

## DYNAMIC TRACTION OF A MECHANIZED SET BASED ON TECHNICAL AND OPERATIONAL PARAMETERS

Doi: <http://dx.doi.org/10.1590/1809-4430-Eng.Agric.v37n3p484-492/2017>

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**ABSTRACT:** The objective of this study was to evaluate and model the traction performance parameters of a tractor 4x2 FWD, according to the tractor speed, the internal pressure and the type of tires construction. For each type of tire construction was assembled an experiment in which we evaluated the influence of internal pressures of the front and rear tires and the speed of the mechanical assembly. It was found that the sliding of the diagonal run, presented significant effect in all variables analyzed, since the radial showed no influence of the factors evaluated. The power available in the drawbar was higher when the tractor was equipped for radial tires. The response variables, fuel consumption schedule and specific fuel consumption were more sensitive to the speed of the internal tire pressure. The fuel consumption per area worked, did not affect the analyzed variables. As for the effort prediction models in the tractor drawbar, it was only possible for diagonal run, which are influenced by speed and internal pressure levels of the front and rear tires.

**KEYWORDS:** harrow disc, instrumentation, traction performance.

### INTRODUCTION

In agricultural tractors the tires are of great importance because they provide the balance, the displacement, the steering and the damping of the vibrations due to the irregularities of the ground that can interfere in its operational performance (MONTEIRO et al., 2011).

The internal tire pressure directly affects the contact surface tire / soil, the use of low internal pressure in the tire tends to increase the contact area tire / ground, which provides greater traction capacity (MONTANHA et al., 2011; TAGHAVIFAR & MARDANI, 2013).

Agricultural machine operators normally calibrate tires with an internal pressure above the recommended one, such practice; can reduce the tractive efficiency of the mechanized sets.

The increasing of internal tire pressure results in reduced rolling resistance, leading to a number of problems, such as premature tire wear, greater mechanical impact (vibration) to the tractor set, as well as changing the ergonomic characteristics, as most of the agricultural tractors do not have shock absorbers in the axles, having the tires the responsibility to absorb the impacts and vibrations.

According to the ground conditions and the activity to be performed, the pressure and level of the internal tire weighting should be determined, aiming to improve the operational performance of the tractors, since about 20 to 55% of the available energy of a tractor is lost due to the tire-soil interaction, causing an exceeding tire wear and even soil compaction. The tire allows the torque of a tractor to be transmitted to the ground and enables it to draw a certain load in addition to moving. Tire traction depends on a number of factors including tire geometry (width, diameter, and section height), tire type (diagonal or radial), claw type, internal pressure, dynamic load on the axle and soil type and conditions (MONTEIRO et al. 2011; MONTEIRO et al. 2013; GABRIEL FILHO et al. 2010).

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Received in: 7-19-2016

Accepted in: 10-14-2016

The objective of this research was to evaluate and model the operational performance parameters of a 4x2 FWD tractor, as a function of the tractor speed, internal pressure and construction type of the tires.

## MATERIAL AND METHODS

The experiment was conducted in an experimental area belonging to the Federal University of Viçosa, located in the municipality of Viçosa-MG, at 20° 45' 16" south latitude and 42° 50' 21" west longitudes, with a height of 660 m. The soil classified as Dystrophic Yellow Red Argisol according to EMBRAPA classification (2013), which was resting for 5 years with an average slope of 1%.

Following the methodology proposed by EMBRAPA (2011), the soil was classified as clayey texture, containing 53 dag kg<sup>-1</sup> of clay in composition and at the moment of the research the water content in the soil was 0.19 kg kg<sup>-1</sup>, and its density of 1.17, 1.22 and 1.16 g cm<sup>-3</sup> respectively at the depths of 0 - 0.10, 0.10 - 0.20 and 0.20 - 0.30 m depth.

