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Aggregation and organic matter content in different tillage systems for sugarcane

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Monitoring the physical quality of Cerrado soils under intensive sugarcane production requires sustainable forms of soil use and management. Thus, the objective of this research was to evaluate the aggregation and organic matter content in soil planted with sugarcane under different tillage systems. The experiment was conducted at the Jalles Machado Sugarcane Mill, in the city of Goianésia – Goiás State, Brazil. The statistical design was a randomized block with four replications. The following treatments were evaluated: 1. Moldboard plow + harrow (AA + G); 2. Ripper + harrow (SS + G); 3. Direct furrowing (SD); 4. Ripper + direct furrowing (SS + SD); 5. Stubble thrasher + ripper (DS + SS); 6. Stubble thrasher + harrow + moldboard plow + harrow (DS + GAAG), for the soil layers of 0-0.2; 0.2-0.4 and 0.4-0.6 m depth. The highest soil organic matter (SOM) levels, geometric mean diameter (GMD) values and distribution of aggregates between 4-2 mm were found in the 0-0.2 m layer for the SD and SS + SD treatment. There was a positive correlation between the SOM and GMD values. SD, SS + SD and DS + GAAG systems showed higher soil aggregate classes between 4-2 mm when compared to DS + SS in the 0.2-0.4 m layer. There was also an increase in the <0.25 mm class for AA + G. The AA + G + and DS + GAAG conventional systems had higher sugarcane yields, but these results were statistically similar to the conservation cropping system.

Key words: Soil management, aggregates, Brazilian Cerrado, ratoon.

INTRODUCTION

The intense soil preparation with the use of plows, heavy harrows, rippers and deep furrowing for planting sugarcane are soil impacting practices that directly affect soil structure and the stability of aggregates (Souza and Alves, 2003). Consequently, in recent years, we have started to question the tillage for sugarcane production looking for management alternatives that prioritize minimum soil tilling.

According to Hamza and Anderson (2005), among the soil management components, preparation may influence the attributes of soil physical quality parameters the most, as they act directly on its structure. The fact is that when tillage is not performed with the right technologies for each soil class, the soil physical properties are altered, including aggregation processes (Castro Filho et al., 1998; Choudhurya et al., 2014), soil compaction

Table 1. Chemical characterization of soil for the second ratoon crop, Jalles Machado Sugar Refining Mill, Goianésia-Goiás, Brazil, 2012.

Soil layer (m)	pH	Ca^{+2} cmol$_c$dm^{-3}	Mg^{+2}	Al^{+3}	P mg dm^{-3}	K$^+$	H + Al^{+3} cmol$_c$dm^{-3}	V %	O.M. g kg^{-1}
0.0-0.2	6.02	1.40	0.78	0.04	3.26	52.00	2.22	50.70	23.80
0.2-0.4	5.21	2.30	0.32	0.24	2.24	24.70	2.70	49.80	16.70
0.4-0.6	5.21	0.35	0.24	0.17	0.48	19.08	2.30	21.50	13.90

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}.

(Bangita and Rajashekhar Rao, 2012), pore size distribution, and consequently, the water availability to the crop (Aina, 1979).

The physical state of the soil aggregation has to be well observed when analyzing physical quality (Aratani et al., 2009). However, it is important to consider the soil organic matter levels, which is the main soil formation and stabilization agent (Wendling et al., 2005). Studies conducted in recent years, which explore the relationship between aggregates and soil organic matter, mineral fraction, soil fauna, roots and environmental variables, show that these are the factors which favor the formation of soil aggregates (Salton et al., 2008).

The average aggregate size and the proportion of aggregates are used as stability indices (Reinert and Reichert, 2006), where the microaggregates are more stable and the macroaggregates are more susceptible to changes with the use of agricultural management practices (Pagliarini et al., 2012). According to Almeida et al. (2009), the adoption of soil management systems that provide the addition of a large amount of residues in the soil favors a high energy and matter flow, consequently, tending to form larger aggregates, thus contributing to the soil quality increase process.

