Australian Journal of Crop Science AJCS
AJCS 9(8):781-789 (2015) ISSN:1835-2707

Sugarcane residue incubated in soil at different temperatures and nitrogen fertilization

Risely Ferraz de Almeida[1*], Camila Haddad Silveira[2], Raquel Pinheiro da Mota[2], Everton Martins Arruda[2], Emmanuel Rezende Naves[2], Luma Castro de Souza[1], Eduardo de Sá Mendonça[3] and Beno Wendling[2]

[1]Agrarian and Veterinarian Faculty, São Paulo State University (FCAV/UNESP), Jaboticabal, SP, Brazil
[2]Institute of Agricultural Sciences, ICIAG, University Federal of Uberlandia - UFU, Uberlandia, MG, Brazil
[3]Department of Plant Production, University Federal of Espírito Santo-UFES, Alegre, ES, Brazil

***Corresponding author: rizely@gmail.com**

Abstract

The sugarcane residue deposited on the soil is an alternative source of nutrients, which can serve as a soil conditioner in soil conservation. The effects of sugarcane harvest systems, especially with the residue incorporated into, or left on the soil surface, and the resulting impact on the availability of plant nutrients are little known. The aim of this work was to study the influence of nitrogen fertilization (0 and 120 kg ha^{-1} of N) and the management of sugarcane residue (surface and incorporated) on the availability of nutrients in soils incubated at three temperatures (20, 25 and 30° C). It was concluded that there is an increase of 6.89 % N in the soil with the sugarcane residue incorporation, compared to the surface management. Total soil N increases were obtained with sugarcane residue, especially when incorporated and associated with nitrogen fertilization. There was no effect of the treatments on soil microbial biomass carbon content (S-MBC), labile carbon (Labile-C), calcium (Ca^{+2}), magnesium (Mg^{+2}) and phosphorus (P). Potassium is the nutrient that presents rapid mineralization from the residue into the soil. With the addition of the incorporated and soil surface residue there occurred increases in the final K^{+} mineralization of 42.05 % and 11.98 %, respectively.

Keywords: Carbon; C/N ratio; Immobilization; Nutrients; Straw; Latosol.
Abbreviations: Ca^{+2}_calcium; Mg^{+2}_magnesium; K^{+}_potassium; P_ phosphorus; pH_ pH meter of soil; C/N_ ratio carbon and nitogen; TN_total nitrogen (TN); qCO_2_metabolic coefficient; S-MBC_ microbial biomass carbon; Labile-C_carbon labile; TOC_Total organic carbon; Cmic:Corg_ ratio microbiology carbon and organic carbon; CO2_ cumulative CO2 emission; NH3_ ammonia; U_urease activity: BG_β-glucosidase; LAPED_laboratory of Pedology; FADS_Fine Air-Dried Soil; WRC_water retention capacity; H + Al_ potential acidity; CDR_randomized design; PVC_ vase polyvinyl chloride); FAPEMIG_Fundação de Amparo à Pesquisa do Estado de Minas Gerais; CAPES_Coordenação de Aperfeiçoamento de Pessoal de Nível Superior; CNPQ_Conselho Nacional de Desenvolvimento Científico e Tecnológico.

Introduction

Brazil is the largest producer of sugarcane, as well as sugar derivatives and ethanol (Goldemberg, 2007). In the 2008/2009 crop, production for industry had a volume of approximately 392 million Mg of stalk (Caser et al., 2008). In the 2009/2010 crop that amount almost doubled to approximately 605 million t in 7.4 million ha (Benett et al., 2012). The production is growing due to territorial expansion, driven mainly by the consumption of ethanol in the domestic market and the good sugar prices in the international market (Marin et al., 2011) increased availability of cultivars .and cultivation practices (Souza et al, 2005). Mechanized sugarcane harvesting in Brazil has become one of the main crop managements after the reduction of burning and prohibition of the use of fire as a residue removal method and cutting facilitator in manual harvesting by the year 2021. Mechanized harvesting provides the deposition of 3.6 to 11.0 Mg ha^{-1} of dry matter (Silva Neto et al., 2013) remaining on the soil surface (Panosso et al., 2009; Flores et al., 2012) forming a thickness of 8 to 10 cm (Silva Neto et al., 2013), consisting of dry stalks, pointers and green leaves (Oliveira et al.,1999b). Maintaining this sugarcane residue adds nutrients and improves soil fertility, mainly due to increased availability of calcium (Ca^{+2}), magnesium (Mg^{+2}) and potassium (K^{+}) (Oliveira et al., 1999a), besides contributing to carbon storage in the soil, in a process called soil carbon sequestration (Galdos et al., 2009; Ussiri and Lal, 2009). However, the nutrient liberation rate from the residue depends on activity of soil microorganisms (enzyme activity), for example urease (Balota and Chaves, 2010) and β-glucosidase (Evangelista et al., 2012), and edaphoclimatic factors such as temperature (Almeida et al., 2014), humidity (Oliveira et al., 1999b), oxygen (Panosso et al., 2009), pH of soil (Fuentes et al., 2006), texture (Dilustro et al., 2005), as well as the characteristics inherent in the residue, such as C/N ratio, lignin, cellulose, hemicellulose and polyphenols (Johnson et al., 2008). The C/N ratio is related to N immobilization or mineralization in the soil. The residue from sugarcane has a high C/N ratio, ranging from 90-120, promoting immobilization of total nitrogen (TN) in the absence of N fertilization (Meier et al., 2006; Almeida et al., 2014). To meet the need for TN, the application of 120 kg ha^{-1} of N per cane plant crop is recommend and in the three subsequent ratoons there is a linear response to the nitrogen fertilization with an average productivity of 100 Mg ha^{-1} of stalks, about 1.0 kg of N per Mg of stalk expected (Vitti et al., 2007b). This study aimed to assess the impact of incub-

Table 1. Nutritional characterization of sugarcane residue and chemical and physical attributes of a dystrophic Red Yellow Latosol used in the experiment.

Characteristics*	Soil	Residue
Sand (g kg^{-1})	630	-
Silt (g kg^{-1})	140	-
Clay (g kg^{-1})	230	-
pH (H_2O)	5.6	-
TN (g kg-^{1})	0.69	1.44
TOC (g kg^{-1})	7.40	142
C/N Ratio	-	99.0
P (mg dm^{-3})	2.47	0.8
K^+ (mg dm^{-3})	208.00	9.0
Mg^{2+} ($cmol_c$ dm^{-3})	0.60	1.3
Ca^{2+} ($cmol_c$ dm^{-3})	2.20	5.4
H+Al ($cmol_c$ dm^{-3})	2.20	-
Sum of Bases (SB)	3.33	-

*In table: pH (hydrogenionical potential); NT (total nitrogen); TOC (total organic carbon); C/N (carbon nitrogen ratio); P (phosphorous); K^+ (potassium); Mg^{+2} (magnesium); Ca^{+2} (calcium); H+Al (potential acidity).