It was used a mechanized set, composed by a John Deere® tractor, model 5705 4x2 with auxiliary front wheel drive (FWD), with power of 62.56 kW (85 hp) in the engine at 2400 rpm, and a double-action harrow Tatu Marchesan® brand, APCR model of 14-disc of 24", coupled to the tractor by the drawbar, with the disks spaced at 0.23 m, at the time of the tests the opening between the sections in the intermediate position was maintained, which provided a working depth of 0.3 m.

The tractor was equipped with two types of tire construction, being diagonal and radial. The diagonal tires used were Goodyear® Dyna Torque II 12.4-24 on the front axle and Pirelli® TM 95 18.4-30 on the rear axle. The radials were the models 320 / 85R24 in the front axle and the 460 / 85R30 in the rear axle, both of the OPTITRAC line of Goodyear®.

With the aid of a data acquisition system Hottinger Baldwin Messtechnik (HBM) brand, Spider 8® model, managed by the HBM Catman® 2.2 program, which was installed in a portable computer on board the tractor, the data acquired by the system was stored for further processing. During the tests execution the system was managed for a sampling rate of 50 Hz.

The speed developed by the mechanized set during the operation was obtained with the aid of radar of Doppler effect, from Dickey John® brand, model Radar II.

In order to measure the rotational speed of the tractor's driving wheels, Autonics inductive transducers, model PRCM 18 were used, positioned along a crown arranged with equidistant fins in its surroundings, set up on an encoder type system (spin counter).

For the purpose to measure internal tire pressure, pressure sensors of the brand Sensata Technologies® model 100CP7-1 were used, coupled to each tire of the tractor by means of a kinematic rotor.

A Kratos brand load cell with a capacity of 50 kN was coupled between the tractor and the harrow. A support was used for accommodation of the load cell with the purpose of preserving the integrity of the transducer.

To determine the volume of fuel consumed, a volumetric flow meter FLOWMATE M-III® model LSF41C was used, where the volume was expressed in time unit.

To determine the rolling radius, tests were carried out on a concrete track, recording the angular velocity of each axis by the data acquisition system, with this information the rolling radius was calculated by means of [eq. (1)].

$$r_r = \frac{S_{op}}{2 \pi n} \quad (1)$$

where,

$r_r$  - Rolling radius, m;

$S_{op}$  - operating Speed, m s<sup>-1</sup>; and,

n - Rotation of the drive shaft, rps.

Knowing the force required to draw the harrow and the displacement speed of the assembly during the operation, the power demanded during the execution of the tests was calculated.

$$P = S_t DS \quad (2)$$

where,

P – demanded Power, kW;

$S_t$  - Medium traction Strength, kN; and,

DS - displacement Speed,  $m s^{-1}$ .

The sliding of the wheels was obtained by means of the relation between translational and rotational speed for each of the machine wheels, according to [eq. (3)].

$$\delta = \frac{S_r - S_t}{S_r} 100 \quad (3)$$

where,

$\delta$  - sliding of the wheels %;

$S_r$  - rotational Speed,  $m s^{-1}$ ; and,

$S_t$  – translational Speed,  $m s^{-1}$ .

The specific fuel consumption was determined by the ratio of the hourly fuel consumption in relation to the power demanded.

The efficiency of the drawbar is the ratio of the power in the drawbar and the nominal power of the tractor engine, i.e. it indicates the fraction of the nominal power of the engine that is actually used by the drawbar performing an activity by the tractor.

The tractor used was weighted with 75% of water in the diagonal tires and 40% in the radial tires, and in all the tests the auxiliary front wheel drive (FWD) was kept on, in order to reach the maximum possible traction of the evaluated tractor.

The displacement speeds of the mechanized assembly were determined as a function of the variation of the motor's speed and rotation, according to Table 1.

TABLE 1. Displacement speeds evaluated.

