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Effects of silage production with different mechanized sets on soil physical attributes

Atributos físicos do solo submetido a ensilagem com diferentes conjuntos mecanizados

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ABSTRACT - The evaluation of the physical attributes of the soil in cultivated areas is essential for understanding the impacts of agricultural operations, especially those with intense machine traffic. Therefore, the present study aimed to evaluate the physical attributes of the soil submitted to silage with different mechanized sets. A randomized block design was adopted with three treatments: forage harvester with a one-row cutting platform (T1), forage harvester with a three-row cutting platform (T2), and T2 with a forage harvester with a conveyor wagon. Before ensiling and 24 hours after the operation, intact samples of soil classified as Latossolo Vermelho-amarelo álico, intact, were collected to determine the micro, macro, and total porosity, soil density, and volumetric soil water content according to the methodology proposed by the Brazilian Agricultural Research Corporation (Embrapa). After ensiling, the resistance to soil penetration was measured with an electronic manual penetrometer, before and after ensiling, at the A horizon of the soil in the layers of 0.0-0.2 m and 0.2-0.4 m. We analyzed the data by establishing the confidence interval using the t-test at 10% probability. The sets reduce the macroporosity and total porosity of the soil in the 0.0-0.2 m and 0.2-0.4 m soil layers. T2 promoted greater total density in the 0.0–0.2 m layer. The silage increased the resistance to soil penetration to a depth of 0.15 m.

Keywords: Maize. Soil porosity. Resistance to soil penetration.

RESUMO - A avaliação dos atributos físicos do solo em áreas cultivadas é essencial para a compreensão dos impactos das operações agrícolas, especialmente aquelas com intenso tráfego de máquinas. Sendo assim, o objetivo do trabalho foi avaliar atributos físicos do solo submetido a ensilagem com diferentes conjuntos mecanizados. Adotou-se um arranjo experimental de blocos casualizado com três tratamentos: ensiladora com plataforma de corte de uma linha (T1), ensiladora com plataforma de corte de três linhas (T2) e conjunto ensiladora T2 com carreta de transportadora. Antes da ensilagem e 24 horas após a operação, coletou-se amostras de solo classificado como Latossolo Vermelho-amarelo álico, intactas para determinar a micro, macro e porosidade total, densidade do solo e umidade volumétrica conforme metodologia proposta pela Empresa Brasileira de Pesquisa Agropecuária (Embrapa). Após a ensilagem mediu-se a resistência à penetração do solo com um penetrômetro manual eletrônico, antes e após a ensilagem, no horizonte A do solo nas camadas de 0,0 a 0,2 m e 0,2 a 0,4 m. Analisou-se os dados estabelecendo o intervalo de confiança conforme o teste t, a 10% de probabilidade. Os conjuntos reduzem a macroporosidade e porosidade total do solo, nas camadas de 0,0 a 0,2 m e 0,2 a 0,4 m. T2 propiciou maior densidade total na camada de 0,0 a 0,2 m. A ensilagem aumentou a resistência à penetração do solo até a profundidade de 0,15 m do mesmo.

Palavras-chave: Milho. Porosidade do solo. Resistência a penetração do solo.

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INTRODUCTION

The dry season in Brazil significantly reduces the usage and quality of pastures, which causes direct losses in animal production. To alleviate this problem, producers look for alternative food sources to make available to animals, such as silage (BARCELOS et al., 2018).

Crops aimed at silage are usually planted in the same areas, thus having the precarious replacement of organic matter on the surface, causing problems in nutrient cycling and soil conservation (NAGAHAMA et al., 2016).

Agricultural machines received constant technological packages over the years, increasing weight and power to achieve higher operational and energy efficiency (UNGUREANU et al., 2015). However, the increase in the contact area of tires did not accompany it, which caused growth damage to the soil physical structure.

Reduced porosity affects water and air availability for the root system, reducing crop yield and interfering with soil biodiversity (LEES et al., 2016). Depending on the level of soil compaction, it is necessary to carry out mechanized agricultural operations, which involve energy and economic expenditure, impacting sustainability (JANULEVIČIUS et al., 2019).

