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# Operating performance of an agricultural tractor fitted with two types of tyres under two types of terrain[1]

**Tainara Regina Cerutti Torres Bahia[2]*, Cristiano Marcio Alves de Souza[3], Jackson Antonio Barbosa[4], Roberto Carlos Orlando[3]**

**ABSTRACT** - The correct use of tyres on agricultural tractors, in respect of the terrain and the type and internal pressure of the tyre, are factors that influence the performance of the tractor. The aim of the present study was to evaluate the operating performance of an agricultural tractor fitted with two types of traction device (radial and diagonal tyres) at different pressures, and operating on soil with two levels of moisture. The experiment was conducted on a dystrophic Red Yellow Argisol, with tests to evaluate the performance of the tyres under specific working conditions. Tractive power and tractive force, wheel slip and fuel consumption were evaluated. For each of the conditions under evaluation, the radial configuration showed better performance than the diagonal configuration, the effect being more significant at the lower pressure and under low soil moisture. The use of radial tyres led to an increase in traction capacity and drawbar power, with a reduction in fuel consumption, especially at higher slip rates.

**Key words**: Tractive efficiency. Agricultural mechanisation. Agricultural tyres.

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*Author for correspondence
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[1]This research was part of the master's thesis of the lead author, presented to the Postgraduate Program in Agricultural Engineering of the Federal University of Grande Dourados
[2]Postgraduate Program in Agricultural Engineering, Federal University of Grande Dourados, highway Dourados-Itahum, km 12, Dourados-MS, Brazil, tainara_cerutti@hotmail.com (ORCID ID 0009-0009-9973-1252)
[3]College of Agricultural Sciences, Federal University of Grande Dourados, Dourados-MS, Brazil, csouza@ufgd.edu.br (ORCID ID 0000-0002-5347-1709), robertoorlando@ufgd.edu.br (ORCID ID 0000-0003-4802-7803)
[4]Departament of Agricultural Engineering, Federal University of Lavras, Lavras-MG, Brazil, jackson@ufla.br (ORCID ID 0009-0008-5772-7653)

## INTRODUCTION

The agricultural tractor is one of the main sources of power in farming (Lanças *et al*., 2021), and its basic concept for using energy has remained largely unchanged since it was first introduced. In agricultural production, the tractor is the driving force for transportation and for pulling implements in the field (Souza *et al*., 2022a) by transforming the power of the engine into tractive power (Cavallo *et al*., 2014).

However, it is necessary to analyse the operating conditions of the tractor during farming operations, especially speed, the size and type of the front and rear tyres, axle load and ballast, wheel slip, and tyre inflation pressure, as these are crucial to maximising efficiency and power, and ensuring that there are no negative changes in the productive capacity of the soil (Neres *et al*., 2012).

Among the operating conditions that influence the energy efficiency of the tractor, the tyres are one of the most important, as in addition to guaranteeing the dynamic balance, displacement, steering and damping of the tractor, they are also directly linked to tractive performance. The use of the correct type of tyres, inflation pressure and tractive effort can directly influence the efficiency and fuel consumption of the tractor (Montanha *et al*., 2012).

The use of radial tyres on agricultural tractors has led to a reduction in the power loss that arises from rolling resistance and wheel slip (Barbosa *et al*., 2005), with a consequent improvement in the traction developed by the machines (Zimmermann *et al*., 2022).

It is very important that wheelsets be inflated to the correct pressure for the characteristics of the tyre, the load and the conditions of the terrain, as this can improve traction; while incorrect air pressure can result in excessive flexing of the tyre casing, leading to damage to the cords and wear of the sidewalls, creating the risk of structural damage to the tyre, wear in the centre of the tyre, and a loss of traction when overinflated (Reis *et al*., 2019).

Analysing wheel slip is another very important factor, as this can define premature tyre wear and increase fuel consumption (Shafaei; Loghavi; Kamgar, 2020), which is one of the highest costs in agricultural operations. Fuel consumption is also directly linked to such factors as the suitability and condition of the tractor-implement combination, tractive effort, and the type and condition of the soil (Montanha *et al*., 2012).

In this respect, any improvement that can be made to the performance of traction devices in farming will directly contribute to the efficiency of agricultural production and to conserving energy. This aim of this study was to evaluate the operating performance of an agricultural tractor fitted with radial or diagonal tyres at different tyre pressures, under different levels of soil moisture and required drawbar forces.

## MATERIAL AND METHODS

The experimental area is located between 20°44’41”S and 42°50’31”W, at an altitude of 650 m. According to the Brazilian System of Soil Classification (Santos *et al*., 2018), the soil in the area is a dystrophic Red Yellow Argisol with a very clayey texture (68% clay and 17% silt). The soil cone index in the area was 0.775 ± 0.125 MPa.