Speeds ( $km h^{-1}$ )	Speeds ( $m s^{-1}$ )	Gear	Engine rotation (rpm)
4.00	1.11	3A	2,400
4.81	1.34	1B	2,250
6.00	1.67	2B	2,400
7.19	2.00	3B	2,000
8.00	2.22	3B	2,400

Each experimental unit was 40.0 m long and 2.0 m wide, with a useful area of 80  $m^2$ , 15 m between them in the longitudinal direction for maneuvers, traffic of implements and stabilization of the set before data acquisition.

For each type of tire construction an experiment was set up. The experiments were installed using a central composite rotatable design (CCRD), a factorial  $2^3$ , including 6 axial points and 5 repetitions at the central point, totaling 19 trials, according to Table 2.

TABLE 2. Values used in the CCRD to the factors studied.

Tire	Variables	Code	-1.68	-1	0	1	1.68
Diagonal	Speed (m s <sup>-1</sup> )	S	1.11	1.34	1.67	2.00	2.22
	Front pressure (kPa)*	Fp	68.95	82.94	103.42	123.90	137.90
	Rear pressure (kPa)*	Rp	68.95	82.94	103.42	123.90	137.90
Radial	Speed (m s <sup>-1</sup> )	S	1.11	1.34	1.67	2.00	2.22
	Front pressure (kPa)*	Fp	137.90	151.89	172.37	192.85	206.84
	Rear pressure (kPa)*	Rp	137.90	151.89	172.37	192.85	206.84

\* Diagonal tires: 68.95 kPa = 10.0 psi; 82.94 kPa = 12.0 psi; 103.42 kPa = 15 psi; 123.90 kPa = 18.0 psi and 137.90 kPa = 20.0 psi.

Radial Tires: 137.90 kPa = 20.0 psi; 151.89 kPa = 22.0 psi; 172.37 kPa = 25.0 psi; 192.85 kPa = 28.0 psi and 206.84 kPa = 30.0 psi.

Data from each experiment were analyzed by means of regression analysis. The models were chosen based on the significance of the regression coefficients, the determination coefficient, the lack of adjustment and the phenomenon behavior under study. For the accomplishment of these statistical procedures were used the R computational program.

## RESULTS AND DISCUSSION

The sliding of the tractor wheels using radial tires was not influenced by the displacement speed and not even by the internal pressure of the front and rear wheels.

For this reason, it was represented by the equation of the line consisting of a constant whose value corresponded to the arithmetic mean of the slip values, obtained experimentally in all tests (Table 3 and 4).

This behavior can be understood by treating it in a constructive way, which results in tires with more malleability to soil irregularities. However, this lack of rigidity when compared to the diagonals, allows lateral displacement of the tire, which may have interfered in the characterization of the sliding behavior in front of the established treatments.

The front sliding on the diagonal wheels (Table 3) was significantly altered by the internal pressure, due to the influence of the tires internal pressure on the rolling radius, it is noticed that the influence of the internal pressure on the slip is positive, i.e., for each internal pressure unit (kPa) in the front tires for the same displacement speed, it is promoted to the front wheel an increase of 0.026% in the slip.

TABLE 3. Regression equation adjusted to the sliding of the tractor's front wheel.

Tire	Equation	R <sup>2</sup>
Diagonal	$S_f = 3.148^{**} + 3.211^{*}DS + 0.026^{**}Pf$	0.63
Radial	$S_f = 7.803$	-

\* and \*\* - Significant at 1% and 5% level, respectively, by the t test. S<sub>f</sub> - Sliding of the front wheels (%); DS - Displacement speed (m s<sup>-1</sup>); Pf - Front internal pressure (kPa).

Greater influence is promoted by the displacement speed, raising 3.211% of sliding to the addition of a displacement speed unit, this for the diagonal tires. By increasing the displacement speed reduces the adhesion of the tire to the ground, causing greater levels of sliding, such effect was also evidenced by COELHO et al. (2012), where it was evaluated the effect of the operational speed in different forms of soil preparation, regardless of the operation way, the increase of the displacement speed corroborated to the addition of the sliding wheel.

