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Is localized soil tillage in the planting row a sustainable alternative for sugarcane cultivation?

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ABSTRACT: The aim of this study was to evaluate the physical quality of the soils by evaluating the variation of soil penetration resistance, resulting from tillage with chiseling in the planting row and in total area, and the possible interferences of the managements in sugarcane yield. The study was carried out in southeastern Brazil, in areas under Oxisol and Ultisol, which are the two soils with the greatest representativeness of sugarcane cultivation in the country. The treatments consisted of soil tillage in total area and localized tillage in the sugarcane planting row, with 10 replicates. Undisturbed soil samples were collected in the 0-0.10, 0.10-0.20, and 0.20-0.40-m soil layers in sugarcane rows and interrows in both soil types for penetration resistance determination in laboratory. Samplings were carried out at three times, the first after soil tillage, the second after sugarcane planting, and the third six months after planting. Compared to the system with tillage in total area, localized tillage promoted higher values of soil penetration resistance in sugarcane interrows. However, this was not enough to reduce the crop yield. In the planting row, there are no differences between tillage types for soil penetration resistance. Localized soil tillage in sugarcane crop is a conservation and sustainable alternative that can replace soil tillage in total area, not interfering in the PR determined in the crop row and not altering the stem yield, regardless of the soil type.

Key words: Ultisol, soil compaction, Oxisol, conservation soil tillage, soil penetration resistance.

INTRODUCTION

Sugarcane is considered one of the main alternatives for the biofuel sector due to the great potential in the production of ethanol and its respective by-products (Christofoletti et al. 2013). Due to the semi-perennial cycle of sugarcane, its cultivation is viable only in tropical climate countries, with Brazil being the one with the highest production (753 million tons) and largest planted area (10.1 million hectares) in the world (FAOSTAT 2019).

Although the sugarcane crop has advantages, its cultivation faces some limitations, especially the intense soil turning caused by tillage operations for planting and the loss of soil physical quality resulting from the intense traffic of machines throughout the crop cycle (Cherubin et al. 2016). However, soil tillage is considered fundamental to ensure high yields throughout the sugarcane cycle, as this is the only time when soil correctives and fertilizers can be incorporated in subsurface, ensuring favorable physical and chemical conditions for growth of the crop root system (Moraes et al. 2019).

Soil tillage activities consist of mechanized operations that vary according to the producer. Among these operations, the one that requires more time, tractor power, fuel consumption and, consequently, higher cost is chiseling. These operations are usually performed without considering the type of soil, degree of soil compaction, and the morphology of the sugarcane root system. More than 75% of the sugarcane root system is close to the planting row, being distributed up to 0.40 m deep and up to 0.30 m from the center of the planting row (Otto et al. 2009; Clemente et al. 2017). Thus, localized agricultural managements in the sugarcane planting row tend to be viable for the crop, reducing the cost of chiseling in soil tillage, fuel consumption, and CO2 emissions to the atmosphere, besides not interfering with yield (Tenelli et al. 2019; Cortez et al. 2020).

There is consensus that the soil has a high resilience capacity, that is, naturally after some period of time it can return to its natural conditions (Blanco and Lal 2010; Bavoso et al. 2012). In this context, the effects of soil tillage operations for sugarcane planting may occur for a short period of time and may not directly impact the increase in sugarcane yield. This effect is even more pronounced in sugarcane crop, due to the intense traffic of machines to plant and grow the crop, which can reduce the effects of the tillage operation on the physical attributes of the soil, especially in the interrows.

Among the soil physical attributes, the one which accurately indicates the degree of soil compaction is soil penetration resistance (PR) (Otto et al. 2011). PR analysis assists producers and technicians in decision-making regarding soil structure, as it has high correlations with other soil attributes, such as bulk density, macroporosity, and microporosity (Busscher et al. 2002; Schiavo and Colodro 2012), related to the availability of water for plants, aeration, and degree of soil compaction. It is emphasized that soil moisture standardization is essential to evaluate PR values, since this variable is influenced by soil moisture (Fernandes et al. 2020).

The hypothesis was that the effects of localized soil tillage in the sugarcane planting row are equivalent to those of soil tillage in total area, generating similar physical conditions and, consequently, similar yields of sugarcane. Within this context, the present study was carried out in an Oxisol and in an Ultisol, which are the soils with the greatest representativeness in sugarcane cultivation in Brazil, with the aim of assessing the physical quality of the soils by evaluating the variation of soil PR, caused by tillage with chiseling in the planting row and in total area, and the possible interferences of the managements in sugarcane yield.

