultivation systems on the environment, in this case by focusing on soil biological attributes, is also relevant.

In this work, two hypotheses were tested: i) The substitution of the Cerrado to conventional sugarcane cultivation degrades the soil biological properties; ii) The organic sugarcane cultivation system may contribute to restore the soil biological properties degraded by the conventional cultivation system. To test these hypotheses, the same biological soil properties were evaluated under conventional and organic sugarcane cultivation systems and under native Cerrado and pasture areas. This last treatment (pasture) was included because in this region, normally, sugarcane cultivation is established in pasture areas.

The aim of this work was to study the effect of organic and conventional sugarcane cultivation system on microbial soil properties.

MATERIAL AND METHODS

The study sites were located in a production area at the Usina Jalles Machado, Goianésia, Goiás State, Brazil (15°10'S and 49°15' W, 640 m above sea level) and three sugarcane cultivation systems were studied: organic (Organic Cane - OC), conventional with burning (Burned Cane - BC) and conventional without burning (Raw Cane - RC). Two areas under a native vegetation (Native Cerrado - NC) and pasture (Pasture - PT) were also evaluated as reference. The pasture was included in the study because the raw and burned cane cultivation were implemented on pasture areas (Table 1). These sites did not differ to each other in respect to landscape position, climate and original vegetation (Cerrado).

The soil of evaluated areas was an Oxisol (Latossolo Vermelho in the Brazilian Soil Classification System and Rhodic Ferralsol in WRB). In all these selected sites the soil was clayey, and the ground was slightly undulating, typical for the Cerrado. According to Köppen classification, the climate in the region is humid megathermic tropical savannah (Aw), with dry winter (May-September) and rainy summer (October-April). The annual average precipitation is 1,500 mm (Figure 1).

Table 1. Land-use history, soil management and geographic coordinates of the red Oxisol under the native Cerrado, pasture and the areas under sugarcane production, Goianésia, Goiás State, Brazil.

Before1950	1950	1984	1991	1999	Land-use and cultivation system*	Time under current system in years	Major field operations	Geographic coordinates**
NC	NC	NC	NC	NC	NC		Typical undisturbed Cerrado vegetation (NC), without any exploitation or anthropic interference. Area of ~2 ha.	-15°23'S and -48°99' W
NC	PT	**RC**	RC	RC	RC	25	Area under Raw Cane (RC). Soil management includes liming, application of gypsum and synthetic fertilizer (04-28-20 NPK + 0.4% Zn) at the bottom of the furrows at 50 cm. Crop treatments follow standard sugarcane cultivation in the region. The latest reforms occurred in 2000 and 2005. Area of 122 ha.	-15°30'S and -49°02' W
NC	PT	PT	**BC**	BC	BC	18	Area under Burned Cane (BC). Soil management includes liming, application of gypsum and synthetic fertilizer (04-28-20 NPK + 0.4% Zn) at the bottom of the furrows at 50 cm. Crop treatments follow standard sugarcane cultivation in the region. The latest reforms occurred in 2001 and 2005. Area of 41 ha.	-15°14'S and -48°90' W

NC	PT	RC	RC	**OC**	OC	10	Area under Organic Cane (OC). Since OC has been introduced, highly soluble synthetic fertilisers were not applied. Soil management includes liming and the application of vinasse and filter cake at the bottom of the furrows at 50 cm. Residue of legume plants is used as N supply. The latest reforms occurred in 1998 and 2006. Area of 136 ha.	-15°22’S and -48°98’ W

*NC = Native Cerrado; PT = Pasture; RC = Raw Cane; BC = Burned Cane; OC = Organic Cane. PT (-15°28’S and -49°00’ W); **Coordinates of one selected point of the five sampled ones in each system.

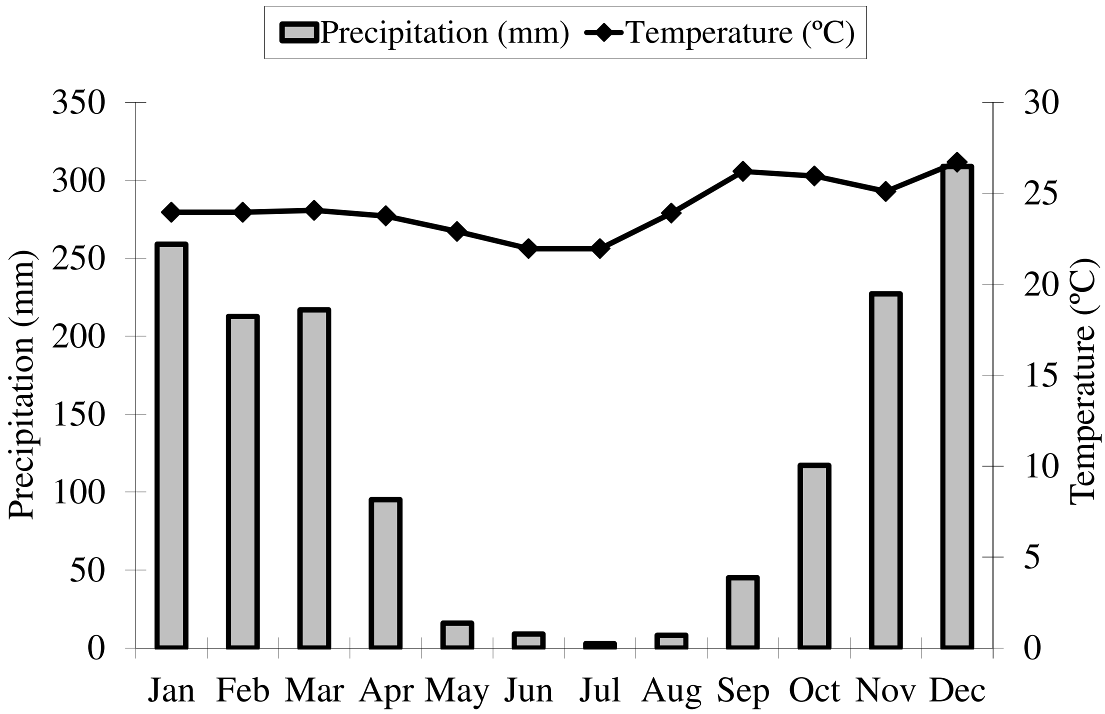

Figure 1. Average monthly precipitation (1985 to 2008) and temperature (2008 to 2009) in the studied areas. The dates were collected at the meteorological station of the Usina Jalles Machado in Goianésia, Goiás State, Brazil.

Soil chemical and physical analyses were determined according to EMBRAPA (1997) and all areas contain more than 30% clay (Table 2). Soil clay content in the Cerrado (NC), OC and BC is very similar. The areas under Pasture and RC contain less clay and are similar to each other.

Table 2. Chemical and granulometric properties of the red Oxisol under the native Cerrado, pasture and the areas under sugarcane production, Goianésia, Goiás State, Brazil*.