As observed in the front diagonal wheels, the greatest effect on the rear sliding wheel (Table 4) was related to the displacement speed, 2.924% at each unit of displacement speed, followed by the internal pressure of the front wheels (0.025%), the increase of the internal pressure in the front tires that alters the rolling radius and thus the kinematic advance, which causes the front wheels to exert a greater traction thus promoting the drag of the rear wheels.

TABLE 4. Regression equation adjusted to the sliding of the tractor's rear wheel.

Tire	Equation	R <sup>2</sup>
Diagonal	$S_r = 6.936^* + 2.924^*DS + 0.025^{**}Pf - 0.021^{**}Pr$	0.68
Radial	$S_r = 8,404$	-

\* and \*\* - Significant at 1% and 5% level, respectively, by the t test.  $S_r$  - Sliding of the rear wheels (%); DS - Displacement speed (m s<sup>-1</sup>); Pf and Pr - Front and rear internal pressure respectively (kPa).

It is also noted that the internal pressure of the rear tires has a negative influence on the sliding, that is, as the internal pressure levels of the tires increased, decreases the sliding percentage of the wheels, this effect occurs as a result of the increase of the stiffness of the tires that when coercing on the ground, favoring the tangential displacement.

FURTADO JÚNIOR (2013), observed in his study that the reduction of internal pressure of the tires from 110.32 to 82.74 kPa led to the reduction of the sliding rates, which was more significant when the tractive force developed by the tractor was higher than 10 kN, effects also verified in this study, which demand force was higher than 10 kN, due to the increase of the tire contact area with the ground.

The results obtained from this situation also confirm those obtained by ŠMERDA & ČUPERA (2010), when analyzing the influence of tire pressure of radial construction on the traction performance of an agricultural tractor.

The demanded force on the drawbar for the radial tires was not affected by the terms of the displacement speed, internal pressure of the front and rear tires (Table 5).

For the tractive force response on the diagonal tires, were found effects generated by the displacement speed and by the front and rear internal pressures associated among them and the displacement velocity. For radial tires the equation was represented by a constant which value corresponds to the arithmetic mean of the force required for the harrow traction, obtained experimentally in the tests (Table 5).

TABLE 5. Regression equation adjusted to the demanded power in the drawbar.

Tire	Equation	R <sup>2</sup>
Diagonal	$DP_d = 13.476^* - 9.647^*DS + 0.082^{**}DSPf + 0.095^{**}DSPr - 0.001^{**}PfPr$	0.71
Radial	$DP_d = 12.037$	-

\* and \*\* - Significant at 1% and 5% level, respectively, by the t test.  $DP_d$  - demanded power in the drawbar (kW); DS - Displacement speed (m s<sup>-1</sup>); Pf and Pr - Front and rear internal pressure respectively (kPa).

The prediction model presented a linear behavior, indicating an explained percentage of variation of 71%.

The association of the rear and front internal pressure variables is possibly related to the soil conformation, which at the moment of traction, the weight transfer promotes the displacement of the load from the front axle to the rear axle, which may aid the traction, this action generates a response that is the longitudinal displacement (agitation) of the tractor, which changes dynamically the load that is applied on the axes, which changes the traction developed by the wheels of the rear and front axles, since this tractor develops traction on both axles (4x2 FWD).

Table 6 presents the equations for power prediction in the drawbar. The percentage of variation explained for diagonal tires was 88%, and for radial ones of 84%, indicating that the values of the determination coefficients suggest that these models are adequate to evaluate the power behavior in the drawbar.

TABLE 6. Regression equations adjusted to the power drawbar.

