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Soil porosity and density in sugarcane cultivation under different tillage systems

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Monitoring the physical quality of soils under intensive sugarcane production requires sustainable forms of use and soil management. Thus, the objective of this research was to evaluate the influence of soil tillage systems on soil porosity and density in ratoon-cane cultivation, in addition to possible changes which may occur during the season. The experiment was carried out in the state of Goiás, Brazil. The Experimental design was randomized blocks with four replications. The following tillage systems were evaluated: 1. Moldboard plow + Harrow; 2. Subsoiler + Harrow; 3. Direct planting; 4. Subsoiler + Direct planting; 5. Stubble thrasher + Subsoiler; 6. Stubble thrasher + Harrow + Moldboard plow + Harrow, in soil layers 0-0.2; 0.2-0.4 and 0.4-0.6 m. Regardless of the tillage system used during sugarcane cultivation, the ratoon crop showed reduced total soil pore volume and macroporosity, as well as increased soil density in the 0.4-0.6 m layer. However, the use of direct planting resulted in +higher soil macroporosity values in the 0-0.2 m layer and yields similar to conventional systems which use the moldboard plow. Therefore, it is recommended for producers to adopt conservation soil tillage systems, combining productivity and soil quality.

Key words: Soil management, ratoon-cane, soil compaction, conservation system.

INTRODUCTION

The current sugarcane crop management techniques involve vigorous soil disturbance at planting, by using plows, harrows and subsoilers (Centurion et al., 2007). Thus, in recent years, soil preparation under sugarcane has been questioned, searching for an alternative to adopt a conservation system that prioritizes minimum

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tillage (Arruda et al., 2015).

Among the management components, perhaps the initial soil preparation influences soil physical quality indicators the most, because it directly acts on the structure (Hamza and Anderson, 2005), influencing the aggregation processes (Choudhurya et al., 2014), compression (Cunha et al., 2009; Bangita and Rao, 2012), soil porosity and density (Tormena et al., 2004; Domingues, 2012) in addition to pores size and water availability to plants (Machado et al., 2008). Therefore, understanding and quantification of the impact of these factors on soil physical properties are important to establish sustainable farming systems (Tormena et al., 2004).

The longevity of the sugarcane production cycle is largely dependent on mechanization. Some producers conduct up to 10 cuts in one area while maintaining satisfactory yields (Domingues, 2012). However, negative effects on sugarcane yield in terms of use and soil management are difficult to measure, especially to isolate the soil compaction factor (Mazurana et al., 2011). In addition to that, there is little research work on sugarcane reporting physical changes over the years regarding ratoon crops.

The successive ratoon cultivation occurring in the same production area (monoculture) and soil disturbance at the time of field reform have prevented the implementation of no-tillage system in sugarcane. Therefore, researchers should develop new minimum tillage systems or even adopt conventional systems with little impact on the environment, with emphasis on soil quality.

The long-term effect of soil preparation systems is not well documented, especially when such preparation involves soil conservation tillage systems and changes in sugarcane ratoon. According to Tormena et al. (2004) understanding and quantifying the impacts of different soil tillage systems on physical quality, such as influences on sugarcane productivity, are fundamental for the development of sustainable agricultural systems.

Thus, the objective of this research was to evaluate the influence of soil tillage systems on soil porosity and density in ratoon-cane cultivation, in addition to possible changes during the plant-cane season.

MATERIALS AND METHODS

The research was conducted during 2009-2010 and 2011-2012 seasons of plant-cane and ratoon-cane respectively, in an experimental area of the Jalles Machado Mill, in the municipality of Goianésia, the state of Goiás, Brazil, at coordinates 15°10'02" south latitude and 49°15'12" west longitude. The climate is classified as Aw type (megathermal) or tropical savannah, with dry winters and rainy summers, according to the Köppen classification. The altitude of this area is 640 m and the average annual rainfall is 1600 mm (Figure 1). The soil was classified as Dystrophic Yellow Red Latosol (Embrapa, 2013). The sieve analysis of the soil showed 432, 450 and 452 g kg^{-1} of clay in the 0-0.2; 0.2-0.4 and 0.4-0.6 m layers, respectively (Embrapa, 2009). Chemical analysis of the soil under plant-cane and the ratoon crop can be seen in Table 1. Historically, the area was intended for grain production (soybean, maize and sorghum) until 2003, when sugarcane was planted. The experiment was established during the reform of the plantation at soil preparation time, before planting for the 2009-2010 seasons.

