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ORIGINAL ARTICLE

Physicochemical properties of soil and biomass in sugarcane harvesting systems

Atributos físicos, químicos do solo e biomassa em sistemas de colheita de cana-de-açúcar

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ABSTRACT: The different crop management systems used and the intense traffic of machines have caused physical and chemical changes in soils cultivated with sugarcane. In this study, we aimed to evaluate the yield of dry biomass and the changes in physicochemical properties of soils under green and burned sugarcane harvesting in Uberaba, state of Minas Gerais, Brazil. The following soil attributes were evaluated: dry biomass, aggregate stability, resistance to penetration measured by impact penetrometer, density, moisture, and chemical properties. The yield of dry biomass in the area of green sugarcane was seventeen times higher compared with the yield from the area of burned cane. The aggregates formed in the areas of green and burned sugarcane are quite stable in water and were mostly retained on 2.00 and 1.00 mm sieves. The highest level of aggregation occurred up to the depth of 0.05 m in all treatments. The soil presents a compacted layer, which was caused by the intense traffic of transshipment machines, between the depths of 0.20 and 0.30 m in the areas of green and burned cane. Values of penetration resistance and bulk density increased significantly and simultaneously up to the depth of 0.30 m. Significant lower values of pH and phosphorus in depth were found in the area where green sugarcane was harvested.

KEYWORDS
Aggregate stability
Density and soil humidity
Resistance to penetration

RESUMO: *O sistema de colheita e o tráfego intenso de máquinas têm causado alterações físicas e químicas nos solos cultivados com cana. Objetivou-se avaliar a produção de biomassa seca e as alterações nos atributos físicos e químicos do solo sob colheita de cana crua e cana queimada em Uberaba-MG. Avaliaram-se os seguintes aspectos: biomassa seca; estabilidade dos agregados; resistência à penetração com penetrômetro de impacto; densidade do solo; umidade volumétrica, e atributos químicos do solo. A produção de biomassa seca na área de cana crua foi 17 vezes maior quando comparada à área de cana queimada. Os agregados formados nas áreas de cana crua e queimada são bastante estáveis em água e ficaram retidos, em sua maioria, nas peneiras de 2,00 e 1,00 mm. Os maiores índices de agregação ocorreram na profundidade de até 0,05 m de profundidade, nos tratamentos avaliados. O solo apresenta-se com uma camada compactada na profundidade entre 0,20 e 0,30 m nas áreas de colheita de cana crua e cana queimada, causada pelo intenso trafego de máquinas de transbordo. Os valores de resistência à penetração e de densidade do solo aumentaram simultânea e significativamente na profundidade até 0,30 m. Foram constatados valores significativamente menores de pH e fósforo em profundidade na área de cana crua.*

PALAVRAS-CHAVE
Estabilidade dos agregados
Densidade e umidade do solo
Resistência à penetração

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1 Introduction

Brazil is the largest producer of cane sugar, which is the main crop used for the production of sugar and alcohol, that are consumed on a large scale in the country. The state of São Paulo ranks first with 52.8% (4.458.310.000 ha) and Minas Gerais with 8.77% (740.150 ha) in second position in the national scenario as a producer and exporter of sugar and ethanol from sugarcane, and more than 70% of this production is concentrated in the Triangulo Mineiro region (IBGE, 2012).

The current management techniques of sugarcane cultivation are based on vigorous soil tillage during preparation and planting, which together with to the harvest system used (manual or mechanized), cause alterations in the physicochemical properties and levels of organic matter (OM) of the soil (VASCONCELOS et al., 2010). The following main changes have been observed in the physical properties of soils: reduction in macroporosity, change in aggregate size, reduction in water infiltration rate, increase in bulk density (BD), and increase in root penetration resistance (RPR) (CAMARGO; MARQUES JÚNIOR; PEREIRA, 2010), which may eventually cause decrease in crop yield.

In sugarcane harvesting systems, harvesters or transshipment machines with total weight ranging from 20 to 30 t are commonly used, and their traffic occurs during several crop cycles at varying conditions of water content in soil with high compaction potential, causing physical and structural degradation of the soil (CAVALIERI et al., 2011). RPR and BD have been used to define the levels of soil compaction so that corrective measures could be implemented. Sene et al. (1985) recorded values between 6.0 and 7.0 MPa as critical for the growing of plant roots in sandy soils, and a value of 2.5 MPa for clayey soils. Regarding bulk density, the critical values are 1.65 Mg m^{-3} (sandy soils) and 1.45 Mg m^{-3} (clayey soils) (ARAUJO et al., 2004).

