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IRRIGAÇÃO POR GOTEJAMENTO SUBSUPERFICIAL EM CULTIVARES DE CANA-DE-AÇÚCAR IMPACTAM A AGREGAÇÃO DO SOLO?

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1 RESUMO

Objetivou-se avaliar o efeito da irrigação por gotejamento subsuperficial em cultivares de cana-de-açúcar, contrastantes na responsividade à irrigação, na agregação de Latossolo argiloso. O experimento foi realizado em Latossolo Vermelho eutroférrico, de textura argilosa (587 g kg^{-1} de argila). Foram coletadas amostras deformadas de solo em vinte pontos em cada uma das quatro áreas de cana-de-açúcar avaliadas nas camadas 0,00-0,10 m e 0,10-0,20 m. As áreas correspondiam ao cultivo irrigado e não irrigado, das cultivares CTC 4 e IACSP93-3046. Foram determinados e calculados o índice de estabilidade dos agregados, diâmetro médio ponderado de agregados, fracionamento físico do carbono orgânico e as classes de agregados. Os dados foram submetidos à estatística descritiva e multivariada de fatores. De acordo com as correlações das variáveis, a agregação do solo foi dividida em dois processos, sendo o primeiro denominado de "Dimensão de agregados" e o segundo "Estabilidade de agregados". Observou-se que a irrigação por gotejamento subsuperficial promove maior "Estabilidade de agregados" do solo em áreas cultivadas com cana-de-açúcar. Além disso, cultivares de cana-de-açúcar proporcionam diferenças na agregação do solo, sendo que a cultivar responsiva à irrigação IACSP93-3046 promove maior "Dimensão de agregados" do solo em relação a cultivar não responsiva CTC 4.

Palavras-chave: diâmetro médio ponderado de agregados, estabilidade de agregados, carbono orgânico, Latossolo.

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DOES SUBSURFACE DRIP IRRIGATION IN SUGARCANE CULTIVARS IMPACT SOIL AGGREGATION?

2 ABSTRACT

The aim was to evaluate the effect of subsurface drip irrigation with sugarcane cultivars, contrasting in the responsiveness to irrigation, in the aggregation of Oxisol clayey. The experiment was conducted in a clayey Oxisol (587g kg^{-1} of clay). Deformed soil samples were collected at twenty points in each four areas of sugarcane evaluated in the layers 0.00-0.10 m

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and 0.10-0.20 m. The areas corresponded to the irrigated and non-irrigated cultivation of cultivars CTC 4 and IACSP93-3046. The aggregate stability index, weighted average diameter of aggregates, physical fractionation of organic carbon and aggregate classes were determined and calculated. The data were submitted to the descriptive and multivariate factor statistics. According to the correlations of the variables, soil aggregation was divided into two processes, the first being called "Aggregates dimension" and the second "Aggregates stability." It was observed that subsurface drip irrigation promotes greater soil "Aggregate stability" in areas cultivated with sugarcane. Additionally, sugarcane cultivars provide differences in soil aggregation, and the cultivar responsive to irrigation IACSP93-3046 promotes a larger soil "Aggregates dimension" than the non-responsive cultivar CTC 4.

Keywords: weighted average diameter of aggregates, aggregate stability, organic carbon, Oxisol.

3 INTRODUCTION

Sugarcane is the third most planted crop in Brazil, with a cultivated area of approximately 10 million hectares (CANA-DE-AÇUCAR, 2020). Owing to the intense traffic of machinery and implements, sugarcane cultivation can reduce soil physical quality, increase density and reduce soil aggregation (CHERUBIN *et al*., 2016; CASTIONI *et al*., 2018). These changes in soil structure can lead to compaction, erosion, and loss of soil use capacity, directly interfering with the conservation of agroecosystems.

Conservation farming systems are commonly employed to improve soil structure and fertility, as well as prevent soil degradation. Among the main physical and chemical attributes of a soil are aggregation variables and organic carbon content, respectively. Particle aggregation and the soil carbon content are key factors in achieving high agricultural yields. These factors work together to provide nutrients, water, oxygen, and an ideal structure for plant root development, thus favoring crop development (OADES, 1984).

Aggregation influences several soil attributes, such as macro- and microporosity, soil aeration, and microbial activity (SILVA; CABEDA; CARVALHO, 2006). Furthermore, aggregation can increase water retention and availability for crops (SILVA; CABEDA; CARVALHO, 2006), allowing for more rational use of irrigation, reducing the amount of water applied and, consequently, operating costs. For aggregation to occur, aggregating substances, known as cementing agents, are necessary. Among the main cementing agents are the clay fraction of the soil, organic carbon, exudates released by roots, and soil microorganisms (OADES; WATERS, 1991; SIX *et al*., 2004; SEBEN JÚNIOR; CORÁ; LAL, 2016).