The tyres used in the study were from Pirelli, and were mounted on an MF5290 4x2 tractor with auxiliary front-wheel drive, maximum engine power of 77 kW (105 hp) at 2,200 rpm, engine transmission efficiency and PTO of 0.84 (540 rpm at the PTO), and transmission efficiency from the PTO to the wheel hub axle of 0.94. The total weight of the tractor was 37.36 kN when equipped with radial tyres, and 38.18 kN when equipped with diagonal tyres, with a static mass distribution of 42.7% and 57.3%, respectively, for the front and rear axles, which were 2286 mm apart.

A Valmet 110 load tractor with 80.9 kW engine power and a maximum ballast weight of 6800 kg was used to apply loads to the drawbar.

An Omega S-shaped load cell with a capacity of 50 kN was used to determine the forces on the drawbar. Inductive and gear-tooth sensors were used to count pulses on the front and rear wheels to determine wheel slip.

A flowmeter, consisting of a glass burette graduated in mL was placed in the supply system of the tractor engine to determine the volume of fuel used in each test (Borges *et al*., 2017).

Univariate analysis was used, in a completely randomised design (CRD), with the treatments comprising the following factors: two types of traction device: diagonal and radial; two types of surface conditions: moisture content of 0.06 and 0.51 $m^3 m^{-3}$; fifteen different loads on the drawbar, i.e. fifteen values of wheel slip caused by the load tractor; different values for inflation pressure, with the internal tyre pressure varying between 97 kPa and 221 kPa for the diagonal tyres, and 97 kPa and 166 kPa for the radial tyres, giving a total of six pressures, split into high pressure and recommended pressure.

In order to find two different levels of moisture, the tests were carried out when the mechanical resistance of the soil was high, i.e. low moisture (0.06 $m^3 m^{-3}$); the tests were then repeated using the same method, when the mechanical resistance of the soil was lower, i.e. high moisture (0.51 $m^3 m^{-3}$), corresponding to 95% of field capacity. The moisture was determined as described in Teixeira *et al*. (2017).

The tractor under test moved for 40 m in reduced second gear at an engine speed of 1,750 rpm, resulting in a displacement speed of 3.51 ± 0.04 km $h^{-1}$ under no load. Each experimental unit was 40 m long by 3 m wide, giving a total of 120 $m^2$.

The tests carried out on the drawbar comprised constant engine acceleration tests, in which different loads were applied until the specified slip limit was reached (Lanças *et al*., 2020).

Varying loads were imposed on the drawbar of the test tractor by altering the gears and rotation of the load tractor to obtain wheel slip values of up to 35%. These values were randomly selected for the first pass of each test. For calculation purposes, wheel slip on the traction device was considered zero when the tractor was not subjected to any load on the traction bar, as established in standard S296.4 (Asae, 1999).

The tractive force on the bar was determined using an S-shaped load cell connected to the data acquisition system. The number of wheel revolutions of the test tractor was determined using inductive and gear-tooth sensors installed on the wheelsets.

To measure the fuel consumption, the procedure used by Godesa, Jejcic and Poje (2010) was adopted, with the flowmeter placed in the supply system of the tractor engine. This system made it possible to measure fuel consumption during the tests by determining the unit volume difference (mL) in flow values before the fuel reached the engine and after returning to the tank.

The displacement speed, slip, drawbar power and hourly fuel consumption were determined based on the methodology described in Lanças *et al*. (2020) and Souza *et al*. (2022a). The displacement speed was obtained as per Equation 1.

$$V_d = \frac{s}{t} 3.6 \tag{1}$$

where:

Vd - average speed of each test, km $h^{-1}$;

s - distance covered in the experimental unit, m;

t - time elapsed in the experimental unit, s;

Wheel slip was determined based on the relationship between the number of rotations of the tractor wheelset with no load and when working, as shown in Equation 2.

$$S = 100\left(1 - \frac{n_0}{n_1}\right) \tag{2}$$

where:

s - wheel slip, %;

$n_0$ - number of revolutions of the drive wheels, operating with no load, dimensionless;

$n_1$ - number of revolutions of the drive wheels, when working, dimensionless.

Drawbar power was determined using Equation 3.

$$P_B = \frac{F_T V_D}{3.6} \tag{3}$$

where:

$P_B$ - drawbar power, kW;

$F_T$ - average tractive force for the route, kN;

$V_D$ - displacement speed, km $h^{-1}$.