In the manual harvesting system, the burning of straw aims to facilitate the process, however, it is a harmful practice to the maintenance of OM levels, because it reduces the supply of total organic matter and favors its mineralization (CEDDIA et al., 1999). The remaining straw deposited on the soil under this type of system is of 3.0 Mg ha^{-1} $year^{-1}$, on the average estimate (SOUZA et al., 2005), so soil coverage will be lower and the loss of soil and nutrients will be greater, in addition to having a negative influence on the physical quality of soils (GARBIATE et al., 2011).

In the mechanical harvesting system, with no burning, the dry and green leaves, and the pieces of stems and stalks deposited on the soil form a layer of straw approximately 0.08 to 0.12 m thick that contributes to reduce erosion and surface compaction, besides influencing the dynamics of OM (CERRI et al., 2011), it increases the cation exchange capacity (CEC), keep the humidity, and reduce the loss of soil and nutrients (MARTINS FILHO et al., 2009). In mechanical harvesting, the straw accumulated on soil surface presents supplies estimated in 10 to 20 Mg ha^{-1} $year^{-1}$ (SOUZA et al., 2005; RESENDE et al., 2006; SCHULTZ et al., 2010; GARBIATE et al., 2011).

When comparing different sugarcane harvesting systems, Souza, Marcelo and Centurion (2012) observed that the greatest changes occurred at 0.10 m depth. They also observed that the highest values of OM, aggregate stability, weighted mean diameter (WMD), microporosity, and water content in soil occurred in the mechanical harvesting system. Souza et al. (2012) found that the organic carbon stock and WMD of the soil were significantly influenced by mechanized harvesting, and that these values were higher in the management involving plant-cane.

Sugarcane is a crop of high yield that requires significant amounts of nitrogen (N), potassium (K), and phosphorus (P) for its development, and maintaining the straw on the soil can increase the availability and absorption efficiency of these nutrients (SCHULTZ et al., 2010), however, Cerri and Magalhães (2012) observed that despite the weak correlations of the physicochemical properties of soil with sugarcane yield, the contents of carbon (C), N, and hydrogen (H) + aluminum (AL) positively influenced the sugarcane yield, while the values of pH, P, and cone index had negative influence. Segato, Mattiuz and Mozambani (2006) point out that the root system of sugarcane explores the deeper layers of the soil during a cycle of five to seven years in most regions, as a result, a close relationship with pH, base saturation, and contents of aluminum and calcium occurs at greater depths.

In this study, we aimed to analyze the yield of dry biomass (DB) and the changes in the physicochemical properties of soil under manual and mechanical harvesting in areas with three cuts of sugarcane in a Latosol in the municipality of Uberaba, Minas Gerais state.

2 Materials and Methods

The study was carried out in the municipality of Campo Florido, Minas Gerais state, located at 19° 45'34'' S and 48° 34' 19° W, 570 m above sea level, in an area belonging to a Sugar Plant, after the third cut in 2010.

The region where the experiment was held presents humid subtropical climate, Cwa according to Köppen classification, with dry cool winters and rainy warm summers, and 1.405.0 mm and 28.0 °C average annual rainfall and temperature, respectively.

Dystrophic Red Latosol (Oxisol) is predominant in the region studied, the soil presents high rates of acidity and aluminum saturation, sandy-clay-loam texture, with 180 g kg^{-1} of clay, 770 g kg^{-1} of sand, and 50 g kg^{-1} of silt at 0.00-0.20 m depth layer. The land topography of the region is flat or slightly undulating, geologically formed by sedimentary rocks, mainly sandstone.

We used a randomized block experimental design with two treatments: manual harvesting (burned cane (BC)) and mechanical harvesting (green cane (GC)), at six sampling depths (0.00-0.05, 0.05-0.10, 0.10-0.20, 0.20-0.40, 0.40-0.50 and 0.50-0.60 m), two for the analysis of aggregate stability, with determination of weighted mean diameter (WMD) and geometric mean diameter (GMD), six for mechanical resistance to penetration (PR), bulk density (BD) and volumetric water content (WC), with five replicates. Each plot comprised ten 50-meter-long rows of sugarcane grown at 1.50 m spacing (15 x 50 m), a total of 750 m^2 per plot.

