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# Evaluation of tractor traffic on soil physical properties and their relationship with white oat yield in no-tillage

*Avaliação do tráfego de trator sobre as propriedades físicas do solo e sua relação com a produção da aveia branca em plantio direto*

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**ABSTRACT**

In a no-tillage system, the absence of soil disturbance combined with increased machine traffic has led to soil compaction in the top layer, negatively affecting its physical quality and hampering crop growth and production. This experiment aimed to assess the impact of tractor traffic, occurring under a no-tillage system, on soil physical properties and their relationship with the growth and yield of white oat crops. The research was conducted in an Oxisol, utilizing a randomized block design with five replications. The treatments consisted of ten consecutive years of no-tillage and additional traffic by 2, 4, 6, and 8 passes of a tractor wheel across the entire plot area. Various soil parameters were evaluated in two soil layers, including soil bulk density, total porosity, macroporosity, and soil resistance to penetration. Additionally, plant height, stem diameter, dry plant mass, mass of one thousand grains, and grain yield were determined. The collected data were analyzed using analysis of variance and linear regression. The results indicated that higher tractor traffic intensity led to increased soil bulk density and reduced macroporosity and soil resistance to penetration in the 0-0.10 m layer compared to the 0.10-0.20 m layer. In the 0-0.10 m layer, bulk density values exceeding 1.44 Mg $m^{-3}$ were found to restrict the growth and yield of white oat crops, while in the 0.10-0.20 m layer, grain yield was limited when soil bulk density surpassed 1.35 Mg $m^{-3}$. Our results show that farmers should be aware of the consequences of machine traffic on soil properties as it can have negative effects on crop yields, especially those of white oats grown in clayey soil similar to the one evaluated in this experiment.

**KEYWORDS:** *Avena sativa*; soil bulk density; morphological characteristic.

**RESUMO**

Em plantio direto, o não revolvimento do solo aliado à intensificação do tráfego de máquinas tem ocasionado compactação da camada superficial do solo prejudiciais à sua qualidade física, impactando negativamente no crescimento e produção das culturas. Este experimento teve como objetivo avaliar o impacto do tráfego de tratores, ocorrido em um sistema de plantio direto, nas propriedades físicas do solo e sua relação com o crescimento e rendimento da cultura de aveia branca. A pesquisa foi conduzida em um Latossolo Vermelho distroférrico, utilizando um delineamento em blocos casualizados com cinco repetições. Os tratamentos consistiram em dez anos consecutivos de plantio direto (zero passagens), juntamente com tráfego adicional de 2, 4, 6 e 8 passagens de roda de trator em toda a área da parcela. Diversos parâmetros do solo, incluindo densidade aparente, porosidade total, macroporosidade, microporosidade e resistência do solo à penetração, foram avaliados em duas camadas do solo. Além disso, altura da planta, diâmetro do colmo, massa seca da planta, massa de mil grãos e produtividade de grãos foram determinados. Os dados coletados foram analisados por meio de análise de variância e regressão linear. Os resultados indicaram que uma maior intensidade de tráfego de tratores resultou em aumento da densidade aparente do solo e redução da macroporosidade e da resistência do solo à penetração na camada de 0-0,10 m em comparação com a camada de 0,10-0,20 m. Na camada de 0-0,10 m, valores de densidade aparente acima de 1,44 Mg $m^{-3}$ foram encontrados como limitantes para o crescimento e produtividade da aveia branca, enquanto na camada de 0,10-0,20 m, a produtividade de grãos foi limitado quando a densidade aparente do solo ultrapassou 1,35 Mg $m^{-3}$. Nossos resultados demonstram que os produtores devem estar atentos às consequências do tráfego de máquinas nas propriedades do solo, pois pode comprometer a produtividade das culturas, principalmente de aveia branca cultivada em solo argiloso como o avaliado neste estudo.

**PALAVRAS-CHAVE:** *Avena sativa*; densidade aparente do solo; característica morfológica.

## INTRODUCTION

The multiple uses of oats justify the importance of this crop that has been growing in Brazil, where its planted area increased from 497.7 thousand ha in 2022 to 502.6 thousand ha in 2023, a growth of approximately 1%, however with a decrease in productivity from 2390 kg $ha^{-1}$ to 2179 kg $ha^{-1}$, which represented a reduction in approximately 8.8% (CONAB 2023). A small increase was observed in the cropped area in comparison to the previous survey as oats are a low-investment crop, in which producers use the grains from the previous harvest as seed and do not use fertilizer (CONAB 2023).

The white oat crop (*Avena sativa* L.) is used for the production of straw in a no-tillage system, no-till grazing, hay or silage production, as well as for grain production (RODRÍGUEZ-HERRERA et al. 2020). Because it is fairly rich in protein and fiber, it is generally used as a functional food in human nutrition (MUT et al. 2018). White oats are mostly used in the production of grains; however, as the market is very unstable, several producers grow oats after the second corn harvest for soil cover and annual winter pastures and, with favorable prices at harvest, grains are sold for industries and animal nutrition (CONAB 2018).

Implementing conservationist management systems, such as no-tillage, brings numerous benefits concerning the conservation of natural resources by prioritizing the maintenance of plant residues on the surface and reducing soil movement. It decreases soil and water loss and increases the biological activity of microorganisms, with a positive response on soil quality and profitability of agricultural activity (CORTEZ et al. 2018).