Understanding and quantifying the impacts caused by different soil tillage systems on physical quality are fundamental in the development of sustainable agricultural systems (Tormena et al., 2004).

The long-term effect of soil preparation systems on the formation of soil aggregates is not well documented for the Cerrado region. Therefore, the objective of this research was to evaluate the aggregation and organic matter content of an Dystrophic Yellow Red Latosol for sugarcane cultivated under different soil tillage systems.

MATERIALS AND METHODS

Area characterization

The experiment was conducted in a sugarcane field at the Jalles Machado sugarcane mill, in the city of Goianésia – Goiás State, Brazil, located at the coordinates 15°10'02 "south latitude and 49°15'12" west longitude. The climate in the region is classified as Aw type (Megathermal) or Tropical savanna climate, with dry winters and rainy summers, according to the Köppen classification.

The altitude is approximately 640 m and average annual rainfall is 1600 mm. The soil was classified as Dystrophic Yellow Red Latosol according to Brazilian System of Soil Classification (Embrapa, 2013). The particle size 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 is presented in Table 1.

Historically, the area was used for grain production (soybeans, corn and sorghum) until the 2003 agricultural year when sugarcane cultivation began. The experiment was established on a sugarcane plantation at the time of soil preparation for the 2009/2010 planting season. The evaluation occurred in the 2011/2012 season.

The experimental units were 19.5 m wide × 50.0 m long, consisting of 13 lines of sugarcane spaced at 1.5 m. The total area of the plots was 975.0 m^2. This study evaluates five central lines, 30.0 m in length each, with a total area of 225.0 m^2. The experimental design was a randomized block design (RBD) with 6 × 3 factorial split-plot (tillage × soil layers). Treatments consisted of tillage systems used in soil preparation as following: 1. Moldboard + harrow (AA + G); 2. Ripper + harrow (SS + G); 3.Desiccation + Direct furrowing (SD); 4.Ripper + Direct furrowing (SS + SD); 5.Stubble thrasher + Ripper (DS + SS); 6. Stubble thrasher + harrow + Moldboard + harrow (DS + GAAG), for the soil layers of 0-0.2; 0.2-0.4 and 0.4-0.6 m depth in four replications (Table 2).

The aim of this experiment was to evaluate the geometric mean diameter (GMD) of the aggregates and the soil organic matter (SOM) in soil layer (0-0.2, 0.2-0.4 and 0.4-0.6). Distribution of aggregate size classes (4-2, 2-1, 1-0.5, 0.5-0.25 and <0.25 mm) was evaluated in a 5 × 6 factorial (tillage × classes aggregates), individually for each soil layer (0-0.2 and 0.2-0.4 m). The experiment began in March 2009 by liming the soil with dolomitic limestone at a dose of 1.5 t ha^{-1}. Gypsum was applied at 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 (MAP), equivalent to 120 kg ha^{-1} of P_2O_5 and 27 kg ha^{-1}of nitrogen (N-NH$_4^+$), was undertakn 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.

Disturbed samples were collected in the 0-0.2, 0.2-0.4 and 0.4-0.6 m layers. Soil sampling was collected with a hoe and spade, opening furrows with dimensions of approximately 0.1 × 0.5 ×0.2 m.

Variables and statistical analysis

The stability of the aggregates was determined via wet sieving

Table 2. Different tillage systems and soil layers in ratoon cane cultivation in the Cerrado region, 2009, in Goianésia, Goiás State, Brazil.