MATERIAL AND METHODS

The experiment was conducted in the state of São Paulo, Brazil, in two different areas, which are 27 km away from each other and have been used for sugarcane production for more than 20 years. Area 1 is located in the municipality of Guariba, close to the geographic coordinates 21°24'25"S and 48°12'12"W and altitude of 618 m. Area 2 is located in the municipality of Monte Alto, close to the geographic coordinates 21°15'23"S and 48°25'52"W and altitude of 735 m (Fig. 1).

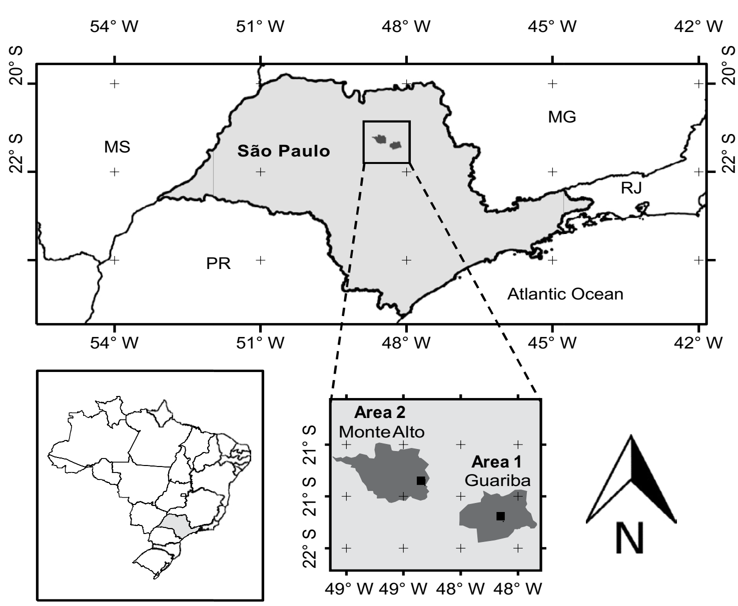

Figure 1. Geographical location of the experimental areas. The area with Oxisol is located in the municipality of Guariba (area 1), and the area with Ultisol is located in the municipality of Monte Alto (area 2).

The climate of the region for the two areas, according to Köppen's classification, is Aw, tropical mesothermal with dry winter, temperature of the hottest month higher than 22 °C and temperature of the coldest month above 18 °C (Alvares et al., 2013). The average annual precipitation is 1,400 mm, with rainfall concentrated in the period from October to March and relative drought between April and September. The accumulated precipitation in the experimental period was 2,380 mm in area 1 and 2,792 mm in area 2.

Using the criteria established by Santos et al. (2018) in the Brazilian Soil Classification System, the soil of area 1 was classified as latossolo vermelho (LV), and as Oxisol, according to the American Soil Survey Staff (2014). It is located near the sandstone-basalt transition, with sandstone from the Vale do Rio do Peixe, former Bauru Group, Adamantina Formation, and basalt from the Serra Geral Formation (IPTSP 1981). The soil is considered a B production environment for sugarcane production (Prado 2008).

Using the criteria established by Santos et al. (2018) in the Brazilian Soil Classification System, the soil of area 2 was classified as argissolo amarelo (PA), and as Ultisol, according to the American classification (Soil Survey Staff 2014). In this soil, the B horizon started at 0.35 m, and the geology of the area is sandstone from Vale do Rio do Peixe, former Bauru Group, Adamantina Formation (IPTSP 1981), which is considered C in the classification for sugarcane production environments (Prado 2008). Both areas have a slope of less than 3%.

Characterization of soil texture, in the 0-0.10, 0.10-0.20 and 0.20-0.40-m layers, and soil fertility, in the 0-0.10 and 0.10-0.20-m layers, was performed before the experiment was set up (Tables 1 and 2).

Sugarcane plants from the previous cultivation were eradicated before the experiment was set up. The operation was performed in a mechanized way in the Oxisol, using a ratoon-eliminating implement, in November 2014. In the Ultisol, eradication was performed using glyphosate (dose of 4 $L \cdot ha^{-1}$) in January 2015, due to the conservation management adopted in these soils with higher erosion potential.

Chemical correction of the Oxisol was carried out in December 2014 with the application of 1.5 $t \cdot ha^{-1}$ of limestone (CaO: 35%, MgO: 15%, and relative neutralization value — RNV: 81%) and 1 $t \cdot ha^{-1}$ of agricultural gypsum. In the Ultisol, the application was carried out in January 2015, with a dose of 3 $t \cdot ha^{-1}$ of limestone (CaO: 35%, MgO: 15%, and RNV: 81%) and 1 $t \cdot ha^{-1}$ of agricultural gypsum.