For each ratoon cane cycle, in both GC and BC areas, 40 kg ha^{-1} of N, 40 kg ha^{-1} of P_2O_5 and the equivalent of 90 kg ha^{-1} of K_2O had been applied in the form of vinasse through irrigation.

The yield of dry biomass (DB) deposited on soil surface was determined in four random spots per plot using a 1-m^2-large metal template. This template was thrown at random, and then all the material inside the delimited area was collected. The plant material was taken to the laboratory, placed in forced air circulation oven at 65 °C for 72 h and then weighed, the results were expressed in kg ha^{-1}.

Making use of a mattock, three deformed soil samples were collected from each plot at the depth layers of 0.00 to 0.05 and 0.05 to 0.10 m. The clods were air dried and manually separated, and aggregate stability was assessed by the method described by Kemper and Chepil (1965). Based on the mass of aggregated soil, the weighted mean diameter (WMD) was caculated (Equation 1), which increases as function of the percent of large aggregates trapped on large-size mesh sieves and the geometric mean diameter (GMD) (Equation 2), which is an estimate of the aggregate class size of greater occurrence. These indices of soil aggregates were calculated as follows:

$$DMP = \Sigma\ (xi.wi) \quad (1)$$

where xi is the mean diameter of classes and wi is the proportion of each class in relation to the total (DEMARCHI; PERUSI; PIROLI, 2011).

$$DMG = \exp\ \{\Sigma[(\ln\ [xi]*[pi])]\ /\ \Sigma[pi]\} \quad (2)$$

where ln[xi] is the natural logarithm of the mean diameter of classes and pi is the weight (g) trapped in each sieve (DEMARCHI; PERUSI; PIROLI, 2011).

Mechanical resistance to soil penetration (PR) was measured with the use of an impact penetrometer IAA/Planalsucar model with cone tip angle of 30° (STOLF, 1991). Three measures of PR were taken at the depths of 0.00-0.05, 0.05-0.10, 0.10-0.20, 0.20-0.40, 0.40-0.50 and 0.50-0.60m in each plot. Field data were obtained by the number of impacts (dm), transformed in kgf cm^{-2} by the equation R (kgf cm^{-2})=5.6 + 6.98 N (SENE et al., 1985). Next, these values were multiplied by the constant 0.098 for transformation in MPa units (ARSHAD; LOWERY; GROSSMAN, 1996).

For the assessment of volumetric soil water content, sampling was performed in the same days and depths (0.00-0.05, 0.05-0.10, 0.10-0.20, 0.20-0.40, 0.40-0.50 and 0.50-0.60 m), with two samples per plot, which were homogenized in order to obtain the wet and dry soil masses. The samples were packed in aluminum cans, weighed and placed to dry in forced air circulation ovens at 105 °C for 24 h. Gravimetric moisture was obtained and then multiplied by the BD to reach the volumetric soil water content (EMBRAPA, 1997).

Bulk density (BD) was determined by the volumetric ring method in samples of undeformed soil collected in 48-mm-diameter and 53-mm-high rings using an Uhland auger at the following depths: 0.00-0.05, 0.05-0.10, 0.10-0.20, 0.20-0.40, 0.40-0.50 and 0.50-0.60 m, the samples were then dried at 105 °C for 24 h (EMBRAPA, 1997).

The samples used for the evaluation of soil chemical properties were collected at the following depths: 0.00-0.05, 0.05-0.10, 0.10-0.20, 0.20-0.40 m, in 2010, two months after the sugarcane was harvested (EMBRAPA, 1997).

The results obtained were analyzed for normality and homogeneity of data by Lilliefors, Cochran and Barttlet tests, respectively, later, analysis of variance was carried out using SISVAR 4.3 statistical software (FERREIRA, 2008), the F test was applied for significance and the means were compared by the LSD Student test (p<0.05).

3 Results and Discussion

The supply of plant material on soil surface in the GC area was significantly (p<0.05) higher (24.7 Mg ha^{-1}) compared with that in BC area (1.4 Mg ha^{-1}), becoming 17 times greater after three cuts (Figure 1), that is, there was dry biomass (DB) supply of 8.2 and 0.47 Mg ha^{-1} year^{-1} in the GC and BC areas, respectively.