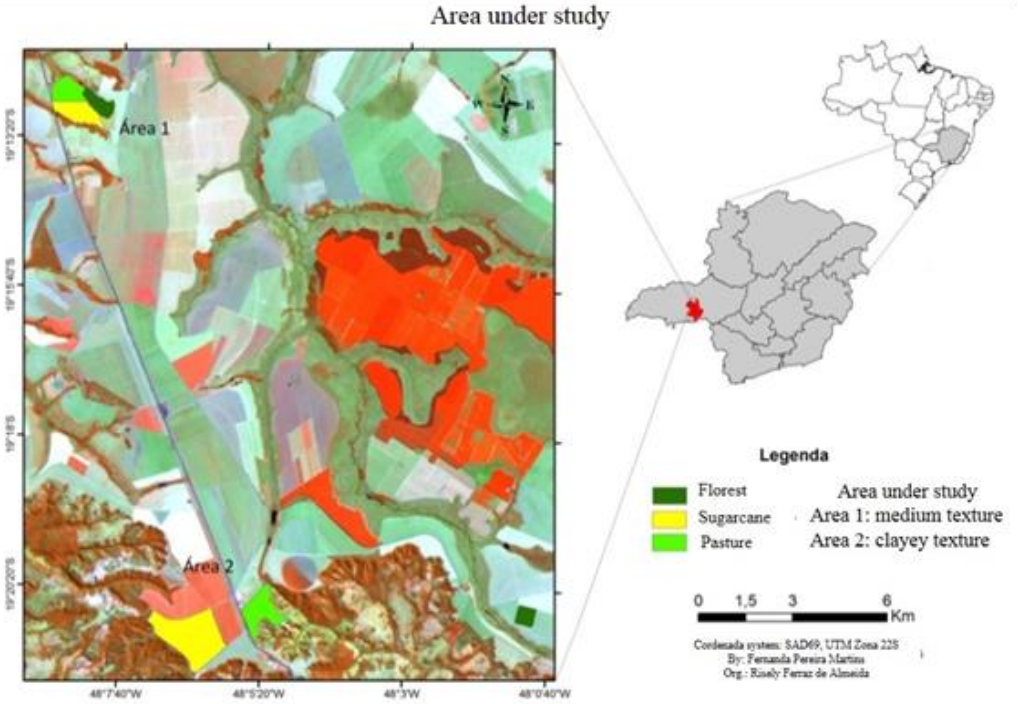

Fig1. Location of soil collection in the sugarcane cultivation area (Area 1) located between the municipalities of Uberlândia - Uberaba, State of Minas Gerais, Brazil.

ation temperature (20, 25 and 30° C) and nitrogen fertilization (0 and 120 kg ha^{-1} of N) on the decomposition rate of sugarcane residue and nutrients when the residue is incorporated into or ramains on the soil surface.

Results and Discussion

Compartments of carbon

The accumulated metabolic coefficient (qCO_2) of the soil after the incubation period showed an oscillation between 0.47 to 0.72 (Fig 2), a result below that estimated as critical. According to Anderson and Domsch (1990) qCO_2 values greater than 2.0 indicate a less efficient soil microbial community. Elevated qCO_2 values are indicative of ecosystems subjected to some stress condition or disorder (Moreira and Siqueira, 2006). Thus, in our study, the metabolic coefficient shows that the soil and the active microbiota are efficient and environmentally sound.

Among the treatments, the qCO_2 grew by 27.27 % in the management of the residue incorporated into the soil when compared to maintaining the residue on the soil surface (Fig 2). There was also a 29.85 % qCO_2 increase with the addition of nitrogen to the soil compared to that without N. There was a distinction between the managements with the addition N and the incorporation of sugarcane residue to the soil due to high SMB activity throughout the experiment. These results are in agreement with those obtained by Gomide et al. (2011), who showed that qCO_2 decreases in more established systems, since under stable conditions less energy consumption is indicated (Cunha et al., 2011). At 79 DAI the S-MBC, Labile-C and soil TOC did not differ among treatments. These results are associated with reduced availability of nutrients in the substrate and at the end of the incubation period (Step, 2000) because there is an increase in CO_2 emissions in the early days of incubation with substrate and addition of nutrients in the soil, with subsequent decrease of the biological activity and labile soil (Almeida et al, 2014; Guillou et al, 2011; Cayuela et al., 2009). The carbon labile

Table 2. Content in soil of labile carbon (Labile-C), total organic carbon (TOC), microbial biomass carbon (S-MBC), accumulated emission, after 79 days of incubation, of cumulative CO_2 (CO_2) and the biomass C (Cmic) and total organic carbon (C org) ratio in soil incubated for 79 days.

	Labile-C [1]	TOC[1]	MBC[1]	CO_2[2]	Cmic: Corg[2]
	----- g kg^{-1} -----		µg g^{-1}		
Residue Management					
Surface	5.05	12.95	238.30	116.55 B	2.58 A
Incorporated	4.77	14.71	289.07	126.22 A	1.63 B
MSD:	0.79	1.44	80.32	0.15	0.28
Nitrogen Fertilization					
0 kg ha^{-1}	5.11	13.68	245.22	103.27 B	2.15 A
120 kg ha^{-1}	4.72	13.98	282.15	139.50 A	2.06 A
MSD:	0.79	1.44	80.32	0.15	0.150
Temperatures					
20 °C	4.66	13.02	285.11	85.00 C	2.60 A
25 °C	5.25	15.38	29914	121.66 B	1.33 B
30 °C	4.83	13.09	30681	157.50 A	2.38 AB
MSD:	1.17	2.13	119.08	0.22	0.15
CV:	23.49	21.06	44.28	38.72	43.0

In the table cumulative CO_2 emission after 79 days of incubation; CV: coefficient of variation and MSD: Minimum significant difference; [2] The variables were significantly different. Expressed in µ mol of CO_2 m^{-2} s^{-1}. For CO_2 emission and Cmic:Corg, averages accompanied by different upper-case letters in the column are different by the Tukey test ($p \leq 0.05$). [1] The variables were not significantly different by Tukey test ($p \leq 0.05$).