Treatments	Operations in soil tillage systems
AA+G	Moldboard (soil layer of 0.35 to 0.4 m) and harrow (soil layer of 0.15 to 0.2 m)
SS+G	Ripper (soil layer of 0.4 m) and harrow (soil layer of 0.15 to 0.2m)
SD	Desiccation (Glyphosate and 2.4 D, doses of 3.0 and 2.0 L ha^{-1}, respectively). Direct furrowing (soil layer of 0.3 to 0.4 m)
SS+SD	Ripper (soil layer of 0.4 m) and direct furrowing (soil layer of 0.3 to 0.4 m)
DS+SS	Stubble thrasher (soil layer of 0.0 to 0.2 m) and ripper (soil layer of 0.4 m)
DS+GAAG	Stubble thrasher (soil layer of 0.0 to 0.2 m), harrow (soil layer of 0.15 to 0.2 m), moldboard (soil layer of 0.35 to 0.4 m) and harrow (soil layer of 0.15 to 0.2 m)

according to Embrapa (1997), where aggregates of 2-4 mm in size were agitated in the Yoder machine (Yoder, 1936) in conjunction with sieves with 1, 0.5 and 0.25 mm mesh openings [GMD in Equation (1) (Mazurak, 1950)],. The distribution of the aggregates into classes was calculated for 4-2, 2-1, 1-0.5, 0.5-0.25 and <0.25 mm. SOM levels were determined by the method of dichromate oxidation and spectrophotometric reading, according to Embrapa (2009).

$$GMD = exp \frac{\sum_{i=1}^{n} wi \ln xi}{\sum_{i=1}^{n} wi} \qquad (1)$$

In = geometric mean diameter (GMD); Wi = mass of aggregates in size class with mean diameter xi; Σ_1^n =1; wi = total mass of the sample

The harvest of sugarcane by hand and without prior burning was carried out taking into consideration a useful area of five central lines and a plot area of 40 m long with 300 m^2 of total area. Subsequently, the sugarcane was weighed with a scale attached to a loader and later the data were extrapolated to hectare. The average yield was estimated in tons of sugarcane culms per hectare.

Statistical analysis of data was performed by analysis of variance (F test) and when significant, comparisons of means were made by Tukey test (P <0.05) (Ferreira, 2008) and variables were correlated by the Pearson linear correlation test (Sigma-plot In. USA).

RESULTS AND DISCUSSION

The GMD showed a significant interaction between tillage systems and soil layers (P <0.05). In the 0.0-0.2 m layer higher values of GMD were observed for direct furrowing (SD) and ripper + direct furrowing (SS + SD), being 17.83 and 16.36% higher compared to the average of other soil preparation systems (Figure 1). These results may be related to low tillage in these soil conservation systems and higher amount of SOM (Figure 2) which comes from the sugarcane crop remains from previous seasons on the soil surface. Similar results were found by Aratani et al. (2009) in red Latosol while comparing irrigated tillage, no-tillage and conventional tillage.

According to Salton et al. (2008), the management systems that provide larger aggregates are desirable as they conserve soil structure without major changes when subjected to external forces, such as animal trampling,

mechanized operations and provide greater resistance to erosion loss.

The use of light harrow and moldboard in soil tillage promoted lower aggregate stability in the 0.0-0.2 m layer. The use of the stubble thrasher to eliminate old ratoons also removed the topsoil layer in a very destructive operation; consequently, the physical disruption of aggregates was inevitable. Fontes et al. (1995) stated that changes in soil physical properties, such as in Latosol, especially in the layer richer in organic matter, may be caused by the mechanical breakdown of aggregates by revolving the soil in the initial soil preparation before planting.

Higher SOM content was observed in the 0.0-0.2 m (23.8 g kg^{-1}) layer compared to the 0.2-0.4 and 0.4-0.6 m layers with average levels of 16.7 and 13.9 g kg^{-1}, respectively (Figure 2).

The SD and SS + SD systems showed higher SOM levels. These results can be justified by the non-incorporation of crop residues before planting. According to Stone and Silveira (2001), in conservation cropping systems where the soil remains covered with plant material, a strong presence of organic matter is expected in the soil surface layer, providing intense biological activity, resulting in products which play a role in the formation and stabilization of aggregates.