Despite this, in Oxisol, whose physical properties are excellent, the inadequate management through intensive turning and the transit of agricultural machinery has favored its compaction in the surface layer (BERGAMIN et al. 2015, VALADÃO et al. 2015, VALICHESKI et al. 2012). This is identified as the main factor responsible for limiting agricultural production, as it causes an increase in soil density values and soil resistance to penetration, as well as reduces the total porosity and macroporosity of the soil (ARCOVERDE et al. 2019, VALADÃO et al. 2015). In addition, these changes restrict the production and growth of several crops, such as soybeans and corn (SECCO et al. 2009), beans (COLLARES et al. 2008), and cover crops (BONELLI et al. 2011, PACHECO et al. 2015, VALICHESKI et al. 2012).

One of the alternatives for soil loosening is the use of cover crops, which, due to the potential for high root growth in dense soil layers, can contribute to managing agricultural systems through biological soil loosening (PACHECO et al. 2015). In these systems, however, in most of these crops, there has been a reduction in root growth (BERGAMIN et al. 2010), which tends to be greater above and below the compacted layer (MÜLLER et al. 2001, PACHECO et al. 2015).

When studying compaction in Poaceas, BONELLI et al. (2011) found a reduction in production, with an increase in density from 1.0 to 1.6 Mg $m^{-3}$. In a study conducted by PACHECO et al. (2015) on a dystrophic Red Oxisol, they investigated the effects of different density levels (1.0, 1.2, 1.4, 1.6, and 1.8 Mg $m^{-3}$) on the growth of aerial parts and roots of Crotalaria species. The results indicated that densities above 1.4 Mg $m^{-3}$ reduced the growth of both the aerial parts and roots of the Crotalaria species.

VALICHESKI et al. (2012), evaluating the effect of compaction caused by up to 8 tractor passes on the soil's physical properties and the development of the black oat (*Avena strigosa*) and forage radish (*Raphanus sativus*), found that with the increase in the number of passes, in the 0-0.10 m layer, there was an increase of density from 1.22 to 1.38 Mg $m^{-3}$, a reduction in height and dry matter production cover plants.

In this sense, even in the case of a crop with soil decompression potential, such as white oats, its growth and production can be influenced when the soil is compacted, and its physical quality is inadequate. The physical quality of soils in a no-tillage system is fundamental for the sustainability of agrosystems, and the study of this theme is even more important when soils susceptible to compaction are included in production systems where there is an increase in machine traffic (BARETA JUNIOR et al. 2022).

This experiment aimed to assess the impact of tractor traffic, occurring under a no-tillage system, on soil physical properties and their relationship with the growth and yield of white oat crops.

## MATERIAL AND METHODS

### Experimental area site and characterization

The experiment with the white oat crop was set up in April 2019 on the Experimental Farm of Agricultural Sciences at the Federal University of Grande Dourados, Dourados, state of Mato Grosso do Sul. The soil is a Red Latosol [Dystroferric] (EMBRAPA 2013) or Oxisol [Rhodic Eutrudox] (SOIL SURVEY STAFF 2022), with 60% clay, 15% silt, and 25% sand in the 0-20 cm layer. The site is located at latitude 22º14'S, longitude 54º59'W, and altitude of 434 m. The region's climate is of the Am type, monsoon, with a dry winter, an average annual precipitation of 1500 mm, and an average annual temperature of 22 ºC (ALVARES et al. 2013).

The area had been managed with the crop succession system with soybean (*Glycine max* L. Merr.) in the summer and corn (*Zea mays* L.) in the second crop for ten consecutive years under a no-tillage system. The climatic data of temperature and precipitation during the period of conduction of the experiment are shown in Figure 1.