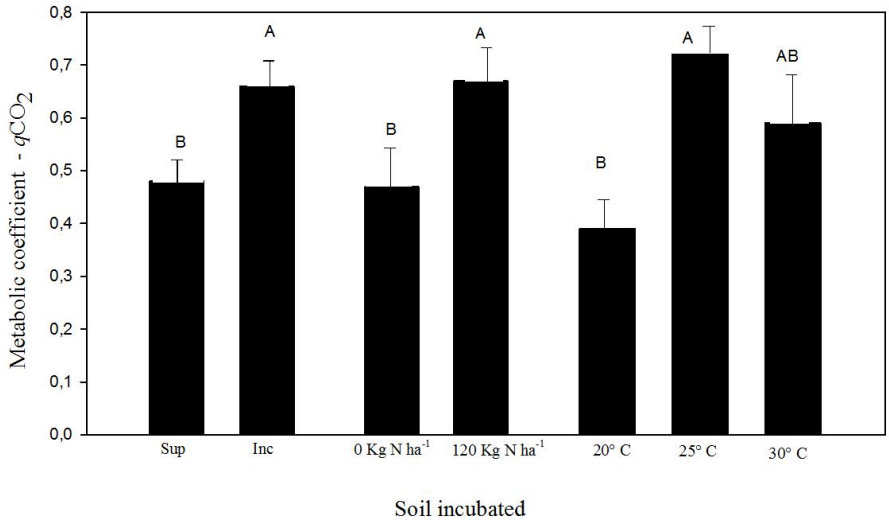

Fig 2. Metabolic coefficient - qCO_2 (µg g^{-1}/ µ mol of CO_2 m^{-2} s^{-1}) in soils incubated with sugarcane residue in incorporated and surface managements, associated with N fertilizer doses of 0 kg N ha^{-1} and 120 kg ha^{-1} at (20°; 25° and 30° C). For qCO_2 in the management of residue on the soil, bars identified with different capital letters differ by the Tukey test ($P \leq 0.05$). Data: CV: 38.72 and MSD $_{residue}$: 0.15; MSD $_{Temperature}$: 0.22; MSD $_{nitrogen\ fertilization}$: 0.15.

fractions in the soil are highly correlated with CO_2 emissions (qCO_2) (Almeida et al., 2014; Panosso et al., 2009; Passos et al., 2007), and the high influence on the quantity of organic material present in the soil (Roscoe et al., 2006; Wendling et al., 2014). The S-MBC showed concentrations between 1.33 to 2.58 % TOC (Cmic:Corg), with higher increases in systems with the residue maintained on the soil surface, contributing to lower residue decomposition (cumulative CO_2 emission), i.e., maintaining plant material on the soil surface for a longer period (Table 2). This Cmic:Corg proportion indicates the contribution of the SMB to the TOC and also the availability of the substrate to the soil microflora (Anderson and Domsch, 1990).

Nitrogen in soil and residue

The management sugarcane residue incorporated into the soil contributed to a 6.89 % increase in soil TN in relation to the residue maintained on the surface (Fig 3), besides the availability of 20.68 % and 14.81 % of TN in relation to the initial content on the soil surface and that incorporated, respectively, in the residue managements (Fig 3 and Table 1). The TN increase in soil with managements with sugarcane residue addition was also found by Faroni et al. (2003), who verified increases from 3 to 30 % mineralized N for the next cycle of the crop under field conditions. According to Vitti et al. (2008), it is noted that in treatments with N as urea, the liberation of total N from the residue is similar to the treatment fertilized with N, whereas in the control treatment (no N addition) the N liberation from residue is low.Nitrogen fertilization in consortium with residue incorporation led to TN immobilization in the residue and N increase of 38.9 %, when compared to treatment without the addition of 120 kg ha^{-1}of N (Table 3). There were also increases in TN contents in the residue at different temperatures when in consortium with the addition of 120 kg ha^{-1}of N, respectively 21.6; 32.9 and 32.0 % at 20, 25 and 30° C (Table 3). The effect of N addition on the TN content of the residue was expected, since the sugarcane residue initially presented a C/N ratio of 99.0 (Table 1). However, in field conditions the C/N is increased

Table 3. Total nitrogen (TN) content in g kg^{-1} soil in the sugarcane residue in incorporated and surface soil managements associated with N fertilizer doses of 0 and 120 kg ha^{-1} at three different temperatures (20, 25 and 30° C), after 79 days in incubated soils.

	Nitrogen Fertilization	
	0 kg ha^{-1} of N	120 kg ha^{-1} of N
Residue management		
Surface	1.21 Ab	1.49 Ba
Incorporated	1.08 Ab	1.77 Aa
MSD: 0.14		
Incubation temperature		
20 °C	1.12 Ab	1.43 Ba
25 °C	1.26 Ab	1.88 Aa
30 °C	1.06 Ab	1.59 Ba
MSD: 0.20		
CV: 10.43		

In the table: CV: coefficient of variation and MSD: Minimum significant difference. Averages accompanied with upper-case letters in the column (Interaction Management of residue with nitrogen fertilization) and lower-case in the line (Interaction Management of residue with temperatures) when distinct, differ by the Tukey test (P≤ 0.05).

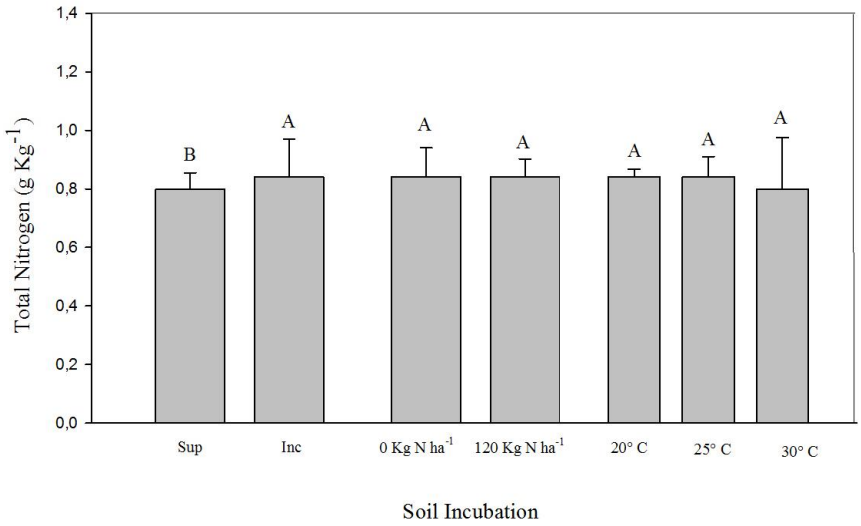

Fig 3. Total nitrogen (TN) in the soil (g kg^{-1}) with incorporated (Inc) or surface (Sur) managements of sugarcane residue, in consortium with nitrogen fertilization (0 kg N ha^{-1} and 120 kg N ha^{-1}) and different temperatures (20, 25 and 30° C). For N in the management of residue on the soil, bars identified with different capital letters differ by the Tukey test (P≤ 0.05). Data: CV: 10.02 and MSD $_{residue}$: 0.05; MSD $_{Temperature}$: 0.85; MSD $_{nitrogen\ fertilization}$: 0.05.