For Simeckova et al. (2021), the magnitude of the effects caused by agricultural equipment on the soil physical properties depends on axle load, tire inflation pressure, contact area, and soil water content. They are also affected by the initial soil density, equipment speed, and the number of passes must also be considered (RENČÍN; POLCAR; BAUER, 2017).

The average pressure applied to the ground by the wheelset is the ratio between the vertical load and its contact area (BATTIATO; DISERENS, 2017). For Berisso et al. (2013), it is the intensity and direction of the stress applied to the soil due to machine traffic, determined according to the deformation suffered, reducing pore size and the connectivity between them, decreasing permeability.

The present study aimed to evaluate soil physical attributes before and after the harvest of maize silage using two whole-plant, single-row, and total-area harvesting machines, with and without a forage transport wagon.

MATERIAL AND METHODS

Experimental area

The experiment occurred at Fazenda Cangüiri, in Pinhais-PR, Brazil, in an Environmental Preservation Area close to central coordinates 7189983.01 latitudes and 688066.38 longitudes, Fuso 22J, Datum WGS84. According to the Köppen climate classification, the climate is Cfb (temperate oceanic climate) with an average temperature of 22ºC (ALVARES et al., 2013).

Was sowed the experimental area of 2.0 ha (Figure 1) in the second half of October with the Hybrid Biomatrix BM950PR03, using a spacing of 0.8 m between rows and a population of 54.6 thousand plants per hectare. The soil was classified as Latossolo Vermelho Amarelo, with a slope of 5% in the sowing direction, with conventional soil preparation (intermediate harrow followed by leveling harrow). The base fertilization was 350 kg ha^{-1} of NPK 08-20-20, and a top one of 400 kg ha^{-1} of urea (46% nitrogen) was applied 45 days after sowing phytosanitary factors during cultivation.

Used harvesting sets

The whole maize plants were processed for silage 120 days after sowing. Two forage harvesters were used for silage processing: the first is composed of a single lateral harvesting row, model JF C120; the second is with the three-row cutting deck, model JF 2000 AT. Both machines have twelve cutting knives, set for 4x10^{-3} m particle cutting, and are not equipped with a grain breaker.

The testing used two tractors, Case IH™ Farmall 80 and New Holland™ T6 130, whose technical specifications are in Table 1. With these tractors, two tractor-forage sets formed: A) C120 harvester and Case IH™ Farmall 80 tractor, and B) 2000 AT harvester with the New Holland™ T6 130 tractor.

Table 1. Technical specifications of A and B tractors sets.

Tractor	Case IH™ Farmall 80		New Holland™ T6 130	
Rated power ISO TR 14396 (kW)	59		97	
Traction Type	4x2 AFT*			
Anticipation Index (%)	2.37		3.02	
Tire Type	Front Tire Goodyear™ 12.4–24	Rear tire Goodyear™ 18.4–30	Front Tire Goodyear™ 14.9-28	Rear tire Pirelli™ 18.4–38
Inflation Pressure kPa	137	110	220	110

*AFT – Auxiliary Front Traction.

The experimental arrangement adopted in randomized blocks (1000 x 8 m), consisting of three treatments (harvest modalities): forage harvester with a single-row cutting platform (T1), forage harvester with a three-row cutting platform lines (T2), and forage harvester set T2 with transport wagon. The harvesting modalities with the sets were divided into three treatments: T1, T2, and T2 with transport wagon. The first ones consist of Set A and B harvest, with a 13 m³ forage transport wagon coupled with the traction bar (Figures 1A and 1B). When those were full, the harvest was interrupted, uncoupled the drawbar replaced it with another one of equal dimensions. For the T2 with transport wagon treatment, we used the B Set, harvesting without interruption and deposing the sillage in 13 m³ forage transport wagons, coupled to the 57-kW tractor traction bar composing the support set (tractor + trailer) (Figure 1C). The support set moved laterally to B Set, working as an overflow receiver. When it got full, it was replaced with another support set of the same size without interrupting the harvest.