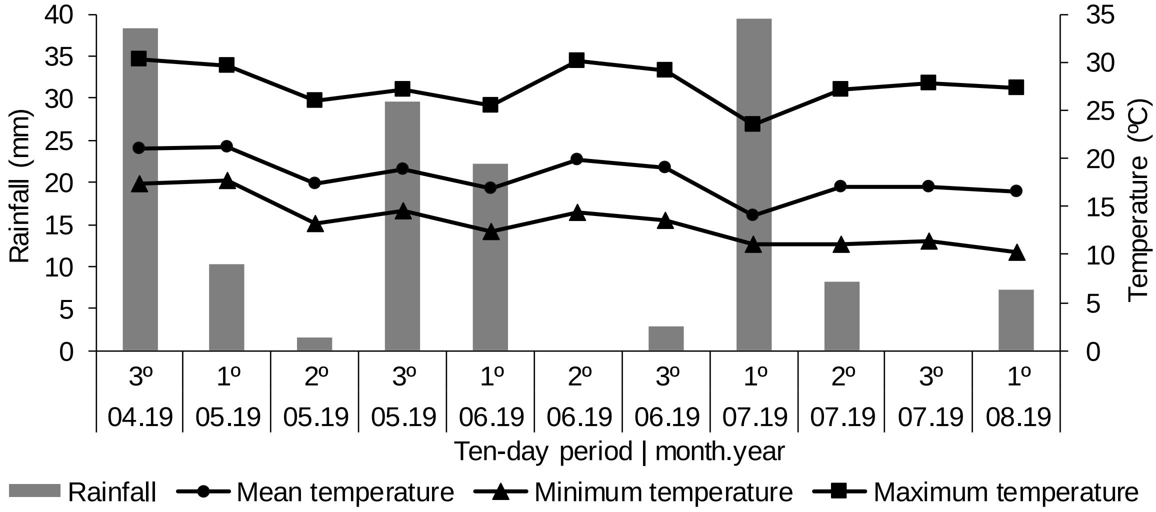


Figure 1. Rainfall per ten-day period (mm) and minimum, mean and maximum temperatures per ten-day period from April (sowing) to August 2019 (harvest) in Dourados, State of Mato Grosso do Sul, Brazil.

**Experimental design**

The experimental design was in randomized blocks, with treatments consisting of a no-tillage system ten years ago (zero past) and additional compaction-induced states by tractor traffic under a no-tillage system in two, four, six, and eight passes, with five replications, totaling 25 experimental plots. Each experimental unit consisted of eight white oat rows measuring 10 m long and spaced at 0.20 m, with a total area of 16 $m^2$. The area corresponded to the three central lines with 2.0 m each, located in the center of the experimental unit.

**Experimental setting**

On November 15, 2018, states of additional soil compaction by tractor traffic were induced. An agricultural tractor, model NH8030, with an engine power of 89.79 kW, wheelset with diagonal tires, a rear gauge of 1.73 m, front gauge of 1.83 m, and mass of 6.78 Mg with ballast and inflation pressure of 83 kPa in the front tires (14.9-28 R1) and 83 kPa in the rear tires (23.1-30 R1), with 43% of the mass distribution on the front axle and 57% on the rear axle. A 0.5 Mg mass mower was attached to the tractor's three-point hydraulic system to ensure additional compaction states, corresponding to 7.28 Mg of mass on the ground in each tractor pass. The front and rear tire contact pressures applied to the ground were 113 and 109 kPa, respectively, determined as described by ARCOVERDE et al. (2020), using the method proposed by O'SULLIVAN et al. (1999).

The displacement of the tractor over the area to be compacted was done using the third reduced gear with an engine speed of 2,200 rpm, corresponding to an average speed of 5.3 km $h^{-1}$. The entire surface of the plot was mechanically trampled so that the tires compressed areas parallel to each other, with the number of times traversed depending on the pre-established state of compaction. Traffic was superimposed on the previous one so that the entire area of each plot was trafficked an equal number of times, according to VALADÃO et al. (2015).

During the tractor passing process, the soil moistures were 0.263 and 0.258 g $g^{-1}$ in the 0-0.10 m and 0.10-0.20 m layers, respectively. Soil moisture was determined using the gravimetric method described by ARCOVERDE et al. (2019).

On November 21, 2018, the soybean sowing was carried out by removing the furrower of the seeder-fertilizer so as not to eliminate the tractor passes effect, using only the cutting disk of the seed metering device, following the recommendations of ARCOVERDE et al. (2020).

After harvesting the soybean grains, which was carried out in March 2019, the plants were crushed using a straw shredder equipped with a curved steel blade rotor. On April 24, 2019, white oat (*Avena sativa* L.) was sown on the straw of the previous crop (soybean) using a seeder-fertilizer model TD 300, with 19 rows spaced between them at 0.2 m, adjusted to distribute 60 seeds per meter. Fertilization consisted of applying 0.25 Mg ha$^{-1}$ of the 07-20-20 formula. As for the soybean crop, the soil furrower of the seeder-fertilizer was removed so as not to eliminate the possible effects of additional compaction induced by tractor traffic, using only the cutting disk of the seed meter. From sowing to the evaluations at harvest, there was no phytosanitary control for diseases, pests, and weeds.

**Soil physical properties**

During the cultivation of the previous crop (soybean), 85 days after sowing, undisturbed soil samples were collected between the rows using metallic cylinders of 5.57 cm in diameter and 4.41 cm in height, centered on the 0-0.10 and 0.10-0.20 m layers, for determination of soil density, total porosity, macroporosity and microporosity, according to the methodology from TEIXEIRA et al. (2017). When the soil samples placed on the tension table reached the equilibrium corresponding to a 60-cm high column of water, they were submitted to tests using an electronic bench penetrograph to determine the resistance of the soil to penetration. The equipment used, its configurations, measurements, and data processing to obtain soil resistance to penetration followed as described in ARCOVERDE et al. (2019).

**White oat agronomic traits**

On August 10, 2019, when the white oat seeds showed physiological maturity, they were harvested, followed by evaluations of the crop's agronomic characteristics.

Each experimental unit determined plant height and stem diameter on ten randomly chosen plants. Plant height was measured between the first internodes (plant collar) and the apex of the panicle using a 1-mm resolution measuring tape. The stem diameter was measured in the lower middle third of the plants using a 0.01-mm resolution caliper.