The yield of dry biomass (DB), 8.2 Mg ha^{-1} year^{-1}, in the GC area was lower the 10.0 Mg ha^{-1} year^{-1} yield verified by Garbiate et al. (2011) and Cavalieri et al. (2011) in studies conducted in the Cerrado and by Resende et al. (2006) and Schultz et al. (2010), and also lower than that observed by Souza et al. (2005) under different edaphoclimatic conditions, 12.0 Mg ha^{-1} year^{-1}. For the BC area, Souza et al. (2005) quantified a supply of 3.0 Mg ha^{-1} year^{-1} in the region of Jaboticabal, Sao Paulo state, which is six times higher than that obtained in this study. These lower values of biomass yield in the GC and BC areas can be justified by the short period of sugarcane implementation in the areas – three years, by the fact of being cultivated in a Latosol with sandy-clay-loam texture (18% of clay and 77% of sand) that is poor in fertility, and probably by the fertilization management carried out in the area - considering that the sugarcane field is renewed after seven cuts in this region. Regarding the area of BC harvesting, most studies conducted in the Cerrado do not report the yields of DB in those areas, perhaps for being negligible, making it difficult to assess the significance of the values verified in this study.

The highest percent of aggregates was trapped on 2.0 mm mesh sieves in both study areas (GC and BC), indicating that the aggregates formed are quite stable in water in larger sizes and that there were no significant differences up to 0.10 m depth on larger sieves (2.00 and 1.00 mm). This may be related

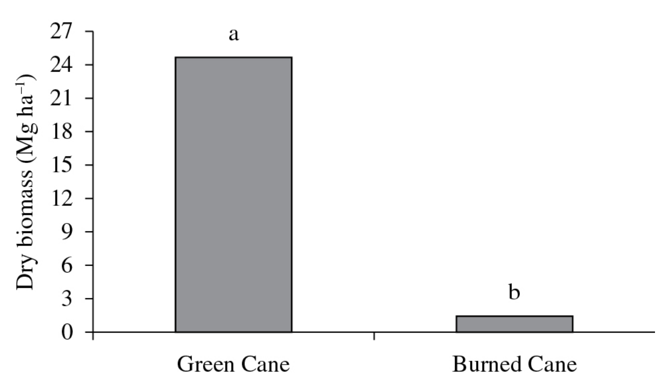

Figure 1. Mean values of dry biomass yield in the GC and BC areas, after three cuts. (LSD Student test, p<0.05).

to the greater volume of grass roots and the fungal hyphae that they are associated with, which benefit the formation of aggregates of larger size and greater stability in this layer.

Souza et al. (2012) reported that the fasciculated root system of the grasses presents an intense rhizosphere effect, which, when decomposed, releases nutrients and contributes to the formation of soil organic matter (OM), strongly favoring its state of aggregation.

Comparing the GC and BC treatments, in general, the values observed for the diameter of aggregates are higher for the GC area on the 1.00, 0.50, 0.25, 0.106 and <0.106 mm mesh sieves at 0.05 to 0.10 m depths, which can be justified by the greater supply of plant residue on soil surface (Figure 1), favoring increased levels of organic matter in the soil, improving its structure and forming larger and more stable aggregates. Similar results were highlighted by Ceddia et al. (1999), Souza et al. (2005), Garbiate et al. (2011), and Souza, Marcelo and Centurion (2012).

The values of WMD and GMD were higher and significantly different (p<0.05) in topsoil (0.00-0.05 m) in both harvesting systems (GC and BC) (Table 2), however, when comparing the depths studied, differences occurred only in the GC area, and values were higher at 0.05 m depth. This pattern can be explained by the greater supply and maintenance of organic residues on soil surface (Figure 1), which are decomposed by the action of microorganisms resulting in the formation of numerous important compounds for the cementation and stabilization of aggregates. Ceddia et al. (1999), in areas of five sugarcane cuts in Linhares, Espirito Santo state, Souza et al. (2005), in areas of 4 cuts in Jaboticabal, Sao Paulo state, and Garbiate et al. (2011) in areas of three cuts in Navirai, Mato Grosso do Sul state, obtained similar results and justified that the lower values of WMD and GMD in the BC system indicate the occurrence of a destruction process of soil aggregates, which reflects on the increase of BD.

The values observed for the diameter of aggregates (Table 1), WMD and GMD (Table 2), in the superficial layer (0.00-0.05 m) did not present significant differences (p<0.05) between the GC and BC treatments, but the same did occur at the 0.05-0.10 m depth layer. This pattern can be explained by the short period of sugarcane cultivation in the area, with only three cuts, sandy soil, and the supply of plant residues on soil surface, in both areas. Similar results were found by Garbiate et al. (2011) in the Cerrado region, also in an area of three cuts, where no significant differences were found among the same physical parameters assessed because of the short time period of crop implementation.

