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Conference Paper · February 2023

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Application of Industrial Tires in Agricultural Machinery

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Abstract

Different tire models are applied in agricultural mobility, but the impacts on the ground are not completely known. Some models of industrial tires, with applications in construction machines, could meet the agricultural demand, since there is a shortage in the offer of exclusive models for agriculture. The aim of this research was to analyze in a Fixed Tire Testing Unit (FTTU), under controlled conditions, the performance of two tire types, the first for agricultural construction and the second for industrial construction on two different agricultural soils (two surfaces). The characteristics of the tires evaluated were: 620/75R26 (agricultural tire) and 23.5-25 (industrial tire). The soil used to simulate the agricultural surface were: Red Yellow Latosol and the Distroferric Red Nitosol, chosen because they are representative of agricultural areas in Brazil. The research response variables were soil penetration resistance (Cone Index), deformation caused by tires, real and total contact area (obtained through 3D scanner systems of the wheel-ground interaction area). The load applied to the wheelsets was 78.48kN, indicated as the maximum load on these models in field applications, and the tire inflation pressure was 331kPa. The results showed that regardless of the type of surface (soil), the agricultural tire had the best performance, defined by the impression of greater total contact areas and lower average resistance to penetration into the soil (Cone Index). The research opens new fronts study's, relating the rolling resistance provided by tires and the energy consumption of each technology. The industrial tire has a smaller total contact area and provides greater stress in the subsoil, reaching critical levels of compaction for the root development of crops, therefore, they are not recommended for agricultural application.

Introduction

Agricultural machines have gotten bigger and heavier over time and soil compaction has been one of the biggest challenges faced in modern agriculture [14]. In compacted soils, porosity and permeability are severely reduced [3; 10], compromising the final productivity of vegetable crops [9; 15].

Agricultural tires represent the interface between soil machine [6] and are responsible for the highest pressures applied in agricultural areas [7], causing soil compaction [9]. The stresses generated by the external action of the tires are normally of short duration [16], being applied only in a small loading area, represented by the tire/ground contact area [15; 11]. However, the mechanical characteristics of agricultural soils allow varying the response to applied loads [17; 5].

The market for mobility tires in agricultural areas presents limitations of models offered and high prices, while industrial models can represent an interesting alternative for acquisition, due to the abundant supply of models and lower prices [14]. However, industrial tires can negatively impact soil structure when compared to agricultural models. Tests with tires and agricultural wheels are important for improvements in agricultural production processes [21; 24].

The physical limitation provided by the traffic of machines to crop productivity, through soil compaction, can be better understood through controlled tests and performance tests of wheels and tires, as well as through simulations and predictions obtained by mathematical modeling [23].

In-depth knowledge of the tire contact area allows predicting the traction behavior and rolling resistance of agricultural machines [23; 8]. However, the stochastic behavior of the tire in dynamic processes, in contact with the plastic surface of the soil, makes the task of carrying out tests related to this theme challenging [11;12].

The contact area measurements at the ground-wheel interface can be overestimated, depending on the method used [24]. The authors evaluated contact areas directly in the field and compared the results with mathematical methods of inference, the results showed significant differences between the different methodologies.

The ground surface can influence the traction capacity of the machines, since it is through this that the power available in the engine is converted into traction by the wheelsets [24; 25]. In the case of pneumatic wheelsets, it is necessary to work with the correct pressure and correctly select the tire model for each operation and agricultural condition [13].

New models of wheels that provide greater traction capacity, due to larger areas of contact with the ground, are in full expansion in modern agriculture, because in addition to performing more efficient work, they cause less impact to the soil. Significant improvements in the traction coefficients of an agricultural tractor undergoing replacement of the pneumatic wheels with rubber tracks [19].

Another fundamental point of view in the development of tests and trials with wheelsets is energy rationalization, since new construction and traffic models can impact on the reduction of fuel, lubricant and operational costs [14].