When the seeds reached physiological maturity, the white oat plants within each experimental unit's area were cut and taken to the laboratory to determine the production of cover biomass, the mass of a thousand grains, and the grain yield. After the harvested grains were sorted, the cut plants were dried in an oven at 65 °C for 72 hours (BONELLI et al. 2011, VALICHESKI et al. 2012) to measure the dry mass of the aerial vegetative part (leaves, stems, and sample residues). Coverage biomass production was determined using Equation 1. White oat grain yield was done using Equation 2, and its data was corrected for 13% w.b. of grain moisture.

$$P_b = 10\,\frac{m_p}{A_u} \quad (1)$$

$$P_g = 10\,\frac{m_g}{A_u} \quad (2)$$

where, Pb – cover dry biomass production, kg ha$^{-1}$; mp – dry mass of the aerial part of the plants contained in the useful area of the experimental unit, g; Au – area of the experimental area, m$^2$; mg – mass of the grains harvested in the experimental unit useful area, g; Pg – grain yield, kg ha$^{-1}$.

**Statistical analysis**

Data on soil physical attributes and agronomic characteristics of white oats were submitted to analysis of variance at 5% probability. Qualitative (soil layers) and quantitative treatments were compared using the t-test ($p<0.05$) and regression analysis, respectively, with the models selected based on the minimum determination coefficient of 0.5 and significance of 5% by the t-test of the coefficients.

## RESULTS AND DISCUSSION

**Soil attribute analysis**

The tractor traffic intensity which the soil was submitted altered the bulk density, macroporosity, and soil resistance to penetration in the 0-0.10 and 0.10-0.20-m layers (Table 1). The mean microporosity and total porosity were similar in the two soil layers; however, density was higher in the 0-0.10 m layer, and macroporosity and soil resistance to penetration were lower. This may have occurred mainly due to the influence of soil moisture, whose value was higher in the 0-0.10 m layer and lower in the 0.10-0.20 m layer, in agreement with VALICHESKI et al. (2012). In addition, this layer was less affected by tractor loads due to the damping effect caused by the surface layer.

Table 1. Summary of analysis of variance and means of total porosity (TP), density (SD, Mg m$^{-3}$), micro (Mi, %) and macro porosity (Ma, %) and resistance to penetration (RP, kPa) in the two soil layers as a function of the intensity of tractor traffic.

| Factor of variation | DF | Mean squares |
|---|---|---|

| | | SD | Ma | Mi | TP | RP |
|---|---|---|---|---|---|---|
| Block | 4 | 0.0003 | 0.87453 | 1.5464 | 5.7102 | 41136.7 |
| Passes (N) | 4 | 0.0105* | 26.1604* | 13.065* | 19.592* | 159800* |
| Depth (D) | 1 | 0.0496* | 19.9893* | 1.49580 | 0.6111 | 1.27x10$^{7*}$ |
| N x D | 4 | 0.0075* | 5.6867 | 6.8890* | 16.2155* | 154010* |
| Residue | 36 | 0.0009 | 2.3271 | 2.0905 | 4.0970 | 47244.4 |
| CV (%) | | 2.1 | 14.6 | 3.3 | 3.8 | 9.5 |
| Soil depths | | ---------------------------- Averages ---------------------------- | | | | |
| 0-10 cm | | 1.45 a | 9.81 b | 43.55 a | 53.75 a | 1776.48 b |
| 10-20 cm | | 1.39 b | 11.07 a | 43.21 a | 53.53 a | 2788.18 a |

DF: degrees of freedom. CV: coefficient of variation. *p<0.05. Different letters indicate statistical for the Tukey test, p ≤ 0.05.

RICHART et al. (2005) comment that in the no-tillage system, even with the absence of soil turning, surface compaction problems have been diagnosed as the rigidity presented by the lateral part of diagonal band tires prevents the tire from molding to the soil according to the irregularities of the terrain, so its contact area is reduced, increasing the pressure on the soil surface.

The results for soil density corroborate those found by VALICHESKI et al. (2012), who explain that the most significant changes in the physical attributes of the soil occur in the soil top layers and soon after the first tractor passes, therefore, the higher soil moisture when the levels of compression were implemented is appointed as one worsening factor.

Soil density responded differently in each layer to the continuous load applications made by the tractor, demonstrated by the quadratic behavior in the top layer and linear behavior in the 0.10-0.20 m layer (Figure 2). Soil density data indicate that the decrease in its values in the last two passes, mainly in the 0.10-0.20 m layer, may be associated with the agricultural management that it was submitted to in the no-tillage system, its mineralogy, and, or to its texture, which was not controlled during experimentation. And so, the configuration of the load-soil moisture binomial could not change the soil densities in the plots where the numbers 6 and 8 passes were conducted.

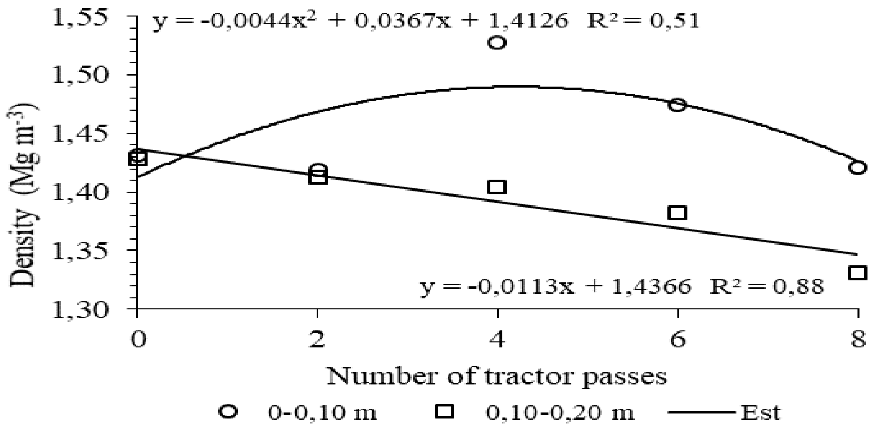


Figure 2. Soil density in the no-tillage system under different intensities of tractor traffic for both layers.