The SOM and GMD values were significantly correlated (r = 0.64), as shown in Figure 3. According to Wendling et al. (2012) one of the main soil particle cementing agents is the organic matter, and it is likely that part of the variation in the aggregate size and aggregation index is attributed to the SOM content variation.

Castro Filho et al. (1998) studying the stability of aggregates and their relation to organic carbon in Latosol under different tillage systems, confirmed increased soil particle aggregation in areas with higher concentrations of organic matter. Wendling et al. (2005) also observed positive correlations between soil organic carbon and aggregate stability index in a Latosol when evaluating tillage systems and stubble.

A significant interaction was found between the distribution of aggregates in classes and soil preparation
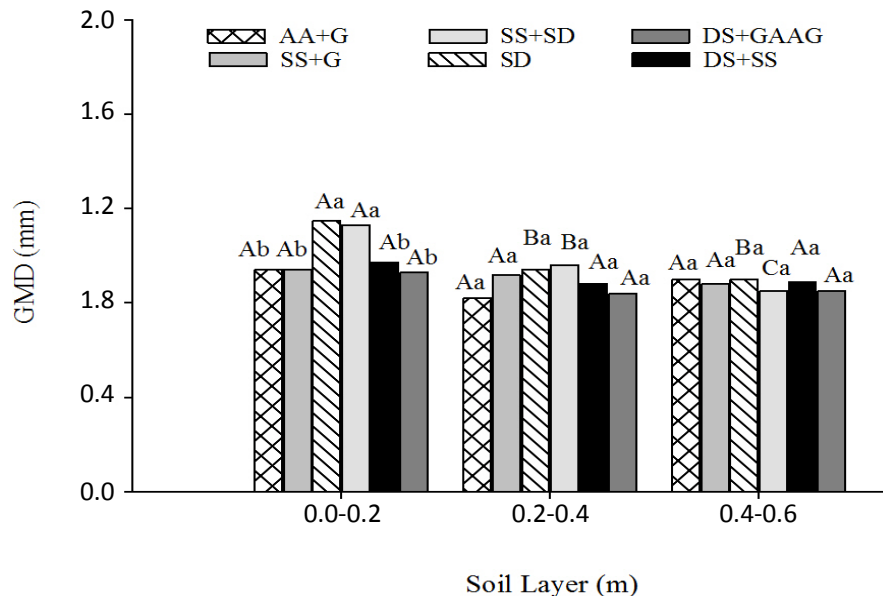
Figure 1. Geometric mean diameter (GMD) in mm in different tillage systems and cultivation layers of ratoon cane in the Cerrado region, 2012. Means followed by distinct lowercase letters differ between soil preparation systems and uppercase letters differ between layers, by the Tukey test (P <0.05).
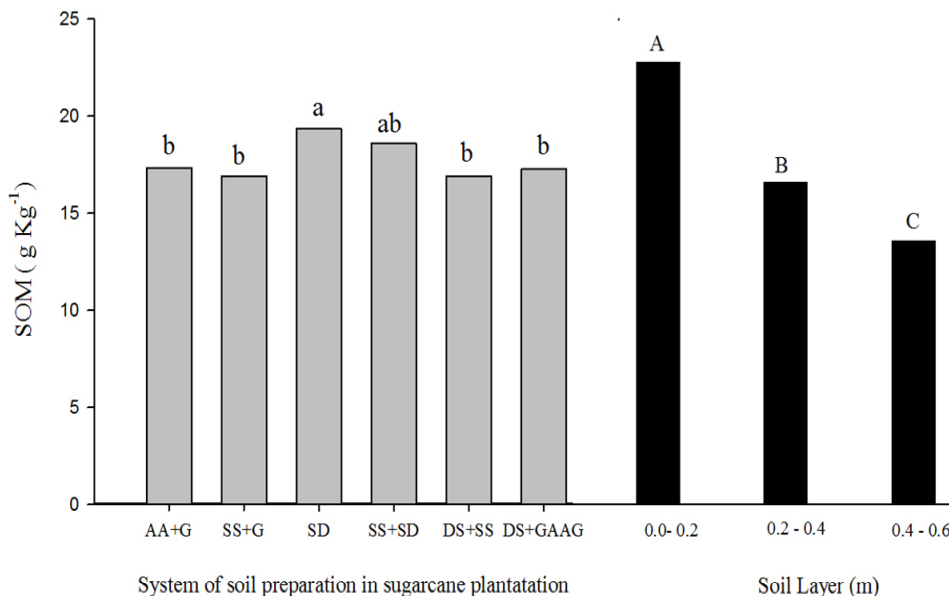