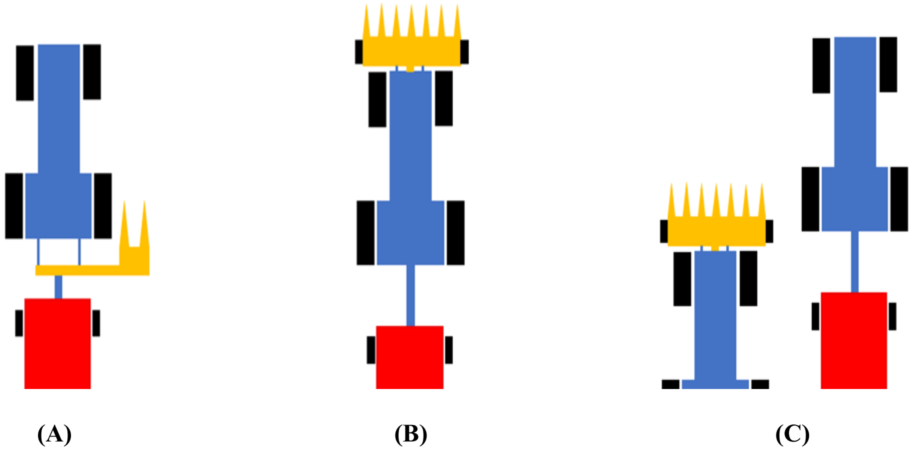

Figure 1. Representation of the T1 (A), T2 (B), and T2 with transport wagon (C) collection modalities.

The support set had a 57-kW tractor (New Holland™ TL75E) fitted with Pirelli™ tires of dimensions 12.4-24 and 18.4-30 on the front and rear axles. The tires were inflated with pressures of 137 kPa at the front and 110 kPa at the rear, generating a kinematic anticipation index of the front wheel over the rear wheel of 2.33%. The forage transport wagon (IPACOL™, model VFA12) has Maggion™ 7.50-16 tires, single on the front axle and dual on the rear axle, and an inflation pressure of 344 kPa for all tires.

For the tractor of set A, a GII M1 gear with engine rotation of 2,100 RPM was adopted, aiming to guarantee 540 RPM in the rear power take-off (PTO). We used the GI M1L gear with engine rotation of 2,200 RPM on the tractor of B set to guarantee 1,000 RPM in the front PTO. Both tractors had full fuel tanks and auxiliary front-wheel-drive engaged during the experiment.

The operational harvesting speed was determined with Agrosystem™ speed antenna model SVA-60, using the number of pulses emitted by the sensor during the experiment. The means acquired for T1, T2, and T2 with transport wagon were 1.01, 0.73, and 0.84 m s^{-1}, respectively.

The static load of the sets (including the tractor used in the transshipment set) and the mass distribution on the axles (Table 2), with the harvesting equipment in the working position, were determined with a CELMIG™ model CM-1002 scale.

Table 2. Amount of solid ballast, mass distribution over the axle, and total mass of sets A, B, and the support set.

	Added solid ballast – kg		Axle Mass - kg (%)		Total mass - kg
	Forward	rear	Front Axle	Rear axle	
Set A	180	100	1,484 (34)	2,884 (66)	4,368
Set B	-	920	5,730 (69)	2,575 (31)	8,305
Support Tractor	160	200	1,602 (42)	2,221 (58)	3,823

The mass of the cart used in the harvest was measured using the same scales. The trailer mass after harvesting the plot was 5,450 kg, which is the value adopted for the calculations.

The contact area of tires was determined by printing the wheelset on a flat concrete surface on all wheels for the sets A, B, and the support tractor with the forage wagon. The tire contour was measured with particles, and the impressions were recorded in digital photographs and analyzed using AutoCAD™ 2021 software, with scale correction and contact area.

The average contact pressure of the wheelset with the ground is the ratio between the total mass on the wheelset and the tire contact area, as stated by Mialhe (1980). Table 3 presents the tire contact pressures with the ground obtained for sets A and B, the support tractor, and the forage wagon.