RICHART et al. (2005) point out that agricultural operations occur dynamically, that soil density and porosity are strongly dependent on management, and that other factors are almost always disregarded, such as the type of tire, inflation pressure, contact pressure, soil moisture, working depth and technical specifications of the implements used. Thus, the first tractor passes caused greater changes in soil density due to the greater disruption of soil aggregates, undoubtedly promoting the approximation of particles and, consequently, soil compaction (VALICHESKI et al. 2012). On the other hand, at higher traffic intensities, the pressures applied to the soil may have been lower than its pre-consolidation pressure, which would explain the lower soil density obtained in the treatments with higher numbers of tractor passes.

The tractor traffic loads did not influence the soil resistance to penetration in the 0.10-0.20 m layer, and in the superficial layer, there was a quadratic trend, with an increment up to the maximum value that was reached with six passes, and from then onwards, it stabilized (Figure 3).

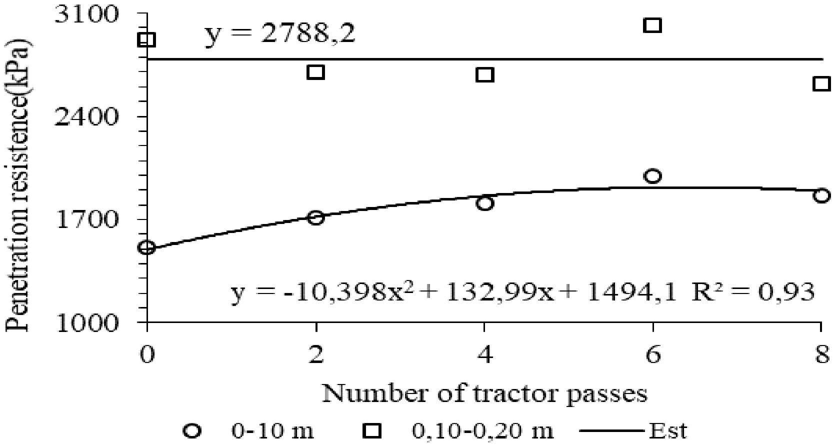


Figure 3. Soil penetration resistance in no-tillage system under different tractor traffic intensities for both layers.

As the soil dries, there is naturally greater resistance to deformation or root penetration (LIN et al. 2016). As humidity increases, the action of cohesion forces between soil particles and internal friction decreases, resulting in a reduction in the soil resistance to penetration (CUNHA et al. 2002). The value of 2000 kPa is common in limiting the growth and development of the roots of the soil (LAPEN et al. 2004, TAYLOR et al. 1996). This was verified by LIN et al. (2016) when observing a stoppage in the elongation of corn roots in a no-tillage system up to 0.20 m deep when the soil resistance to penetration reached 2200 kPa. In this work, the collections were analyzed with soil moisture close to field capacity, where the resistance to penetration presented a limiting factor in the 0.10-0.20 m layer and not a limiting factor in the 0-0.10 m layer.

The soil resistance to penetration results can be attributed to the consolidated no-tillage system in the area, where crops in succession/rotation systems are responsible for creating biopores. As reported by GENRO JUNIOR et al. (2004), the soil resistance to penetration is related to the permanence of pore continuity, which is likely to have occurred more pronouncedly in the 0.10-0.20 m layer than in the 0.00-0.10 m layer, which explains the non-significance of the soil resistance to penetration compared to the traffic intensity of tractor traffic.

Soil macroporosity in the no-tillage system, when subjected to a gradient of consecutive loading levels, decreased values up to the minimum of 3 passes when an increasing trend occurs (Figure 4). The macroporosity decreases as compaction increases are related to the average increase in microporosity (Figure 5), while the model was not adjusted for total porosity. However, the moisture at which the soil was compacted did not change its condition in the treatment with eight passes, as the macroporosity at this level of compaction was greater than that obtained in the control plot (zero passes).

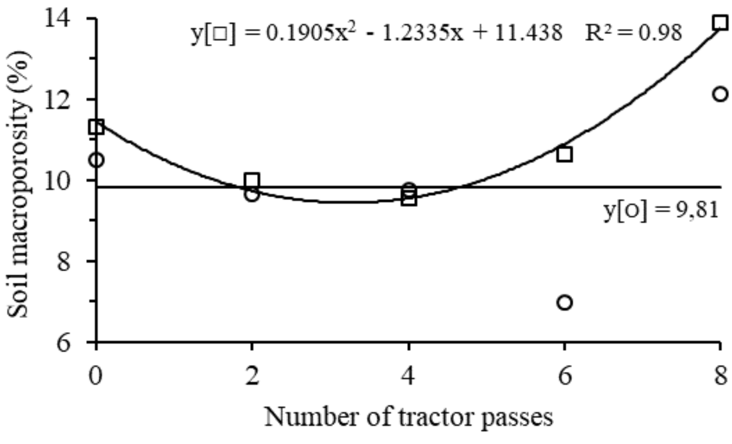


Figure 4. Soil macroporosity in no-tillage system under different intensities of tractor traffic, for both layers.

