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Agricultural tractor traction efficiency by changing the mass distribution between axles and speed[1]

Eficiência em tração de trator agrícola alterando a distribuição de massa entre eixos e velocidade

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HIGHLIGHTS:

Operating performance was altered by the variation in mass distribution between axles and speed in the traction operation.
The energy performance was altered by the variation in mass distribution between axles and speed in the traction operation.
In the mass distribution 39%/61% for the speed close to 10 km h^{-1} there was a greater performance.

ABSTRACT: The traction efficiency of the agricultural tractor can be maximized by adjusting the total mass and its distribution between the axles. The experiment's objective was to determine the configuration of mass distribution between axles and the displacement speed that provides greater traction efficiency in the harrowing operation. A randomized block design in a 2 × 3 factorial scheme with five replications was used. The first factor was two mass distributions between axles, and the second factor was three gears. The collected data were submitted to analysis of variance and the Tukey test. The condition that maximizes the tractor's performance corresponds to 39% of the total mass on the front axle and 61% on the rear axle, with a gear that provides speed close to 10 km h^{-1}.

Key words: agricultural machinery, specific consumption, dynamic load, harrowing

RESUMO: A eficiência em tração do trator agrícola pode ser maximizada ajustando a massa total e sua distribuição entre os eixos. O objetivo do experimento foi determinar a configuração de distribuição de massa entre eixos e velocidade de deslocamento que proporcione maior eficiência em tração na operação de gradagem. O experimento foi conduzido no delineamento em blocos casualizados no esquema fatorial 2 × 3, com cinco repetições, sendo o primeiro fator duas distribuições de massa entre eixos e o segundo fator três marchas. Os dados coletados foram submetidos à análise de variância e ao teste de Tukey. A condição que maximiza o desempenho do trator corresponde a 39% da massa total no eixo dianteiro e 61% no eixo traseiro, com marcha que proporcione velocidade próxima a 10 km h^{-1}.

Palavras-chave: máquinas agrícolas, consumo específico, carga dinâmica, gradagem

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Introduction

Brazil has undergone several changes in the agricultural scenario in recent decades due to the improvement of the crops that move agribusiness, the so-called commodities of agricultural interest. As a result, the mechanical fleet increased to meet the cultivars' increasingly restricted windows with characteristics of short cycles, super early (Silva et al., 2019). Mechanization promoted the possibility of increasing the area's productivity, without the need for expansion, due to the greater operational efficiency of the mechanized sets (Boyer et al., 2017).

Studies on operating and energy efficiency of mechanized systems are based on adequacy factors (mass distribution between axles, ballast factor, and tire inflation pressure) from past decades (Shafaei et al. 2019), without taking into account the modern construction projects and the new technologies embedded in these agricultural machines. Thus, there is a need for further studies to review the consolidated concepts. The modernization of mechanized assemblies ensures better use of their operational efficiency; therefore, greater savings in agricultural production costs (Mantovani et al., 2019).

The factors that interfere in the efficiency of the set (tractor + implement) such as displacement speed (Jasper et al., 2016), mass distribution between axles (Peeters et al., 2018) and its total mass (Lankenau et al., 2018), directly imply operational and energy efficiency. When there are no assertive adjustments to the factors mentioned above, mechanized assemblies' operational and energy performance are impaired (Lopes et al., 2019).

In this context, the objective was to determine the configuration of mass distribution between axles (MDBA) and displacement speed, which provides greater traction efficiency in the harrowing operation, analyzing variables related to the energy performance of the agricultural tractor.

Material and Methods

The experiment was carried out in the municipality of Pinhais, PR, Brazil, on firm soil, presenting the following particle-size properties of 249 g kg^{-1} of sand; 88 g kg^{-1} of silt, and 663 g kg^{-1} of clay, classified as Oxisol, with 12.16% average gravimetric moisture and 1870 kPa of resistance to penetration in the layer of 0 to 0.20 m of soil.

The experiment was conducted in a randomized block design, in a 2 x 3 factorial arrangement, with five replications, as described by Ferreira (2018). The first factor was composed of two conditions of mass distribution between axles (MDBA), and the second factor consisted of three gears, chosen based on ASABE D497.7 (2011), totaling 30 experimental units, 200 m long and 3 m wide (600 m^2).

In the longitudinal direction (from A to B) of the tractor's displacement, the measured slope was 3%; aiming at smoothing it, the traffic during the experiment in the acquisition of data consisted of three repetitions in a sense from A to B and two in the sensing from B to A. In the transversal, the slope was 1%.