One way to identify and characterize compacted soil layers in the field is with the use of penetrometers, in which the mechanical resistance to penetration that the soil offers to these equipments can be correlated with the resistance imposed on the root system of the plants [22].

The objective of the present study was to evaluate the impact of different types of tires on two agricultural soils, one for industrial or construction and other for agricultural application. Specifically, the contact area and soil compaction caused by each of the models were evaluated.

Material and Methods

This research was carried at the Agroforestry Machinery and Tire Testing Center, in Experimental Farm Lageado, belonging to the Faculty of Agronomic Sciences, UNESP, Botucatu - SP campus.

To carry out the tests, the Fixed Tire Test Unit (FTTU) was used, being carried out in two phases, Rigid Surface Tests (RST) and Deformable Surface Tests (DST). FTTU was built and updated by several researchers [13;15], allowing the simulation of different conditions of interaction between the pneumatic wheels and the different patterned surfaces.

At FTTU, the wheelsets of interest are fixed on a central axis, where controlled loads are applied to a deformable surface (ground tank) and/or rigid surface (steel table). The loads are imposed on the wheelset/surface through an electro-hydraulic system, controlled by maneuvering devices, electric motor, hydraulic pump and piston acting on the axle of the wheelset.

Figure 1. Fixed Tire Test Unit (FTTU)

Rigid Surface Test

In hard surface tests, the tires were previously calibrated in relation to the internal inflation pressure recommended by the Latin American Tire and Rim Association [1]. The tread of the tires was previously moistened with black ink, in order to provide the demarcation of the tire's contact area with the cardboard sheet after the load was applied at FTTU. The FTTU hydraulic system was activated to lower the tire with constant speed, applying an increasing and controlled load, reaching 50.52 kN (5150 kgf), remaining at this maximum value for 10 seconds. After the load is applied, the tire is lifted back to its initial position and the cardboard sheet is removed.

The contact areas demarcated by the wheels on the cardboard, after the load was applied, were transferred using a conventional image (RGB), removed at right angles and with parallax correction using a tape measure, to the Surfer image interpretation software. v.11. Through this digital referencing program, measurements of length, width, total contact area and real contact area (grips) were obtained.

The values were transferred to an electronic spreadsheet and statistical software to verify the differences between the averages of the treatments. Figure 10 demonstrates the RGB image of the contact area on a rigid surface after applying a load to the Fixed Tire Test Unit.

Deformable Surface Test (DST)

In the DST, the hydraulic system of FTTU was activated to lower the tire with constant speed, applying an increasing and controlled load, reaching 50.52kN (5150 kgf), remaining at this value for 10 seconds, on a soil sample confined in tank, for three different surfaces, with three repetitions. The tank had a total volume of 0.8 m^3 with the following dimensions: 1.03 m wide, 1.30 m long and 0.60 m high. The soil used was classified as Red Yellow Latosol according to Brazilian soil classification [20].

The assembly of the tanks followed the standardization of the amount of soil sample, arranged in five layers, with previously homogenized water content and, later, submitted to Mesh sieve n°30 with two meshes, totaling 200 kg of soil sample per layer.

For each layer, mechanical compaction was carried out by impact of a wooden bar with a total mass of 12 kilograms and a length of 1.25 m, impacts were applied at a height of 0.3 m, in order to obtain a constant height of 10 cm in each layer of the soil sample. The homogenization of the water content of the soil was carried out by the volumetric compensation method, analyzing the volume of water present in the soil at the time of the tests and compensating, when necessary, with the amount of water to maintain the water content standard on each tank.

After the pressing process at FTTU, the settlement was obtained via Scanner reading and the evaluation of the compaction in depth with the use of an electromechanical penetrometer.

Evaluated tire models

Agricultural Tire - (P1)

Radial tire, 712 mm wide, 1602 mm diameter, 26' rim, internal volume of 516 liters, maximum inflation pressure of 241.32 kpa, maximum load of 5,670 kgf (Figure 2).