From the data for fuel consumption and the time spent on each test, the hourly consumption was calculated, as follows:

$$C_h = 3.6 \frac{c}{t} \tag{4}$$

where:

$C_h$ - hourly fuel consumption, L $h^{-1}$;

C - fuel consumption in the experimental unit, mL;

t - time spent in the experimental unit, s.

The data were submitted to regression analysis, with the models being selected based on the significance of the F-test, the highest coefficient of determination, and from a study of the phenomenon. A level of 5% probability was adopted for each analysis.

Comparisons between the performance curves of the tractor equipped with each type of wheelset were made using the method for model similarity described in Souza *et al*. (2022b). For the generalised comparison of two vectors of quantitative data, the Graybill F-test and the mean error t-test were used, together with the correlation coefficient. A 5% probability was adopted in the analyses.

## RESULTS AND DISCUSSION

### Tractive performance on dry soil with a moisture content of 0.06 $m^3$ $m^{-3}$

Figures 1, 2 and 3 show the performance of the tractor equipped with the tyres used in the test on soil with a low moisture content, i.e. with high mechanical resistance. The values for tractive force showed a quadratic trend as the wheel slip increased, the same behaviour as seen for tractive power. Hourly fuel consumption adjusted to the quadratic model as a function of drawbar power.

Considering the radial tyres, for the same amount of slip (30%), there was a reduction in the fuel consumption of the tractor of 10.4%, with an increase in drawbar power of 25% using the low-pressure radial tyres compared to the high-pressure radial tyres (Figures 2 and 3), clearly showing that tyre pressure plays a fundamental role in the contact area between the tyre and the ground. Feitosa *et al*. (2015) obtained a 25% increase in contact area for the rear tyres when the internal tyre pressure was reduced from 124 to 83 kPa.

**Figure 1** - Drawbar force ($F_B$) as a function of wheel slip (s) developed by the traction devices tested under a soil moisture content of 0.06 m³ m⁻³, for diagonal tyres at the recommended pressure (bpD) and at high pressure (apD), and radial tyres at the recommended pressure (bpR) and at high pressure (apR)

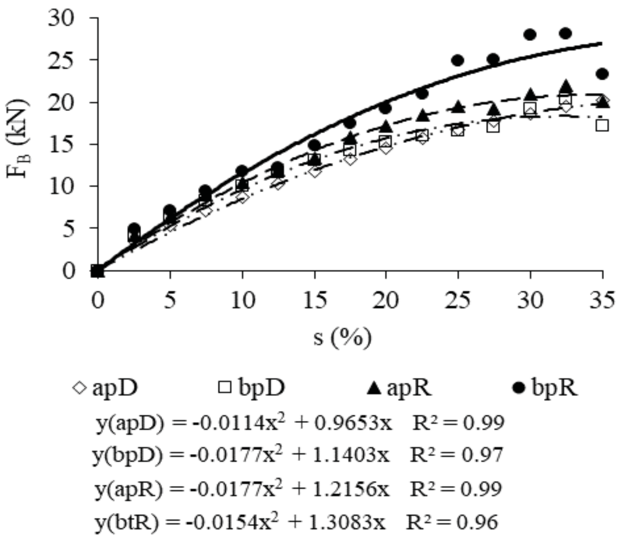



**Figure 2** - Drawbar power ($P_B$) as a function of wheel slip (s) developed by the traction devices tested under a soil moisture content of 0.06 m³ m⁻³, for diagonal tyres at the recommended pressure (bpD) and at high pressure (apD), and radial tyres at the recommended pressure (bpR) and at high pressure (apR)

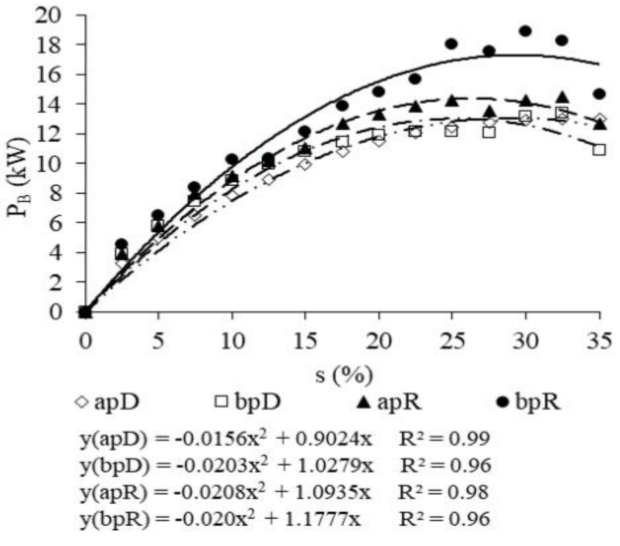
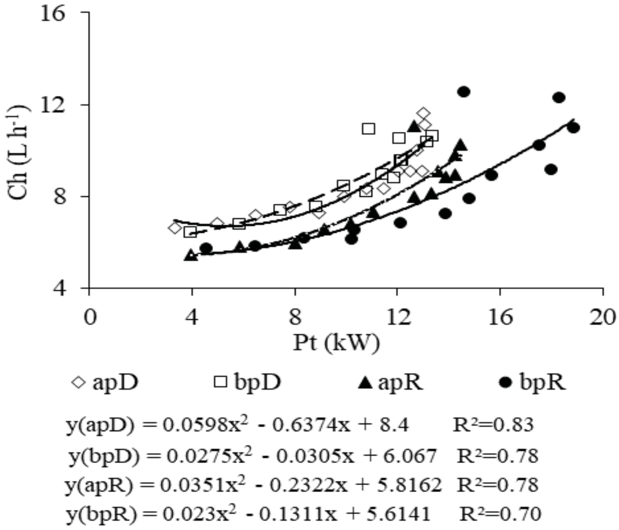