The experimental units were 19.5 m wide x 50 m long, made up of 13 lines of sugarcane spaced at 1.5 m apart. The total area of the plots was 975 m^2. The useful area had 5 central lines and was 10 m long, totaling 300 m^2. The experimental design was randomized blocks with four replications. Assessments during the ratoon crop (2011-2012) were performed with factorial 6 x 3 in split plots (plot factors were the soil tillage systems and subplot factors were the soil layers). However, evaluations comparing ratoon-cane season with the plant-cane season were conducted with a factorial 6 x 2 in split plots (plot factors were the soil tillage systems and subplot factors were the harvest season), in isolation for each layer of soil (0-0.2; 0.2-0.4 and 0.4-0.6 m). Treatments consisted of tillage systems used in soil preparation as following: 1. Moldboard plow + harrow (MP+H); 2. Subsoiler + harrow (S+H); 3. Desiccation + Direct planting (DP); 4. Subsoiler + Direct planting (S+DP); 5. Stubble thrasher + Subsoiler (ST+S); 6. Stubble thrasher + harrow + Moldboard plow+ harrow (HMPH).

At the beginning, soil acidity correction was performed using dolomitic limestone at a dose of 1.5 t ha^{-1}. Gypsum was applied on the soil surface at a dose of 800 kg ha^{-1}. Manual planting of sugarcane was performed with furrowing (average depth of 0.35 to 0.4 m), placing 18 buds per m^{-2} of the CTC 02 variety. Fertilization with 250 kg ha^{-1} of monoammonium phosphate, equivalent to 120 kg ha^{-1} of P_2O_5 and 27 kg ha^{-1}of nitrogen ($N\text{-}NH_4^+$), was done at planting. Cover fertilization of the crop was done in September 2009 with liquid formulation N-P-K of 05-00-13 + 0.3 % zinc + 0.3 % Boron. The fertilization for ratoon-cane (2010-2011 and 2011-2012 crop seasons) was performed according to the requirements of the plant and estimated productivity by surface application of 90 kg ha^{-1} N, 30 kg ha^{-1} P_2O_5 and 110 kg ha^{-1} of K_2O in both seasons.

The evaluations were performed after the plant-cane (2009-2010) and ratoon-cane (2011-2012) were harvested, by collecting undisturbed soil samples from the layers 0-0.2; 0.2-0.4 and 0.4-0.6 m. Uhland-type sampler and a Koppecky metal ring with an internal volume defined to determine the total porosity, macroporosity, microporosity and soil density were used. All determinations were carried out according to the methodology of Embrapa (1997).

The sugarcane harvest was done manually and without burning, considering a useful area with five central lines and length of 40 m of the parcel, totaling 300 m^2. Subsequently, the plants were weighed (kg) using a scale attached to a stem loader. Later, the data were extrapolated to a hectare (average productivity in tons of stems per hectare).

Statistical analysis

Statistical analysis was performed by analysis of variance (F test), and when significant (P<0.05), comparisons of means were made using the Tukey test (Ferreira, 2008).