Considering the application of vinasse as an irrigation management method, sugarcane is the crop with the largest irrigated area in Brazil, with 1.7 million hectares (AGÊNCIA NACIONAL DE ÁGUAS, 2017). In addition to the application of vinasse via self-propelled irrigation systems, the most commonly used irrigation systems for sugarcane are subsurface drips and center pivot sprinklers.

The advantages of subsurface drip irrigation for increasing sugarcane productivity are undeniable, with increases of up to 60% observed compared with nonirrigated areas (COELHO *et al*., 2018a). Studies have shown that irrigation, in addition to increasing crop productivity, can increase the total biomass production of areas and, consequently, the soil organic carbon content, promoting direct benefits in terms of soil aggregation (SEBEN JÚNIOR; CORÁ; LAL, 2016) and indirect benefits through soil carbon sequestration and reduced CO2 emissions into the atmosphere (NICOLOSO; AMADO; RICE, 2020). However, little is known about the effects of subsurface drip irrigation on the aggregation of soils cultivated with sugarcane.

In Brazil, there are 208 registered sugarcane cultivars (*Saccharum* spp.) (MINISTRY OF AGRICULTURE, LIVESTOCK AND SUPPLY, 2020), each presenting better adaptation in certain production environments (PRADO, 2005). Sugarcane cultivars present high variability in the distribution and density of their root system (SOUSA *et al*., 2013), which directly affects the response in irrigated and nonirrigated areas (COELHO *et al*., 2018a; FISCHER FILHO, 2018).

Differences in root systems can affect soil aggregation differently, as the root density of sugarcane cultivars in the most superficial soil layers can vary by more than 100% (LANDELL; BRESSIANI, 2008). Therefore, studies on the effects of subsurface drip irrigation and sugarcane cultivars on soil aggregation are essential to determine the best management practices for this crop and to aid in soil conservation in cultivated areas.

With the hypotheses that subsurface drip irrigation improves soil aggregation in areas cultivated with sugarcane and that this effect depends on the cultivar used, the aim was to evaluate the effects of subsurface drip irrigation on the aggregation of clayey Latosols in sugarcane cultivars.

4 MATERIALS AND METHODS

The experiment was conducted at São Paulo State University (Unesp), Faculty of Agricultural and Veterinary Sciences, Jaboticabal, São Paulo, Brazil. The experimental area is located near the coordinates of latitude 21°14'50" S, longitude 48°17'05" W and altitude 570 m, with a slope of 8%.

According to the Köeppen classification, the region's climate is Aw, characterized by an average annual rainfall of 1,425 mm, with average rainfall for the wettest month of 255 mm (December) and 25 mm for the driest month (July).

The soil in the experimental area is classified as a eutroferric Red Latosol (EMPRESA BRASILEIRA DE PESQUISA AGROPECUÁRIA, 2013) with a clayey texture, with 582 g kg $^{-1}$ of clay, 235 g kg $^{-1}$ of silt and 183 g kg $^{-1}$ of sand in the 0.00–0.10 m layer, and 591 g kg $^{-1}$ of clay, 231 g kg $^{-1}$ of silt and 178 g kg $^{-1}$ of sand in the 0.10–0.20 m layer.

Four plots, consisting of the sugarcane cultivars CTC 4 and IACSP93-3046, were evaluated; these plots were subjected to subsurface irrigation and were not irrigated. The plots originated from an experiment maintained under a partially balanced incomplete block design in a split-plot arrangement. In the original experiment, the treatments consisted of two irrigation management practices (irrigated and nonirrigated) allocated within the plots and five sugarcane cultivars (CTC 4, IACSP93--3046, RB86--7515, IAC95--5000 and IAC91--1099) allocated within the subplots, with six replicates.

To evaluate the soil aggregation attributes and organic carbon content, areas under treatments with cultivars CTC 4 and IACSP93-3046 maintained with and without irrigation were used, totaling four areas.

The cultivars CTC4 and IACSP93-3046 were chosen because they presented the greatest differences in growth and productivity when cultivated with and without irrigation, as observed in the works of Coelho *et al*. (2018a) and Fischer Filho (2018). In the first four cuts, the productivity of the cultivar CTC 4 was not increased by the use of irrigation, whereas the cultivar IACSP93-3046 presented the greatest percentage increase in productivity when irrigated.