Figure 2. Soil organic matter content in various soil preparation systems and layers in ratoon cane cultivation in the Cerrado region, 2012. Means followed by lowercase letters (tillage) and uppercase (layers) differ by Tukey test (P <0.05).

systems (P <0.05). According to Salton et al. (2008) soil management systems, by influencing the soil matter and energy flow intensities and dynamics, result in different degrees of soil mass organization in aggregates

In the 0-0.2 m layer aggregate classes between 4-2 mm predominated in SD and SS + SD systems, with

fractions of 37.26 and 39.59%, respectively (Figure 4). Therefore, the minimum soil tillage coupled with biological activities of roots and the sugarcane biomass, must have contributed to the highest percentages in this classes. According to Almeida et al. (2009), systems that provide the addition of a large amount of plant residues
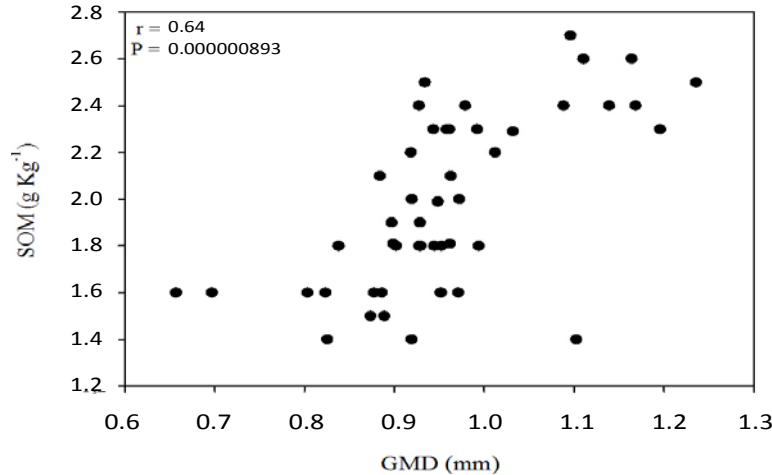
Figure 3. Pearson correlation: Geometric mean diameter - GMD (mm) and soil organic matter – SOM (g K^{-1}) in different tillage systems and soil layers in ratoon cane cultivation in the Cerrado region, 2012.
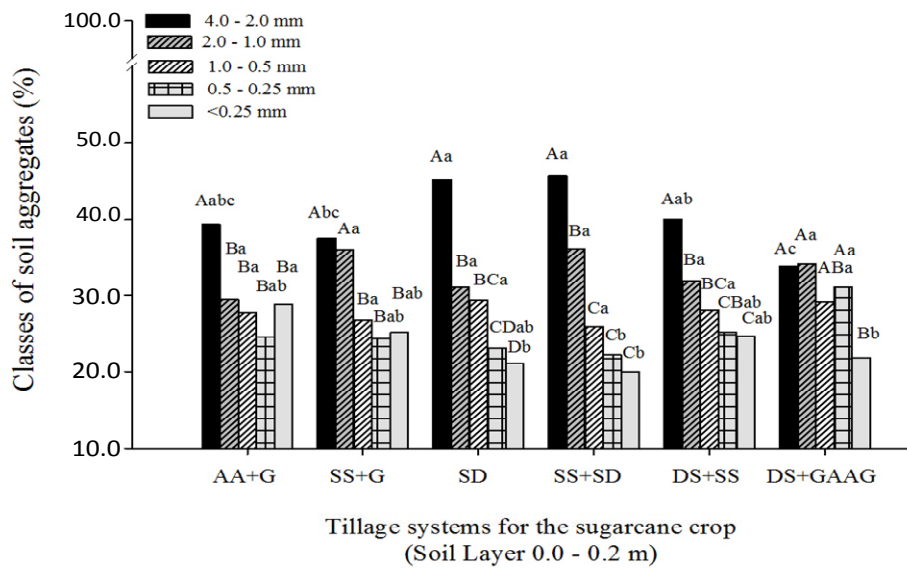