System	pH	P	K	Ca	Ca:Mg	H+Al	Al	T	V	SOC	N_{Tot}	Clay
		mg kg^{-1}		-----------------cmol$_c$ dm^{-3}-----------------					%	g kg^{-1}		%
0 - 10 cm												
Native Cerrado	4.58	5.00	0.080	2.59	2.66	6.48	0.49	4.16	35.4	26.77	2.42	48
Pasture	5.64	4.24	0.088	3.42	2.57	2.88	0.00	4.92	61.4	17.83	1.31	36
Organic Cane	5.94	33.60	0.564	6.23	3.80	1.98	0.00	8.51	75.7	23.00	1.55	52
Raw Cane	5.50	12.38	0.022	2.25	2.32	2.22	0.00	3.24	59.0	10.21	0.83	34
Burned Cane	5.98	19.24	0.120	3.39	1.85	2.28	0.00	5.44	67.3	13.48	0.88	45
10 - 20 cm												
Native Cerrado	4.24	3.24	0.026	0.71	1.39	6.50	1.11	2.37	15.9	18.62	1.46	49
Pasture	5.68	3.62	0.005	3.81	2.81	2.82	0.00	5.32	64.5	17.87	1.31	38
Organic Cane	6.02	18.34	0.764	4.18	2.50	2.32	0.00	6.65	65.7	20.51	1.33	55
Raw Cane	5.50	13.06	0.005	1.93	2.38	2.50	0.00	2.75	51.7	9.72	0.77	34
Burned Cane	6.02	12.48	0.043	3.13	1.80	2.46	0.00	4.94	65.0	13.68	0.88	45

*Chemical and granulometric properties were determined in representative sample from each system

Within each production system, five circular plots were selected in random. The radius of each plot was 50 m and the area 78.50 m^2. The central point of each plot was georeferred (Table 1). These five circular plots were treated as five replicates within each studied area (system). In each circular plot 10 samples were collected randomly and were carefully mixed to obtain a composite sample per plot. The soil samples were collected during the dry (Jul/2008) and rainy (Feb/2009) seasons from two layers 0-10 and 10-20 cm depths. The soil samples were collected at a distance of 30 cm from the crop row. In Cerrado and pasture areas, the samples were collected using a pathway (transect) in each area. In all areas, the plots were spaced approximately 100 m apart. The chemical and particle size analysis of soil samples collected from the different areas, and from two depths are described in Table 2.

Sugarcane is a semi-perennial crop, planted, on average, every five years and harvests are made annually. Because the yield decreases drastically after five years, the fields are sprayed with glyphosate in the conventional sugarcane cultivation systems (RC and BC) to kill the old plants and then the area is replanted for a new five-year production period. In the organic cultivation area it is not allowed to use herbicides, so the old sugarcane plants are cut. Before replanting sugarcane, the residues are incorporated into the soil in all systems.

RC in our study was implemented on a degraded pasture area in 1984, and the BC in 1991, 25 and 18 years prior to soil sampling, respectively. The pasture areas were brought into production substituting the native Cerrado (NC) vegetation in 1950. The OC was converted from RC ten years prior to soil sampling, in 1999.

In RC system burning is omitted and harvest is mechanized. In BC the leaves are annually burned before the harvest, in order to improve the efficiency of the workers in the cutting process. In OC the harvest system is the same employed in the RC. RC and BC fertilization is described in Table 2. In OC a legume mixture (*Crotalaria* sp. and *Glycine max* L.) is sown about three months before planting the sugarcane. When the legumes are at flowering stage, plants are cut and their residues deposited on the soil surface serve as a source of nitrogen. The OC area receives filter cake compost at the bottom of the furrows (at ~ 50 cm depth) at planting also based on the necessity for nutrients that is calculated after soil fertility analysis.

Only OC received 60 mm vinasse annually by irrigation. The conventional sugarcane (RC and BC) areas received water at the same rate as the OC received vinasse. Data on the land-use history and soil management of these sites are shown in Table 1. All sugarcane areas chosen for the study have been harvested three times before the time of sampling, meaning, that the crop has been being cultivated on these areas for 4 years after the last renewing of the plantation (replanting).

The soil samples were kept refrigerated in styrofoam coolers during transportation to laboratory and were preserved at 4°C. In the laboratory, samples were passed through 8-mm mesh sieves to remove roots and fragments of plant debris. Each composite soil sample was divided into six 20 g subsamples, and the moisture content was adjusted to 80% field capacity.

For each sample collected, three analytical replications were performed, and these three replications were averaged. The basal respiration

(Br) was determined following the method described by Alef and Nannipieri (1995). The microbial biomass nitrogen (N_{SMB}) was calculated using the fumigation and extraction method (BROOKES et al., 1985). The N_{SMB} content of the soil was calculated using the following formula: $N_{SMB} = (N_F - N_{NF})\ K_{EN-1}$, in which N_F and N_{NF} are the total amounts of N released from the fumigated and the non-fumigated soil at the same time. K_{EN} (0.54) is a constant representing the mineralized proportion of the N_{SMB} (WARDLE, 1994).

The microbial biomass carbon (C_{SMB}) was also quantified using the fumigation and extraction method (VANCE et al., 1987). The amount of C_{SMB} was determined by calculating the difference between the organic C extracted from the fumigated and the non-fumigated samples. To calculate the C_{SMB} content, a Kc value equal to 0.38 was used (VANCE et al., 1987). The soil organic carbon (SOC) was analyzed using the potassium dichromate-oxidation method, described by Nelson and Sommers (1996). The total soil nitrogen was quantified by sulfuric acid digestion and Kjeldahl distillation as described by Bremner and Mulvaney (1982).

The model used in the data analysis was as follows: $y_{ijkl} = \mu + S_i + R_j(S_i) + E_k + (SE)_{ik} + R_jE_k(S_i) + P_l + (SP)_{il} + (EP)_{kl} + (SEP)_{ikl} + \varepsilon_{ijkl}$, where S_i is the effect of the system i; $R_j(S_i)$ is the effect of the sample j, within the system i; E_k is the effect of the season k; $(SE)_{ik}$ is the effect of the system vs. season interaction; $R_jE_k(S_i)$ is the effect of replication vs. season interaction within the system; P_l is the effect of depth l; $(SP)_{il}$ is the effect of the system vs. depth interaction; $(EP)_{kl}$ is the effect of the season vs. depth interaction; $(SEP)_{ikl}$ is the effect of the system vs. season vs. depth interaction; and E_{ijkl} is an error. This is a mixed model, where S_i, E_k, $(SE)_{ik}$, P_l, $(SP)_{il}$, $(EP)_{kl}$, and $(SEP)_{ikl}$ are fixed effects; $R_j(S_i)$ and $R_jE_k(S_i)$ are random effects; and E_{ijkl} is random error.

The restricted maximum likelihood analysis was used, as described by Searle et al. (1992). Because this research is an observational study, not an experiment, the variance and covariance structure of the data are unknown; therefore, a statistical study to indicate the best structure was performed. Other studies were also conducted; one study tested the normal distribution of the data, and a second study detected outliers. The techniques used for the three studies are described in Littell et al. (2006). Statistical analysis was performed using the SAS program (SAS INSTITUTE Inc., Cary, NC, USA), and the means were compared using the t test at 5% probability.