due to the presence of stem pieces from mechanical harvesting, which increase the C/N ratio: N, decreasing the mineralization rate (Vitti et al., 2008) and probably increasing immobilization of N from the plant material. It is considered that the C/N ratio in the range from 10 to 12:1 lowers and provides the N release from soil organic matter and for organic waste, from 25 to 35:1 there occurs decomposition without immobilization of soil N (Ambrosano et al., 2011). Residues that have high C/N ratio provide immobilization of soil N in the residue (Vitti et al., 2008). A high contact surface between the fertilizer and the residue contributes to the immobilization of microbial N. Moreover, the residue, promoting ureolytic activity, also favors the NH_3 loss, by functioning as a barrier between the N-fertilizer and soil, causing the NH_3 product of the urea hydrolysis to remain together with the crop debris (Vitti et al., 2007a). With the immobilization of the soil TN in the residue there occurred decreases in the residue C/N ratio (Table 4) and negative soil C/N ratio correlation with S-MBC (r = -0.35 **), Table 5, thus verifying that the activity of the SMB was affected by the reduction of soil N availability. These conditions are due to the TN immobilization in the residue (Oliveira et al., 1999b) and the C loss via CO_2 emission from the microbial respiration (Table 2).

Enzymatic activity in soil

The urease activity (U) showed a concentration between 0.10 and 0.14 of S-MBC. With the incorporated residue associated with the addition of 120 kg ha^{-1} there was 39.89 % increase in enzymatic activity of the urease compared to the same treatment, but without the N addition (Table 6). The results of this study were therefore consistent with other studies reporting that urease activity was significantly affected by different soil management systems (Balota and Chaves, 2010; Longo and Melo, 2005). This occurred because the urea contributed to increase the U activity in the soil (Lanna et al., 2010), since this enzyme participates in the hydrolysis reaction of urea to NH3 and CO2, which is a fundamental process for the supply of nitrogen to plants after the mineral fertilization (Balota and Chaves, 2010). The β-glucosidase (BG) activity increased by 37 % in the incorporated residue management in relation to the surface management, besides the BG activity decreases with increasing incubation temperatures. The BG concentration in the SMB also followed this trend with higher concentrations in the incorporated residue (Table 6). This occurred because in residue maintenance systems there is the addition of organic matter in the soil and BG activity is higher because of the

Table 4. pH (H2O), calcium (Ca^{+2}), magnesium (Mg^{+2}) and phosphorus (P) and carbon nitrogen ratio (C/N) in the soil and total organic carbon (TOC) and C/N ratio of residue after 79 days of incubation of soils with sugarcane residue in incorporated and surface soil managements associated with N fertilizer rates of 0 and 120 kg ha^{-1} of N at three temperatures (20, 25 and 30° C) after 79 days in incubated soils.

	Soil pH (H_2O)**	Ca^{+2}(2)	Mg^{+2}*	P(1)	C/N(2)	Residue TOC(2)	C/N(2)
	$cmol_c\ dm^{-3}$			$mg\ dm^{-3}$	$g\ Kg^{-1}$		
Residue management							
Surface	5.4B	1.9A	0.8	3.0	9.6A	132.0A	84.4 B
Incorporated	5.9A	2.0A	0.9	2.9	10.2A	118.1B	101.0 A
MSD	0.04	0.32	0.19	42.58	0.98	6.98	10.56
Nitrogen fertilization							
0 kg N ha^{-1}	6.0A	6.0A	0.9	3.0	9.7A	121.1A	106.2A
120kg N ha^{-1}	5.3B	5.3B	0.8	2.9	10.1A	128.9A	81.1 B
MSD	0.01	0.32	0.19	63.13	0.98	6.98	10.56
Temperatures							
20° C	5.7A	2.0A	0.8	2.9	10.3A	127.3A	102.7A
25° C	5.6B	2.0A	0.9	3.0	10.8A	127.7A	83.3B
30° C	5.6B	2.0A	1.0	3.0	8.6B	120.1A	102.7AB
MSD	0.06	0.48	0.29	42.58	1.46	7.47	20.56
CV	10.9	23.57	31.49	16.94	14.42	12.5	11.5

In table: CV: coefficient of variation and MSD: Minimum significant difference. (1) The variables were not significantly different by Tukey test ($p \leq 0.05$). (2)The variables were significantly different by Tukey test ($p \leq 0.05$). For the residue TOC, C/N (Soil and Residue), Ca^{+2} and pH (H_2O) the averages accompanied with upper-case letters in the column, when distinct, are different by the Tukey test ($p \leq 0.05$).

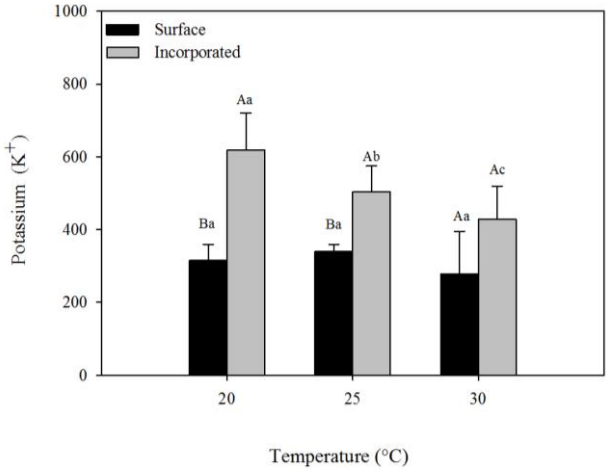

Fig 4. Soil Potassium (mg dm^{-3}) in the soil after incubation of the sugarcane residue in incorporated and surface managements at 20; 25 and 30° C. Bars identified with upper-case letters (residue management) and lower-case (temperature) when distinct, differ by the Tukey test ($P \leq 0.05$). Data: CV: 16.94 and $MSD_{residue}$: 73.75, $MSD_{Temperature}$: 89.28.

higher amount of substrate (Piotrowska and Koper, 2010), since BG is a widely distributed enzyme in nature and operates in the degradation of organic matter in the carbon cycle (Evangelista, 2012). Successive harvests and residue maintenance in soil with high C:N ratio (Table 1), cane sugar straw for example, contributed to increase the activity of this enzyme (Evangelista et al., 2012). In the pulp decomposition process the BG acts in the final stage promoting the hydrolysis of the residue, important sources of energy for soil microorganisms (Silva and Gouveia, 2008). Abiotic factors such as temperature and humidity affect the BG activity decreasing the enzyme activity (Zhang et al., 2011). The BG and U activity are thus considered good indicators, sensitive to change in crop management and may indicate in soil alterations (Matsuoka et al., 2003), as observed in the present experiment (Table 6).