Table 3. Average pressure (kPa) applied to the soil by the wheels in the two harvesting and support sets used in the experiment.

	Left front	Right front	Left rear	Right rear
	------------------- kPa -------------------			
Set A	27.70	25.82	21.11	21.64
Set B	47.07	43.58	21.67	21.26
Support Tractor	29.90	27.87	16.25	16.65
Harvest wagon	113.67	116.32	55.57	57.36

Soil analysis

To determine the soil particle size, samples in the experimental area, in four trenches, in the layers of 0.0 – 0.2 m and 0.2 – 0.4 m, were collected. The samples were analyzed using the Bouyoucos densimeter method, proposed by Gee and Bauder (1986). The soil has 375 g kg^{-1} of sand, 265 g kg^{-1} of silt, and 360 g kg^{-1} of clay, corresponding to the clay-loam texture class.

At the beginning of the silage harvesting operation, undisturbed soil samples were collected at depths of 0.0 - 0.2 m and 0.2 - 0.4 m at four random points along the experimental area, between the crop rows, totaling eight samples. Twenty-four hours after the silage harvest, we collected volumetric rings in the traffic lane at the same depths to verify the damage caused to the soil after the traffic of the sets at harvest. These samples were collected at four points of the experimental ranges, totaling 24 samples. The values of micro, macro, and total soil porosity, volumetric soil water content, and soil density were obtained according to the methodology proposed by EMBRAPA (2017).

For the resistance to soil penetration (SPR), we used a portable electronic penetrometer, model PLG 1020 (Falker™), configured to take readings every 0.01 m until reaching a depth of 0.4 m. The type 2 cone was used, with a diameter of 0,013 m and an angle of 30. It had a nail insertion speed of 0.02 m s^{-1}, following the S313.3 standard (ASABE, 2012). We acquired sixty readings for each treatment, 50% on the wheeled crossing line and the other half between the lines (where there was no traffic during the harvest). The RSP collection included the variation of the trailer mass along the harvesting shot caused by its filling. In total, 180 points were collected.

Statistical analysis

The results of resistance to penetration were analyzed by establishing the confidence interval by the t-test at 10% probability, every 0.05 m of depth. The same analysis was used for macro, micro, and total porosity, soil density, and volumetric soil water content in the 0.0 – 0.2 and 0.2 – 0.4 m layers. To calculate the confidence interval, Equation 1 was used.

$$CI=\frac{(T \text{ x } SD)}{\sqrt{nr}} \quad (1)$$

CI – Confidence Interval;
T – T-value tabulated at 10% probability;
SD – Standard deviation, and,
$\sqrt{nr}$ – Square root of the number of repetitions.

RESULTS AND DISCUSSION

Figures 2 to 3 show the macro, micro, and total porosity values in the experimental area, in the T1, T2, and T2 with transport wagon before the silage production in the 0.0-0.2 m and 0.2-0.4 m soil layers.