RESULTS AND DISCUSSION

Soil Microbial Biomass Carbon (C_{SMB})

With the exception of the conventional cultivation areas, the C_{SMB} content was influenced by the harvesting season (Table 3 and 4) and higher values were obtained during the rainy season (Table 4), which corroborates reports by Alves et al. (2011) who attributed this fact to the higher soil moisture, improving soil microbial activity and growth. The C_{SMB} decreased with soil depth, showing an average of 227.54 and 173.25 mg $C.Kg^{-1}$ soil at 0-10 and 10-20 cm, respectively.

Table 3. Test of significance for C_{SMB}, N_{SMB}, Br, qCO_2, C_{SMB}/C_{org} and N_{SMB}/N_{Total}, in five systems studied measured across two seasons and two soil depth.

S.V.	DF	F Value					
		C_{SMB}	N_{SMB}	Br	qCO_2	C_{SMB}/C_{org}	N_{SMB}/N_{Total}
System (S)	4	385.38 **	206.18 **	9.58 **	7.25 **	34.43 **	27.68 **
Season (Se)	1	229.25 **	9.91 **	73.57 **	52.85 **	79.72 **	1.63 ns
(S) *vs*. (Se)	4	59.24**	2.82 *	4.17 **	2.59 ns	22.04 **	5.03 **
Depth (De)	1	50.93 **	27.24 **	23.19 **	1.16 ns	7.75 **	0.33 ns
(S) *vs*. (De)	4	21.80 **	7.88 **	0.50 ns	3.04 *	4.03 **	7.78 **

S.V – Source of Variation; DF – Degrees of Freedom ; C_{SMB} (Microbial C); N_{SMB} (Microbial N); Br (Basal respiration); qCO_2 (Metabolic quotient). *; **: Significant at 5% and 1% of probability respectively; ns: not significant. Systems: Cerrado (NC), Pasture (PT), Raw Cane (RC), Burned Cane (RC) and Organic Cane (OC). Seasons: Dry and Rainy. Soil depths: 0-10 and 10-20 cm.

There was significant interaction between the cultivation systems vs. season, as well as between the cultivation systems vs. depth (Table 3). Higher values of C_{SMB} were obtained in the NC than in the cultivated areas and PT (Table 4), corroborating with Fialho et al. (2006), Silva et al. (2010) and Santos et al. (2012). The amount of soil microbial biomass found in the soil is related to the carbon content (PEREZ et al., 2004), which enters in the soil by leaf litter deposition (CORREIA; ANDRADE, 2008). Furthermore, the undisturbed soils in native areas favor higher root abundance, which increases the carbon input (FIALHO et al., 2006), mainly through rhizodeposition (PATERSON, 2003).

The substitution of Cerrado for land-use systems lead to decrease in C_{SMB} of 27.1%, 84.5% and 80.3% in the PT, RC and BC, respectively, in the rainy season, and by 50.2%, 73.5% and 73.6% in the dry season, by 50.9%, 80.2% and 80.1%, in the 0-10 cm layer, and by 12.4%, 80.4% and 74.1% in the 10-20 cm layer (Table 4).

Table 4. Mean observed values obtained for interaction systems *vs.* season in the microbial biomass carbon (mg C. $Kg^{-1}$of soil) in soils from sugarcane cultivated areas, pasture, and native Cerrado areas during two seasons and from two soil layers[(1)].

System	Systems *vs.* seasons		Systems *vs.* Depth	
	Dry	Rainy	0-10 cm	10-20 cm
Cerrado	307.9 aB	498.2 aA	492.3 aA	313.9 aB
Pasture	153.2 bB	363.2 bA	241.5 bB	274.9 bA
Raw cane	81.7 cA	77.2 dA	97.2 dA	61.6 dB
Burned cane	81.1 cA	98.1 dA	98.0 dA	81.3 dA
Organic cane	153.6 bB	189.6 cA	208.6 cA	134.6 cB

[(1)] Means followed by the same letter do not differ statistically in the t test ($p \leq 0.05$). Lowercase letters compare the land-use systems in the column during the same season or from the same depth. Capital letters compare the land-use systems in the same row, considering the same variable (season or depth).

The PT also featured higher C_{SBM} than in the areas cultivated with sugarcane, except for the OC, that did not differ from the PT in the dry season. It showed that in adverse conditions to microbial biomass growth, like the dry season in the Brazilian Cerrado, the OC was as efficient as the pasture to restore the microbial biomass and, therefore, to improve soil quality. According to Kaschuk et al. (2010) this is likely due to the use of organic fertilizer and to the lack of agrochemicals in both the OC and PT.

The lowest values were obtained in the RC areas, being 81.7 and 77.2 mg C Kg^{-1} of soil, and in the BC, being 81.1 and 98.1 mg C Kg^{-1} of soil, in the dry and the rainy seasons, respectively. According to Marchiori-Júnior and Melo (2000) this is likely due to the insufficient additions of oxidizable C to supply the existing biomass demand and also to the use of herbicides that have negative effects on the beneficial soil microorganisms (KASCHUK et al., 2010). Although there is a high amount of sugarcane crop residues in the soil after harvest, these are slowly mineralized due to the high C/N ratio (VITTI et al., 2011), varying from 31.5 to 46.6 in this work, resulting in a lack of readily oxidizable substrate, compared to the NC, which reduces C and nutrients availability for growth and development of microbial biomass (COSER et al., 2007; PEREZ et al., 2004). The area under OC (C_{SMB} = 153.6 and 189.6 mg C Kg^{-1} of soil in the dry and the rainy season, respectively), was lower than CN and PT and superior to the conventional sugarcane cultivation (RC and BC).

Ten years after the conversion from the RC to the OC there was a recovery of 145.7% and 93.1% of C_{SMB}, compared to the raw and burned sugarcane, respectively, in the rainy season, and a recovery of 88.1% e 89.3% in the dry season, of 114.5% and 112.8% in the 0-10 cm layer and of 118.5% and 65.6% at 10-20 cm (Table 4). The OC and BC are directly comparable as those areas had similar clay content (Table 2). The RC area, however, had lower clay concentration, and for this reason the conclusions drawn from the comparison of the RC and OC areas for C_{SMB} has to be made with caution because higher clay content increases the ability of the soil to accumulate C and, as mentioned before, the soil organic carbon content may affect C_{SMB} (PEREZ et al., 2004).

The increase in the C_{SMB} in the OC is most likely due to fertilization in the OC with filter cake and vinasse, that provide organic substrate, biodegradable and rich in C and energy (PRATA et al., 2001), easily decomposable due to the low C/N ratio of 23/1 (MODESTO et al., 2009), improving soil microorganisms growth. Maluche-Baretta et al. (2007), Freitas et al. (2011) and Santos et al. (2012) also reported increases in C_{SMB} content of 64.4%, 147.6% and 300.0% in organic apple, grapes and cherry production systems, respectively, compared to the conventional ones.