The experiment consisted of two types of soil tillage (Fig. 2). Tillage in total area (TTA) was performed using a chisel plow with five shanks, with a configuration consisting of one shank in the center of the implement and two more shanks on each side, all spaced apart by 0.5 m. Localized tillage (LT) was performed using a chisel plow with four shanks to till two consecutive rows, and each row was tilled by the action of a pair of shanks spaced apart by 0.5 m. The spacing between the two central shanks was 1 m, and the spacing between the two end shanks was 2 m. This arrangement aimed to provide the spacing of 1.5 m between the centers of the two rows tilled.

The two chisel plows had shanks with length of 0.80 m and width of 0.04 m, triangular tip with length of 0.25 m and width of 0.1 m, and clod-breaking rollers located behind the shanks to break clods and level the soil. For both treatments, the working depth was 0.40 m.

The experimental design used was large and paired plots (Perecin 2008; Perecin et al. 2015). The area was composed of 20 plots, 10 for TTA and 10 for LT, each plot with approximately 5,000 m^2 in the Oxisol and 4,500 m2 in the Ultisol. Chiseling in the area under LT and TTA was performed on January 31, 2015, with soil moisture equal to 0.18 $g \cdot g^{-1}$ in the Oxisol, and on February 17, 2015, with soil moisture equal to 0.11 $g \cdot g^{-1}$ in the Ultisol.

The crop was planted on March 7, 2015 in the Oxisol (cultivar CTC 14) and on March 26, 2015 in the Ultisol (cultivar CTC 4). These operations were performed by a mechanized set composed of a planter and a tractor, with furrowing at 0.30-m depth, spacing of 1.5 m between furrows, application of 500 $kg \cdot ha^{-1}$ of 10-25-25 fertilizer, distribution of seedlings, application of pesticides and covering.

In both areas, immediately after planting, pre-emergent herbicides were applied. In June 2015, in both soils, the *quebra-lombo* operation (breaking clods and leveling the soil in the interrows) and a new herbicide application were carried out.

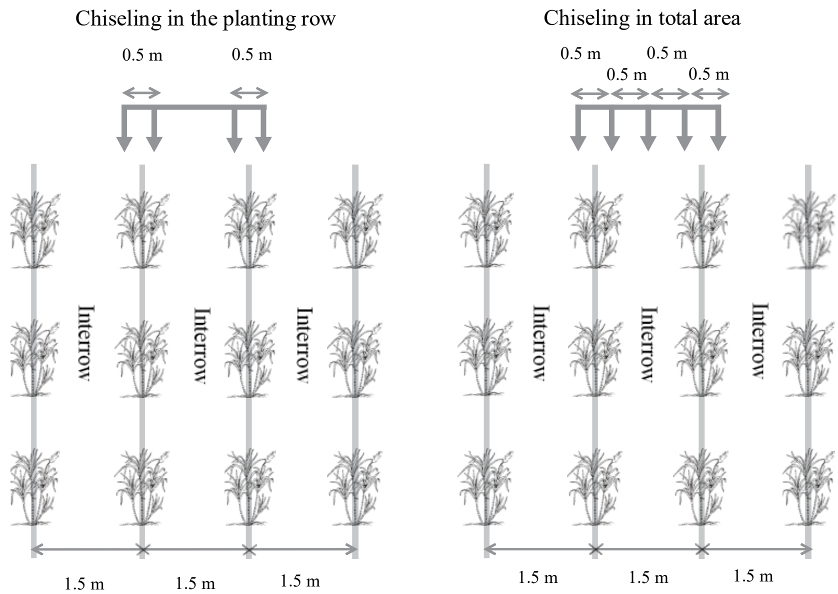

Figure 2. Scheme of soil tillage (a) with chiseling in the sugarcane planting row and (b) with chiseling in total area.

Samplings to determine soil PR were carried out in the 0-0.10, 0.10-0.20 and 0.20-0.40-m layers in the planting row and interrow. The collections in the planting row were carried out at 0.20 m away from the center of the furrow, and the collections in the interrows were performed at 0.75 m away from the center of the furrow. For the evaluation, three samplings were carried out:

- First sampling: after soil chiseling (T1);
- Second sampling: after sugarcane planting (T2);
- Third sampling: six months after planting (T3).