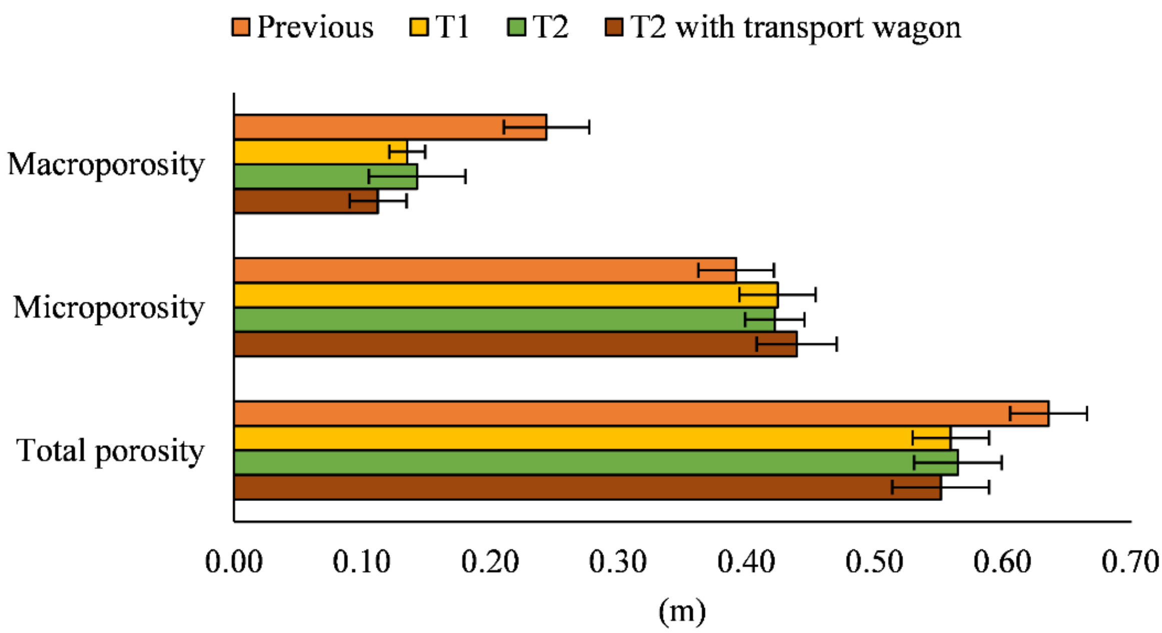

Figure 2. Macro, micro, and total porosity (m^3 m^{-3}) at the experimental area in the treatments: previous (before silage harvest), T1, T2, and T2 with transport wagon in the layer of 0.0 – 0.2 m.

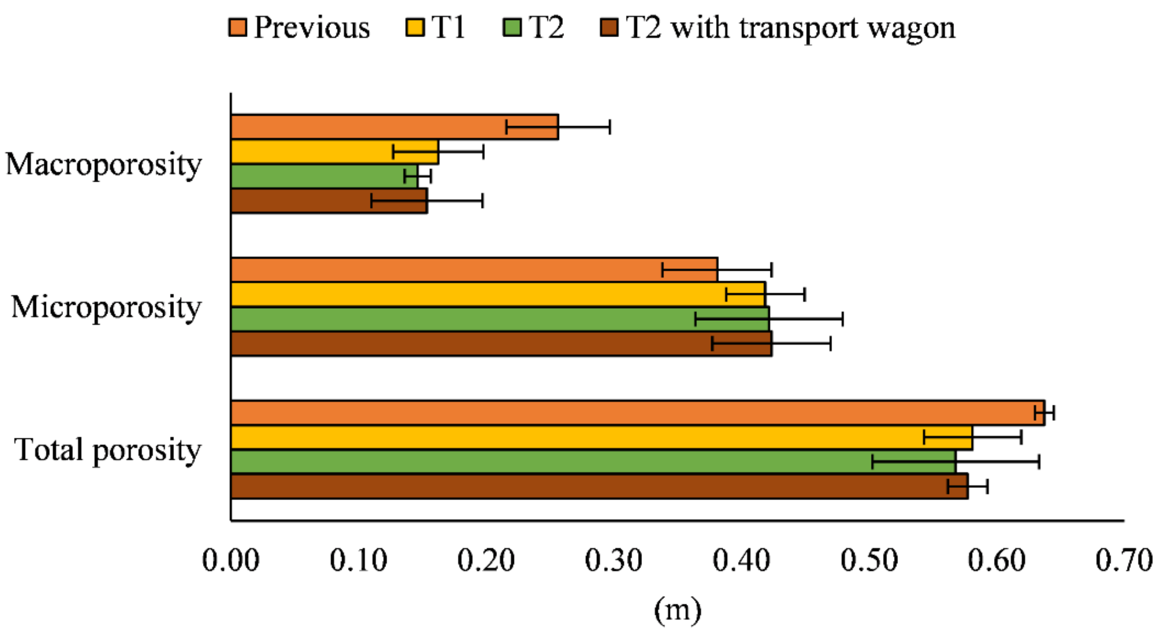

Figure 3. Macro, micro, and total porosity (m^3 m^{-3}) of the experimental area in the treatments: previous (before silage harvest), T1, T2, and T2 with transport wagon in the layer of 0.2 – 0.4 m.