Tire	Equation	R <sup>2</sup>
Diagonal	$P_d = -18.360^* + 22.479^*DS + 0.008^{**}Pf$	0.88
Radial	$P_d = -5.483^{**} + 16.665^{**}DS$	0.84

\* and \*\* - Significant at 1% and 5% level, respectively, by the t test.  $P_d$  - power in the drawbar (kW); DS - Displacement speed (m s<sup>-1</sup>); Pf - Front internal pressure (kPa).

The power in the drawbar for the diagonal tires was affected only by the displacement speed and internal pressure of the rear tires. It can be observed that the internal pressure of the rear tires had little influence on the demanded power in the drawbar, as can be seen by the coefficient associated to this variable, being inferior to the one related to the displacement speed.

The displacement speed showed of great influence on the response variable, being its effect more relevant on the diagonal tires, which promotes an increase in the average power of 22.479 kW per speed unit (in condition of constant rear internal pressure), while the radial tires of 16.665 kW per speed unit.

Although the effect of the pressure is small, it was positive, showing that the increase of the internal pressure in the diagonal rear tires, results in the increase of the tire rolling radius, having a direct effect on the sliding of the wheels, which results in a better use of the power in the drawbar.

As already understood, the power in the drawbar is inversely proportional to the sliding percentage presented by the tractor rotations, because the greater the sliding the smaller the displacement speed, what conditions the reduction of the result of the tractive force and speed, which was also confirmed by FURTADO JÚNIOR (2013).

For the radial tires only the effect of the displacement speed was observed, which can be explained by the tire deflection capacity, where the internal pressures evaluated were not able to change significantly in the rolling radius of these tires.

For the fuel hourly consumption in the two constructive tires' forms, only the linear term displacement speed was statistically significant (Table 7), what were generated models that presented an explained percentage of variation around 66%.

TABLE 7. Regression equations adjusted for fuel consumption per hour.

Tire	Equation	R <sup>2</sup>
Diagonal	$C_h = 2.951^{**} + 5.539^*DS$	0.66
Radial	$C_h = 3.481^{**} + 4.726^*DS$	0.66

\* and \*\* - Significant at 1% and 5% level, respectively, by the t test.  $C_h$  Fuel Consumption per hour (L h<sup>-1</sup>); DS - Displacement speed (m s<sup>-1</sup>).

When comparing the fuel consumption by the tractor with diagonal tires with radial tires, it was observed that under the conditions to which the tractor uses diagonal tires (8.491 L h<sup>-1</sup>) had a higher average consumption of 0.284 L h<sup>-1</sup> above the consumption caused by the use of radial tires (8.206 L h<sup>-1</sup>), i.e. based on the prediction models, the use of radial tires can lead to a saving of 3.34% of fuel.

The hourly consumption is closely related to the demanded power by the engine, which will be converted into the tractive force and the displacement speed developed by the tractor, because the higher the torque demand the greater the fuel flow directed to the engine.

High values of hourly fuel consumption for diagonal tires were possibly due to the sliding of the tractor wheels, which acts as a drain, consuming energy that is not transformed into mechanical work, that is, the levels addition of the sliding of the wheels generates rotation which is not converted into displacement, which in turn reduces energy efficiency in the traction conditions.

SPAGNOLO et al. (2012) and FURTADO JUNIOR (2013), rehearsing a similar tractor used in this study, found that the tire pressures were not responsible for causing major changes in the tractor hourly consumption.

The model for diagonal wheels presented a higher percentage of explained variation (92%) than the radial ones (88%) (Table 8), this was due to the greater number of significant variables related to the specific fuel consumption model for diagonal wheels.

TABLE 8. Regression equations adjusted to specific fuel consumption.

Tire	Equation	R <sup>2</sup>
Diagonal	$SF_c = 1.272^* - 0.733^*DS - 0.001^{**}Pr + 0.164^*DS^2$	0.92
Radial	$SF_c = 1.385^* - 0.849^*DS + 0.193^*DS^2$	0.88

\* and \*\* - Significant at 1% and 5% level, respectively, by the t test. SF<sub>c</sub> - Specific Fuel Consumption (L kW<sup>-1</sup> h<sup>-1</sup>); DS - Displacement speed (m s<sup>-1</sup>), Pr - Rear internal pressure (kPa).