Soil Microbial Biomass Nitrogen (N_{SMB})

The N_{SMB} was higher in the rainy than in the dry season (Table 3), with average in the dry and rainy of 30.19 and 33.48 mg N.Kg^{-1} soil, respectively. Soil depth affected N_{SMB} which decreased from top to deeper layer (Table 3), being 35.06 and 28.62 mg N.Kg^{-1} soil, in the 0-10 cm and

10-20 cm layer, respectively. The substitution of the NC for other land-use reduced the N_{SMB} by 47.7%, 63.5% and 77.0% in the PT, RC and BC, respectively, in the rainy season, by 45.0%; 71.7% and 73.3% in the dry season, by 54.3%, 73.3% and 78.5% at 0-10 cm and by 36.9%, 75.4% and 71.0% at 10-20 cm (Table 5).

There was interaction in the effect of cultivation systems vs. season as well as of cultivation system vs. depth for N_{SMB} (Table 3). The highest value of N_{SMB} was found in NC in the rainy season (Table 5). According to Perez et al. (2004) this possibly happens due to plant residues that remain on the soil surface in the low natural fertility of Cerrado soils, which exhibit a low decomposition rate, leading to the immobilization of N in the microbial biomass.

Table 5. Mean observed values obtained for interaction systems *vs.* season in the microbial biomass nitrogen (mg N. Kg^{-1} of soil) in soils from sugarcane cultivated areas, pasture, and native Cerrado areas during two seasons and from two soil layers[(1)].

System	Systems *vs.* Seasons		Systems *vs.* Depth	
	Dry	Rainy	0-10 cm	10-20 cm
Cerrado	55.60 aB	63.44 aA	67.72 aA	51.32 aB
Pasture	30.18 bA	33.17 cA	30.97 cB	32.39 bA
Raw cane	15.76 cA	14.95 dA	18.08 dA	12.62 cB
Burned cane	14.84 cA	14.57 dA	14.53 dA	14.88 cA
Organic cane	34.57 bB	41.29 bA	43.98 bA	31.88 bB

[(1)] Means followed by the same letter do not differ statistically in the t test ($p \leq 0.05$). Lowercase letters compare the land-use systems in the column during the same season or from the same depth. Capital letters compare the land-use systems in the same row, considering the same variable (season or depth).

Only NC and OC areas showed differences in relation to the sampling seasons, being the highest values found in the rainy season, crucial period for the management of nitrogen fertilization because this is the season when the highest N losses by leaching and/or volatilization occur. In this season the OC showed higher values than the other production systems, except for the NC. In dry season the OC did not differ from the PT, and these areas presented higher nitrogen microbial biomass values than conventional sugarcane (RC and BC) and inferior to Cerrado, showing that in the most critical season for soil microorganisms growth, the organic system has the same potential for immobilization of N in the microbial biomass than the pasture and it is superior to the conventional systems. According to Araújo and Melo (2010), the organic cultivation practices, by avoiding the use of synthetic fertilizers and pesticides, applying organic matter to the soil, cycling nutrients and using biological processes for pest management, are key for increasing soil fertility and maintaining environmental sustainability.

In NC, OC and RC the highest values of N_{SMB} were observed in the 0-10 cm layer (Table 5). The other systems (PT and BC) did not show differences between the studied layers. The highest values of N_{SMB} were observed in the NC, 67.72 and 51.32 mg N Kg^{-1} soil, at 0-10 and 10-20 cm, respectively. Xavier et al. (2006) reported higher N_{SMB} for organic cultivation areas compared to a native forest area. The lowest values of N_{SMB} were found in the RC, 18.08 and 12.62 mg N Kg^{-1} soil, and BC, 14.53 and 14.87 mg N Kg^{-1} soil, at 0-10 and 10-20 cm, respectively. In OC the N_{SMB} (43.98 mg N Kg^{-1} soil at 0-10 cm) was superior to the other systems, with exception of the NC. In 10-20 cm layer (31.88 mg N Kg^{-1} soil) it was superior to the conventional sugarcane areas, and it did not differ from the PT (30.97 and 32.39 mg N Kg^{-1} soil at 0-10 and 10-20 cm, respectively) and it was inferior to the NC.

Ten years after the conversion from RC to the OC, the recovery in N_{SMB} was of 176.2% and 183.3% related to the RC and BC, respectively, in the rainy season, of 119.4% and 133.0% in the dry season, of 143.2% and 202.6% in the 0-10 cm layer and of 152.5% and 114.3% at 10-20 cm. The recovery was likely due to the different sources of N applied in the organic and conventional land-use systems. In the conventional system, highly soluble nitrogen fertilizer (ammonium sulphate and urea) was applied, which is rapidly transformed into ammonia, whereas with the organic fertilizers (filter cake, vinasse and green manure) the mineralization occurs slowly while they are degrading, with higher possibility of synchronization between the availability of N in the soil and crop demand.

Onwonga et al. (2010) also reported higher levels of N_{SMB} in the treatments with organic fertilizers compared to mineral ones (ammonium sulphate and urea). According to Xavier et al.

(2006) and Lambaris and Carmo (2008), N fixation by leguminous species and the addition of organic compost stimulated and increased the N_{SMB}. Coser et al. (2007) reported that applying higher doses of soluble nitrogen (ammonium sulphate) does not promote the mineralization of organic nitrogen, and it is not immobilized in the soil microbial biomass regardless the C/N ratio of the straw on soil surface. Delbem et al. (2011) verified that high doses of nitrogen fertilizer in the ammonium sulphate form produced negative effects on the soil microbiota, reducing the microbial biomass and increasing the stress level.

Basal Respiration (Br) and Metabolic Quotient (qCO_2)

Basal respiration (Br) was higher in the dry than in the rainy season (Table 3) being, on average, 76.58 and 40.46 mg CO_2-C $Kg^{-1}.7days^{-1}$, in the dry and rainy seasons, respectively. Its value decreased with soil depth being, on average, 69.72 and 47.04 mg CO_2-C $Kg^{-1}.7day^{-1}$ at 0-10 and 10-20 cm, respectively.

The highest values of metabolic quotient (qCO_2) were observed in the BC (Table 6), corroborating with Graham and Haynes (2006) that reported higher qCO_2 in burned than in raw cane areas. OC did not differ from the others.

There was significant interaction between the effect of cultivation systems vs. season for the Br, and of cultivation system vs. depth for the qCO_2 (Table 3). It is reported in the literature that the microbial activity (Br) would be related to the size of the microbial biomass (MENDONZA et al. 2000; FIALHO et al., 2006; DELBEM et al., 2011), however, microbial communities subjected to stress may react by expending more energy to maintain the microbial biomass what would also result in an increase of both Br and qCO_2 (LAMBARIS; CARMO, 2008). According to Alves et al. (2011), when considering identical microbial community compositions, an efficient biomass would have a lower respiration rate.