Undisturbed soil samples were collected in volumetric rings (0.05 × 0.05 m) using a Uhland-type auger. In each plot, three volumetric rings containing the undisturbed soil samples were collected in each of the three layers evaluated. Soil PR was determined using the laboratory static electronic penetrometer, standardizing soil moisture at the 100 hPa tension, as described by Tormena et al. (1998).

Sugarcane was harvested raw and mechanically on July 1st, 2016 in both areas. The operation was carried out using a harvester, which cut the stems and transferred them to a set of two wagons equipped with load cells to measure the harvested mass. Stem production was determined in each of the plots, which made it possible to calculate stem yield ($t \cdot ha^{-1}$). To estimate stem yield, the entire plot was harvested mechanically, and the stems were transferred to a wagon. This wagon was equipped with load cells, allowing the material to be weighed immediately. According to stem mass and harvested area, stem yield was estimated.

Analysis of variance was performed in a large paired-plot design (Perecin 2008; Perecin et al. 2015). The means of the variables under study were compared by Tukey's test, at 5%-significance level ($p < 0.05$), for each soil layer.

A study of Pearson's linear correlation ($p < 0.05$) between PR and sugarcane yield was conducted for each area. For this, the mean values of PR obtained in each layer, sampling site and at times 2 and 3 were correlated with sugarcane yield in each type of soil. The data from time 1 were not used in the correlation analysis, because during this period the sugarcane crop had not yet been planted.

RESULTS AND DISCUSSION

In the Oxisol, the values of soil PR in the 0-0.10 and 0.20-0.40-m layers (Table 3) were not influenced by LT and TTA. However, in the 0.10-0.20-m layer, the PR was higher in the soil under LT than TTA (Fig. 3). The difference found in this layer was due to the higher value of the attribute in the interrow and greater amplitude between the PR values in the interrow of the two treatments (Fig. 3c) compared to the other layers. This fact can also explain the behavior of PR in the soil of the layers 0-0.10 (Fig. 3b) and 0.20-0.40 m (Fig. 3f) in the Ultisol. In this soil, only the 0.10-0.20-m layer (Table 3) was not influenced by LT and TTA.