The volume of macropores and total porosity in all treatments, except the set with a T2 without the forage wagon in the 0.2-0.4 m soil layer, were statistically lower about the moment before harvest. There was no difference between treatments for microporosity. In addition, the different harvest sets were similar to the changes they caused in soil porosity.

For Brady and Weil (2008), soil can be considered with the ideal structure and good root growth conditions when it presents total porosity close to 0.50 m^3 m^{-3}. In addition, they define adequate pore size distribution being 1/3 for macropores and about 2/3 for micropores. Therefore, considering the different harvesting sets, all allowed the soil to maintain a higher amount than recommended by the literature.

Cambi et al. (2015) point out that the machinery traffic in the cultivation areas causes significant changes in the physical properties of the soil, with the first pass being responsible for 75 to 80% of the total damage. In the present work, we noted that regardless of the size of the harvest set or the number of passes in the area (considering the use of the support set in T2 with a transport wagon), the reduction in macroporosity and total soil porosity was similar. However, when we used the forage wagon, there was higher pressure on the ground (Table 3) because of the smaller contact area of the wagon tires.

It is important to emphasize that for Lanzanova et al. (2007), soils with macroporosity less than 0.10 m^3 m^{-3} become critical for crop development. In the 0.0–0.2 m layers, the T2 with transport wagon harvesting modality obtained the lowest absolute value of macroporosity among the treatments, being close to the established by the author, paying attention to the management of the area when this type of harvesting occurs.

Figure 4 shows the values of volumetric soil water content (Vm) in the experimental area, in treatments T1, T2, and T2 with transport wagon, and before harvest in the 0.0–0.2 m and 0.2–0.4 m soil layers.

Volumetric soil water content (Vm) values ranged from 0.20 to 0.32 cm^3 cm^{-3}, with the lowest values found in the surface layer in each treatment. The prime losses of moisture on the surface (0.0–0.2 m) about the greatest depths occur by evaporation (PERES; SOUZA; LAVORENTI, 2010), and in silage, this because the harvest leaves as little vegetation cover as possible over the area (JEMISON et al., 2019).

The volumetric soil water content before the harvest (Previous) was lower in absolute values in the samples collected 24 hours after the passing of the harvesting equipment. That is due to the localized rain that occurred after the first harvest sets and before the second data collection. Szymczak et al. (2014) prove that water content significantly influences the soil physical properties when evaluating the difference in these properties during the presence of rain. In their study, after three and seven days, the rain did not provoke significant variation in the physical quality of the soil.

The Vm in the T1, T2, and T2 with transport wagon treatments were within the normal range to measure soil penetration resistance defined by Molin, Dias and Carbonera (2012), which is between 0.20 and 0.40 cm^3 cm^{-3}. It is noteworthy that these Vm values did not differ statistically between the harvesting modalities and between the evaluated depths.

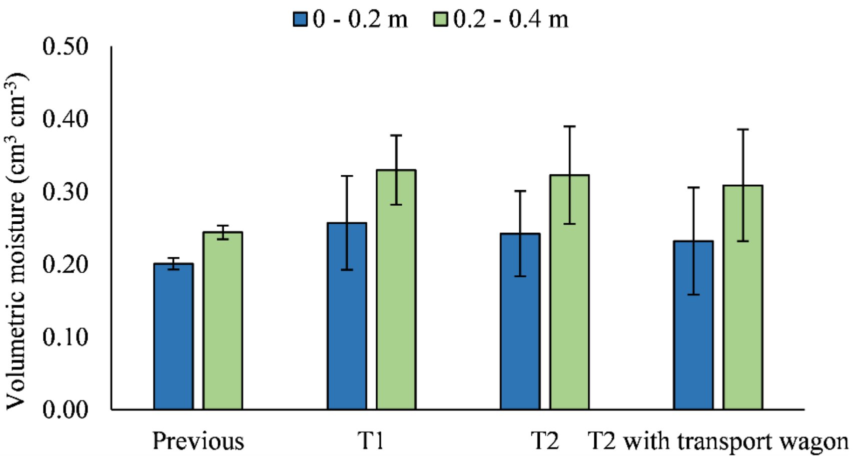

Figure 4. Volumetric soil water content (cm^3 cm^{-3}) of the experimental area in the treatments: previous (before silage harvest), T1, T2, and T2 with transport wagon in the evaluated layers.