**Figure 3** - Hourly fuel consumption (Ch) as a function of drawbar power (Pt) measured based on the type of traction device, under a soil moisture content of 0.06 m³ m⁻³, for diagonal tyres at the recommended pressure (bpD) and at high pressure (apD), and radial tyres at the recommended pressure (bpR) and at high pressure (apR)




On the other hand, analysing Figure 1, it can be seen that the diagonal wheelsets showed no significant difference in behaviour with the change in pressure. While the low-pressure radial tyres achieved a 33% increase in tractive force compared to the high-pressure tyres, the diagonal tyres did not exceed 12%. This shows that among the variations in tyre pressure, the pressure applied to the radial tyres (56 and 62 kPa, front and rear, respectively) resulted in a greater reduction in traction capacity than the variation applied to the diagonal tyres (82 and 111 kPa), due to an increase in pressure greater than that recommended for the operation.

When evaluating a 4 x 2 AFT tractor with different configurations of wheel pressure and ballast, Montanha *et al*. (2012) obtained similar results for fuel consumption at all the pressures used. However, when using high and low tyre pressures for the same load, there was less wheel slip when using low pressures.

Having obtained similar results, Jadoski *et al.* (2016) concluded that in order to achieve the maximum tractive force with the lowest power consumption, it is first necessary to select the most appropriate permitted tyre pressure.

Table 1 shows the results of applying the model-comparison test to compare the drawbar force, drawbar power and hourly fuel consumption data obtained on dry soil for diagonal tyres at the recommended pressure (bpD) and at high pressure (apD), and radial tyres at the recommended pressure (bpR) and at high pressure (apR).

**Table 1** - Comparative analysis between the models for drawbar force, drawbar power, and hourly fuel consumption on dry soil, for diagonal tyres at the recommended pressure (bpD) and at high pressure (apD), and radial tyres at the recommended pressure (bpR) and at high pressure (apR)

| Factor for analysis | bpR x apR | bpD x apD |
|---|---|---|
| | Drawbar force | |
| F(H0) | 0.3915$^{ns}$ | 0.7035$^{ns}$ |
| T-test for variability | 11.143* | 2.814* |
| $r_{Y_j Y_1} \geq \lvert 1-\overline{e} \rvert$? | Yes | Yes |
| | Drawbar power | |
| F(H0) | 0.6306$^{ns}$ | 1.1850$^{ns}$ |
| T-test for variability | 10.212* | 1.856$^{ns}$ |
| $r_{Y_j Y_1} \geq \lvert 1-\overline{e} \rvert$? | Yes | Yes |
| | Hourly fuel consumption | |
| F(H0) | 1.4430$^{ns}$ | 4.6175* |
| T-test for variability | 1.483$^{ns}$ | 1.464$^{ns}$ |
| $r_{Y_j Y_1} \geq \lvert 1-\overline{e} \rvert$? | Yes | Yes |

$^{ns}$ – not significant. * - significant at 5% probability

The precision of the data was determined by t-test for the intersection and slope parameters and by the coefficient of determination. The evaluators whose estimates allowed the linear model to be fitted with the highest values for the coefficient of determination ($r^2$) were considered to be the most accurate.

Taking as a reference the rules for comparing analytical methods, there were only two situations for which the models were validated and considered statistically identical by both the t-test and the F-test at a level of 5%: drawbar power for diagonal tyres at the recommended pressure ($Y_1$) and at high pressure ($Y_j$) and hourly fuel consumption for radial tyres at the recommended pressure (Y1) and at high pressure (Yj).