The time of sugarcane cultivation, the number of cuts, and the harvesting system interfere with soil aggregation, WMD and GMD, as observed by Centurion et al. (2007), who compared areas of plant-cane, second cut cane, and fourth cut cane and observed that the time of cultivation interfered in soil structure, reducing aggregation and WMD, in addition to providing increased BD and decreased total porosity. Similar results were found by Souza, Marcelo and Centurion (2012),

Table 1. Distribution of the diameter classes of aggregates in the green cane (GC) and burned cane (BC) areas after three cuts.

Depths (m)	Diameter classes of aggregates (%)					
	2.00	1.00	0.50	0.25	0.106	< 0.106
			CC			
0.00-0.05	41.57 a A	8.86 a A	13.50 a A	20.88 a A	11.89 a A	3.18 a A
0.05-0.10	29.30 a B	12.36 a A	20.03 a A	29.21 a A	15.02 a A	4.03 a A
			CQ			
0.00-0.05	48.87 a A	8.23 a A	12.45 a A	16.93 a B	9.72 a B	3.78 a A
0.05-0.10	42.87 a A	8.97 a B	12.72 b B	20.50 b B	11.65 b A	3.45 a A
F	7.89	3.12	5.79	11.74	9.38	0.29
CV (%)	20.97	21.61	20.48	14.63	12.97	22.85

Means followed by lower case letters in the column compare depths in the treatment and uppercase letters in the column compare treatments (GC and BC) and depth, by LSD Student test (p <0.05).

Table 2. Geometric mean diameter (GMD) and weighted mean diameter (WMD) in the GC and BC harvesting areas, in Campo Florido, Minas Gerais state.

Depth layers (m)	WMD (%)		GMD (%)	
	CC	CQ	CC	CQ
0.00-0.05	2.42 a A	2.74 a A	1.26 a A	1.50 a A
0.05-0.10	1.44 b B	2.47 a A	0.70 b B	1.28 a A
F	8.07		6.09	
CV (%)	18.29		24.4	

Means followed by the same letters in lower case in the column compare treatments and the same letters in uppercase compare depths; differ at 5% significance by LSD Student test (p<0.05).

who verified values of WMD similar to those of this study in the up to 0.10 m depth layer.

Conte et al. (2011) highlight that increased WMD is observed in soils under management systems that promote large biomass supply, which soil carbon contents with the presence of species of abundant root systems, mainly grasses, because the formation and stability of macroaggregates are associated with the growth of roots and organic matter dynamics.

In the GC and BC treatments, there is greater PR in the 0.20 to 0.30 m depth layer when compared with other depths, and the values are significantly higher (p<0.05) in the BC area (Table 3). The values obtained can be justified by the biomass supply on soil surface of 8.2 Mg ha^{-1} year^{-1} in the GC area, which provide a layer of straw that, according to Cerri et al. (2011), can vary from 0.08 to 0.12 m, contributing to reduce superficial compaction and erosion. Other studies show that higher values of PR occur in areas of BC owing to the intense traffic of harvesters and transshipment machines (SOUZA et al., 2005, 2012; VASCONCELOS et al., 2010) and the lack of soil protection provided by the straw (CERRI et al., 2011; GARBIATE et al., 2011).

Regarding bulk density (BD), there were no differences (p<0.05) in the GC area up to 0.40 m depth, while the values were greater at 0.20-0.30 and 0.30-0.40 m depth layers in the BC area. These differences were not influenced by volumetric water content (WC), which remained constant at all depths evaluated in both areas, except for the depth of 0.10 m in the BC area, which is exposed to sun light owing to the lack or minimum plant cover left after harvest (Table 3). The values observed for BD were below 1.65 Mg m^{-3}, which is the minimum critical value established by Araujo et al. (2004) for sandy soils, except for the 0.010-0.20 m and 0.20-0.30 m depth layers for the GC and BC areas, respectively.