In the condition that the tractor equipped with diagonal tires, the effect of the displacement speed and the internal pressure of the rear tires was observed, although the implication of the rear tires internal pressure is small, for each increase of the pressure unit promotes in average a decrease of 0.001 L kW<sup>-1</sup> h<sup>-1</sup> in the specific fuel consumption.

The displacement speed promoted a quadratic effect on the specific fuel consumption in both tire construction forms, the point of lower specific consumption for the diagonal tires was 0.367 L kW<sup>-1</sup> h<sup>-1</sup>, what occurred with the operating speed of 2.24 m s<sup>-1</sup> and the internal pressure of the rear tires of 138.0 kPa, as this operating speed is outside of the evaluated range it is adopted 2.22 m s<sup>-1</sup>.

The lowest specific fuel consumption value for radial tires was 0.454 L kW<sup>-1</sup> h<sup>-1</sup>, which occurred at the maximum rated speed of 2.22 m s<sup>-1</sup>.

Possibly the fact that the diagonal tires are weighted with 75% of water in the radial tires with 40%, it justifies the fact that the results of this study present values of specific consumption of fuel superior in the radial tires, being able to have occurred losses by the sliding of the wheels.

Table 9 shows the models for efficiency in the drawbar, which in the diagonal tires showed effect of the displacement speed and the internal pressure of the rear tires that result to each unit of internal pressure that is added to the tire an increase of 0.1% in the drawbar efficiency.

TABLE 9. Regression equations adjusted for drawbar efficiency.

Tire	Equation	R <sup>2</sup>
Diagonal	$E_d = -0.293^* + 0.3593^*V + 0.001^{**}Pr$	0.88
Radial	$E_d = -0.087^{**} + 0.266^*DS$	0.84

\* and \*\* - Significant at 1% and 5% level, respectively, by the t-test. E<sub>d</sub> - Efficiency in the drawbar; DS - displacement speed (m s<sup>-1</sup>); Pr - Rear internal pressure (kPa).

The wheels using radial tires had effect only by the displacement speed showing a positive relation, where the increase of the displacement speed resulted in the increase of the efficiency.

For the diagonal wheels the maximum efficiency point was 0.68, which means that only 68% of the nominal motor power is being used for traction. This performance was achieved based on the model with the speed of 2.2 m s<sup>-1</sup>, and the internal pressure of the rear tires of 137.0 kPa.

In compatible conditions with this study MONTEIRO et al. (2013) evaluated the efficiency of the 4x2 FWD tractor equipped with diagonal tires with a displacement speed of 1.94 m s<sup>-1</sup>, where it was found that in the power range in the drawbar of 15 to 20 kN, efficiency values of 50.9 and 54.1%, respectively. These values are lower than those presented in this study.

The maximum efficiency in the drawbar showed a linear behavior as a function of the displacement speed, it is implied that as increases the displacement speed there is an increase in the efficiency.

## CONCLUSIONS

The conditions, under which the experiment was conducted, it can be concluded that:

- The sliding of the diagonal tires had an effect in function of all the analyzed variables, and the radial ones, did not show influence by the evaluated terms.
- The power available on the drawbar was higher when the tractor was equipped with radial tires.
- Only the displacement speed influenced the variation in the tractor hourly consumption, where the lowest consumption was found in the radial tires. On the other hand, the lowest specific fuel consumption occurred when the diagonal tires are under a lower internal tire pressure (138 kPa) and a higher displacement speed ( $2.22 \text{ m s}^{-1}$ ).
- Regarding the effort prediction models in the drawbar of the tractor, it was only possible for diagonal wheels, which showed influence of the displacement speed and internal pressure levels of the front and rear tires.

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