Soil moisture is a variable that must be associated with penetration resistance, as water acts as a lubricant for soil particles. It means that the lower the soil moisture, the larger its resistance, which can create the false idea of compaction.

Soil density (Sd) is the relation between the dry soil mass and the sum of the volumes occupied by particles and pores. In all conditions evaluated, the value of soil density (Sd) remained between 1.06 and 1.29 g cm^{-3}. Several authors present values of Sd over 1.4 g cm^{-3} to be considered critical for the productivity or root growth of countless cultures.

Figure 5 shows the soil density values (Sd) in the experimental area, in the treatments T1, T2, and T2 with transport wagon, and before harvest in the 0.0–0.2 m and 0.2–0.4 m soil layers.

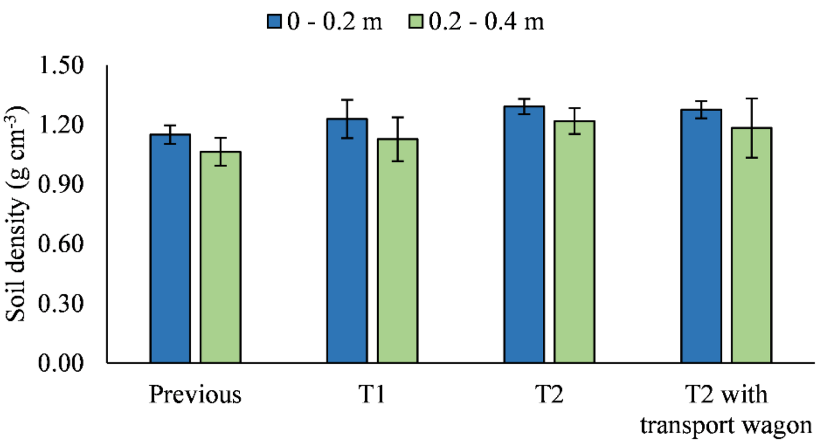

Figure 5. Soil density (g cm^{-3}) of the experimental area in the treatments: previous (before silage harvest), T1, T2, and T2 with transport wagon at the evaluated depths.

There was an increase of Sd in the depth of 0.0 – 0.2 m with the passage of the harvest sets. As explained by the pass of the wheelset, the porous spaces are completed with soil expelling the air, reorganizing the disposition of the particles, and reducing porosity.

Linhares et al. (2020), in a study on the effect of soil compaction on silage quality in a Latossolo Vermelho, noted an increase in soil density and a consequent reduction in total porosity with the rise in the number of subsequent passes.

In the superficial layer (0.0 – 0.2 m), the soil density changes with the set that uses the forage harvester with a three -row cutting platform. The increase in the weight of sets results in more soil pressure, elevating Sd values. However, for the single-row harvester in the same layer, the results did not differ from the others.

For the thicker layer evaluated, the set with the front harvester without the forage wagon promoted higher Sd in the pre-harvest condition, not differing from the other treatments. Moraes et al. (2020) observed that the increase in soil density with traffic equipment (tractors or grain harvesters) did not differ statistically.

Figure 6 shows the value of soil penetration resistance in the experimental area, in the treatments T1, T2, and T2 with transport wagon and between rows at a depth of 0.0 – 0.4 m.