Figure 2. Agricultural Tire Testing

Industrial Tire - (P2)

Model tire Bias, 681 mm wide, 1598 mm diameter, 25’ rim, 550 liters internal volume, maximum inflation pressure of 575 kPa (Figure 3).

Figure 3. Industrial Tire Testing

To carry out the work, two types of soil were used, whose identification and classification was based on the Brazilian Soil Classification System [20], one being classified as red/yellow Latosol (Lva) with sandy texture and the second a dystroferric red Nitosol (Lvd) with a clayey texture (50%). Both taken from two areas of Lageado farm (UNESP-BOTUCATU).

Soil water content was standardized in all sample soil tank replicates. The average water content in the tanks was 14.6±1% for the Latosol and 23±1% for the Nitosol. The results were analyzed analytically based on descriptive statistics, relating the contact areas presented by the different tire models and the respective impacts on the two types of soil studied.

Results and Discussion

The printing of the agricultural tire tread on a white paper on the rigid surface, after the application of the standard load, provided the punctual contact area of the grips in 626 cm² and the total contact area an ellipsoid of 1881 cm² for 331 kPa of inflation pressure (Figure 4a.). However, the industrial tire, under the same conditions, presented a punctual area of lugs of 778 cm² and a total area of 1445 cm² (Figure 4b.).

It was observed that the point area of the agricultural tire was equivalent to 80.4% of the point area of the industrial tire, considering the latter as a reference. However, even with the smallest point area, the agricultural tire had the largest total contact area with 1881cm², an increase of 30% in the contact area when compared to the industrial tire.

It should be noted that on traffic surfaces such as roads and firm ground the point area may represent the actual area for tire traction. In prepared and soft agricultural soils, the real contact area is expressed by the total perimeter of the contact area on a hard surface, plus lateral deformations caused by tire deformation dynamics.

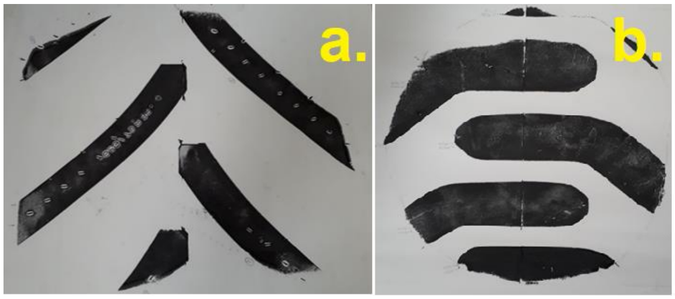

Figure 4. Contact Area in rigid surface of each tire types

The contact area of the tire and grip is the result of deflection when a load is applied and according to the inflation pressure [24], this area can increase or decrease. It is noteworthy that in field conditions, the result of the real contact area is the one with the greatest significance, since through it, total values of area affected by machine traffic can be inferred. In this sense, [17], emphasizes that the contact area adjusted according to the ideal working pressure of a tire has a significant influence on the performance of agricultural equipment.

The tire ground contact in three models of agricultural tires also in hydraulic press [15; 18], with internal pressure of 30 psi for the radial tire (14.9R26) and load of 20 kN, obtained a real contact area of 0.26 m2, values very close to those obtained in the present work. The same authors reported that the factor that most influences the contact area between tire and soil is the applied load, which increases elastic deformations, settlement and soil penetration resistance.

On the deformable surface, confined to soil samples in the box, the total contact area presented by the different tire models is evidenced. The soil tank was assembled under controlled conditions and simulates an agricultural soil condition in a state of traditional agricultural management. The total areas were evidenced in the laser monitoring system of the settlement caused by the tires on the ground. In these tests it was possible to observe the smallest contact areas for the industrial model, plus the severe impact of its punctual area in the center of the settlement area (Figure 5).