Nutrients in soil

The incorporation of residue contributed to an average K^+ increase of 68.43 % in the soil in relation to the surface management at all incubation temperatures, except 30° C (Fig 4). With the addition of the incorporated and soil surface residue there occurred increases in the final K^+ availability of 42.05 % and 11.98 %, respectively, compared to the initial K^+ quantity in the soil (Table 1). Our results corroborate those reported by Oliveira et al. (1999a) and Oliveira et al. (1999b), who found a K^+ liberation of around 93 % with surface management in one year of cultivation. Rapid K^+ cycling is due to this element not being part of any plant structure and it being in an ionic form, which facilitates its release into the soil after plant tissue disruption (Malavolta et al., 1989). In addition, sugarcane has a high amount of K^+, since it is the nutrient most extracted by this species. There was no effect of the treatments on Ca^{+2}, Mg^{+2} and P (Table 4). However, they presented increases of 9.09; 31.14 and 16.47 %, respectively (Table 4) when compared to the existing initial contents in the soil (Table 1) and a negative correlation of Mg^{+2} with the labile C (r = - 0.37) and positive correlation of Mg^{+2} with Ca^{+2} (r = 0.88), Table 5. This correlation was verified by Coletto et al. (2015). The low amount of these elements available 79 days after incubation

Table 5. Correlation coefficient among the soil variables: Phosphorus (P), calcium (Ca^{+2}), magnesium (Mg^{+2}), C/N, nitrogen (N), total organic carbon (TOC), labile carbon (LC), soil microbial biomass (SMB), β-glucosidase (B), and urease (U).

	K	P	Ca^{+2}	Mg^{+2}	C/N	N	TOC	LC	SMB	B	U
pH	0.41*	0.18	0.04	0.31	0.03	0.08	0.08	0.01	-0.19	-0.00	-0.59*
K	-	0.28	0.06	0.4*	-0.06	0.18	0.17	-0.03	-0.33	0.53*	0.01
P	-	-	-0.09	0.02	-0.16	0.03	0.17	-0.05	-0.23	0.19	0.09
Ca^{+2}	-	-	-	0.88*	0.02	0.04	0.13	-0.43	-0.06	-0.07	-0.03
Mg^{+2}	-	-	-	-	-0.00	0.22	0.25	-0.37*	-0.15	0.15	-0.08
C/N	-	-	-	-	-	-0.30	0.07	-0.17	-0.35**	-0.19	-0.02
N	-	-	-	-	-	-	0.20	0.22	-0.09	0.23	0.10
TOC	-	-	-	-	-	-	-	-0.07	-0.03	0.22	0.13
LC	-	-	-	-	-	-	-	-	-0.21	-0.02	-0.09
B	-	-	-	-	-	-	-	-	-	-0.04	0.07
U	-	-	-	-	-	-	-	-	-	-	0.04

Variables are considered significant with $p \leq 0.05$. *Significant positive correlations. **Significant negative correlations.

Table 6. Urease (U) and β-glucosidase (BG) activity and their relationship to the microbial biomass (SMB) (U/SMB and BG/SMB) in soils with sugarcane residue in incorporated and surface managements, associated with N fertilizer rates of 0 kg N ha^{-1} and 120 kg N ha^{-1} at three different temperatures (20, 25 and 30° C) after 79 days in incubated soils

	U[1]		BG	U/SMB	BG/SBM
	0 kg ha^{-1}	120 kg ha^{-1}			
Residue management					
Surface	14.00 Bb	38.66 Aa	106.66 B	0.10 A	0.45 B
Incorporated	23.11 Aa	29.77 Ba	169.43 A	0.14 A	0.84 A
Nitrogen fertilization					
0 kg ha^{-1}	-	-	123.03 A	0.14 A	0.68 A
120 kg ha^{-1}	-	-	153.06 A	0.14 A	0.61 A
Temperatures					
20° C	-	-	171.67 A	0.11 A	0.78 A
25° C	-	-	155.79 B	0.14 A	0.85 A
30° C	-	-	86.67 C	0.10 A	0.31 B

In the table: Urease (U) expressed in μg NH_4^+ g^{-1} dry soil h^{-1} and (BG) in μg PNF g^{-1} dry soil h^{-1} [1]Dual interaction for urease variable (Residue management and nitrogen fertilization). Averages accompanied with upper-case letters in the column and lower-case in the line when distinct differ by the Tukey test ($P \leq 0.05$). For BG, U/SMB and BG/SMB averages accompanied by upper-case letters in the column, when distinct, are different by the Tukey test ($p \leq 0.05$).

of the soils is related to their function within the plant, as they are found bound to ionic and molecular compounds (Malavolta et al., 1989). The mineralization/liberation of Ca^{+2} and Mg^{+2} to the sugarcane residue soils in a crop cycle is about 44 % and 39 %, respectively (Oliveira et al., 1999a), and may reach 60 % of the total existing in the newly harvested cane residue for Ca^{+2} as well as Mg^{+2} (Oliveira et al., 1999b). The pH (H_2O) was negatively correlated with the urease activity (r = -0.59), Table 5, and the lower pH of the soil contributed to the increased urease activity. Lower pH values were obtained in soils with N fertilizer addition, while the highest occurred with the incorporated residue (Table 4). A reduction in soil pH with the addition of nitrogen fertilizers also observed by Mantovani et al. (2007). The correlation between pH and U is due to the hydrolysis reaction of nitrogen that consumes protons (H^+) which leads to the pH increase around the particles (Cantarella et al., 2007) Furthermore, in the soil with nitrogen fertilizer addition, the ammonium into nitrate transformation process also releases H^+ ions into the soil solution (Sá, 1999; Cantarella et al., 2007; Malavolta, 2006). With the incorporation of residue to the soil, biological activity is accelerated due to the larger contact area with the microorganisms, favoring higher base mineralization rates (Ca^{+2} and Mg^{+2}) for the soil solution and by the base cations promoting the increase in pH. Concurrently, in the initial organic matter decomposition phase the liberation of water-soluble, low molecular weight organic compounds occurs, which contributes to soil neutralization (Diehl et al., 2008).