In NC, PT, BC and OC higher levels of Br were observed in the dry season (Table 6) that can be explained with a stress effect due to water deficiency, compared to the rainy season. Pimentel et al. (2011) also reported higher Br in the dry than in the rainy season. Among the sugarcane areas, in the rainy season, the BC presented higher Br (47.49 mg CO_2-C $Kg^{-1}.7days^{-1}$) than the other sugarcane areas, likely due to the stress that the burning inflicted to the soil microorganisms, as also observed by Baretta et al. (2005) who reported that burning lowered the metabolic efficiency and raised the losses of C as CO_2. The lower Br in the PT and OC (35.90 and 33.45 mg CO_2-C $Kg^{-1}.7days^{-1}$, respectively) also indicated that the microorganisms in these systems are more efficient in the immobilization and recycling of C in the soil (Table 6). The immobilization of carbon in the microbial biomass in the OC was also supported by the high C_{SMB} (Table 4). In the BC carbon is lost as CO_2, observed by the relatively high levels of Br and qCO_2 (Table 6) and low C_{SMB} (Table 4). In the rainy season the Br in the OC was low that suggests low activity and was not differing from the RC. In the conventional cultivation systems (RC and BC), however, low carbon was incorporated into the biomass (low C_{SMB}, Table 4). PT and OC in the rainy season the microorganisms diminished their activity (Br), lowering the decomposition rate and consequently the losses of organic matter. The same occurred under natural vegetation (NC); however, in the conventional sugarcane cultivation systems (RC and BC) there was no difference between the seasons.

Table 6. Basal respiration (mg CO_2-C Kg^{-1}soil seven $days^{-1}$) and metabolic quotient - qCO_2 (mg C-CO_2 kg^{-1} soil day^{-1}) in soil from sugarcane cultivated areas, pasture, and native Cerrado areas during two seasons and from two soil layers[1].

Systems	Basal respiration		qCO_2	
	Systems vs. Seasons		Systems vs. Depth	
	Dry	Rainy	0-10 cm	10-20 cm
Cerrado	128.17 aA	60.78 aB	0.039 bA	0.056 bA
Pasture	76.59 bA	35.90 bcB	0.062 bA	0.029 bB
Raw cane	36.18 cA	24.67 cA	0.057 bA	0.058 bA
Burned cane	77.81 bA	47.49 abB	0.113 aA	0.098 aA
Organic cane	71.91 bA	33.45 cB	0.046 bA	0.049 bA

[1] Means followed by the same letter do not differ statistically as determined by a t test at 5% probability. Lowercase letters compare the land-use systems in the column during the same season or from the same layer. Capital letters compare the land-use systems in the same row, considering the same variable (season or layer).

C_{SMB}/C_{org} and N_{SMB}/N_{Total} ratios

C_{SMB}/C_{org} and N_{SMB}/N_{Total} ratios express the amount of organic C and N in the soil immobilized in the microbial biomass. The higher the C_{SMB}/C_{org} ratio the greater is the efficiency of the microorganisms to immobilize and recycle carbon in the soil (GAMA-RODRIGUES et al., 2005).

The C_{SMB}/C_{org} ratio, in general, was higher in the rainy than in the dry season (Table 7) having an average of 0.79 and 1.23 in the dry and rainy seasons, respectively. It decreased with soil depth (Table 3) in RC and OC.

In this work, there was interaction in the effect of the cultivation system and the season as well as of the system and the depth for the C_{SMB}/C_{org} and N_{SMB}/N_{Total} (Tables 3, 7 and 8).

The interaction between cultivation systems vs. season showed that the highest C_{SMB}/C_{org} was observed in NC and PT in the rainy season (Table 7). Ferreira et al. (2010) and Silva et al. (2010) also reported a higher C_{SMB}/C_{org} in Cerrado when compared to areas under different land-use systems. This occurs mainly due to input of soil organic carbon from leaves (CARNEIRO et al., 2008) and roots (VAN VEEN et al., 1989).

Among the areas cultivated with sugarcane there was no difference regarding the C_{SMB}/C_{org} ratio except for OC in the rainy season that was higher compared to the BC in the dry season. The same area (BC/dry season), besides having lower C_{SMB} compared to the OC, had higher Br. This implicates in the loss of C from the area under BC in the form of CO_2, while in the OC the C is being incorporated in the microbial biomass.

Table 7. Mean observed values obtained for interaction systems *vs.* season in the C_{SMB}/C_{org} in soils from sugarcane cultivated areas, pasture, and native Cerrado areas during two seasons and from two soil layers[(1)].

Systems	Systems vs. Seasons		Systems vs. Depth	
	Dry	Rainy	0-10 cm	10-20 cm
Cerrado	1.12 aB	1.89 abA	1.50 aA	1.52 Aa
Pasture	0.81 bB	1.98 aA	1.33 aA	1.45 aA
Raw cane	0.76 bA	0.74 cA	0.88 bA	0.61 bB
Burned cane	0.58 bA	0.73 cA	0.72 bA	0.59 bA
Organic cane	0.72 bA	0.83 bcA	0.91 bA	0.64 bB

[(1)] Means followed by the same letter do not differ statistically in the t test ($p \leq 0.05$). Lowercase letters compare the land-use systems in the column during the same season or from the same depth. Capital letters compare the land-use systems in the same row, considering the same variable (season or depth).

Table 8. Mean observed values obtained for interaction systems *vs.* season in the N_{SMB}/N_{total} in soils from sugarcane cultivated areas, pasture, and native Cerrado areas during two seasons and from two soil layers[(1)].

Systems	Systems vs. Seasons		Systems vs. Depth	
	Dry	Rainy	0-10 cm	10-20 cm
Cerrado	2.97 aB	3.38 aA	2.85 aB	3.50 aA
Pasture	2.29 bB	2.56 bA	2.35 bA	2.50 bA
Raw cane	1.94 bcA	1.81 cA	2.21 bA	1.55 cB
Burned cane	1.73 cA	1.36 dA	1.52 cA	1.57 cA
Organic cane	2.32 bA	2.54bA	2.64 aA	2.22 bA

[(1)] Means followed by the same letter do not differ statistically in the t test ($p \leq 0.05$). Lowercase letters compare the land-use systems in the column during the same season or from the same depth. Capital letters compare the land-use systems in the same row, considering the same variable (season or depth).

In systems vs. depth interaction the highest C_{SMB}/C_{org} were observed in the NC and PT, in both depths (Table 7). The areas cultivated with sugarcane did not differ from each other. In these areas the highest C_{SMB}/C_{org} was observed in the 0-10 cm layer, except in the BC where there was no difference between the sampling depths.

The highest N_{SMB}/N_{Total} in the systems vs. season interaction was observed in the NC, being higher in the rainy season than in the dry one (Table 7). In the rainy season the OC was as efficient as the PT in the immobilization and recycling N, and showed higher values than the conventional (RC and BC) sugarcane areas. In the dry season the OC was also similar to PT, as well as to the RC, however it was still better than the BC, indicating that in the BC the efficiency of microorganisms to immobilize N was lower than in other areas.

Therefore the area under BC is likely more susceptible to losses of N by leaching and/or volatilization.