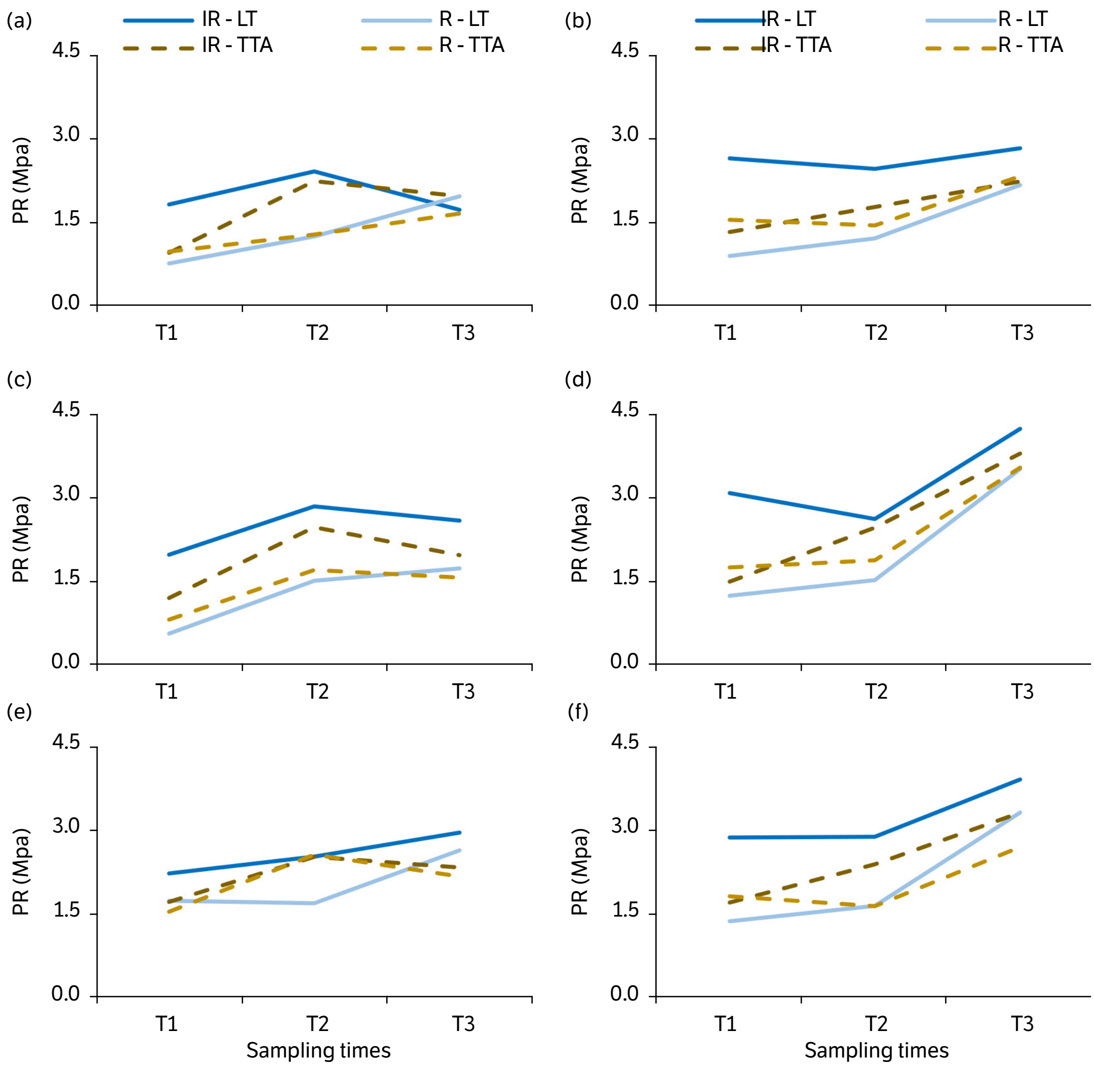

Figure 3. Values of soil penetration resistance (PR), evaluated in the rows (R) and interrows (IR) of the areas subjected to soil tillage in the planting row (LT) and in total area (TTA), (a and b) in the 0-0.10, (c and d) 0.10-0.20 and (e and f) 0.20-0.40-m layers at three sampling times (T1, T2 and T3). (a, c and e) Oxisol and (b, d and f) Ultisol.

Immediately after tillage (T1), the crop interrow in the TTA area had lower PR in all layers evaluated (Fig. 3) compared to LT for both soils. At T1, Oxisol PR interrow under LT was 92% higher in the 0-0.10-m layer and 65% higher in the 0.10-0.20-m layer compared to TTA. In turn, in the 0.20-0.40-m layer, the differences were not significant (Table 3). This result may be explained by the reduction in the efficiency of the chiseling operation in changing the PR, due to the working depth of the implement, causing changes mainly in the surface layers.

In the Ultisol, all PR values in the interrow showed differences between the treatments at T1 (Table 3). Under LT, PR interrow in the 0-0.10-m layer was 100% higher compared to TTA. In the 0.10-0.20-m layer, it was 108% higher, and in the 0.20-0.40-m layer, 70% higher. The results, as in the Oxisol, show a tendency of reduction in the efficiency of the chiseling operation as a function of the working depth, but this effect was minimized in the Ultisol, because it had lower clay contents in all layers (Table 1), resulting in lower resistance to machine displacement.

Table 1. Particle-size analysis of the soils of the experimental areas.

Layer (m)	Clay	Sand	Silt	Clay	Sand	Silt
	g·kg^{-1}			g·kg^{-1}		
	Oxisol			Ultisol		
0-0.10	548	321	131	136	794	70
0.10-0.20	572	321	107	163	799	38
0.20-0.40	619	328	53	187	763	50

Table 2. Chemical attributes in the 0-0.10 and 0.10-0.20-m layers of the Oxisol and Ultisol subjected to soil tillage in the planting row and in total area.

Attributes	Oxisol		Ultisol	
	Layer (m)			
	0-0.10	0.10-0.20	0-0.10	0.10-0.20
pH (H_2O)	5.7	5.5	5.6	5.5
OC (g·kg^{-1})	30	26	8	6
P (mg·dm^{-3})	37	31	16	14
K (cmol$_c$·dm^{-3})	0.2	0.1	0.1	0.1
Ca (cmol$_c$·dm^{-3})	3.9	3.5	2.3	2.1
Mg (cmol$_c$·dm^{-3})	1.7	1.4	0.8	0.7
Al (cmol$_c$·dm^{-3})	0	0	0	0
H + Al (cmol$_c$·dm^{-3})	2.2	2.5	1.6	1.7
SB (cmol$_c$·dm^{-3})	5.8	5	3.3	2.9
CEC (cmol$_c$·dm^{-3})	8	7.5	4.9	4.6
V (%)	72	67	66	63

OC: organic carbon; SB: sum of bases; CEC: cation exchange capacity; V: base saturation.