Materials and Methods

Characterization of soil

The incubation experiment was conducted in the Pedology laboratory, LAPED, at the Federal University of Uberlandia. The soil in this study was collected on April, 2012, in a sugarcane cultivation area with dystrophic Red-Yellow Latosol with medium texture according to the Embrapa soil classification (2013) and located between the cities Uberlandia and Uberaba, Minas Gerais state, Brazil (19º13'00,22" S and 48º08'24,80" W), Fig 1. In area 1 with sugarcane (Fig 1), soil samples were collected in the 0 - 20 cm layer, at 5 different points, and in the laboratory the samples were mixed, air-dried and sieved (≤ 2 mm) to obtain the FADS (Fine Air-Dried Soil) and moistened up to 60 % of the water retention capacity (WRC) to start the experiment. The cut sugarcane residue was randomly collected in the same place as the soil samples, from 5 different points. The area was in its 3rd year of cultivation with plants at 1.5 m of height in April 2014. The residue was then dried at room temperature and fractionated to an average size of 1 cm² in the laboratory of LAPED. Part of soil and residue was targeted for chemical and physical attributes characterization in the Fertility laboratory at the Federal University of Uberlandia. For determining the soil texture we used the pipette method (Ruiz, 2005), for potassium (K^+), calcium (Ca^{+2}), magnesium (Mg^{+2}), potential acidity (H + Al), pH (H_2O) and available phosphorous (P), determination was according to Embrapa (1997). The total soil nitrogen (TN)

and that of the residue was determined according to the Kjeldahl (Embrapa, 1997) and total organic carbon (TOC) by Yeomans and Bremner (1988), Table 1.

Incubation of soil

The experiment was established in a completely randomized design (CRD) with a factorial 2x2x3, with three replicates, referring to 2 residue managements (surface and incorporated), two nitrogen doses (0 and 120 kg ha^{-1} of N) and three incubation temperatures (20, 25 and 30° C). The treatment with 0 kg ha^{-1} of N was control treatment. An amount of soil (700 g), reaching 13 cm were packed in a column in a PVC vase (polyvinyl chloride); height 15 cm, diameter 10.5 cm and a total volume of 1298.2 cm³, which was fixed on a polystyrene base properly insulated to prevent soil water loss. The treatments were added and incorporated to the soil in the amount corresponding to the recommendation of 120 kg ha^{-1} of N in the form of granulated urea. Subsequently, 17 g of sugarcane residue cut into pieces of about 1 cm² were added, corresponding to 20 Mg $ha^{-1}$of residue, incorporated in the soil in its respective vases, while in the surface management, the residue was placed on the soil surface. The standard dose of 120 kg ha^{-1} of N is recommended for cover fertilization for ratoon cane. The nitrogen fertilization can result in high crop productivity (Vitti et al., 2007b). Subsequently the assemblies were incubated in chambers at 20, 25 and 30° C. The majority of the soil microorganism activity is concentrated between 20-30° C, which provides growth and activity conditions for the mesophilic microorganisms, between 20-40° C (Moreira and Siqueira, 2006). The soil was maintained at 60 % of the water retention capacity (WRC) during the experiment by total weight difference because the soil water availability favors higher sugarcane crop production and microbial activity (Barros et al., 2012).

Variables analyzed

For P, Ca^{+2} and Mg^{+2} availability and pH in water (active acidity) in the soil, the methodologies recommended by Embrapa (1997) were used. To determine soil and residue total nitrogen (TN), the Kjeldahl method was used (Embrapa, 1997), and for the TOC the methodology described by Yeomans and Bremmer (1988). The microbial biomass carbon (S-MBC) was determined using the method described by Vance et al. (1987), using a microwave oven for irradiation of the samples (Islam and Weil, 1998). Meanwhile, the Labile C was determined according to Mendonça and Matos (2005). The cumulative CO_2 emission was obtained by the sum of the CO_2 collections on the 1st, 2nd, 3rd, 4th, 6th, 8th, 10th, 13th, 16th, 19th, 22nd, 25th, 28th, 31st, 34th, 37th, 44th, 51st, 58th, 65th, 72nd and 79th days after incubations (DAI) in incubator type BODs, using an Li-Cor 8100A infrared gas analyzer (IRGA). The Irga has a closed system with an internal volume of 854.2 cm^3 and soil contact area of 83.7 cm² (Li-Cor Inc. Linclon, NE, USA). The system chamber quantifies the CO_2 concentration within it by infrared absorption spectroscopy. Having the daily emission values, the total cumulative CO_2 emission at 79 DAI was obtained. We then calculated the qCO_2, through the ratio of CO_2 emissions and the S-MBC in the same period, following the recommendations of Anderson and Domsch (1990). The β-glucosidase enzymatic activity was measured in PNG solution (nitrophenyl-β-D-glucopyranoside) and calcium chloride (Eivazi and Tabatai, 1988) and the urease activity in $KMnO_4$ solution (Guan, 1986). Both activities were quantified by spectrophotometry.

Statistical analysis

Variable variability was calculated by first determining descriptive statistics such as mean, standard deviation, minimum, maximum and median. Normality assumptions were evaluated by the Shapiro-Wilk test (SPSS Inc., USA) and variance homogeneity by the Bartlett test (SPSS Inc., USA). Based on these, the H0 hypothesis was accepted without data transformation. Next, the data was tested by the F-test with analysis of variance. When the H0 hypothesis was rejected and H1 accepted, the means were compared by the Tukey test at 5 % probability (Sisvar Inc., Brasil). The variables were correlated by the Pearson linear correlation test (Sigma-plot In., USA) considering the correlations significant ($p \leq 0.05$).

Conclusions

The incorporation of sugarcane residue to the soil contributes to increase total N in the soil and immobilization in the residue. With the addition of the incorporated and soil surface residue caused increases in the final K^+ mineralization of 42.05 % and 11.98 %, respectively. While for Ca^{+2}, Mg^{+2} and P, there is no meaningful distinction in relation to the treatments. Higher CO_2 emissions occur with lower Cmic:C-org in the soil.

Acknowledgement

The authors would like to thank the following Brazilian institutions for their financial support: Fundação de Amparo à Pesquisa do Estado de Minas Gerais (FAPEMIG), Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES), Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq).