In cultivation system vs. depth interaction, the highest N_{SMB}/N_{Total} was also found in NC in the 10-20 cm layer, followed by the 0-10 cm layer (Table 8). Among areas cultivated with sugarcane, OC at 0-10 cm and 10-20 cm had higher values than the conventional (RC and BC) sugarcane areas and it did not differ from NC at 0-10 cm layer. At 10-20 cm layer, in sugarcane systems, only RC had lower N_{SMB}/N_{Total} compared to 0-10 cm layer.

CONCLUSIONS

Sugarcane cultivation and pasture reduced the C and N content of microbial biomass and altered the cycling (C_{SMB}/C_{org} and N_{SMB}/N_{Total}) of these elements in the soil.

In soils cultivated with sugarcane, microbiological activity is higher in conventional crops with straw burning.

The efficiency of microbial biomass in the burned sugarcane straw proved to be inferior to the other areas (higher qCO_2) and it was also deficient in N (lower N_{SMB}/N_{Total}) likely due to the quality of the original substrate that lost N by burning.

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RESUMO: A cana-de-açúcar é de suma importância na matriz energética brasileira. A avaliação dos atributos bioquímicos do solo nos diferentes sistemas de produção da cana-de-açúcar fornece informações sobre a sustentabilidade ambiental destes sistemas de produção. Os atributos bioquímicos do solo são considerados indicadores muito sensíveis às alterações causadas nas propriedades do solo, em função do manejo nos diferentes sistemas de produção agrícola. O objetivo deste trabalho foi estudar o efeito do cultivo de cana-de-açúcar em sistema orgânico e convencional nas propriedades microbiológicas do solo. As alterações no carbono (C) e nitrogênio (N) microbiano e na atividade microbiana foram avaliadas em um Latossolo Vermelho sob Cerrado no estado de Goiás, Brasil, cultivado com cana-de-açúcar em três diferentes sistemas de produção: cultivo orgânico (CO), convencional com queima (CQ) e cultivo convencional sem queima da palhada e cana crua (CC). Uma área de cerrado nativo (CN) e outra cultivada com pastagem (PT) foram usadas como referências. As amostras de solo foram coletadas em duas épocas: seca e chuvosa; e em duas profundidades: 0-10 cm e 10-20 cm. A ordem cronológica de implementação do uso da terra foram: CN, PT e cana-de-açúcar; os sistemas de cultivo foram: CN, PT, CC/CQ, OC. O carbono da biomassa microbiana do solo (C_{BMS}), nitrogênio da biomassa microbiana do solo (N_{BMS}), respiração basal (Rb), quociente metabólico (qCO_2) e as razões C_{BMS}/C_{org} e N_{BMS}/N_{Total} foram determinados. Os diferentes sistemas de produção da cana-de-açúcar alteraram a biomassa e a atividade microbiana. A substituição do sistema de cultivo convencional pelo sistema de cultivo orgânico recuperou os teores de C_{BMS} e N_{BMS} e melhorou a reciclagem de nutrientes na biomassa microbiana (N_{BMS}/N_{Total}). O sistema de cultivo convencional com queima (CQ) foi o menos eficiente na utilização do carbono como energia (alto qCO_2), resultando em perdas de C-CO_2 para a atmosfera.

PALAVRAS-CHAVE: Cerrado. Cultivo orgânico. Biomassa Microbiana do Solo. qCO_2. C Microbiano. N microbiano.

REFERENCES

ALEF, K.; NANNIPIERRE, P. **Methods in applied soil microbiology and biochemistry**.1 ed. London: Academic Press, 1995, 576p.

ALVES, T. D. S.; CAMPOS, L. L. NETO, N. E.; MATSUOKA, M.; LOUREIRO, M. F. Biomassa e atividade microbiana de solo sob vegetação nativa e diferentes sistemas de manejos. **Acta Scientiarum Agronomy**, Maringá, v. 33, n. 2, p. 341-347, 2011.

ANDERSON, T. H.; DOMSCH, K. H. The metabolic quotient for CO_2 (qCO_2) as specific activity parameter to asses the effects of environmetal conditions, such as pH on the microbial biomass of forest soils. **Soil Biology and Biochemistry**, Amsterdam, v. 25, p. 393-395,1993.

ARAÚJO, A. S. F. D.; MELO, W. J. D. Soil microbial biomass in organic farming system. **Ciência Rural**, Santa Maria, v. 40, n. 11, p. 2419-2426, nov, 2010.

ARAÚJO, R.; GOEDERT, W. J.; LACERDA, M. P. C. Qualidade de um solo sob diferentes usos e sob cerrado nativo. **Revistra Brasileira de Ciência do Solo**, Viçosa, v. 31, n . 5, p. 1099-1108, set/out 2007.

BARETTA, D.; SANTOS, J. C. P.; FIGUEIREDO, S. R.; KLAUBERG-FILHO, O. Efeito do monocultivo de Pinus e da queima do campo nativo em atributos biológicos do solo no Planalto Sul Catarinense. **Revistra Brasileira de Ciência do Solo**, Viçosa, v. 29, n. 5, p. 715-724, set/out, 2005.

BLAIR, G. J.; CHAPMAN, L.; WHITBREAD, A. M.; BALL-COELHO, B.; LARSEN, P.; TIESSEN, H. Soil carbon changes resulting from sugarcane trash management at two locations in Queensland, Australia and in North-East Brazil. **Australian Journal of Soil Research**, Collingwood, v. 36, n. 1, p. 873-881, Nov. 1998.

BREMNER, J. M.; MULVANEY, C. S. Nitrogen Total. In: PAGE, A. L.; MILLER, R. H.; KEENEY, D. R. (Eds.). **Methods of soil analysis**, Part 2. Chemical and Microbiological Properties. Agronomy Monograph n. 9, 2nd ed. Madison: American Society of Agronomy, 1982. p 595-624.

BROOKES, P. C.; LANDMAN, A.; PRUDEN, G.; JENDINSON, D. S. Chloroform fumigation and the release of soil nitrogen: a rapid direct extraction method to measure microbial biomass nitrogen in soil. **Soil Biology and Biochemistry**, Amesterdam, v. 17, n. 6, p. 837-842, 1985.

CARNEIRO, M. A. C.; CORDEIRO, M. A. S.; ASSIS, P. C. R.; MORAES, E. S.; PEREIRA, H. S.; PAULINO, H. B.; SOUZA, E. D. de. Produção de fitomassa de diferentes espécies de coberturas e suas alterações na atividade microbiana de solo de cerrado. **Bragantia**, Campinas, v. 67, n.2, p. 455-462, 2008.

CONAB. **Avaliação da safra agrícola de cana-de-açúcar 2010/2011**: Terceiro levantamento – Janeiro de 2011. Ministério da Agricultura Pecuária e Abastecimento, 19.

CORREIA, M. E. F.; ANDRADE, A. Formação de serrapilheira e ciclagem de nutrientes. In: Santos, G.A., SILVA, L. S.; CANELLAS, L. P.; CARMARGO, F. A. O. (Eds.), **Fundamentos da matéria orgânica do solo: ecossistemas tropicais & subtropicais**. Porto Alegre, 2008. p. 137- 158.