The PR in the interrow under TTA increased after the planting operation (T2), demonstrating the impact of mechanized planting operations (Fig. 3). In all layers, there was reduction in the difference of PR in the interrow under TTA compared to LT, demonstrating a tendency to equality (Fig. 3). According to Soracco et al. (2018), this is associated with the machine traffic on the soil, whose structure was damaged by tillage in the interrows, resulting in greater transmission of pressure, reducing soil porosity, and impacting soil attributes. When evaluating the PR temporal variability as a function of tillage systems, Kuhwald et al. (2020) verified that soil tillage initially promotes reduction of PR, but over time the values become similar between tillage systems.

In the Oxisol, the PR in the interrow of the soil under LT in the 0-0.10-m layer (Fig. 3a), compared to the same site under TTA, which was 92% higher at T1, changed to 7% higher at T2, showing no differences (Table 3). Therefore, the non-chiseled interrow (LT) had greater resistance to the disturbances caused by mechanization, because it showed increase of 0.49 MPa, while in the chiseled interrow (TTA) the increase was 1.29 MPa. This variation was also observed in the interrow of the 0.10-0.20 and 0.20-0.40-m layers (Figs. 3c and 3e).

In the Ultisol, the PR in the interrow of the soil under LT in the 0-0.10-m layer (Fig. 3b), compared to the same site under TTA, which was 100% higher at T1, changed to 39% higher at T2. This demonstrates a trend of equalization between treatments in a short term. The PR values in the interrow soil under LT were reduced compared to T1 in the 0-0.10 (Fig. 3b) and 0.10-0.20-m layers (Fig. 3d) and remained similar in the 0.20-0.40-m layer (Fig. 3f), demonstrating greater capacity to withstand the impacts of the traffic of machinery and equipment.

In the Oxisol, the PR at T3 decreased compared to T2 in the interrow of the two treatments in the 0-0.10 and 0.10-0.20-m layers and in the 0.20-0.40-m layer under TTA (Fig. 3). This result can be explained by the process of resilience, which may be defined as the intrinsic soil capacity to return to a balance similar to that of the previous state (Blanco and Lal 2010), stimulated by regenerative processes, which include wetting/drying cycles and biological activities, such as root growth (Bavoso et al. 2012).

Table 3. P-value for the comparison of means of soil penetration resistance at the three sampling times (T1, T2 and T3) in the 0-0.10, 0.10-0.20 and 0.20-0.40-m layers, in sugarcane rows and interrows in the Oxisol and Ultisol subjected to chiseling in the planting row (LT) and in total area (TTA).

Treatment	Oxisol			Ultisol		
	0-0.10	0.10-0.20	0.20-0.40	0-0.10	0.10-0.20	0.20-0.40
LT*TTA	0.20ns	0.002*	0.17ns	0.01*	0.10ns	0.0002**
IR-LT * IR-TTA – T1	0.003*	0.008*	0.07ns	< 0.0001**	< 0.0001**	< 0.0001**
IR-LT * IR-TTA – T2	0.54ns	0.19ns	0.99ns	0.006**	0.64ns	0.05*
IR-LT * IR-TTA – T3	0.39ns	0.033*	0.027*	0.018*	0.18ns	0.02*
R-LT * R-TTA – T1	0.45ns	0.38ns	0.48ns	0.010*	0.12ns	0.072ns
R-LT *R-TTA – T2	0.91ns	0.51ns	0.002**	0.35ns	0.27ns	0.99ns
R-LT * R-TTA – T3	0.27ns	0.35ns	0.09ns	0.52ns	0.20ns	0.02*

*Differs statistically at 5%-probability level ($p < 0.05$); **differs statistically at 1%-probability level ($p < 0.01$); ns: not significant at 5% probability level.

Compared to T2, sampling time 3 was characterized in the Ultisol by an increase in the interrow PR of the two treatments and all layers (Fig. 3). This phenomenon was also observed by Busscher et al. (2002), who verified the reconsolidation of a sandy loam soil through the increase in the values of PR and that this result was correlated with the volume of accumulated precipitation and the respective soil water infiltration.

As Ultisol has a higher sand content compared to Oxisol (Table 1), it tends to have higher macroporosity. The presence of larger pores in the soil promotes more favorable conditions for soil particles accommodation. In addition, due to the lower content of organic carbon and clay (Tables 1 and 2), Ultisol has less aggregates compared to Oxisol. This promotes a greater amount of free clay, silt and sand particles that favor accommodation in soil pores and, consequently, support the PR increase over time.