References

Almeida RF, Silveira CH, Mikhael JER, Franco FO, Ribeiro BT, Ferreira AS, Mendonça ES, Wendling B (2014) CO2 emissions from soil incubated with sugarcane straw and nitrogen fertilizer. Afr J Biotechnol. 13:3376-3384.

Ambrosano EJ, Cantarella H, Ambrosano GMB, Schammas EA, Dias FLF, Rossi F, Trivelin PCO, Muraoka T, Sachs RCC, Azcón R (2011) Produtividade da cana-de-açúcar após o cultivo de leguminosas. Bragantia 70(4): 810-818.

Anderson TH, Domsch KH (1990) Application of eco-physiological quotients (qCO2 and qD) on microbial biomasses from soils of different cropping histories. Soil Biol Biochem. 22(1): 251–255.

Balota E L, Chaves JCD (2010) Enzymatic activity and mineralization of carbon and nitrogen in soil cultivated with coffee and green manures. Revista Brasileira de Ciência do Solo. 34(5): 1573-1583.

Barros AC, Coelho RD, Marin FR, Polzer DL, Aguiar Netto AO (2012) Utilização do modelo CANEGRO para estimativa de crescimento da cana-de-açúcar irrigada e não irriga da para as regiões de Gurupi–TO e Teresina–PI. Revista Irriga. 17(2): 189-207.

Benett CGS, Buzetti S, Silva KS, Teixeira Filho MCM, Garcia CMP, Andreotti M (2012) Fontes e doses de manganês no acúmulo de nutrientes na palha em cana-de-açúcar. Revista Bioscie J. 28: 8-16.

Cantarella H (2007) Nitrogênio. In: Novais R F, Alvarez V V H, Barros N F, Fontes R L F, Cantarutti R B, Neves J C L (eds.), Fertilidade do Solo. Sociedade Brasileira de Ciência do Solo, Viçosa/MG, p. 376-449.

Caser DV et al (2008) Previsões e estimativas das safras agrícolas do Estado de São Paulo, ano agrícola 2008/09, 2º levantamento, novembro de 2008. Revista Informações Econômicas. 39(2): 90.

Cayuela ML, Sinicco T, Mondini C (2009) Mineralization dynamics and biochemical properties during initial decomposition of plant and animal residues in soil. Appl Soil Ecol. 41(1) 118–127.

Coletto A F, De-Almeida R F, Mikhael J E R, Wendling B, Camargo R. (2015) Chemical attributes of soil fertirrigated with biodigester effluent of swine origin. Aust J Crop Sci. 9(5): 431-437

Cunha EQ, Stone LF, Ferreira EPB, Didonet AD, Moreira JAA, Leandro WM (2011) Sistemas de preparo do solo e culturas de cobertura na produção orgânica de feijão e milho. II - Atributos biológicos do solo. Revista Brasileira de Ciência do Solo. 35(2): 603-611.

Diehl RC, Miyazawa M, Takahash HW (2008) Compostos orgânicos hidrossolúveis de resíduos vegetais e seus efeitos nos atributos químicos do solo. Revista Brasileira de Ciência do Solo. 32:2653-2659.

Dilustro J J, Collins B, Duncan L, Crawford C (2005) Moisture and soil texture effects on soil CO2 efflux components in southeastern mixed pine forests. Forest Ecol Manag. 204(1): 87-97.

Eivazi F, Tabatai MA (1988) Glucosidase and galactosidases in soils. Soil Biol Biochem. 20(1): 601-606.

Embrapa - Empresa Brasileira de Pesquisa Agropecuária (2013) Sistema Brasileiro de Classificação de Solos. 3 ed. rev. ampl. Brasília, DF: Embrapa, 353p.

Embrapa. Centro Nacional de Pesquisa de Solos (1997). Manual de métodos de análise de solo. 2.ed. Rio de Janeiro, 212 p.

Evangelista CR, Partelli FL, Ferreira EPB, Correchel V (2012) Atividade enzimática do solo sob sistema de produção orgânica e convencional na cultura da cana-de-açúcar em Goiás. Revista Semina: Ciências Agrárias. 33(4): 1251-1262.

Faroni CE, Vitti AC, Gava GJC, Manzoni CS, Penatti CP, Trivelin PCO (2003) Degradação da palha (15N) de cana-de-açúcar em dois anos consecutivos. In: CONGRESSO BRASILEIRO DE CIÊNCIA DO SOLO, 29., Ribeirão Preto, 2003. Anais... Ribeirão Preto, UNESP/SBCS, CD ROM.

Flores RA, Prado RM, Politi LS, De Almeida TBF (2012) Potássio no desenvolvimento inicial da soqueira de cana crua. Revista Pesquisa Agropecuária Tropical. 42(1): 106-111.

Fuentes J P, Bezdicek D F, Flury M, Albrecht S, Smith J L. (2006) Microbial activity affected by lime in a long-term no-till soil. Soil Tillage Research. Amsterdam 88(2): 123-131.

Galdos MV, Cerri CC, Cerri CEP (2009) Soil carbon stocks under burned and unburned sugarcane in Brazil. Geoderma. 153(1): 347-352.

Goldemberg J (2007) Ethanol for a sustainable energy future. Science. 315 (5818): 808-810.

Gomide PHO, Silva MLN, Soares CRFS (2011) Atributos físicos, químicos e biológicos do Solo em ambientes de voçorocas no município de lavras – MG. Revista Brasileira Ciência do Solo. 35(2): 567-577.

Guan SY (1986) Soil Enzymes and is methodology. Agricultury Press, Beijing. pp 274-340 (in Chinese).

Guillou C L, Angers D A, Leterme P, Menasseri-Aubry S (2011) Differential and successive effects of residue quality and soil mineral N on water-stable aggregation during crop residue decomposition. Soil Biol Biochem. 43(1): 1955-1960.

Islam KR, Weil RR (1998) Microwave irradiation of soil for routine measurement of microbial biomass carbon. Biol Fertil Soil. 27(4): 408-416.

Johnson MS, Lehmann J, Riha SJ, Krusche AV, Richey JE et al (2008) CO_2 efflux from Amazonian headwater streams represents a significant fate for deep soil respiration. Geophys Res Lett. 35(17): 17401.

Lanna AC, Silveira PM, Silva MB, Ferrares TM, Kliemanniv HJ (2010) Atividade de urease no solo com feijoeiro influenciada pela cobertura vegetal e sistemas de plantio. Revista Brasileira Ciência Solo. 34(6):1933-1939.

Longo RM, Melo WJ (2005) Atividade da urease em Latossolos sob influência da cobertura vegetal e da época de amostragem. Revista Brasileira Ciência Solo. 29 (4): 645-650.