RESULTS AND DISCUSSION

Porosity and density of soil under ratoon-cane

Soil macroporosity values showed statistical difference (P<0.05) between tillage systems and layers (Table 2). The highest soil macroporosity values were observed in

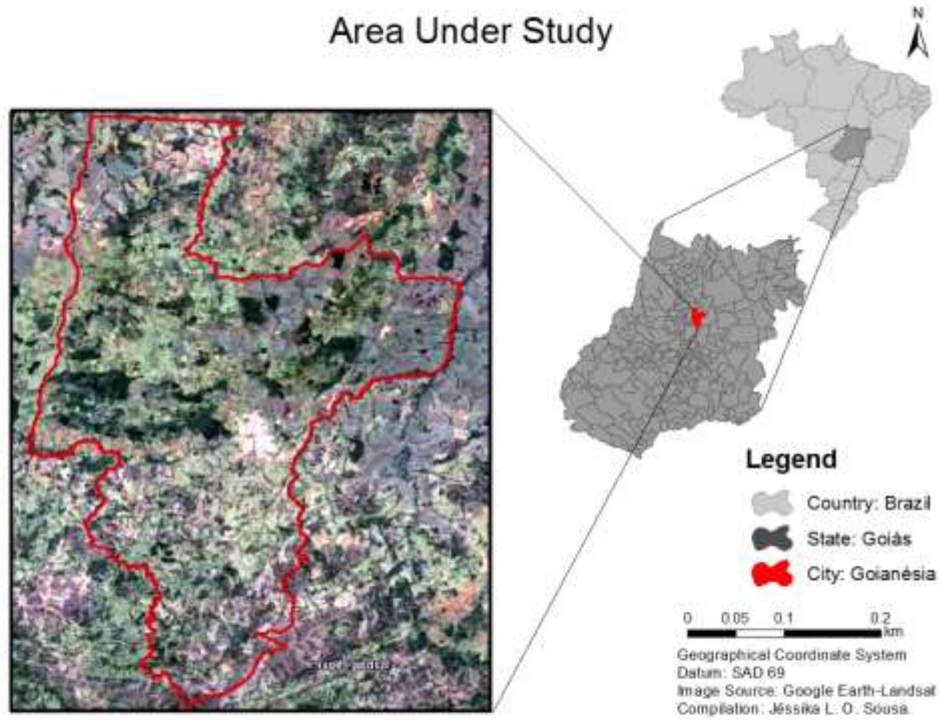

Figure 1. Geographical location of the area that was conducted the survey, Brazil.

Table 1. Chemical analysis of soil from the experimental area of the Jalles Machado Mill, Goianésia, state of Goiás, Brazil, during the 2009-2010 and 2011-2012, under plant-cane and ratoon-cane, respectively.

pH	Ca	Mg	P	K	Al	H + Al	V	MOS
	$cmol_c\ dm^{-3}$		$mg\ dm^{-3}$		$cmol_c\ dm^{-3}$		%	$g\ kg^{-1}$
Plant-cane								
0 – 0.2 m								
4.01	0.45	0.29	1.4	78.0	1.6	8.25	10.2	19.2
0.2 – 0.4 m								
3.97	0.23	0.17	0.7	19.2	2.0	8.70	4.8	10.4
0.4 – 0.6 m								
3.24	0.17	0.12	0.4	18.7	2.4	9.23	3.9	10.2
Ratoon-cane								
0 – 0.2 m								
6.02	1.40	0.78	3.26	52.0	0.04	2.22	50.7	23.8
0.2 – 0.4 m								
5.21	2.30	0.32	2.24	24.7	0.24	2.70	49.8	16.7
0.4 – 0.6 m								
5.21	0.30	0.24	0.48	19.1	0.17	2.30	21.5	13.9

pH in H_2O; Ca^{+2}, Mg^{+2} and Al^{+3} in KCl (1 mol L^{-1}); P and K^+ in HCl (0.05 mol L^{-1}) + H_2SO_4 (0.0125 mol L^{-1}); H + Al in Buffer (SMP at pH 7.0); Base saturation (V); O.M: Organic Matter (Colorimetric Method). Embrapa (2009). The Ca^{+2}, Mg^{+2} and Al^{+3} in $cmol_c dm^{-3}$; P and K^+ in mg dm^{-3}; H+Al in $cmol_c dm^{-3}$.

the 0-0.2 m layer in Direct planting (DP), Subsoiler + direct planting (S+DP) and Stubble thrasher + harrow + moldboard plow + harrow (HMPH) systems.