As mentioned above, when operating on low-moisture soil, there was no significant difference in the behaviour of the diagonal wheelsets for the change in pressure, compared to the radial wheelsets; however, the models are only equal ($Y_1 = Y_j$) for drawbar power. This can be explained by the fact that the tractive force of the diagonal tyres inflated to the recommended pressure, compared to the high-pressure diagonal tyres, is inversely proportional to the displacement speed under the same conditions, so that there is no variation in drawbar power for the sets of data under analysis.

Similarly, it can be seen that the variation in pressure of the radial tyres does not affect hourly fuel consumption. However, the same is not true for the diagonal tyres, for which, despite the t-test not being significant, the similarity of the analytical methods was rejected by the proposed procedure as the $F_{(H0)}$ condition was not met.

The construction of the radial tyre means that the tread is flat and rigid compared to the diagonal tyre, with any deformation confined to the sides. For this reason, any variation in pressure, whether up or down, is only felt in radial tyres when working with very high or very low pressures, whereas in the present case, such pressures were not reached.

The data shown in Figures 1, 2 and 3 show the better performance of the low-pressure radial tyres compared to the other conditions, i.e. high- and low-pressure diagonal tyres, and high-pressure radial tyres.

It should also be noted that even using radial tyres under low tractive force, i.e. at high pressure, the performance is superior to diagonal tyres whatever the pressure, showing greater tractive force at the drawbar and lower hourly fuel consumption. This is because traction between the tyres and the ground can be increased by increasing the area of contact, and radial tyres have a larger area of contact with the ground. Furthermore, according to Machado *et al.* (2015), the fuel consumption of a tractor is dependent on rolling resistance, which also depends on the contact between the ground and the tyre.

For test where the wheelsets were at the same pressure, the results showed a 13.9% increase in tractive force and a 17.1% reduction in hourly fuel consumption in favour of the radial wheelsets.

Lopes *et al*. (2003) also carried out field tests with a 4 x 2 AFT tractor with 89 kW of engine power equipped with two types of tyres (radial and diagonal) for scarifying. The authors concluded that the radial tyre resulted in lower specific fuel consumption, lower rolling resistance, and lower slip rates compared to diagonal tyres subjected to the same tractive force.

Based on the results shown in Table 2, the type of wheelset construction affects drawbar force, drawbar power and hourly fuel consumption, even when maintaining the same pressure. Despite a relatively high correlation being found in the graphs, and the $r_{Y_jY_1} \geq (1-\overline{e})$ condition being met, none of the cases were identical. This was due to the significance of the t-test for variability.

Wheel slip is a determining factor for traction to occur more easily. Godinho Júnior *et al*. (2017) comment that there has to be a certain amount of wheel slip to avoid excessive wear on the tractor parts or tyres. The recommendation made by technicians in the field of agricultural mechanisation is that agricultural operations be carried out within a wheel-slip range of 8% to 12% for diagonal tyres and 10% to 15% for radial tyres, both on firm ground (Leite *et al*., 2020). The present study found that radial tyres offer more benefits at high slip rates, allowing for greater force on the drawbar, albeit at the cost of reduced forward speed and lower operating capacity.

Figures 1 and 2 show that the tractive force tends to increase with wheel slip, and that drawbar power reached maximum performance at slip rates of 28.9% (apD); 25.3% (bpD); 26.3% (apR) and 29.4% (bpR), equal to a power of 13.1, 13.0, 14.4 and 17.3 kW, respectively. At these maximum values for tractive power, hourly fuel consumption was 10.3, 10.3, 9.8 and 10.2 L $h^{-1}$, showing that for a 5.1% variation in consumption there is a 33% increase in drawbar power.

It is recommended that tests be carried out on the wear of agricultural tyres at different slip rates for later correlation with data on operating capacity, in order to obtain more conclusive data on the best working range for heavy-duty agricultural operations.

**Tractive performance in wet soil, with a moisture content of 0.51 $m^3$ $m^{-3}$**

Figures 4, 5 and 6 show the performance of the tyres used in the tests on soil with a high moisture content, i.e. soil with low mechanical resistance. The behaviour of the tyres under these conditions is similar to that of tyres on soil with a low moisture content, highlighting the quadratic trend of drawbar force and power with wheel slip, and fuel consumption with power.

Using low-pressure radial tyres compared to high-pressure radial tyres, both with 30% slip, there is a 17.79% increase in drawbar power and a 9.03% reduction in hourly fuel consumption, in favour of the low-pressure radial tyres. Although there is a notable improvement in traction capacity for the change in pressure, it is not as marked as the results obtained on dry soil.