COSER, T. R.; RAMOS, M. L. G.; AMABILE, R. F.; JÚNIOR, W. Q. R. Nitrogênio da biomassa microbiana em solo de Cerrado com aplicação de fertilizante nitrogenado. **Pesquisa Agropecuária Brasileira**, Brasília, v. 42, n. 3, p. 399-406, mar 2007.

DELBEM, F. C.; SCABORA, M. H.; FILHO, C. V. S.; HEINRICHS, R.; CROCIOLLI, C. A.; CASSIOLATO, A. M. R. Fontes e doses de adubação nitrogenada na atividade microbiana e fertilidade do solo cultivado com *Brachiaria brizantha*. **Acta Scientiarum. Agronomy**, Maringá, v. 33, n.2, p. 361-367, 2011.

DICK, R. P.; BREAKWELL, D. P.; TURCO, R. F. Soil enzyme activities and biodiversity measurements as integrative microbiological indicators. In: DORAN, J. W.; JONES, A. J. (Eds.). **Methods for assessing soil quality**. Madison: Soil Science Society of America, 1996. p. 247-272.

DORAN, J. W.; PARDIN, T. B. Quantitative indicators of soil quality: a minimum data set. In: DORAN, J. W.; JONES, A. J. (Eds.). **Methods for assessing soil quality**. Madison: Soil Science Society of America, 1996. p. 25-37.

DUXBURY, J. M.; SMITH, M. S.; DORAN, J. M. Soil organic matter as a source and a sink of plant nutrients. In: COLEMAN, D. C.; OADES, J. M.; UEHARA, G. (Eds.). **Dynamics of soil organic matter in tropical ecossystems.** Honolulu: University of Hawaii, 1989. p. 33-67.

EMBRAPA. **Manual de métodos de análise de solos**. 2 ed. Rio de Janeiro: Centro Nacional de Pesquisa de Solos, 1997. 212 p.

FALEIRO, F. G.; GAMA, L. C.; FARIAS-NETO, A. L.; SOUZA, E. S. O simpósio nacional sobre o cerrado e o simposio internacional sobre savanas tropicais. In: FALEIRO, F. G.; FARIAS-NETO, A. L. (Eds.). **Savanas:** desafios e estratégias para o equilíbrio entre sociedade, agronegócio e recursos naturais. Planaltina: Embrapa Cerrados; Embrapa Informação Tecnológica, 2008. 1198p.

FIALHO, J. S.; GOMES, V. F. F.; OLIVEIRA, T. S. D.; JÚNIOR, J. M. T. D. S. Indicadores da qualidade do solo em áreas sob vegetação natural e cultivo de bananeiras na Chapada do Apodi-CE. **Revista Ciência Agronômica**, Fortaleza, v. 37, n. 3, p. 250-257, 2006.

FREITAS, N. D. O.; YANO-MELO, A. M.; SILVA, F. S. B. D.; MELO, N. F. D.; MAIA, L. C. Soil biochemistry and microbial activity in vineyards under conventional and organic management at Northeast Brazil. **Scientia Agricola**, Piracicaba, v. 68, n. 2, p. 223-229, mar/abr 2011.

GAMA-RODRIGUES, E. F.; GAMA-RODRIGUES, A. C.; BARROS, N. F. Biomassa microbiana de carbono e de nitrogênio de solos sob diferentes coberturas florestais. **Revista Brasileira de Ciência do Solo**, Viçosa, v. 21, n. 3, p. 361-365, Jul. 1997.

GAMA-RODRIGUES, E. F. D.; BARROS, N. F. D.; GAMA-RODRIGUES, A. C. D.; SANTOS, G. D. A. Nitrogênio, carbono e atividade da biomassa microbiana do solo em plantações de eucalipto. **Revista Brasileira de Ciência do Solo,** Viçosa, v. 29, n. 6, p. 893-901, Nov/Dez. 2005.

GRAHAM, M. H.; HAYNES, R. J. Organic matter status and the size, activity and metabolic diversity of soil microbial communit in the row and inter-row of sugarcane under burning and trash retention. **Biology and Biochemistry**, Amesterdam, v. 38, p. 21-31, 2006.

JENKINSON, D. S.; BROOKES, P. C.; POWLSON, D. S. Measuring soil microbial biomass. **Soil Biology and Biochemistry**, Amesterdam, v. 36, p. 5-7, 2004.

JENKINSON, D. S.; LADD, J. N. Microbial biomass in soil: measurement and turnover. In: PAUL, E. A.; LADD, J. N. (Eds.), **Soil biochemistry**. New York: M. Dekker, 1981. p. 415-471.

KASCHUK, G.; ALBERTON, O.; HUNGRIA, M. Three decades of soil microbial biomass studies in Brazilian ecosystems: Lessons learned about soil quality and indications for improving sustainability. **Soil Biology and Biochemistry**, Amesterdam, v. 42, p. 1-13, 2010.

KIMPE, C. R.; WARKENTIN, B. P. Soil functions and the future of natural resourses. In: BLUME, H. P.; EGER, H.; FLEISHHAUER, E.; HEVEL, A.; REIJ, C.; STEINER, K.G. (Eds.). **Towards sustainable land use - Furthering cooperation between people and institutions.** Geoecol: Advances, 1998. p. 3-10.

LAMBARIS, M. R.; CARMO, J. B. D. Impactos da aplicação de biossólidos na microbiota de solos tropicais. **Revista Brasileira de Ciência do Solo**, Viçosa, v. 32, n. 3, p. 1129-1138, 2008.

LITTELL, R. C.; MILLIKEN, G. A.; STROUP, W. W. **SAS system for mixed models**. Cary, NC: SAS Institute Inc., 2006. 633p.

MALUCHE-BARETTA, C. R. D.; KLAUBERG-FILHO, O.; AMARANTE, C. V. T. D.; RIBEIRO, G. M.; ALMEIDA, D. Atributos microbianos e químicos do solo em sistemas de produção convencional e orgânico de maçãs no estado de Santa Catarina. **Revista Brasileira de Ciência do Solo**, Viçosa, v. 31, n. 4, p. 655-665, ago 2007.

MAPA, 2010. Lei nº 10.831, 23 de Dezembro, 2003. Ministério da Agrocultura, Pecuária e Abastecimento. Disponível em: http://www.extranet.agricultura.gov.br/sislegis-consulta/consultar Legislação.

MENDONZA, H. N. S.; LIMA, E.; ANJOS, L. H. C.; SILVA, L. A.; CEDDIA, M. B.; ANTUNES, M. V. M. Propriedades químicas e biológicas de solo de tabuleiro cultivado com cana-de-açúcar com e sem queima da palhada. **Revistra Brasileira de Ciência do Solo**, Viçosa, v. 24, n. 1, p. 201-207, 2000.