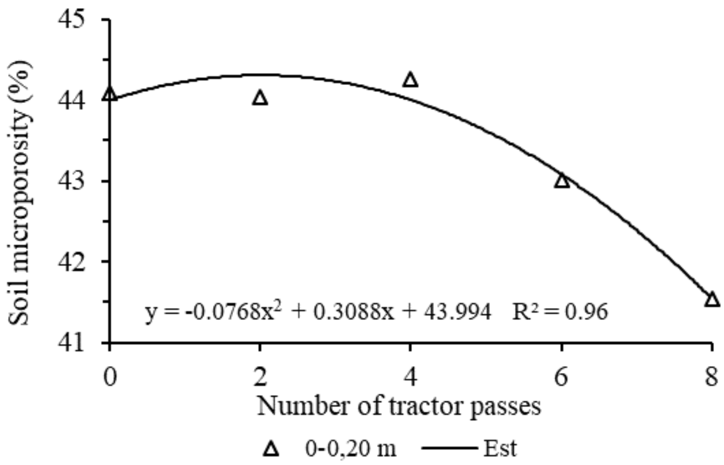


Figure 5. Soil microporosity in no-tillage system under different intensities of tractor traffic, for the 0-0.20 m layer.

The mean values of macroporosity are close to 0.10 $m^3$ $m^{-3}$. Some of them were lower than this value; therefore, they are in a state considered non-restrictive to the development of the plants, showing satisfactory aeration conditions. It should be observed that, according to SILVA et al. (2020), aeration porosities smaller than 0.10 $m^3$ $m^{-3}$ did not cause a significant reduction in gas exchange values and corn growth and that values greater than 0.10 $m^3$ $m^{-3}$ are more limiting for plants due to changes in soil attributes such as resistance to penetration and least limiting water range (SOUZA et al. 2022).

In the 0-10 m layer, the macroporosity values of less than 10% were found in one block (where six passes were made), demonstrating that there may be a reduction in productivity due to the lack of aeration for the roots and a reduction in the water content for the soil optimal hydric interval.

This shows that the increase in the number of tractor passes in a consolidated no-tillage system does not always result in an increase in compaction and reduction of soil structural quality, and even intermediate soil densification may benefit the productivity of crops (ARCOVERDE et al. 2020, ARCOVERDE et al. 2022, SUZUKI et al. 2007). According to ARCOVERDE et al. (2022), the intermediate densification in the 0.00-0.10 m layer, likely to have increased the volume of pores responsible for storing water in a voltage available for the plants. It should be observed that this superficial soil consolidation is expected in the no-tillage system, considering that in this management, there is no soil turning and, according to the higher density values found in the topsoil, it is likely that it haven't reached the pre-consolidation tension. On the other hand, in the same disturbed soil, lower values of soil density were observed in the 0.00-0.10 m layer, in comparison to the 0.10-0.20 m layer, consequently a lower load bearing capacity of the soil attributed to mechanical management, which promotes disaggregation with less contact between primary soil particles, especially at higher levels of humidity (ARAÚJO et al. 2022).

**White oat traits analysis**

As the microporosity and macroporosity data and soil resistance to penetration are within a range that is not limiting to crop development in the 0.0-0.10 m layer, and the soil resistance to penetration in the 0.10-0.20 m layer can be limiting in all treatments, it was decided to investigate the production components as a function of density.

The analysis of growth and production characteristics of white oats was based on soil bulk density, considering its variation within the range of 1.346 to 1.489 Mg $m^{-3}$.

**White oat growth**

A quadratic behavior of the stem diameter was observed as a function of the soil density in the 0.00-0.10 m layer, reaching its maximum value at the density of 1.451 Mg $m^{-3,}$ and from this value, it decreased (Figure 6). In the 0.10-0.20 m layer, the density was not influenced by the diameter of the oat stem. The reduction in the diameter of the white oat stem can affect its good development by supporting the productive aerial part of the plant, and its harvestability, showing grain losses at harvest.

The highest plant height occurred at the density of 1.448 Mg $m^{-3}$, observed in the 0.00-0.10 m layer (Figure 7), while in the 0.10-0.20 m layer, there was no effect of density on plant height. AHMAD et al. (2013) observed that white oat green mass was positively correlated with plant height, number of leaves, number of tillers, and dry plant mass. BIBI et al. (2012) found that plant height ranged between 66.2 and 175.3 cm in 108 white oat accessions, which were higher than the average values in this experiment.