**Table 2** - Comparative analysis between the models for drawbar force, drawbar power, and hourly fuel consumption on dry soil, for radial and diagonal tyres at the recommended pressure (bpR and bpD), and for radial and diagonal tyres at high pressure (apR and apD)

| Factor for analysis | bpR x bpD | apR x apD |
|---|---|---|
| | Drawbar force | |
| F(H0) | 0.07268$^{ns}$ | 0.4843$^{ns}$ |
| T-test for variability | 8.513* | 9.602* |
| $r_{Y_jY_1} \geq \lvert 1-\overline{e} \rvert$? | Yes | Yes |
| | Drawbar power | |
| F(H0) | 0.13$^{ns}$ | 1.49$^{ns}$ |
| T-test for variability | 8.039* | 8.228* |
| $r_{Y_jY_1} \geq \lvert 1-\overline{e} \rvert$? | Yes | Yes |
| | Hourly fuel consumption | |
| F(H0) | 0.12$^{ns}$ | 2.32$^{ns}$ |
| T-test for variability | 2.759* | 4.002* |
| $r_{Y_jY_1} \geq \lvert 1-\overline{e} \rvert$? | Yes | Yes |

$^{ns}$ – not significant. * - significant at 5% probability

**Figure 4** - Tractive force ($F_B$) as a function of wheel slip (s) developed by the traction devices tested on wet soil with a moisture content of 0.51 m³ m⁻³, for diagonal tyres at the recommended pressure (bpD) and at high pressure (apD), and radial tyres at the recommended pressure (bpR) and at high pressure (apR)

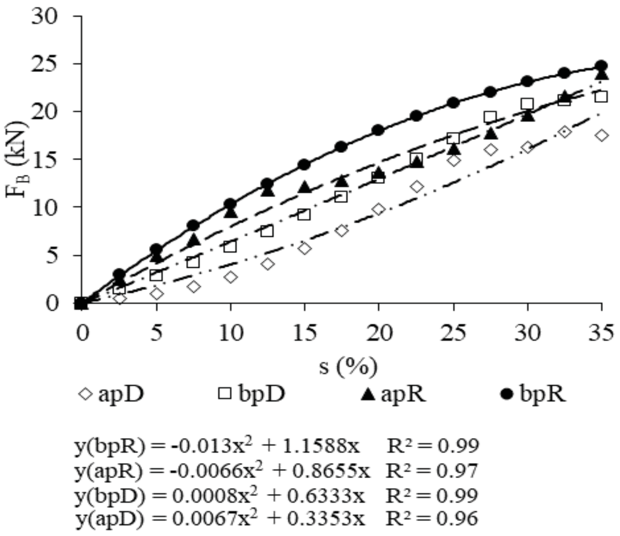
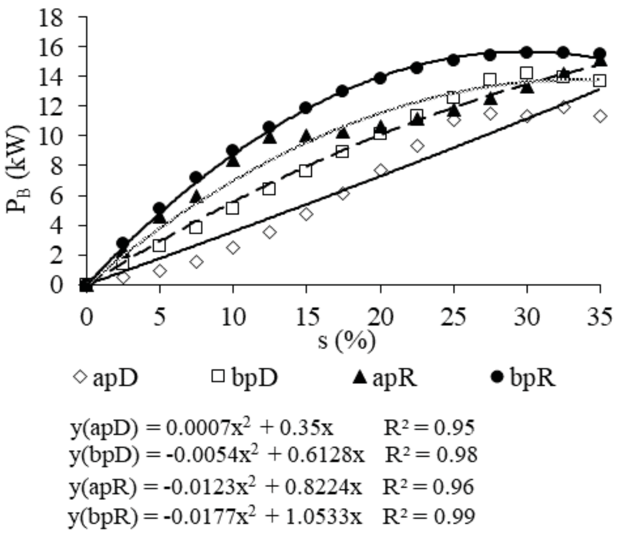
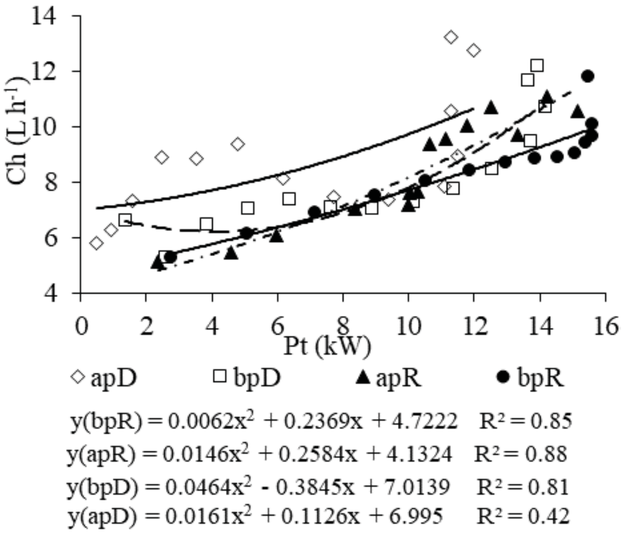