Sugarcane was planted in November 2014 via presprouted seedlings, with 1.5 m spacing between rows and 0.50 m spacing between plants. Fertilization at planting, carried out in the furrow, consisted of 160 kg ha $^{-1}$ P_2O_5 (single superphosphate) and 60 kg ha $^{-1}$ K_2O (potassium chloride). The first and second cuts of the experiment were performed in May 2015 and 2016, respectively, whereas the third and fourth cuts were performed in July 2017 and 2018, respectively.

Topdressing from the first year of cultivation was carried out with 120 kg ha $^{-1}$ N (ammonium sulfate) and 160 kg ha $^{-1}$ K_2O (potassium chloride). Fertilization in the irrigated area was carried out via fertigation, which was divided into six applications in the first year, with equal doses between November and April, and was divided into eight applications from the second to fourth harvests, between September and April. For the nonirrigated area, topdressing was applied to the soil, which was divided into two applications: once 60 days and once 90 days after planting or harvesting in the previous season.

The adopted irrigation management supplied 100% of the crop evapotranspiration (ETc), applying 20 mm of water when the area water deficit (ETc – rainfall) was equal to 20 mm (DALRI; CRUZ, 2002). The reference evapotranspiration was calculated according to the FAO 56 method, as was the cultivation coefficient for sugarcane (ALLEN *et al*., 1998). The adopted Kc values were 0.50 (0–30 days after harvest or planting – DAC); 0.60 (31–60 DAC); 0.75 (61–90 DAC); 0.85 (91–120 DAC); 0.95 (121–180 DAC); 1.10 (181–240 DAC); 1.20 (241–335 DAC); and without irrigation (336–365 DAC). The nonirrigated management system received water only from rainfall.

Soil sampling was conducted in October 2018, after the fourth sugarcane harvest in July 2018. The soil was collected along the sugarcane row between the clumps formed by presprouted seedlings. To determine the soil properties, disturbed soil samples were collected from the 0.00–0.10 m and 0.10–0.20 m layers via a mattock.

For each layer, twenty points were sampled in each of the four areas, totaling one hundred and sixty (160) samples. Each sample was divided into two parts: one part was used to separate aggregates with diameters between 6.3 and 4.0 mm, and the weighted mean diameter of the soil aggregates (WMD) was subsequently determined (NIMMO; PERKINS, 2002). The other part was divided into two more parts: one part was used to separate aggregates with diameters between 2.0 and 1.0 mm to determine the soil aggregate stability index (SAI) (NIMMO; PERKINS, 2002), and the other part was used to obtain air-dried fine soil (ADF), a fraction of the soil smaller than 2.0 mm.

From the TFSA, through the process of physical fractionation of organic carbon (CO) (CAMBARDELLA; ELLIOTT, 1992), the material for the determination of the particulate organic carbon (POC) content was obtained. The CO and POC contents were determined via a colorimetric method (YEOMANS; BREMER, 1988). The mineral-associated organic carbon (MAOC) content was obtained from the difference between the CO and POC contents.

To determine the DMP, the aggregate classes 6.3 - 4.0 mm (CA1), 4.0 - 1.0 mm (CA2), 1.0 - 0.5 mm (CA3) and <0.5 mm (CA4) were calculated and used as variables in the statistical analyses.

For the analysis, descriptive statistics of the soil attributes for each treatment were first performed, using the mean and standard error of the mean. Owing to the dependent structure of the analyzed variables, a multivariate factor analysis was subsequently performed, which allowed the projection of all the information contained in the original variables into new latent variables, which are the processes (HAIR *et al*., 2009). Since multivariate analysis does not use variables calculated on the basis of other variables present in the original set of variables, CO was not used in the multivariate analysis, as it is a variable obtained by the sum of COP and COAM, preferring to use these two individual variables.

The data were standardized, with the aim of all variables having the same weight in the analysis, presenting a zero mean and unitary variance. The number of factors was chosen via the Kaiser criterion (1958), selecting factors with eigenvalues greater than 1.

Eigenvalues were extracted from the covariance matrix of the original variables. For factor analysis, variables with factor loadings above 0.60 were considered relevant to the process. Attributes with coefficients of the same sign correlate directly with each other within the process, whereas attributes with coefficients of different signs correlate indirectly. After factor analysis, the scores generated for each sample and process were tested via a generalized linear model (MILSTEIN *et al*., 2005), aiming to compare the treatments in the obtained processes. When significant in the generalized linear model, treatment scores were analyzed via Tukey's mean test at the 5% probability level. Statistical analyses were performed via Statistica® software, version 7.0.