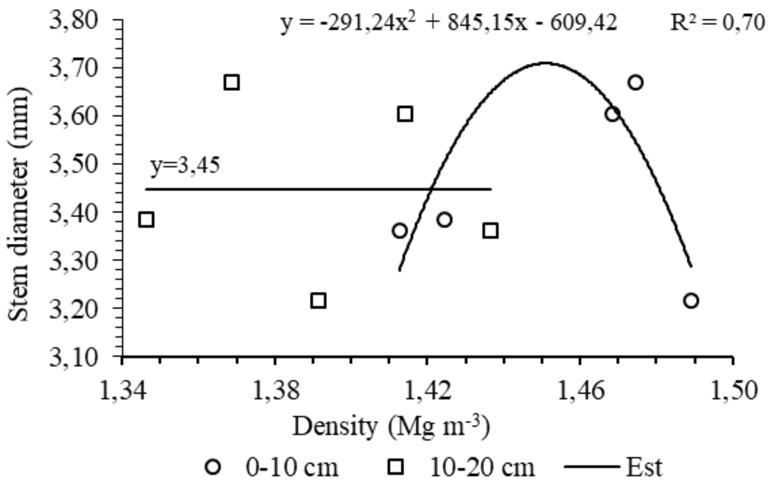


Figure 6. White oat stem diameter as a function of the soil density obtained in the layers.

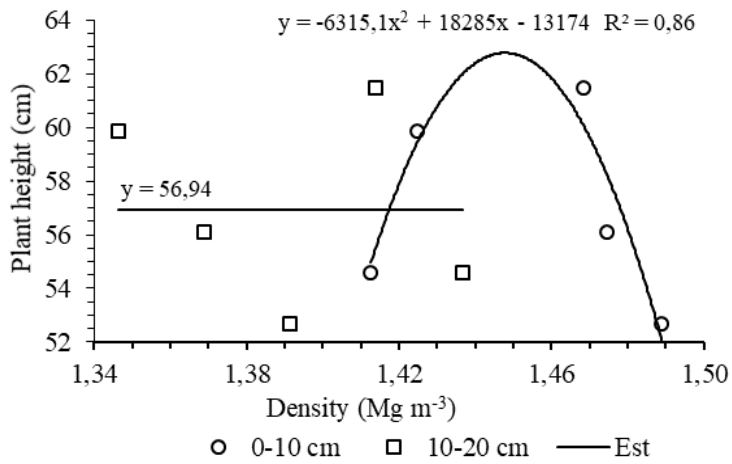


Figure 7. White oat plant height as a function of soil bulk density obtained in the two layers.

The production of dry cover biomass is proportional to the increase in soil density up to a critical value. From this value, the tendency was to reduce its values (Figure 8). The critical value for soil density was 1.45 Mg $m^{-3}$ in the 0-0.10-m layer and 1.369 Mg $m^{-3}$ in the 0.10-0.20 m layer. According to NIRMALAKUMARI et al. (2013), both the number of tillers per plant and the dry mass of white oats, in addition to other variables, contribute positively to a higher grain yield per plant. BARETA JUNIOR et al. (2022) observed that soil compaction by machine traffic reduced black oat biomass yield by up to 44%.

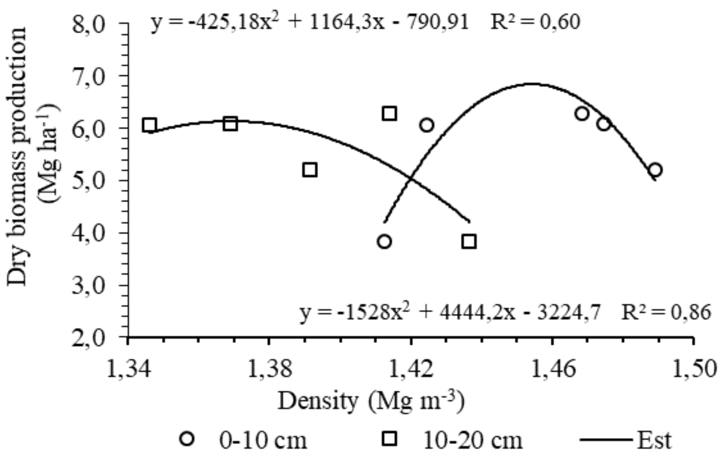


Figure 8. Dry biomass production of white oat cover as a function of soil density, in both layers.

**Crop production components**

The mass of one thousand grains (MTG) of white oats was influenced by density differently in both layers (Figure 9). In the 0-0.10 m layer, the increase in density resulted in an increase of 6.1% in the MTG up to 1.443 Mg $m^{-3}$. From this value onwards, a decrease in the MTG was observed, as also occurred for the stem diameter, height, and dry biomass production, which confirms the positive correlation between these characteristics of white oats. In the 0.10-0.20 m layer, the density range between 1.346 and 1.437 Mg $m^{-3}$ did not affect MTG.