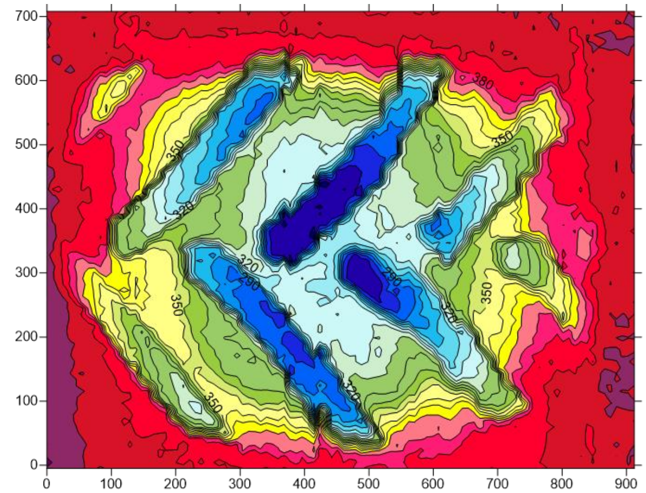

Figure 5. Contact Area in deformable surface of agricultural tire

In red yellow latosol a result of the tire footprint, a settlement with 0.65 m wide, 0.89 m long and 0.15 m high was obtained. The contact area was 0.45 m². However, in the Nitosol, the settlement was 0.65 m wide, 0.81 m long and 0.14 m high. The contact area was 0.41 m². The results showed that the different types of soil interfere in the determination of the wheel-soil interaction area.

For the industrial model tire, the determinations of the contact area in the Latosol were: settlement with 0.60 m wide, 0.75 m long and 0.13 m high, contact area 0.35 m². On Nitosol, the same tire had a 0.59 m wide, 0.86 m long and 0.10 m high boost. The contact area was 0.39 m² (Figure 6).

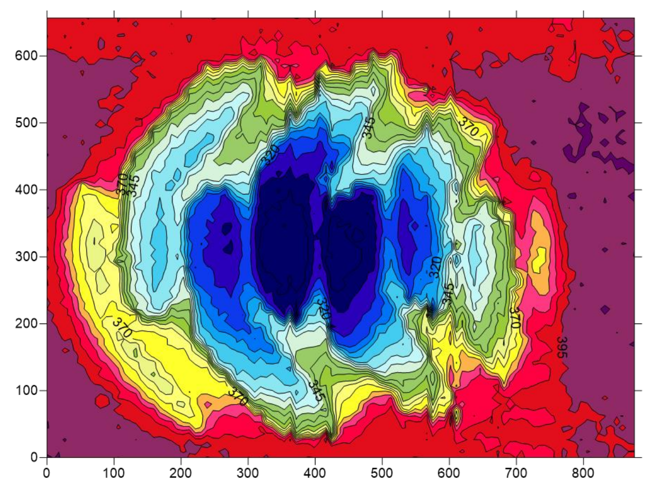

Figure 6. Contact Area in deformable surface of industrial tire

The critical compaction of a soil is dependent on its degree of preparation, depending on its granulometry [3], water content and texture [2; 4; 7; 22]. The first passes of the machine over the productive area under inadequate conditions, cause severe impacts to the soil [8; 9]. This observation emphasizes the importance of traffic control to avoid the transit of machines on or close to the crop lines [13].

The soil resistance penetration makes it possible to identify areas of compaction in each of the tires evaluated. The results show that in the Latosol, the agricultural tire presented the lowest resistance to penetration, indicating that it affects less the physical structure of the soil after one pass (Figure 7).