The highest soil macroporosity in minimum tillage systems (DP and S+DP) may occur due to higher contribution of organic material, which these conservation

Table 2. Total volume of pores, macroporosity, microporosity and soil density in ratoon-cane under different tillage systems in the cerrado region, in Goianésia – the State of Goiás, Brazil, crop 2011-2012.

Layers (m)	Soil preparation systems					
	MP+H	S+H	DP	S+DP	ST+S	HMPH
Total volume of pores (m^3 m^{-3})						
0.0 – 0.2	0.45	0.44	0.47	0.47	0.44	0.49
0.2 – 0.4	0.49	0.46	0.43	0.44	0.45	0.46
0.4 – 0.6	0.46	0.47	0.43	0.47	0.46	0.45
Macroporosity (m^3 m^{-3})						
0.0 – 0.2	0.08^{bA}	0.09^{bA}	0.14^{aA}	0.12^{abA}	0.09^{bA}	0.12^{abA}
0.2 – 0.4	0.09^{aA}	0.11^{aA}	0.09^{aB}	0.10^{aA}	0.11^{aA}	0.11^{A}
0.4 – 0.6	0.08^{aA}	0.09^{aA}	0.09^{aB}	0.10^{aA}	0.10^{aA}	0.09^{A}
Microporosity (m^3 m^{-3})						
0.0 – 0.2	0.36	0.35	0.34	0.35	0.35	0.38
0.2 – 0.4	0.39	0.34	0.34	0.33	0.34	0.34
0.4 – 0.6	0.38	0.37	0.35	0.38	0.35	0.36
Soil density (g cm^{-3})						
0.0 – 0.2	1.29	1.32	1.30	1.29	1.40	1.25
0.2 – 0.4	1.29	1.38	1.40	1.42	1.42	1.39
0.4 – 0.6	1.36	1.30	1.38	1.31	1.38	1.43

MP+H: Moldboard plow + harrow; S+H: subsoiler + harrow; DP: direct planting; S+DP: subsoiler + direct planting; ST+S: stubble thrasher + subsoiler; HMPH: stubble thrasher + harrow + moldboard plow + harrow. Means followed by different letters in the upper column (compare depths within treatments) and lower in line (compare treatments) differ by Tukey test ($P<0.05$).

systems provide (Arruda et al., 2015), and also due to high sugarcane root accumulation in the 0-0.2 m layer (Blackburn, 1984), especially in ratoon (Faroni and Trivelin, 2006) which favors the formation of macropores (Mazurana et al., 2011). The root system residue of sugarcane from the previous production cycle and the continuous root renewal process among the ratoons of the current cycle, through the decomposition of secondary roots, was expected to promote the emergence of new pores (biopores).

Similar results were found by Paulino et al. (2004) who, when researching soil tillage systems in ratoon, found higher soil macroporosity values in minimum tillage. Similar results were also found by Camilotti et al. (2005), studying conventional tillage and no-tillage, including the subsoil, but statistical difference in soil macroporosity was not identified.

The HMPH system also showed high soil macroporosity levels, being statistically similar to DP and S+DP. Tormena et al. (2004) in a study of dystrophic red Latosol detected increased soil macroporosity values in areas cultivated under conventional systems (moldboard plow and light harrow), compared with those cultivated under conservation system (direct planting) and minimum tillage (scarification and light harrow).

Only the DP system showed statistical difference ($P<0.05$) among soil layers where 0-0.2 m showed higher soil macroporosity values in relation to the 0.2-0.4 and 0.4-0.6 m layers. This fact can be attributed to soil disturbance in conservation systems in the surface layers. The lack of statistical difference ($P>0.05$) in soil macroporosity for conventional systems probably occurred via the action of agricultural implements in the deeper soil layers, homogenizing the soil profile, which usually does not happen in conservation tillage systems (DP).