5 RESULTS AND DISCUSSION

For the multivariate statistical analysis of factors, two processes were obtained, with the first process (P1) explaining 53.66% of the variance of the original dataset and the second process (P2) explaining 16.12%, making it possible to retain 69.78% of the general variability of the data (Table 1).

Table 1. Factor loadings of the factor analysis of the evaluated soil aggregation attributes, with two processes (P1 and P2), according to sugarcane cultivars subjected to irrigation and nonirrigated

Attribute	Dimension of aggregates (P1)	Stability of aggregates (P2)
Weighted mean aggregate diameter (WMD)	-0.977	0.049
Particulate organic carbon (POC)	-0.631	-0.004
Aggregate class between 6.3 - 4.0 mm (CA1)	-0.975	0.134
Aggregate class between 4.0 - 1.0 mm (CA2)	0.714	-0.563
Aggregate class between 1.0 - 0.5 mm (CA3)	0.938	-0.086
Aggregate class <0.5 mm (CA4)	0.525	0.600
Aggregate Stability Index (ASI)	-0.366	-0.753
Mineral-associated organic carbon (MAOC)	-0.437	-0.165
Explained variance	4,293	1,290
% of variance explained	53.66	16.12

Source: The authors (2021)

P1 was named the “Aggregate Dimension” because the relevant variables in this process, with scores greater than 0.60, were related to the size and formation of the soil aggregates, which are the weighted mean aggregate diameter (WMD), particulate organic carbon (POC), and the aggregate classes (AC) CA1, CA2, and CA3. P2 was named “Aggregate Stability” because the relevant variables for this process, with scores greater than 0.60, were related to the aggregate stability index in water and the aggregate class CA4.

For the present study dataset, soil aggregation can be divided into two independent factors: one related to aggregate size and the other related to aggregate stability. These findings demonstrate that aggregate size and stability are not associated and act differently on soil aggregation. For "aggregate size," OPC directly influences the formation of larger aggregates; for "aggregate stability," no physical fractionation of organic carbon directly influences this soil process (Table 1).

In the "aggregate size" process (P1), the soil attributes with negative correlation coefficients (DMP, COP, and CA1) were directly correlated with each other, and these attributes were indirectly correlated with attributes CA2 and CA3. By acting as a cementing agent for the formation of larger aggregates, COP binds the aggregates of CA3 together, forming aggregates of CA2. In turn, the aggregates of CA2, through COP, bind together, forming aggregates of CA1. This process increases the amount of aggregate retained in CA1 and, consequently, the DMP values. Thus, increasing the COP content increases the variables DMP and CA1, reducing CA2 and CA3, justifying the inverse relationship of the variables DMP, COP, and CA1 with the variables CA2 and CA3.

In the aggregate stability process (P2), the negative attribute IEA has an inverse relationship with CA4. Thus, the higher the IEA value is, the lower the amount of soil retained in the smallest aggregate class (CA4). This occurs because aggregates are more resistant to agents that cause rupture; for example, they have greater resistance to the impact generated by raindrops (splashing) and do not break into small aggregates (CA4).

According to the generalized linear model, there was no significant effect of the interactions for any of the processes, only for the isolated factors (Table 2). For the “aggregate dimension” process, there was a significant effect for cultivar and layer, whereas for the “aggregate stability” process, there was a significant effect only for irrigation, confirming the independence of the processes obtained in the multivariate analysis.

Table 2. Generalized linear model for the processes “Aggregate dimension” (P1) and “Aggregate stability” (P2)

Source of variation	Aggregate dimension P1		Aggregate stability P2	
	F	**p- value**	**F**	**p -value**
Cultivate	3,600*	0.049	0.712	0.400
Irrigation	0.698	0.405	56,072**	<0.001
Layer	99,027**	<0.001	0.183	0.669
Cultivation vs. Irrigation	0.009	0.924	1,617	0.206
Cultivar x Layer	0.279	0.598	0.004	0.947
Management x Layer	0.193	0.661	2,904	0.091
Cultivar x Management x Layer	0.732	0.394	0.588	0.445

*Significant at 5% probability; **Significant at 1% probability
Source: The authors (2021)

The results of the mean test for process 1 revealed that the "aggregate dimension" was greater for the 0.00--0.10 m soil layer and for the areas cultivated with the IACSP93--3046 cultivar (irrigation responsive). For process 2, the "aggregate stability" was greater for irrigated management (Table 3). The negative scores generated by the mean test (Table 3) are related to the negative scores from the factor analysis (Table 1), and the positive scores are related to the positive scores from the factor analysis. Thus, the areas with negative scores in P1 (Table 3) have higher DMP, COP, and CA1 values, just as those in P2 do; the areas with negative scores have higher IEAs, and those with negative scores have higher CA4 values.