MODESTO, P. T.; SCABORA, M. H.; COLODRO, G.; MALTONI, K. L.; CASSIOLATO, A. M. R. Alterações em algumas propriedades de um Latossolo degradado com uso de lodo de esgoto e resíduos orgânicos. **Revistra Brasileira de Ciência do Solo, Viçosa**, v. 33, n. 5, p. 1489-1498, 2009.
MUELLER, C. C.; MARTHA-JUNIOR, G. B. A agropecuária e o Desenvolvimento Socioeconômico Recente do Cerrado. In: FALEIRO, F. G.; FARIAS-NETO, A. L. (Eds.), **Savanas:** desafios e estratégias para o equilíbrio entre sociedade, agronegócio e recursos naturais**.** Brasília: Embrapa Informação Tecnológica, 2008. 1198p.

NELSON, D. W.; SOMMERS, L. E. Total carbon, organic carbon and organic matter. In: SPARKS, D. L.; PAGE, A. L.; HELMKE, P. A.; LOEPPERT, R. H.; SOLTANPOUR, P. N.; TABATABAI, M. A.; JOHNSTON, C. T.; SUMNER, M. E. (Eds.). **Methods of soil analysis**. Part 3. Chemical methods. Madison: Soil Science Society of America, 1996. p. 961-1010.

NEVES, C. M. N. D.; SILVA, M. L. N.; CURI, N.; CARDOSO, E. L.; MACEDO, R. L. G.; FERREIRA, M. M.; SOUZA, F. S. D. Atributos indicadores da qualidade do solo em sistema agrossilvopastoril no noroeste do estado de Minas Gerais. **Scientia Forestalis**, Piracicaba, v. 74, p. 45-53, jun 2007.

ONWONGA, R. N.; LELEI, J. J.; MOCHOGE, B. B. Mineral nitrogen and microbial biomass dynamics under different acid soil management practices for maize production. **Journal of Agricultural Science**, North America, v. 2, n. 1, p. 16-30, Feb. 2010.

PATERSON, E. Importance of rhizodeposition in the coupling of plant and microbial productivity. **European Journal of Soil Science**, Oxford, v. 54, n. 4, p. 741-750, Oct. 2003.

PEREZ, K. S. S.; RAMOS, M. L. G.; MCMANUS, C. Carbono da biomassa microbiana em solo cultivado com soja sob diferentes sistemas de manejo nos Cerrados. **Pesquisa Agropecuária Brasileira**, Brasília, v. 39, n. 6, p. 567-573, Jun. 2004.

PEREZ, K. S. S.; RAMOS, M. L. G.; MCMANUS, C. Nitrogênio da biomassa microbiana em solo cultivado com soja, sob diferentes sistemas de manejo, nos Cerrados. **Pesquisa Agropecuária Brasileira**, Brasília, v. 40, n. 2, p. 137-144, Fev. 2005.

PIMENTEL, M. S.; DE-POLLI, H.; AQUINO, A. M. D.; CORREIA, M. E. F.; ROUWS, J. R. C. Bioindicators of soil quality in coffe organic cultivation systems. **Pesquisa Agropecuária Brasileira**, Brasília, v. 46, n. 5, p. 545-552, mai 2011.

PRATA, F.; LAVORENTI, A.; REGITANO, J. B.; TORNISIELO, V. L. Degradação e sorção de ametrina em dois solos com aplicação de vinhaça. **Pesquisa Agropecuária Brasileira**, Brasília, v. 36, n. 7, p. 975-981, jul 2001.

RICE, C. W.; MOORMAN, T. B.; BEARE, M. Role of microbial biomass carbon and nitrogen in soil quality. In: DORAN, J. W.; JONES, A. J. (Eds.). **Methods for assessing soil quality**. Madison: Soil Science Society of America, 1996. p. 203-215.

SANT'ANNA, S. A. C.; FERNANDES, M. F.; IVO, W. M. P. M.; COSTA, J. L. S. Evaluation of soil quality indicators in sugarcane management in Sandy Loam Soil. **Pedosphere**, Nanjing, v. 19, n. 3, p. 312-322, Jun. 2009.

SANTOS, V. B.; ARAÚJO, A. S. F.; LEITE, L. F. C.; NUNES, L. A. P. L.; MELO, W. J. Soil microbial biomass and organic matter fractions during transition from conventional to organic farming systems. **Geoderma**, Amesterdam, v. 170, p. 227-231, Jan. 2012.

SEARLE, S. R.; CASELLA, G.; McCULLOCH, C. E. Variance Components. **SAS Institute. Proc Mixed**. Release 9.1, 1992.

SILVA, R. R. D.; SILVA, M. L. N.; CARDOSO, E. L.; MOREIRA, F. M. D. S.; CURI, N.; ALOVISI, A. M. T. Biomassa e atividade microbiana em solo sob diferentes sistemas de manejo na região fisiográfica campos das Vertentes - MG. **Revista Brasileira de Ciência do Solo**, Viçosa, v. 34, n. 5, p. 1585-1592, out. 2010.
SOUZA, R. A.; TELLES, T. S.; MACHADO, W.; HUNGRIA, M.; TAVARES-FILHO, J.; GUIMARÃES, M. F. Effects of sugarcane havesting with burning on the chemical and microbiological properties of the soil. **Agriculture, Ecosystems and Environment**, Amesterdam, v. 155, p. 1-6, 2012.

SPARLING, G. P. Ratio of microbial biomass carbon to soil organic carbon as a sensitive indicator of changes in soil organic matter. **Australian Journal of Soil Research**, Collingwood, v. 30, n. 2, p. 195-207, 1992.

VAN VEEN, J. A.; MERCKX, R.; VAN DE GEIJN, S. C. Plant- and soil related controls of the flow of carbon from roots through the soil microbial biomass. **Plant and Soil**, v. 115, p. 179-188, 1989.

VANCE, E. D.; BROOKES, P. C.; JENKINSON, D. S. An extraction method for measuring soil microbial biomass C. **Soil Biology and Biochemistry**, Amesterdam,v. 19, n. 6, p. 703-707, 1987.

VITTI, A. C.; FRANCO, H. C. J.; TRIVELIN, P. C. O.; FERREIRA, D. A.; OTTO, R.; FORTES, C.; FARONI, C. E. Nitrogênio proveniente da adubação nitrogenada e de resíduos culturais na nutrição da cana-planta. **Pesquisa Agropecuária Brasileira**, Brasília, v. 46, n. 3, p. 287-293, mar. 2011.

WARDLE, D. A. Metodologia para quantificação da biomassa microbiana do solo. In: HUNGRIA, M.; ARAÚJO, R. S. **Manual de métodos empregados em estudos de microbiologia agrícola**. Brasília: Empresa Brasileira de Pesquisa Agropecuária, 1994. p. 542.

XAVIER, F. A. D. S.; MAIA, S. M. F.; OLIVEIRA, T. S. D.; MENDONÇA, E. D. S. Biomassa microbiana e matéria orgânica leve em solos sob sistemas agrícolas orgânico e convencional na Chapada da Ibiapa - CE. **Revista Brasileira de Ciência do Solo**, Viçosa, v. 30, n. 2, p. 247-258, mar/abr. 2006.