The soil preparation system with moldboard plow + harrow (MP+H) showed low soil macroporosity values (close to 0.08 m^3 m^{-3}), values below this limit are considered critical, signaling soil compaction process. The minimum amount of pore space occupied by air should be 0.10 m^3 m^{-3} (Dexter, 1988; Tormena et al., 2004), which still allows for normal sugarcane root system development (Vomocil and Flocker, 1961) and that of most crops (Argenton et al., 2005). Other tillage systems had average values over 0.10 m^3 m^{-3}, and this indicates that the aeration and water availability conditions were adequate for the sugarcane development.

The microporosity values and soil density were not

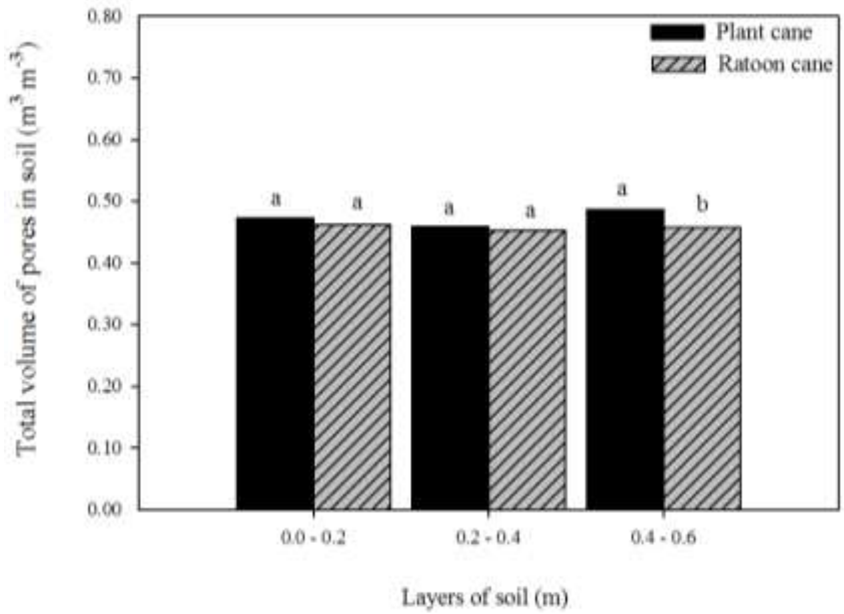

Figure 2. Total volume of pores in soil (m^3 m^{-3}) layers under plant-cane and ratoon-cane in the Brazilian Cerrado region, in 2010 and 2012 respectively. Means followed by lower case letters differ among themselves between growing seasons, by Tukey test (P<0.05).

statistically different (P>0.05) between soil tillage systems and soil layers (Table 2). Similar results were found by Centurion et al. (2007) and Cunha et al. (2009), respectively.

The average soil density values were found to be 1.32 g cm^{-3}. According to Argenton et al. (2005), the average values considered critical for clay soils are 1.30 g dm^{-3}. Displaying said textured soils from 200 to 550 g kg^{-1} clay can reach the critical density of 1.55 g cm^{-3} (Reinert et al., 2001) and texture soils of about 480 g kg^{-1} can reach 1.36 and 1.64 g cm^{-3} (Silva et al., 2008). The performance of sugar cane roots may be damaged as the values exceed 1.20 g cm^{-3} (Segato et al., 2006).

Porosity and density of soil under ratoon-cane in relation to plant-cane

Significant differences were found between the total pore volume, macroporosity and soil density of ratoon-cane's growing seasons and plant-cane cultivation, and this difference was only found in the 0.4-0.6 m layer of soil (P<0.05). However, there were no significant differences between tillage systems (P>0.05).

The total volume of pores in soil under the ratoon-cane crop decreased by 7% (0.45 m m^{-3}) in comparison to the previous plant-cane crop (0.48 m m^{-3}) in the 0.4 to 0.6 m soil layer (Figure 2). Soil macroporosity under ratoon-cane showed a reduction of 18% (0.09 m^{-3}) when compared to the plant-cane crop (0.12 m^{-3}) in 0.4 to 0.6 m soil layer (Figure 3).