Usually, an increase in soil bulk density (BD) in the compacted layer interferes with root growth, helps reduce aeration, increases soil resistance to penetration (PR), and causes changes in the dynamics of water in the soil. However, in this study, BD remained constant with no significant variations and PR increased up to the 0.30 m depth in the GC area, while in the BC area, PR and BD reached their highest values at 0.30 m depth. This behavior of PR and BD in both areas proves that straw deposited on the surface offers protection to soils, keeping moisture levels constant and alleviating the problem with compaction. This was demonstrated by Garbiate et al. (2011) in a study in the Cerrado under similar conditions, where they highlighted that harvest plant residue coverage can minimize the effect of traffic on soils, enabling them to withstand greater pressure compared with soils with no plant residue due to the burning of straw before harvest and that the value of BD decreased as the amount of straw on soil surface increased.

The highest PR value was verified in the BC area (Table 3), which can be attributed to the intense traffic of harvesters and transshipment machines in the area as well as to the lack of plant residue protection due to the burning of straw before harvest.

The values obtained for penetration resistance (PR), bulk density (BD) and volumetric water content (WC) showed significant correlations. PR and BD correlated positively in the GC and BC areas, while correlations between PR x WC and BD x WC were negative for the GC area and positive for the BC area (Table 4).

The positive correlation found between PR and BD in the BC and GC areas indicate that the variables increased significantly and simultaneously; however, the correlations were negative in the GC area, which demonstrates that they did not influence the values of PR, once they remained constant. The same did not occur with respect to the BC area, because as PR increased, the values of BD and WC also increased in the superficial depth layer between 0.00-0.10 and 0.10-0.20 m (Table 3).

Analyzing Table 5, where the values of chemical properties are quantified, it is possible to verify that there were significant differences (p<0.01) in the values of pH, hydrogen (H) and phosphorus (P) in the BC area when compared with the depths evaluated, and the same values occurred in the deeper depth layers (0.20-0.40 m).

Table 3. Penetration resistance (PR), bulk density (BD), and volumetric water content (WC) assessed in Dystrophic Red Latosol in an area of green (GC) and burned (BC) sugarcane harvested after three cuts, in Campo Florido, Minas Gerais state.

Depths (m)	Treatments					
	GC			BC		
	PR (MPa)	BD (kg dm^{-3})	WC (cm^3 cm^{-3})	PR (MPa)	BD (kg dm^{-3})	WC (cm^3 cm^{-3})
0.0-0.10	1.88 a C	1.62 a A	0.19 a A	1.37 b E	1.54 a B	0.17 b A
0.10-0.20	2.32 a B	1.65 a A	0.18 a A	2.17 a C	1.58 a AB	0.17 a A
0.20-0.30	2.72 b A	1.64 a A	0.19 a A	3.14 a A	1.66 a A	0.18 a A
0.30-0.40	2.24 a B	1.61 a A	0.19 a A	2.41 a B	1.61 a A	0.18 a A
0.40-0.50	1.96 a C	1.51 a B	0.19 a A	2.02 a C	1.55 a B	0.18 a A
0.50-0.60	1.57 a D	1.51 a B	0.19 a A	1.63 a D	1.51 a C	0.18 a A
F	8.06	5.38	9.49	8.06	5.38	9.49
CV (%)	6.39	3.62	6.47	6.39	3.62	6.47

Means followed by same low case letters in the column compare treatments and the same uppercase letters compare depths; differ at 5% significance by LSD Student test (p<0.05).

The pH values close to 6.0 in all layers can be justified by the tillage of the area, which was performed above the 0.40 m depth; the low mobility of the limestone that was used for soil correction, and the brief period of cultivation in the area. This can be verified by the values of Ca, Mg and Al in the depth up to 0.20 m; however, the values of Ca and Mg decrease and the value of Al increases at the 0.20-0.40 m depth layer, which can be justified by the amount of nutrients absorbed in the resprouting of sugarcane for the formation of new clumps, leaving the subsurface layers with higher values of Al and H. These values can be justified by the development of the root system of these plants, because about 75% of the roots are concentrated until the depth of 0.40 m (SEGATO; MATTIUZ; MOZAMBANI, 2006).