Figure 4. Distribution of aggregate classes in different tillage systems in the 0 - 0.2 m soil layers in sugarcane cultivation in the Cerrado region, 2012.

favor a high energy and matter flow, therefore, tending to form classes of larger aggregates contributing to a higher soil quality.

Conventional systems with ripper + harrow (SS + G) and stubble thrasher + harrow + moldboard plow + harrow (DS + GAAG) had lower percentages of aggregate classes between 4-2 mm (22.89 %). According to Salton et al. (2008) the macroaggregates formed by physical processes through mechanical operations of machinery and equipment or animal treading, may not be stable. However, the greater stability of aggregates is provided by cementing agents linked to biological

aspects, such as microbial activity, exudate release by roots, root growth and functioning tissue growth and death, among others.

In the 0.2-0.4 m layer, SD, SS + SD and DS + GAAG systems showed higher values for aggregate classes between 4-2 mm in relation to stubble trasher + ripper (DS + SS). There was a sharp increase in the <0.25 mm class of aggregates for the tillage system which uses moldboard plow + harrow (AA + G), as observed in Figure 5.

Beutler et al. (2001), when comparing conservation and conventional systems in dystrophic red Latosol in the
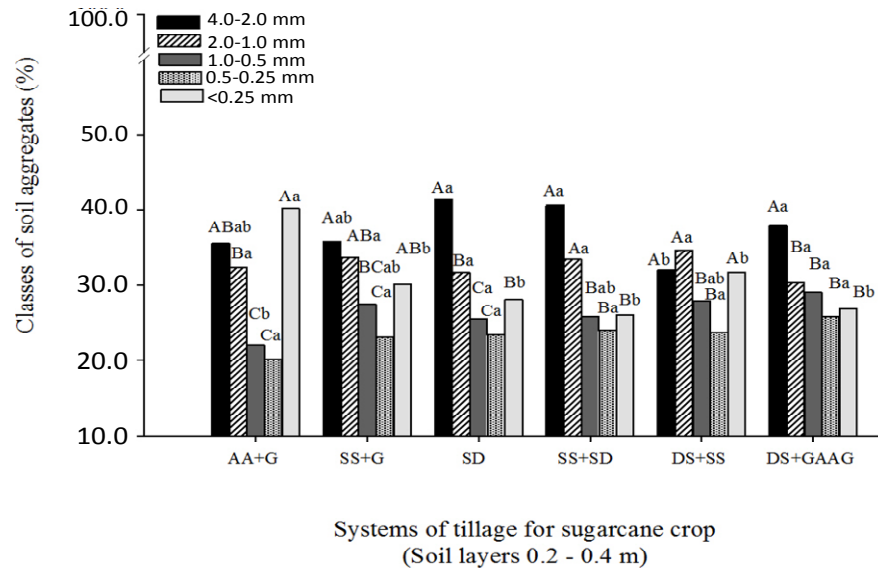
Figure 5. Distribution of aggregate classes in different tillage systems in the 0.2 - 0.4 m layer of ratoon cane cultivation in the Cerrado region in 2012.
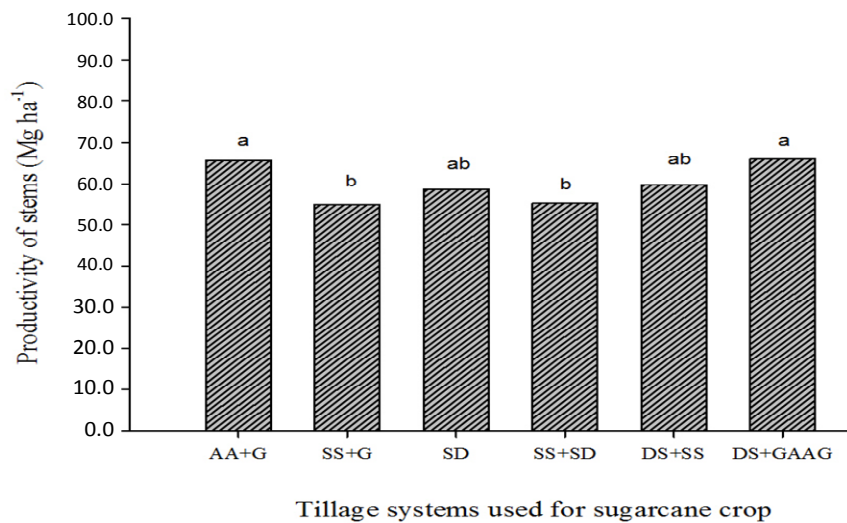