Centurion et al. (2007), in their plant-cane cultivation research, observed reduction in total porosity and soil macroporosity only in the fourth year of ratoon crop. The authors did not find any difference between plant-cane and second ratoon-cane crop, which may be due to the short cultivation time of sugarcane. The difference between plant-cane and the fourth ratoon-cane season probably occurred because of heavy traffic of agricultural machinery and implements on the sugarcane plantation. Camillotti et al. (2005), when evaluating the effect of soil tillage systems over time, also observed reduced soil macroporosity after the fourth year of sugarcane cultivation in the subsurface layers, regardless of the soil preparation system studied (P>0.05).

An increase of 8.8% in the mean of soil density wasobserved under the ratoon-cane crop (1.36 g cm^{-3}) when compared to that of the plant-cane crop which was 1.24 g cm^{-3} in the 0.4-0.6 m soil layer (Figure 4). Soil density tends to increase with the greater depths of the soil profile, which is probably due to reduced presence of organic matter, aggregation and amount of roots, in addition to compression caused by the soil layers above (Reinert and Reichert, 2006).

The results of soil density of this research agree with those of Centurion et al. (2007), who observed increases in soil density values in the second ratoon-cane season in relation to the plant-cane season. Camilotti et al. (2005) observed increased soil density after the fourth sugarcane harvest in the 0.2-0.5 m soil layer, regardless

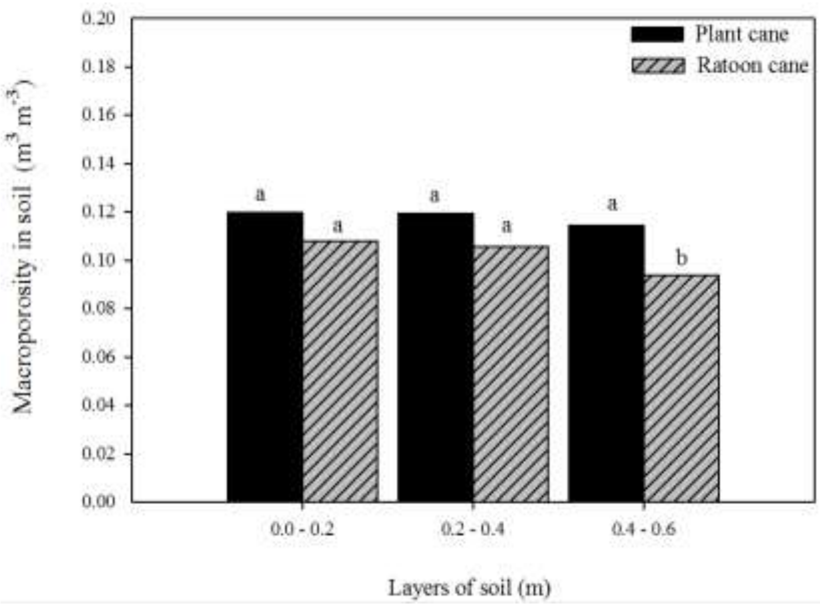

Figure 3. Macroporosity in soil ($m^3 m^{-3}$) layers under plant-cane and ratoon-cane in the Brazilian Cerrado region, in 2010 and 2012 respectively. Means followed by lower case letters differ among themselves between growing seasons, by Tukey test (P<0.05).