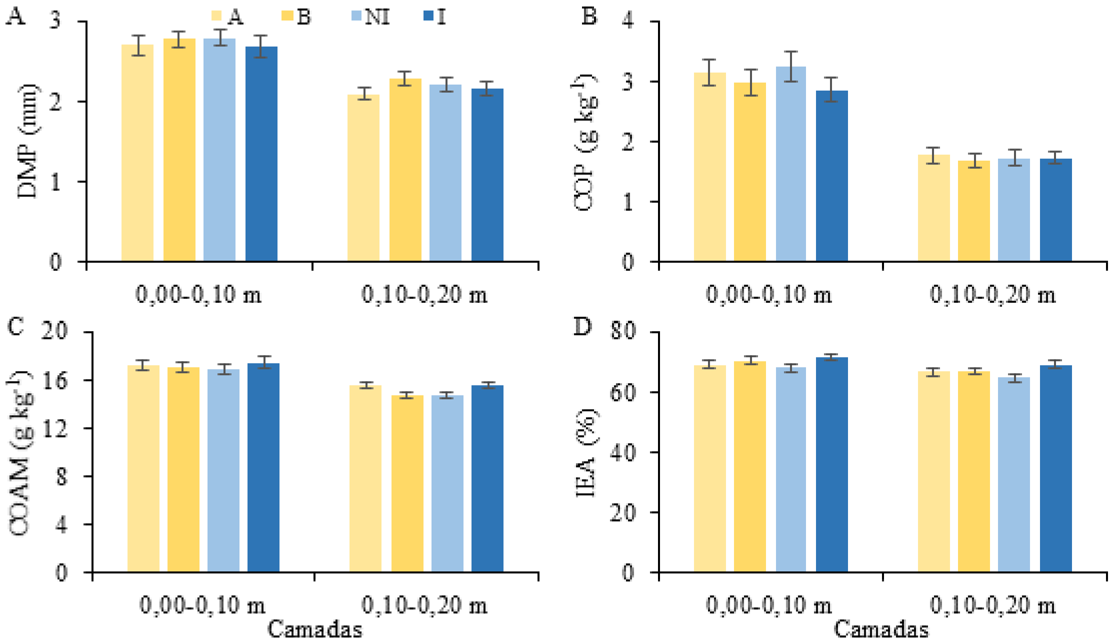
Table 3. Mean score test for significant effects of the generalized linear model for each process

Source	Aggregate dimension - P1		Aggregate stability - P2	
Cultivate	CTC 4 (A)	IACSP 93-3046 (B)		
Average	0.13 b	-0.13 a		
Irrigation			Irrigated (I)	Non-Irrigated (NI)
Average			-0.53 to	0.54 b
Layer (m)	0.00-0.10	0.10-0.20		
Average	-0.66 a	0.62 b		

Source: The authors (2021)

The descriptive statistics of the soil attributes DMP, COP, COAM, and IEA are presented in Figure 1. For DMP, considering the standard error of the mean, differences in mean values were observed only between the areas with cultivars CTC 4 (A) and IACSP93-3046 (B) in the 0.10--0.20 m layer, with a value 9.0% greater for the area with cultivar IACSP93--3046 (responsive to irrigation). Notably, all areas presented a relatively high DMP value in the 0.00–0.10 m layer, with an average DMP value 25.0% higher than that in the 0.10–0.20 m layer.

Figure 1. Weighted average aggregate diameter (WMD - A), particulate organic carbon (POC - B), mineral-associated organic carbon (CMAO - C) and aggregate stability index (ASI - D) of clayey-textured red latosol cultivated with irrigation (I) and without irrigation (NI) as a function of two sugarcane cultivars (A - CTC 4; B - IACSP93-3046)