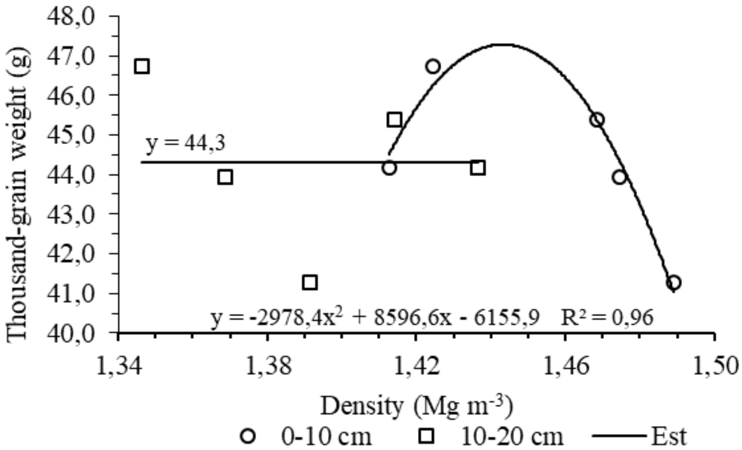


Figure 9. Mass of one thousand grains of white oat as a function of the soil bulk density in both layers.

In the 0.10-0.20 m layer, the increase in density from 1.35 Mg $m^{-3}$ linearly reduced white oat grain yield (Figure 10). Grain productivity raised to the density of 1.448 Mg $m^{-3}$ obtained in the top layer, with a maximum value of 1661.49 kg $ha^{-1}$. This shows the positive correlation between plant height and coverage production with grain yield with the behavior of the models obtained as a function of soil density.

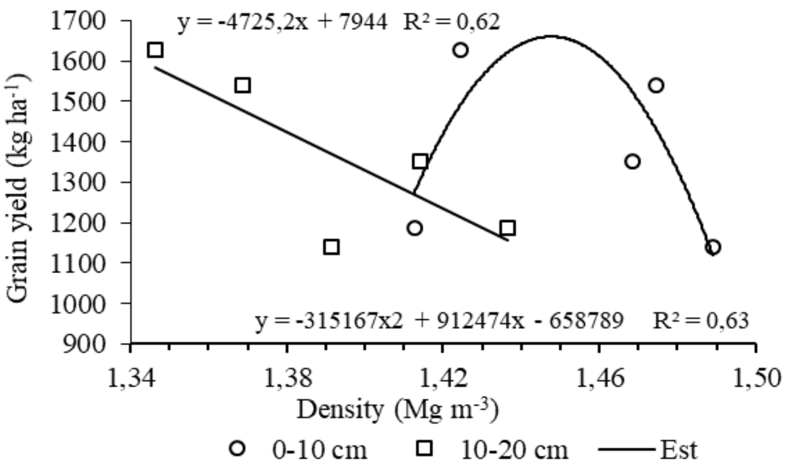


Figure 10. White oat grain yield as a function of soil bulk density obtained in the two layers.

The white oat grain production values are below the yields between 2150 kg $ha^{-1}$ and 5810 kg $ha^{-1}$ found by MUT et al. (2018) when evaluating 25 genotypes in different environments and attributed such variation to the genotype x environment interaction. Despite the low grain productivity, the results demonstrate the influence of soil compaction on the variation of its values, indicating that this is a factor to be investigated, together with climatic variations, opposite to soil fertilization, which may not significantly influence white oat production components (RODRÍGUEZ-HERRERA et al. 2020).

These results corroborate those shown by ARCOVERDE et al. (2020), who, in studying a dystroferric Red Latosol in a no-tillage system, observed similar density values in the same soil layers, restraining soybean grain productivity, therefore suggesting, according to the same authors, that surface soil compaction that does not restrict root growth can benefit crop production.

It should be observed that the effect of the induced compaction, with different traffic intensities, affects 32.5% of white oat productivity, according to BARETA JUNIOR et al. (2022), that observed that soil compaction by machine traffic reduced maize yield up to 33% and black oat biomass yield up to 44%.

According to BARETA JUNIOR et al. (2022), microporosity is limited. When soil compaction overcomes this limit at the expense of the macropore volume, it can increase water retained in the soil, or pores become unavailable for water retention, reducing the water availability and aeration to the roots.

In contrast, even white oats grown during the winter can develop their root system in lightly compacted surface layers as densities greater than 1.35 Mg $m^{-3}$ can cause yield losses. These results were also observed by VALICHESKI et al. (2012) when studying black oats and forage radishes as cover crops preceding the soybean crop. In addition, in an area with consolidated no-tillage production, there is a natural formation of biopores that allow greater root growth and, consequently, access to water in wetter and deeper layers of the soil, especially in those that are more compact and less conductive (LANDL et al. 2019).

## CONCLUSION

The traffic intensity of the tractor wheels causes higher soil density and lower macroporosity and soil resistance to penetration in the 0-0.10 m layer than in the 0.10-0.20 m layer.

The growth of white oat plants in height and stem diameter is reduced from the average soil density values of 1.448 and 1.451 Mg $m^{-3}$ in the 0-0.10 m layer, while the 0 .10-0.20 m density does not influence crop growth.

In the 0-0.10 m layer, dry biomass production, the mass of one thousand grain, and grain yield per white oat plant decrease when soil density values exceed 1.451, 1.443, and 1.448 Mg $m^{-3}$, respectively, while in the 0.10-0.20 m layer, decreases were found in the production of dry biomass and grain yield per plant from density values of 1.369 and 1.351 Mg $m^{-3}$, respectively.

Our results show that growers should be aware of the consequences of machine traffic on soil properties, as it can negatively affect crop yields, especially of white oats grown in clayey soil similar to the one evaluated in this experiment.

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