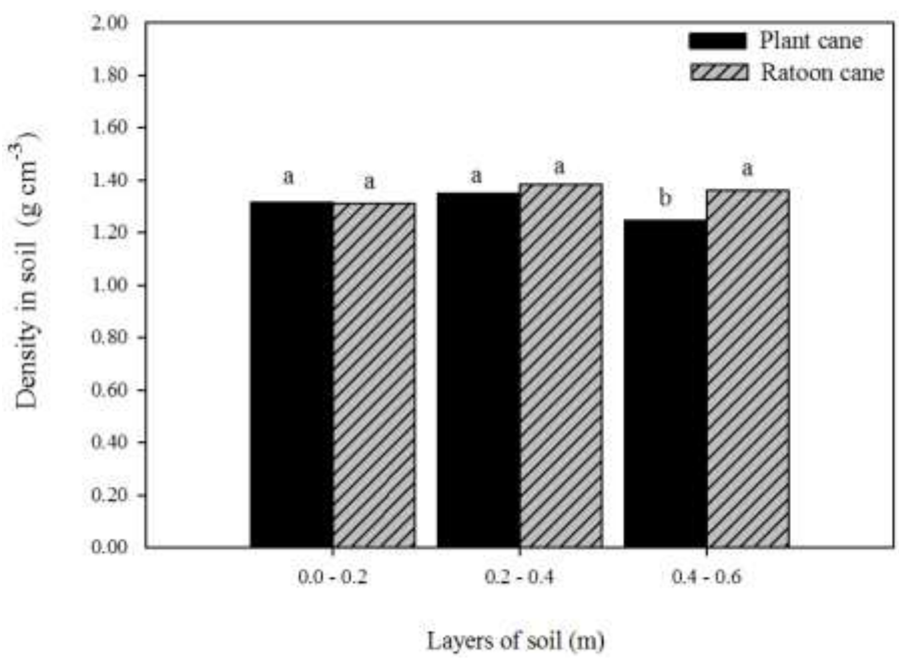

Figure 4. Density in soil (g cm^{-3}) layers under plant-cane and ratoon-cane in the Brazilian Cerrado region, in 2010 and 2012 respectively. Means followed by lower case letters differ among themselves between growing seasons, by Tukey test (P<0.05).

of soil tillage system used. Soil microporosity values were not statistically different (P>0.05) in the assessments of soil layers (Figure 5). Similar results were obtained by Tormena et al. (2004) and Centurion et al. (2007). Soil microporosity is strongly influenced by texture and organic carbon content and is little influenced by increased soil density caused by traffic of agricultural machinery and equipment (Araújo et al., 2004).

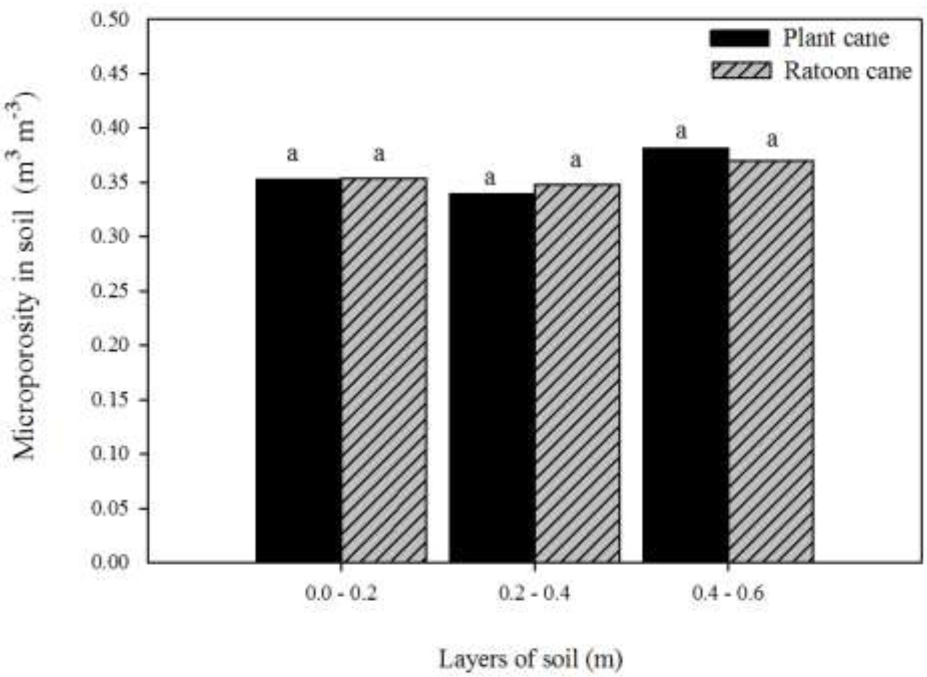

Figure 5. Microporosity in soil (m^3 m^{-3}) layers under plant-cane and ratoon-cane in the Brazilian Cerrado region, in 2010 and 2012 respectively. Means followed by lower case letters differ between themselves among growing seasons, by Tukey test (P<0.05).