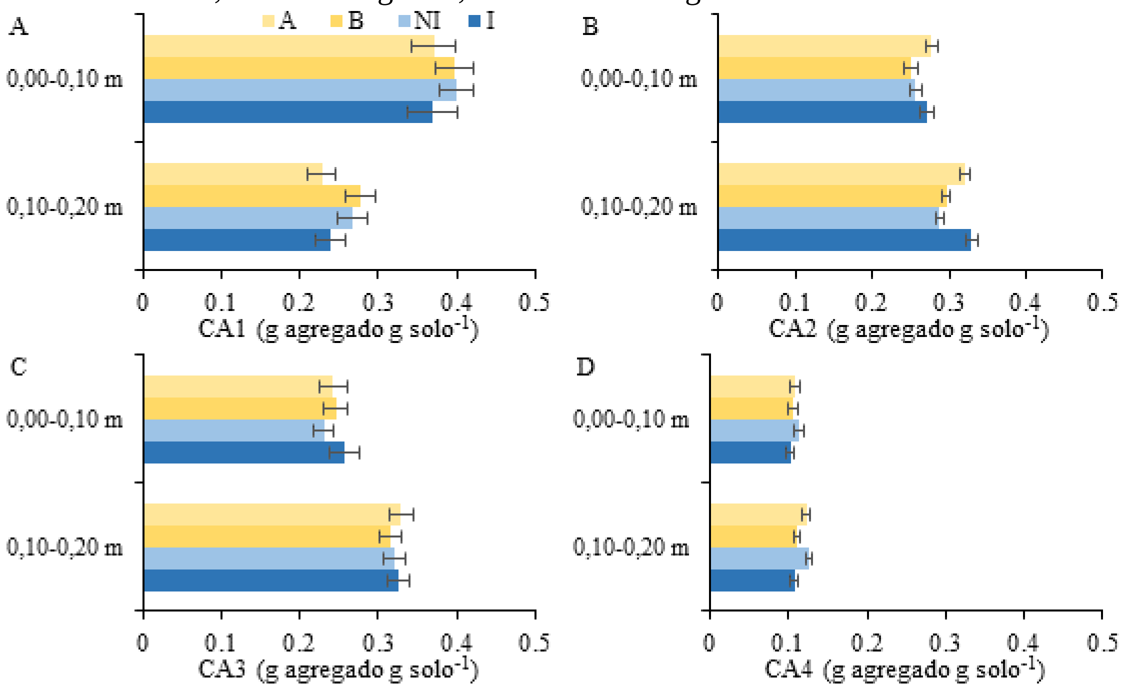
Source: The authors (2021)

In terms of the COP, differences were observed only between the soil layers, in which the 0.00–0.10 m layer presented an average value that was 76.2% greater than that of the 0.00–0.10 m layer, whereas between areas, the values were similar in both layers. This same observation can be applied to COAM, in which the 0.00–0.10 m layer presented an average value that was 13.4% greater than that of the 0.10–0.20 m layer. However, differences were observed between areas in the 0.10–0.20 m layer, in which the CTC4 cultivar and the area under irrigation presented higher average COAM values.

For the IAS, similar values were observed between the evaluated soil layers. Furthermore, in both layers, the irrigated area presented a greater IAS than did the nonirrigated area, with values 5.1% and 7.1% higher in the 0.00–0.10 m and 0.10–0.20 m layers, respectively. No significant differences in IAS were detected between sugarcane cultivars for any of the evaluated soil layers.

Among the aggregate classes, the 0.00–0.10 m layer presented the highest aggregate mass in CA1, whereas the 0.10–0.20 m layer presented the highest aggregate masses for the aggregate classes CA2 and CA3. In CA4, the aggregate mass values between the layers were similar for all areas.

Figure 2. Aggregate distribution in aggregate classes (CA). CA1: 6.3–4.0 mm (A); CA2: 4.0–1.0 mm (B); CA3: 1.0–0.5 mm (C); and CA4: <0.5 mm (D). A – CTC 4; B – IACSP 93--3046; I – with irrigation; NI – without irrigation



Source: The authors (2021)

Comparing the areas within the layers, differences between cultivars in the 0.10–0.20 m layer in the largest diameter aggregate class (CA1) were observed, with higher values for cultivar IACSP93–3046. In CA2, cultivar CTC 4 presented a greater aggregate mass than cultivar IACSP93-3046 did in both soil layers, whereas the irrigated area presented a greater aggregate mass than did the nonirrigated area in the 0.10–0.20 m layer. In CA3, no differences were detected between areas for any of the soil layers evaluated, whereas in the smallest aggregate class (CA4), a greater aggregate mass occurred in the areas with cultivar CTC 4 and nonirrigated areas in the 0.10–0.20 m layer.