The absence of significant differences (p<0.05) in the values of pH, Ca, Mg, Al, H and K at all depths and in the values of P at 0.00 – 0.05 and 0.05-0.10 m depths in the BC area can be justified by the annual supply of plant residue on soil surface after three years of cultivation (Figure 1). This pattern is also observed in the BC area, but the values are lower because the yield amounts for BC were 17 times smaller than those for GC. Exception is made for the values of Ca, Mg and Al in the superficial layer (up to 0.10 m), which were higher even with lower supply of plant residue on soil surface and, in this case, seemed to have been influenced by the ashes left on the soil after the the burning of cane before the harvest, causing changes in the process of nutrient cycling in this layer. Ferreira, Fageria and Didonet (2012) observed a similar effect with the application of ash from sugarcane bagasse in a Red Latosol (Oxisol) in the Cerrado, which resulted in a significant increase in the values of K, Mg, base saturation and pH, and a decrease in total acidity (H+Al).

Concerning P, the higher values observed on soil surface are justified by fertilization, which is performed in total dose along the planting line, and by the low mobility of this nutrient in the soil. The high values of K observed at all depths in both areas can be justified by its high mobility in the soil and its very fast release in the decomposition process of plant residue, in addition to the application of high amounts of vinasse during the regrowth of ratoon and by the ash resulting from sugarcane burning, as demonstrated by Correia and Alleoni (2011).

In general, the values found for the physicochemical properties of the soil in the green cane area presented better results in comparison with those observed in the burned cane area, confirming the potential of the use of this system under the environmental conditions of the Cerrado region in the state of Minas Gerais, which will influence the the yield potential of sugarcane. According to Vasconcelos et al. (2010), management systems that provide supply of organic residue on soil surface can cause changes in its physical properties, favoring the growth of root systems and the yield of sugarcane.

Table 4. Pearson's correlations between the values of penetration resistance (PR), bulk density (BD), and volumetric water content (WC) in the GC and BC areas after three cuts.

Variable analyzed	Correlation coefficient	r^2
	GC	
PR x BD	0.74*	0.99
PR x WC	–0.25	0.98
BD x WC	–0.46	0.99
	BC	
PR x BD	0.94*	0.99
PR x WC	0.44	0.99
BD x WC	0.22	0.98

* Significant with p<0.01 by the F test; r^2 = determination coefficient.

Table 5. Chemical properties of soils under different harvesting systems (manual-GC and mechanized-BC) in Uberaba, Minas Gerais state in 2010.

System	Chemical properties of soils						
	pH	Ca	Mg	Al	H	K	P
				$cmol_c\ kg^{-1}$			$mg\ kg^{-1}$
				0.00-0.05			
GC	6.00 aA	1.33 aA	1.33 aA	0.03 aA	4.53 aA	1.17 aA	4.04 aA
BC	5.67 aB	0.67 aA	1.67 aA	0.20 aA	4.33 aC	0.08 aA	3.38 aA
				0.05-0.10			
GC	6.00 aA	1.00 aA	1.67 aA	0.10 aA	4.53 aA	0.10 aA	3.28 aA
BC	6.00 aB	1.33 aA	1.00 aA	0.17 aA	4.60 aB	0.09 aA	2.13 aA
				0.10-0.20			
GC	6.02 aA	0.67 aA	1.67 aA	0.13 aA	4.47 aA	0.11 aA	1.27 aB
BC	6.33 aA	1.33 aA	0.67 aA	0.13 aA	4.87 bA	0.09 aA	1.10 aB
				0.20-0.40			
GC	5.44 aA	0.33 aA	0.67 aA	0.23 aA	4.57 aA	0.14 aA	1.92 aB
BC	5.33 aC	0.67 aA	0.67 aA	0.13 aA	4.73 aB	0.07 aA	0.91 aB
CV (%)	6.84	20.83	21.42	4.71	1.86	2.18	12.72

Means followed by lower case letters in the column compare treatments and uppercase letters compare depths; do not differ at 5% significance by LSD Student test (p<0.05). The values of Ca. Mg. Al. K. P and H were adjusted using the formula: $(x+1)^{0.5}$ to meet the criteria for normality and homogeneity.

4 Conclusions

The yield of dry biomass in the Green cane area was 17 times higher than in the burned cane area;

The aggregates formed in the green cane and burned cane areas were quite stable in water and were mostly trapped on the 2.00 and 1.00 mm mesh sieves;

The highest indices of aggregation occurred at 0,05 m depth in the treatments assessed;

Soil compaction was observed at the layer comprised between 0.20 and 0.30 m depths in both harvesting system, green cane and burned cane, caused by the intense traffic of transshipment machines;

The values of penetration resistance and bulk density increased significantly and simultaneously at 0.30 m depth;

Significantly lower values of pH and phosphorus in depth were observed in the green cane area.

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