Table 3. Productivity of sugarcane culms (Mg ha^{-1}) during plant-cane and ratoon-cane production seasons under different tillage systems in the Brazilian cerrado region.

Growing Season	Tillage systems					
	MP+H	S+H	DP	S+DP	ST+S	HMPH
Plant-cane	104.8^{aA}	94.4^{abA}	98.9^{abA}	93.6^{bA}	93.5^{bA}	105.2^{aA}
Ratoon-cane	65.7^{aB}	54.9^{bB}	58.7^{abB}	55.2^{bB}	59.8^{abB}	65.9^{aB}

MP+H: Moldboard plow + Harrow; S+H: Subsoiler + Harrow; DP: Direct planting; S+DP: Subsoiler + Direct planting; ST+S: Stubble thrasher + Subsoiler; HMPH: Stubble thrasher + Harrow + Moldboard plow + Harrow. Means followed by different uppercase letters in the column (compare growing seasons within the same treatment) and lowercase in line (compare tillage systems) differ by Tukey test (P<0.05).

Yield of culms in plant-cane and ratoon-cane

The productivity of sugarcane stalks (Mg ha^{-1}) showed a significant interaction between tillage systems and crop seasons (P<0.05). The plant-cane season showed higher yields with MP+H and HMPH tillage systems, but not statistically different from S+H and DP. The ratoon-cane season showed that the highest yields continued to prevail with MP+H and HMPH tillage systems, but statistically did not differ from ST+S and DP (Table 3).

The fact that the conservation system (DP) presented productivity statistically similar to conventional systems (MP+H and HMPH) for both plant-cane and ratoon-cane is a positive sign for the sugarcane production due to low production costs with: energy (diesel oil), manual labor, depreciation of agricultural machinery, among others (Arruda et al., 2015). The advantages of DP should also be pointed out regarding soil physical quality, as with the higher macroporosity values verified under ratoon-cane crop (Table 2).

During the plant-cane season, the S+DP and ST+S systems presented lower productivity compared to HMPH system. During the ratoon-cane season the S+DP and S+H systems produced lower yields compared with the HMPH system. The fact that the minimum tillage system (S+DP) showed lower plant-cane and ratoon-cane productivity when compared with the conventional system (HMPH) can be attributed to the use of subsoiler in these tillage systems, which also occurred in S+DP (plant-cane) and S+H (ratoon-cane). The deep soil decompression with a subsoiler can have negative effects on sugarcane growth. The formation of large clumps in the soil reduces the stem contact with the soil, which in turn reduces budding and initial root growth (Arruda et al., 2015).

The average plant-cane stalk yields in the 2009-2010 seasons (98.46 Mg ha^{-1}) were higher than those found in ratoon-cane in the 2011-2012 season (60.08 Mg ha^{-1}). The drop in ratoon-cane productivity may be related to lower total porosity and macroporosity in soil, and the subsequent increase of soil density in the 0.4-0.6 m layer. Some destructive evaluations of plant root system development, for a study also held in the same area of research, may have also contributed to the low productivity during the ratoon-cane season.

Conclusions

Regardless of the planting system used during the preparations for sugarcane plantation, the ratoon-cane season showed reduced total pore volume and soil macroporosity, as well as increased soil density in the 0.4 to 0.6 m layer. However, the use of direct planting presented higher soil macroporosity values in the 0-0.2 m layer, and yields similar to conventional systems with the use of the moldboard plow.

Therefore, producers are recommended to adopt soil conservation tillage systems, combining productivity and soil quality.

Conflict of Interests

The authors have not declared any conflict of interests.

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