The largest "aggregate dimension" in layer 1 is directly associated with the variables DMP, COP, and CA1 (Table 1). The literature shows that organic carbon is one of the main soil cementing agents that forms aggregates (SEBEN JÚNIOR; CORÁ; LAL, 2016). This study revealed that, due to physical fractionation, the COP was more closely associated with the "aggregate dimension." COP is the fraction of organic carbon linked to soil management and is less stable than COAM is, which is linked to the clay fraction of the soil. Higher COP values in the surface layer (0.00–0.10 m) are due to factors such as the high presence of organic material on the surface and in more superficial layers of the soil, such as roots and straw, from the sugarcane cycle and harvest, and the greater soil microbial activity in this layer (STONE; FOREST; PLANT, 2014).

When evaluating straw production in the second agricultural year by the sugarcane cultivars used in this study, Coelho *et al.* (2018b) reported values of up to 12 t ha $^{-1}$ straw from sugarcane tops and stalks. Thus, the amount of sugarcane straw that accumulated on the soil surface during the 4 years prior to this study, together with the greater quantity of crop roots in more superficial soil layers (SOUSA *et al.*, 2013) associated with greater microbiological activity on the soil surface for the degradation of these residues, promoted a greater COP in the 0.00–0.10 m layer, a variable that directly affects the formation of larger aggregates (Table 1).

When evaluating the aggregation of an Oxisol under corn and soybean cultivation systems, Seben Júnior, Corá, and Lal (2016) reported that COP was the fraction of CO that promoted an increase in soil aggregate size. However, the authors reported that, although significant, the correlation between COP and soil DMP was low (0.32), probably due to the high amounts of Fe and Al oxides present in tropical soils, such as the Oxisol in this study. According to Oades and Waters (1991), the high oxide contents in Oxisols limit the explanation of hierarchical aggregate theory, in which organic carbon promotes an increase in aggregate size, as oxides are the main stabilizing and aggregate-forming agents in this type of soil. As in the work of Seben Júnior, Corá and Lal (2016), it was observed in the present study that although significant, there was a low correlation between the COP (0.631) and the "aggregate dimension" process (Table 1).

In addition to the difference between layers, differences were observed between cultivars for process 1, with a greater "Aggregate Size" for the area with the irrigation-responsive cultivar IACSP93--3046 (Table 3). The greater "aggregate size" in the area with the cultivar IACSP93-3046 is associated with the greater straw production of the cultivar IACSP93-3046 and, possibly, with differences in the morphology of the root system between the evaluated cultivars.

When evaluating straw production by the sugarcane cultivars used in the second cut of this study, Coelho *et al*. (2018b) reported no differences in straw production between the cultivars CTC 4 and IACSP 93--3046, which were grown without irrigation. However, under irrigated conditions, the authors reported that the cultivar IACSP93--3046, which is responsive to irrigation, presented greater straw production than did the cultivar CTC4, with an average value that was 26% greater. Notably, cultivar IACSP93-3046 was responsive to irrigation; that is, its productivity increased when it was irrigated, whereas cultivar CTC4 showed no difference in productivity when it was irrigated or not (COELHO *et al*., 2018a; FISCHER FILHO, 2018).

These differences in cultivar responsiveness may be associated with different root system distributions. Sugarcane cultivars that are less responsive to irrigation have deeper root systems and are more tolerant to water deficit (LANDELL; BRESSIANI, 2008). These cultivars tend to respond poorly to irrigation in regions with high rainfall, as in this study, where the average annual rainfall is 1,425 mm. However, cultivars with greater root distributions in more superficial soil layers tend to respond more strongly to irrigation, as they are less tolerant to water deficit and, under these conditions, have lower productivity.

When evaluating the root density and distribution of sugarcane cultivars, Landell and Bressiani (2008) reported that the cultivar IACSP93--3046 presented the highest root density in the 0.00--0.20 m layer (1.62 g dm^{-3}) among the six cultivars analyzed. This value was more than 100% greater than that of the two cultivars, which presented the lowest root density in the 0.00–0.20 m layer. This finding demonstrates the high root density of this cultivar in the surface soil layer, which helps to explain the high responsiveness of this genotype to irrigation. Furthermore, as sugarcane undergoes root renewal throughout the year and cultivation cycles, the amount of roots left in the soil, together with the greater amount of straw from this cultivar in relation to the CTC 4 cultivar (COELHO *et al*., 2018b), promoted a greater "Aggregate Dimension" in areas with the IACSP93--3046 cultivar.