Overall, the two treatments caused similar effects on the PR determined in the planting row for both soils. This finding was expected because the site was affected by the chiseling shanks during tillage and by the planter furrower at the time of planting. On average, the LT treatment promotes lower PR in the crop row compared to TTA treatment for both soils. This result can be explained by the lower resistance of the soil to the action of four shanks (LT) when compared to the action of five shanks (TTA), thus optimizing the traction force of the tractor, causing greater rupture of the soil layers. In addition, the action of the planter furrower has standardized the structural conditions of the soil, which suggests the possibility that such machine may replace, under the same conditions presented, the chisel plow.

The two types of soil tillage showed the tendency to equality for the attribute soil penetration resistance, and their different actions did not influence the values of sugarcane stem yield ($t \cdot ha^{-1}$) (Table 4). When evaluating the effect of no-tillage on sugarcane, that is, the opening of only the furrows for planting in soils with different textures (87 and 547 $g \cdot kg^{-1}$ of clay in the 0-0.10-m layer), Tenelli et al. (2019) observed no differences in crop yield compared to conventional soil tillage. In the clay soil, the authors also verified higher yield under no-tillage system, a factor that according to them may be associated with the maintenance of soil structure interrows, favoring greater soil microporosity and, consequently, greater water supply for plants compared to conventional tillage. In the study conducted by Tenelli et al. (2019), the planting furrows were 0.30-m deep and 0.50-m wide, that is, the tillage operation in reduced tillage system encompassed the area of greater amount of sugarcane roots, which justifies the similarity of yield between the tillage systems. Otto et al. (2009) and Clemente et al. (2017) observed that more than 75% of the roots are found at 0.40-m depth and, horizontally, at 0.30 m from the center of the planting row. According to the authors, this occurs due to the natural morphology of the crop root system and the compaction in the interrows caused by the mechanization, which limits root development in this region.

In the area with Oxisol, there was a significant correlation of PR determined in the row in the 0-0.10-m layer with sugarcane yield at the sampling time T3 (Table 5). In this situation, the variation in sugarcane yield as a function of PR was quadratic, with maximum value obtained with PR of 2.74 MPa. This quadratic variation indicates that PR values lower or greater than 2.74 MPa reduce crop yield, but by different factors. Low PR values indicate sites with higher macroporosity and lower microporosity, that is, with lower water availability, whereas high values indicate sites with a higher degree of compaction, restrictive to crop growth. In sugarcane interrow, significant correlations were observed in deeper soil layers, in the 0.20-0.40-m layer at T2. In this situation, the correlation of PR with yield was negative, with reduction of 8.6 t·ha^{-1} for each unit increment of soil PR in the 0.20-0.40-m layer.

Table 4. Sugarcane stem yield (t·ha^{-1}) in Oxisol (CTC 14) and Ultisol (CTC 4) subjected to chiseling in the planting row and in total area.

Treatment	Oxisol	Ultisol
	Yield (t·ha^{-1})	
Localized tillage	103.97 a	109.40 a
Tillage in total area	101.09 a	111.22 a

*Same letters indicate that there was no difference by Tukey's test (p > 0.05).

Table 5. Correlation (r) between soil penetration resistance (PR) and sugarcane yield as a function of sampling time and site in each evaluated layer of the Oxisol.

Time	Site	Layer (m)	Equation	r	Point of maximum
T2	Row	0-0.10	y = -3.563*PR + 107.0	-0.25ns	-
		0.10-0.20	y = -2.196*PR + 106.0	-0.14ns	-
		0.20-0.40	y = -2.032*PR + 106.9	-0.14ns	-
	Interrow	0-0.10	y = -2.764*PR + 108.9	-0.21ns	-
		0.10-0.20	y = -1.875*PR + 107.5	-0.11ns	-
		0.20-0.40	y = -8.604*PR + 124.3	-0.58**	-
T3	Row	0-0.10	y = -2.51*PR2 + 13.77*PR + 87.6	0.48*	2.74 MPa
		0.10-0.20	y = 1.868*PR + 98.8	0.22ns	-
		0.20-0.40	y = 2.392*PR + 98.3	0.09ns	-
	Interrow	0-0.10	y = -3.259*PR + 108.5	-0.17ns	-
		0.10-0.20	y = 1.501*PR + 99.1	0.14ns	-
		0.20-0.40	y = 3.118*PR + 94.3	0.24ns	-

T2: sampling after sugarcane planting; T3: sampling six months after planting; ns: not significant at 5% probability level.