**Figure 5** - Drawbar power ($P_B$) as a function of wheel slip (s) developed by the traction devices tested under a soil moisture content of 0.06 m³ m⁻³, for diagonal tyres at the recommended pressure (bpD) and at high pressure (apD), and radial tyres at the recommended pressure (bpR) and at high pressure (apR)




According to Grecenko and Prikner (2014), the best performance for the wheelset of a tractor is achieved by adjusting the tyre pressure based on the type of soil and the conditions under which the tractor is used.

**Figure 6** - Hourly fuel consumption ($C_h$) as a function of drawbar power ($P_t$) measured based on the type of traction device, under a soil moisture content of 0.51 m³ m⁻³, for diagonal tyres at the recommended pressure (bpD) and at high pressure (apD), and radial tyres at the recommended pressure (bpR) and at high pressure (apR)




On dry soil, the models for drawbar power were identical using diagonal tyres operating at the recommended pressure ($Y_1$) and at high pressure ($Y_j$), and for hourly fuel consumption using radial tyres also at the recommended ($Y_1$) and at high pressure ($Y_j$), as shown in Table 3. However, their behaviour differs when operating in wet soil, as no model was validated under these conditions.

In the same way as in high-resistance soil, radial wheelsets perform better; however, where soil resistance is critical, radial wheelsets show a more marked increase in performance. The fact that the wheelsets show poorer tractive performance in wet soil compared to dry soil is due to an increase in rolling resistance, the result of the soil being more disturbed.

Table 4 shows the F-test applied to compare drawbar strength, drawbar power and hourly fuel consumption data on wet soil, for diagonal and radial tyres operating at the recommended pressure and at high pressure. In each case, the variability of $F(H_0)$ is non-significant and the condition $r_{Y_jY_1} \geq (1-e)$ is met; however, the models can only be defined as statistically identical when fuel consumption is used as the variable.

### Tractive performance as a function of soil moisture

Among the soil properties that affect the tractive efficiency of an agricultural tractor, Antunes Júnior *et al.* (2017) include soil texture, moisture, slope, and surface conditions that depend on the existence of ground cover.

**Table 3** - Comparative analysis between the models for drawbar force, drawbar power and fuel consumption on dry soil, for diagonal tyres at the recommended pressure (bpD) and at high pressure (apD), and for radial tyres at the recommended pressure (bpR) and at high pressure (apR)

| Factor for analysis | bpR x apR | bpD x apD |
|---|---|---|
| | Drawbar force | |
| F(H0) | 0.8928$^{ns}$ | 0.5001$^{ns}$ |
| T-test for variability | 14.525* | 10.975* |
| $r_{Y_j Y_1} \geq \lvert 1-\bar{e} \rvert$? | Yes | Yes |
| | Drawbar power | |
| F(H0) | 2.3374$^{ns}$ | 1.5484$^{ns}$ |
| T-test for variability | 17.203* | 20.957* |
| $r_{Y_j Y_1} \geq \lvert 1-\bar{e} \rvert$? | Yes | Yes |
| Hourly fuel consumption | | |
| F(H0) | 6.9367* | 2.5815$^{ns}$ |
| T-test for variability | 0.994$^{ns}$ | 4.268* |
| $r_{Y_j Y_1} \geq \lvert 1-\bar{e} \rvert$? | Yes | Yes |

$^{ns}$ – not significant. $^{*}$ - significant at 5% probability

**Table 4** - Comparative analysis between the models for drawbar force, drawbar power and hourly fuel consumption obtained on dry soil, for radial and diagonal tyres at the recommended pressure (bpR and bpD), and for radial and diagonal tyres at high pressure (apR and apD)

| Factor for analysis | bpR x bpD | apR x apD |
|---|---|---|
| | Drawbar force | |
| F(H0) | 0.22$^{ns}$ | 0.05$^{ns}$ |
| T-test for variability | 7.276* | 8.084* |
| $r_{Y_j Y_1} \geq \lvert 1-\bar{e} \rvert$? | Yes | Yes |
| | Drawbar power | |
| F(H0) | 0.46$^{ns}$ | 0.24$^{ns}$ |
| T-test for variability | 7.000* | 5.456* |
| $r_{Y_j Y_1} \geq \lvert 1-\bar{e} \rvert$? | Yes | Yes |
| | Hourly fuel consumption | |
| F(H0) | 0.18$^{ns}$ | 0.08$^{ns}$ |
| T-test for variability | 0.976$^{ns}$ | 1.340$^{ns}$ |
| $r_{Y_j Y_1} \geq \lvert 1-\bar{e} \rvert$? | Yes | Yes |

$^{ns}$ – not significant. $^{*}$ - significant at 5% probability

In both types of soil, tyres that use a lower pressure develop better tractive performance. The most important factor in tyre performance is the mechanical resistance offered by the soil, since the drier the soil, the greater its mechanical resistance, and consequently the greater the tractive force developed.