Figure 6. Productivity of culms in different tillage systems in sugarcane in the second year.

mountains of Minas Gerais, found that direct seeding showed a higher percentage of aggregates for the class over 2 mm, lower for the 2 and 1 mm classes and higher GMD in the surface soil aggregates.

Almeida et al. (2009), in dystrophic red Latosol in the State of São Paulo, in a sugarcane cultivation area during the first year, found predominance of aggregates in the larger diameter classes.

According to Mendes et al. (2003) a sharp increase in the amounts of microaggregates in soils under conventional tillage is a consequence of macroaggregate

breakdown, due to the constant mechanical cultivation and the operational features of plows. These authors also stated that the conventional tillage decreases the stability of macroaggregates, making them more susceptible to breakage when submitted to a wet separation process.

The yield of culms for the second ratoon was influenced by different tillage systems (P <0.05). The AA + G and DS+ GAAG systems had higher yields, 65.77 and 65.97 Mg ha^{-1}, respectively, but with no statistically significant difference for SD and DS + SS (Figure 6).

Similar results were found by Domingues (2012) in the

same environment of research. However André (2009) found higher sugarcane yields in conventional tillage in relation to other systems, however, also without statistical significance for the minimum tillage + harrow + no-tillage. The (SS + SD) minimum tillage system showed lower productivity compared to the conventional system (DS + GAAG). This lower productivity can be attributed to the use of the subsoiler, as occurred in SS + G. The deep decompacting operation with the subsoiler can cause negative sugarcane growth effects, due to the formation of large soil clods; this interferes with the stalk contact with the soil, reducing the budding and the initial emission of roots. However, as the OSM levels of the SS + SD system were statistically identical to those of the DS + GAAG, it is expected that over the ratoon sugarcane years, the yields become equivalent.

The fact that the conservation system (SD) presents productivity statistically similar to conventional systems (AA + G and DS + GAAG) was beneficial for the sugarcane production due to lower production costs that these systems provide: As energy (diesel oil), labor, depreciation of agricultural machinery, among others. The advantages of SD in relation to soil quality should also be emphasized, such as higher SOM (Almeida et al., 2014) and GMD values and the prevalence of classes with larger aggregates.

Conclusions

The direct furrowing system and ripper + direct furrowing show higher geometric mean diameter values and bigger aggregate classes (4-2 mm) in the 0-0.2 m layer in the second ratoon cane, positively correlated with the soil organic matter level.

The use of direct furrowing shows greater soil organic matter conservation and improved soil physical quality, besides productivities similar to conventional systems using the moldboard plows and harrows. It is thus recommended that farmers adopt minimum tillage systems in agriculture, such as these that associate productivity and soil quality.

Conflict of Interest

The authors have not declared any conflict of interest.

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