In the Ultisol, there was a significant correlation between PR and yield only in the sugarcane row at T2 (Table 6). The significant correlation occurred only for the 0-0.10-m layer, with a quadratic variation. In this situation, the maximum sugarcane yield was reached with the PR value of 1.35 MPa. These results indicate that the PR determined in the interrows of sugarcane cultivated in Ultisol does not interfere in its yield, confirming that soil tillage in the interrows is dispensable.

The discussion presented refers to the practice of localized chiseling as an important alternative compared to chiseling in total area, since the differences were minimized in a short term and the results of plant growth were similar. In the same experimental area, Melo et al. (2019) observed close to sugarcane harvest that plant height, number of stems per meter and dry mass per plant were similar between tillage systems in both types of soil.

Soil tillage with chiseling only in the row presents itself as an alternative to conventional management with chiseling in total area, resulting in economic and environmental gains, with no impact on plant growth. Cortez et al. (2020) observed that the localized subsoiling operation led to saving of 43.5% in fuel consumption and increasing of 59.4% in operating capacity, factors that reduce the cost of production and mitigate CO_2 emission to the atmosphere. When evaluating CO_2 emission due to tillage systems in the same area of the Oxisol of the present study, Souza et al. (2017) identified increase of 315.4 kg CO_2·ha^{-1} in the emission at the site with chiseling in total area, when compared to localized chiseling. In the Ultisol, the authors observed no statistical difference as a function of the tillage system, but there was a higher tendency of CO_2 emission under tillage in total area. This indicates that localized chiseling in the planting row reduces CO_2 emissions because of both the reduction in fuel consumption due to tillage operations and the soil tillage itself, maintaining the interrow with no soil mobilization.

Table 6. Correlation (r) between soil penetration resistance (PR) and sugarcane yield as a function of sampling time and site in each evaluated layer of the Ultisol.

Time	Site	Layer (m)	Equation	r	Point of maximum
T2	Row	0-0.10	y = -21.168*PR2 + 57.348*PR + 72.6	0.49*	1.35 MPa
		0.10-0.20	y = 1.552*PR + 107.1	0.12ns	-
		0.20-0.40	y = 4.981*PR + 100.4	0.39ns	-
	Interrow	0-0.10	y = -3.124*PR + 116.4	-0.22ns	-
		0.10-0.20	y = -6.037*PR + 125.1	-0.33ns	-
		0.20-0.40	y = -6.421*PR + 126.7	-0.37ns	-
T3	Row	0-0.10	y = -0.013*PR + 109.8	-0.06ns	-
		0.10-0.20	y = 0.475*PR + 108.1	0.09ns	-
		0.20-0.40	y = 0.051*PR + 109.6	0.02ns	-
	Interrow	0-0.10	y = -1.323*PR + 113.1	-0.08ns	-
		0.10-0.20	y = -0.624*PR + 112.3	-0.10ns	-
		0.20-0.40	y = 1.226*PR + 105.3	0.09ns	-

T2: sampling after sugarcane planting; T3: sampling six months after planting; ns: not significant at 5% probability level

In addition to the benefits such as reduction of costs with fuel and CO_2 emission, localized soil tillage preserves the structure of sugarcane interrows. Almeida et al. (2016), evaluating soil loss in various soil production and tillage systems, observed that conservational tillage systems reduce soil loss due to erosion by more than 80%.

CONCLUSION

Localized soil tillage in sugarcane planting row is a conservation and sustainable alternative that may replace soil tillage in total area, not interfering in soil PR determined in the crop row and in sugarcane yield, in addition to other economic and ecosystem benefits. Compared to the system with tillage in total area, localized tillage promotes higher values of soil PR in sugarcane interrows. However, as sugarcane has a more distributed root system close to the planting row, this was not enough to reduce the crop yield. In the planting row, regardless of the layer, type of soil and sampling time, there are no differences between tillage types for soil PR.

AUTHORS' CONTRIBUTION

Conceptualization: Mazaron, B. H. S. and Fernandes, C.; **Methodology:** Mazaron, B. H. S. and Fernandes, C.; **Investigation:** Mazaron, B. H. S. and Fernandes, C.; **Data curation:** Mazaron, B. H. S. and Coelho, A. P.; **Formal analysis:** Mazaron, B. H. S., Coelho, A. P. and Fernandes, C.; **Funding Acquisition:** Mazaron, B. H. S. and Fernandes, C.; **Resources:** Mazaron, B. H. S. and Fernandes, C.; **Supervision:** Fernandes, C.; **Writing – Original Draft:** Mazaron, B. H. S. and Coelho, A. P.; **Writing – Review and Editing:** Fernandes, C..

DATA AVAILABILITY STATEMENT

All dataset were generated and analyzed in the current study.

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