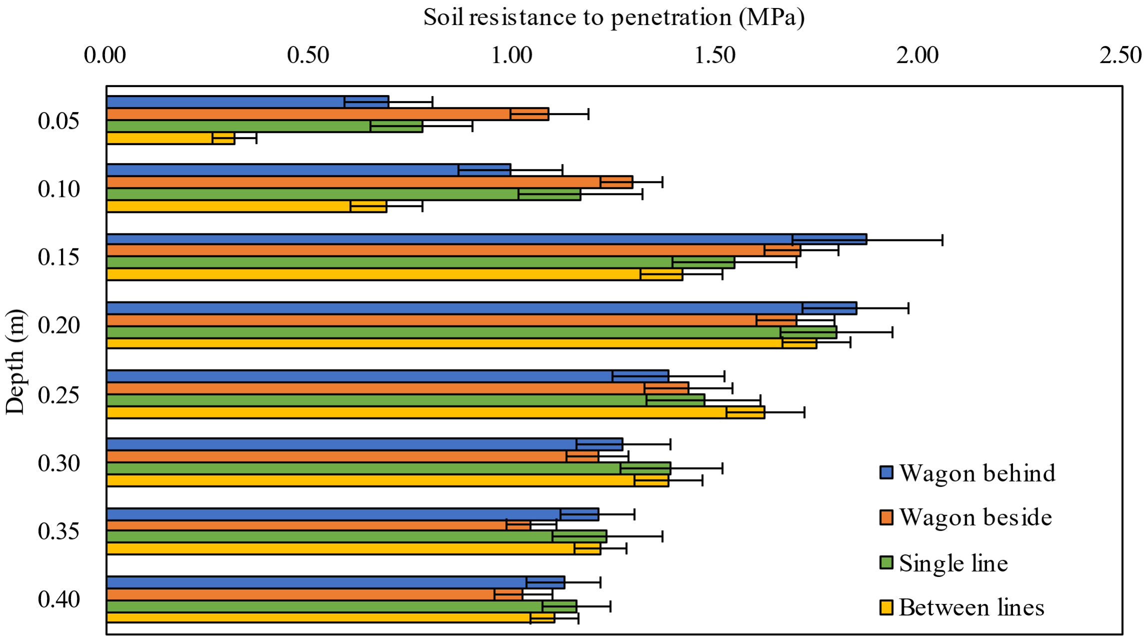

Figure 6. Resistance to soil penetration (MPa) of the experimental area in the treatments: T1, T2, and T2 with transport wagon.

The resistance to soil penetration (SPR) was influenced by treatments mainly in the surface layer. There was an increase in SPR caused by machinery traffic in the area at the initial depth of 0.15 m, regardless of the harvest type. The support set combined with the T2 harvester promoted a higher SPR index than the pre-harvesting condition. In this layer, the traffic of another tractor impacts this physical parameter of the soil.

At depths of 0.15 m, the single-row harvester did not differ in soil damage from SPR between rows or the T2. But the treatments that involved the B set differed statistically from the value found between the rows. This result corroborates with Shah et al. (2017), who reported that the causes of soil compaction involve the size of the machines and the vibration caused by them, as well as the crop production system.

In conventional soil preparation, the most used implement is the plow, which works in subsurface layers and promotes better operational performance. The frequent use of this implement can reorganize soil particles, creating layers with high values of SPR, called plow pans. At depths of 0.20 and 0.25 m, the harvesting modalities did not differ from each other or from between the rows. They also showed high SPR but below the 2.0 MPa critic value. The accumulated load of the harrowing caused the plow pan, corroborating with Oliveira et al. (2017).

At depths of 0.30, 0.35, and 0.40 m, the harvesting modalities did not differ in evaluating SPR and were not different from the value found between the rows. For Salire, Hammen and Hardcastle (1994), soil compaction can occur in the superficial or subsurface layers. Superficially it occurs due to the tire inflation pressure, and in the subsurface, it happens as a function of the total load on the axle. This could not be observed because the treatments did not differ so deep in the soil profile. This is believed to be due to the "plow pan" mentioned above and found at a depth of 0.2 m.

CONCLUSIONS

The harvest sets promoted a reduction in soil macroporosity and total porosity in the 0.0–0.2 and 0.2–0.4 m soil layers. The T2 promoted greater soil density than pre-harvesting conditions in 0.0 – 0.2 m depths. Mechanized harvesting for silage increased soil penetration resistance up to the first 0.15 m of depth.

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