Furthermore, the tractor equipped with radial tyres developed greater traction and power in dry soil compared to wet soil, the same being true for diagonal tyres. Jadoski *et al*. (2016) confirms this result, stating that generally tractor performance is poorer, and wheel slip greater on tilled surfaces, followed by surfaces with ground cover, and firm surfaces, respectively.

**Table 5** - Comparative analysis between the models for drawbar force, drawbar power and fuel consumption obtained on dry (U1) and wet (U2) soil, for diagonal tyres at the recommended pressure (bpD) and at high pressure (apD), and radial tyres at the recommended pressure (bpR) and at high pressure (apR)

| Factor for analysis | apR | bpR | apD | bpD |
|---|---|---|---|---|
| | U1 x U2 | U1 x U2 | U1 x U2 | U1 x U2 |
| | | Drawbar force | | |
| F(H0) | 0.2824$^{ns}$ | 18.3540* | 0.1298$^{ns}$ | 0.1338$^{ns}$ |
| T-test for variability | 4.884* | 42.650* | 6.659* | 2.631* |
| $r_{Y_j Y_1} \geq \lvert 1-\bar{e} \rvert$? | Yes | Yes | Yes | Yes |
| | | Drawbar power | | |
| F(H0) | 0.5394$^{ns}$ | 140.1481* | 0.2338$^{ns}$ | 0.1827$^{ns}$ |
| T-test for variability | 5.136* | 90.088* | 9.617* | 2.455* |
| $r_{Y_j Y_1} \geq \lvert 1-\bar{e} \rvert$? | Yes | Yes | Yes | Yes |
| | | Fuel consumption | | |
| F(H0) | 1.7183$^{ns}$ | 0.4683$^{ns}$ | 32.8545* | 2.5806$^{ns}$ |
| T-test for variability | 1.419$^{ns}$ | 1.389$^{ns}$ | 3.038* | 2.296* |
| $r_{Y_j Y_1} \geq \lvert 1-\bar{e} \rvert$? | Yes | Yes | Yes | Yes |

$^{ns}$ – not significant. * - significant at 5% probability

The highest fuel consumption was found using the high-pressure diagonal wheelset (U2). This result may have been influenced by the physical condition of the soil surface, which had been tilled, making it difficult for the tractor to move forward, and requiring greater engine speed and consequently higher fuel consumption in order to maintain the operating speed. The lowest consumption was seen using the high-pressure radial wheelset, for which the surface conditions were more stable, requiring less effort from the tractor and consequently lower fuel consumption.

Monteiro *et al.* (2013) found a similar situation, where the hourly fuel consumption was higher on a tilled surface. He concluded that tilling the soil leads to higher fuel consumption as there is a tendency to increase the engine speed to maintain forward gear.

When comparing the data in Figures 4 and 5 with the results shown in Figures 1 and 2, it can be seen that the use of radial tyres at high slip rates is also advantageous in high-moisture soil. However, in soil with a greater moisture content, the tractive force and tractive power at the drawbar reached their maximum value when wheel slip was at 35%.

Taking into account all the parameters that were analysed, there are advantages to using low-pressure radial wheelsets when operating under low levels of soil moisture.

When evaluating Table 5, none of the models for tractive force or drawbar power were identical. This can also be understood as the direct effect of the levels of soil moisture at the time of the operations, corroborating Cunha, Cascão and Reis (2009), who report on the influence of soil moisture on operating efficiency.

On the other hand, using statistical analysis, it can be concluded that soil moisture does not affect the hourly fuel consumption of the tractor when operating with radial tyres (Table 5).

## CONCLUSIONS

The tractor equipped with radial tyres showed better performance than when equipped with diagonal tyres, the effect being more significant at greater slip rates, with an average increase of up to 33% in drawbar power for a 5.1% increase in fuel consumption;

The radial tyres at an internal pressure of 110 kPa on the front wheelset and 97 kPa on the rear wheelset afforded better performance when operating on both wet and dry ground.

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