In addition to COP, the larger "Aggregate Dimension" in areas with the IACSP93--3046 cultivar may be related to other factors (Tables 1 and 3). The formation of larger aggregates is not only associated with the increase in COP levels, especially in oxidic soils but also with exudates released by the roots and microbial activity through the formation of hyphae and the release of polysaccharides from the metabolism of microorganisms (SIX *et al*., 2004; MELLONI; MELLONI; VIEIRA, 2013; SEBEN JÚNIOR; CORÁ; LAL, 2016). Thus, the greater amount of straw produced in areas with the IACSP93-3046 cultivar than in areas with the CTC4 cultivar (COELHO *et al*., 2018b) possibly promoted greater microbial activity in the areas with this cultivar, facilitating the formation of larger aggregates. Zhao *et al*. (2019) reported that greater soil microbiological activity occurred with greater amounts of straw on the soil surface, increasing the number of hyphae and the production of exudates, such as polysaccharides, aiding the soil aggregation process. Furthermore, the greater number of roots of the IACSP93-3046 cultivar in the surface layers of the soil (LANDELL; BRESSIANI, 2008) than that of the CTC4 cultivar may promote greater release of exudates that aid in the formation of aggregates, in addition to the greater amount of organic material that may generate greater microbiological activity in areas with this cultivar.

Since none of the attributes resulting from the physical fractionation of organic carbon were significant in process 2 (Table 1), the greater "aggregate stability" in irrigated areas (Table 3) can be explained by soil wetting and drying cycles. Compared with nonirrigated areas, sugarcane irrigation generates soil wetting and drying cycles throughout the year, promoting greater cohesion between soil particles in irrigated areas.

Pires and Bacchi (2010) observed, through computed tomography, that wetting and drying cycles promote greater approximation and cohesion of soil particles, which can increase aggregate stability in irrigated areas. Additionally, irrigated areas tend to have greater microbial activity than nonirrigated areas do, as soil moisture remains close to field capacity moisture throughout the year (GONG *et al*., 2015). Thus, the greater microbiological activity in irrigated areas than in nonirrigated areas results in greater release of exudates and hyphae, contributing to greater aggregate stability in water (SIX *et al*., 2004).

Campos, Pires, and Costa (2020), evaluating the organic carbon content in medium-textured soils (200 g kg^{-1} of clay) in areas with and without irrigation after 20 years of using these systems, reported that, after this period, the organic carbon content of the irrigated areas was similar to that of the region's native vegetation, whereas in the nonirrigated areas, the values were up to 30% lower than those of the native vegetation. According to the authors, this occurs because irrigated areas produce greater total crop biomass, promoting a greater amount of organic material that will be converted into organic carbon in the soil. Because the soil has a medium texture (200 g kg^{-1} clay), agricultural management practices that increase biomass production in the system, such as irrigation, more easily increase the soil carbon content than areas with more clayey soils do, as in the present study, where no relevant differences in soil COP and COAM were observed between the treatments evaluated (Figure 1). This may have occurred in clay soils because, although irrigated areas have higher total biomass production, soil moisture conditions are more favorable for crop residue degradation. Clay soils also tend to have a greater natural balance between organic carbon inputs and outputs, requiring greater amounts of organic matter to increase their organic carbon content than sandy and medium-textured soils do.

The process related to aggregate size, called "aggregate size," was directly correlated with the COP; that is, the higher the soil COP was, the greater the "aggregate size," whereas the process called "aggregate stability" did not present any variables related to SOC. This demonstrates that for oxidic soils such as the one in this study (Oxisol), the COP is essential for increasing the soil "aggregate size" process but not for "aggregate stability." Oades and Waters (1991) reported that in more weathered soils, such as Oxisols, Fe and Al oxides are the main stabilizing agents of soil aggregates, unlike in less weathered soils, where CO is essential for the formation and stability of soil aggregates.

Choosing the right sugarcane cultivar and irrigation are fundamental agricultural practices for soil conservation. This is because choosing the right cultivar directly contributes to the formation of larger aggregates, aiding in soil structuring, retention, and infiltration. This can maximize irrigation efficiency and reduce the amount of water needed. Additionally, soil carbon sequestration increases, reducing CO2 emissions $_{\text{into}}$ the atmosphere. Irrigation promotes greater aggregate stability, aiding in erosion control in sugarcane-growing areas, as these aggregates are more resistant to agricultural practices and the impact of raindrops.

6 CONCLUSION

Irrigation and proper cultivar selection are essential to generate greater aggregation and, consequently, greater soil conservation in sugarcane cultivation areas. Subsurface irrigation promotes greater aggregate stability in sugarcane cultivation areas with clayey soils. Sugarcane cultivars result in differences in soil aggregation, with the irrigation-responsive cultivar (IACSP93--3046) promoting greater soil aggregation than the nonresponsive cultivar (CTC 4).

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