Malavolta E, Vitti GC, Oliveira AS (1989) Avaliação do estado nutricional das plantas: princípios e aplicações. Associação Brasileira para Pesquisa da Potassa e do Fosfato, Piracicaba, 201p.

Malavolta E (2006) Manual de nutrição mineral de plantas. São Paulo: Ed. Agronômica Ceres. 638p.

Mantovani A, Ernani PR, Sangoi L (2007) A adição de superfosfato triplo e a percolação de nitrogênio no solo. Revista Brasileira de Ciência do Solo. 31(5):887-895.

Marin FR, Jones JW, Royce F, Suguitani C, Donzeli JL, Pallone Filho WJ, Nassif DSP (2011) Parameterization and evaluation of predictions of DSSAT/CANEGRO for sugarcane brazilian production systems. Agron J. 103(2): 304-315.

Matsuoka M, Mendes I C, Loureiro M F (2003) Biomassa microbiana e atividade enzimática em solos sob vegetação nativa e sistemas agrícolas anuais e perenes na Região de Primavera do Leste. Revista Brasileira de Ciência do Solo. 27(3): 425-433.

Meier EA, Thorburn PJ, Wegener MK, Basford KE (2006) The availability of nitrogen from sugarcane residue on contrasting soils in the wet tropics of North Queensland. Nutr Cycl Agroecosys. 75(1): 101-114.

Mendonça ES, Matos ES (2005) Matéria orgânica do solo; métodos de análises. Viçosa: Universidade Federal de Viçosa, 107 p.

Moreira FM de S, Siqueira JO (2006) Microbiologia e Bioquímica do Solo. 2.ed. atual. e ampl. Lavras: UFLA, 729 p.

Oliveira MW, Trivelin PCO, Gava GJC, Penatti CP (1999b) Degradação da palha de cana-de-açúcar. Scientia Agricola. 56(4):803-809.

Oliveira MW, Trivelin PCO, Penatti CP, Piccolo MC (1999a) Decomposição e liberação de nutrientes da palha de cana-de-açúcar em campo. Pesquisa Agropecuária brasileira. 34(12): 2359-2362.

Panosso AR, Marques J, Pereira GT, La Scala N (2009) Spatial and temporal variability of soil CO_2 emission in a sugarcane area under green and slash-and-burn managements. Soil Till Res. 105(2):275-282.

Passos RR, Ruiz HA, Mendonça ES, Cantarutti RB, De Souza RP (2007) Substâncias húmicas, atividade microbiana e carbono orgânico lábil em agregados de um Latossolo vermelho distrófico sob duas coberturas vegetais Revista Brasileira Ciência do Solo. 31(5): 1119-1129.

Piotrowska S, Koper J (2010) Soil Beta-glucosidase activity under Winter wheat cultivated in crop Rotation systems

depleting and enriching the soil in organic matter. J Elementol. 15 (3): 593-600.

Ruiz H A (2005) Incremento da exatidão da análise granulométrica do solo por meio da coleta da suspensão (silte + argila). Revista Brasileira de Ciência do Solo. 29 (2): 297-300.

Roscoe R et al (2006) Biomassa Microbiana do Solo: Fração mais Ativa da Matéria Orgânica. In: ROSCOE, R.; MERCANTE, F. M.; SALTON, J. C. Dinâmica da Matéria Orgânica do Solo em Sistemas Conservacionistas: modelagem matemática e métodos auxiliares. Dourados – MS, Embrapa Agropecuária Oeste, 2006, 163-198 p.

Sá J CM (1999) Manejo da fertilidade do solo no sistema plantio direto. In: Siqueira JO et al. Inter-relação fertilidade, biologia do solo e nutrição do solo. Viçosa: SBCS, Lavras: UFLA/DCS, Cap.2, p.267–319.

Souza Z M, De Prado R M, Paixão ACS, Cesarin LG (2005) Sistemas de colheita e manejo da palhada de cana-de-açúcar. Pesquisa Agropecuária Brasileira. 40(3): 271-278.

Silva JC, Gouveia ER (2008) Algumas propriedades de endoglucanases produzidas por *Streptomyces* spp. em meio à base de bagaço de cana-de-açúcar. Revista Brasileira de Tecnologia Agroindustrial. 2(2): 60-70.

Silva Neto HF, Homem BFM, Tasso Junior LC, Marques MO (2013) Produção de palha por cultivares de cana-de-açúcar RB E CTC e potencial controle de plantas daninhas. Revista de Biologia e Ciências da Terra. 13(1): 116-120.

Ussiri AN, Lal R (2009) Long-term tillage effects on soil carbon storage and carbon dioxide emissions in continuous corn cropping system from an alfisol in Ohio. Soil Till Res. 104(1):39-47.

Vance ED, Brookes PC, Jenkinson DS (1987) An extraction method for measuring soil microbial biomass-C. Soil Biol Biochem. 19(6): 703-707.

Vitti AC, Trivelin PCO, Cantarella H, Franco HCJ, Faroni CE, Ottovi R, Trivelin MO, Tovajar JG (2008) Mineralização da palha e crescimento de raízes de cana-de-açúcar relacionados com a adubação nitrogenada de plantio. Revista Brasileira de Ciência do Solo. 32(1): 2757-2762.

Vitti AC, Trivelin PCO, Gava GJC, Franco HCJ, Bologna IR, Faroni CE (2007a) Produtividade da cana-de-açúcar relacionada à localização de adubos nitrogenados aplicados sobre os resíduos culturais em canavial sem queima. Revista Brasileira de Ciência do Solo. 31(1): 491-498.

Vitti AC, Trivelin PCO, Gava GJC, Penatti CP, Bologna IR, Faroni CE, Franco HCJ (2007b) Produtividade da cana-de-açúcar relacionada ao nitrogênio residual da adubação e do sistema radicular. Revista Pesquisa Agropecuária Brasileira. 42(3): 249-256.

Yeomans JC, Bremner JM (1988) A rapid and precise method for routine determination of organic carbon in soil. Comm Soil Sci Plant Anal. 19(13):1467-1476.

Zhang Y, Chen L, Wu Z, Sun C (2011) Kinetic parameters of soil β-glucosidase response to environmental temperature and moisture regimes. Revista Brasileira de Ciência do Solo. 35(4): 1285-1291.

Wendling B, Jucksch I, Mendonça E S, De-Almeida R F, Martins C E; Domingues L A S. (2014) Simulação dos efeitos do uso e manejo sobre os compartimentos da matéria orgânica no solo no bioma da florestal atlântica, Brasil Biosci J. 30:5 1278-1290.