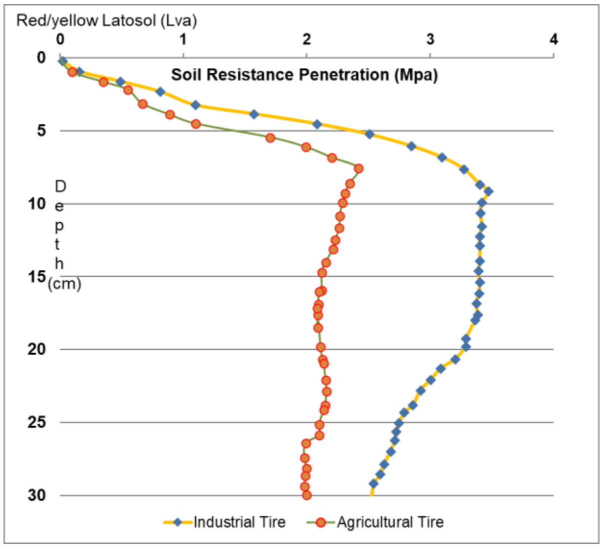

Figure 7. Resistance to soil penetration after load application with two tire models on red/yellow Latossol

While the agricultural tire had a maximum penetration resistance of 2.4MPa at a depth between 5 and 10 cm, the industrial construction tire had a maximum penetration resistance of 3.5MPa at a depth of 9cm. The highest resistances imply in damage to the soil and restriction of root growth of agronomic crops.

In Nitosol the behavior of the tires was similar, however with smaller difference between the resistances to the penetration of the soil. The agricultural construction tire continued to show the lowest resistance among the models studied, with 2.7MPa at an average depth of 7cm. The industrial tire had a small gain, with 3MPa at 6cm depth (Figure 8).

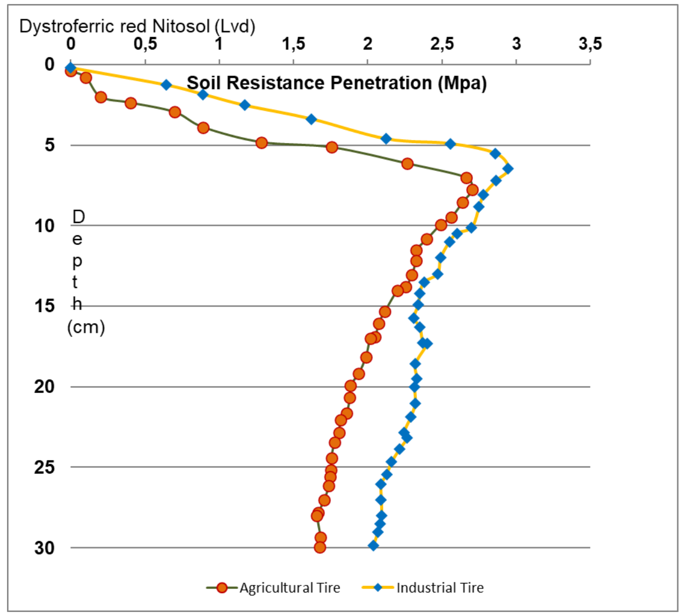

Figure 8. Resistance to soil penetration after load application with two tire models on Distroferric Red Nitossol

Soils with higher clay content, such as Nitosols, have greater plasticity, and as the humidity was around 23% during the tests, there was little differentiation in the determination of penetration resistance, as water acts as a lubricating agent inside the soil. However, when we treat the soil as a covariate, there is an advantage for the agricultural tire in relation to the industrial one, with an average reduction of 10% in compaction in Nitosols and 32% in Latosols.

The presence of water content in the soil contributes to the susceptibility to compaction [12; 2; 16], reducing the internal resistance of the soil and facilitating the deformation process to occur. The energy and mobility parameters in each tire model need to be evaluated, therefore, this research opens the door to new investigations of wheelset performance.

Conclusions

The industrial tire evaluated had a greater impact on the subsoil in relation to the agricultural model, this was due to the increase in the total contact area of the agricultural tire in relation to the industrial model.

Soil type and water content can affect the penetration resistance of standard stems. Regardless of soil type and moisture, the agricultural tire presented the lowest penetration resistance.

The application of agricultural tires reduces from 10 to 32% the resistance to soil penetration when compared to industrial models, therefore, the application of industrial tires in agricultural production areas is not recommended.

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ISSN 0148-7191

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