The tractor used in the experiment was the New Holland, T6 130, with nominal power (ISO TR 14396) in a rotation of 1970 RPM of 99 kW (134 hp), with auxiliary front-wheel drive (FWD) and transmission 16 x 8 Power Shuttle (R) with a hydraulic reversal. 2.62m wheelbase and 0.5m high drawbar height. The tractor was mounted with diagonal tires at the front (14.9-28), with a pressure of 110 kPa (16 psi) in the MDBA of 39%/61% and 124 kPa (18 psi) in the distribution 46%/54%. At the rear, double diagonal tires (18.4-38) were used, with pressures of 110 kPa (16 psi) and 83 kPa (12 psi), internal and external, respectively, in the two MDBA conditions.

When adding mass to the tractor, hydraulic ballast of 75% was used for the front and rear tires (internal tires only) at the MDBA of 39%/61%. In this distribution, the solid front ballast consisted of ten 40 kg plates, and on the rear axle, eight 65 kg rings, totaling 7,598 kg of the total mass. For the MDBA 46%/54%, the front hydraulic ballast was 75%, and 25% for the internal tires on the rear axle, with solid ballast of 22 plates with 45 kg on the front and eight 65 kg rings on the rear axle, totaling 7,699 kg of the total mass.

The static masses on the tested tractor axles were determined with a CELMIG scale, model CM-1002, composed of four shoes. The 39%/61% MDBA resulted in 2,938 kg on the front axle and 4,660 kg on the rear axle. The MDBA of 46%/54% resulted in 3,553 kg and 4,146 kg on the front and rear axles, respectively.

The selected gears were: GI M4 T; GII M1 T; and GII M1 L, being named as MA, MB, and MC, respectively, corresponding to 1.67; 2.22; and 2.78 m s^{-1} (6.0; 8.0; and 10.0 km h^{-1}), in the engine rotation at 1970 RPM, with the FWD activated, and a full fuel tank.

A Baldan intermediate remote-control discing harrow (CRI 18 x 26), with 18 26-inch discs, with a mass of 1,920 kg, was attached to the drawbar to provide resistance to the tractor.

Using Autonics E100S encoders, it was possible to determine the tractor's four driving wheels' slip. Being obtained, through the rotations of the wheelsets, with and without load, and determined, according to Oiole et al. (2019).

From the power take-off (PTO), it was possible to measure the engine speed through an Autonics E100S encoder, and the transmission ratio obtained using a digital tachometer Victor DM6236P according to Strapasson Neto et al. (2020).

From two Flowmate OVAL MIII flowmeters, model LSF 41L0-M2, installed in the tractor's fuel supply system (inlet and return to tank), fuel consumption was measured using the difference in the number of pulses emitted by the flowmeters, and later converted to volume, considering the frequency of one mL per pulse, as described by Strapasson Neto et al. (2020).

Using a Bermann load cell, with a capacity of 100 kN and a sensitivity of 2.0+0.002 Mv V^{-1} with a precision of 0.01 kN, installed on the tractor drawbar, it was possible to measure the force on the drawbar. The average force on the drawbar was determined by the ratio between the instant traction force and the number of recorded data (Oiole et al., 2019). With the Vansco 740030A radar, the displacement speed of the assembly (DS) was determined. The power available on the drawbar was obtained as a function of the displacement speed and the average traction force (Strapasson Neto et al., 2020).

Through the temperatures obtained by type K thermocouples, previously registered at the fuel inlet in the flow meters and outlet, it was possible to determine the density of the diesel oil and later corrected, according to Oiole et al. (2019). Mass-based consumption and specific consumption were determined according to the measured quantity ratio (Lopes et al., 2003).

From the ratio between the available power in the drawbar and the nominal power of the tractor engine, the yield in the drawbar was obtained according to Monteiro et al. (2013). The rated power considered was 99 kW, according to the manufacturer's catalog. The engine thermal efficiency was obtained through the specific consumption and the lower calorific power of the fuel, according to Farias et al. (2017).

The dynamic load values were obtained as a function of the static and dynamic load on the wheelsets, the average traction force, the height of the drawbar, and the distance between axles according to the relationship of quantities described by Gabriel Filho et al. (2010).

The tractor instrumented with sensors, described in Image 1, was connected to the data acquisition system (DAS), according to Jasper et al. (2016). The acquisition frequency was one hertz, and the values were stored directly on the hard disk.

The collected data were analyzed for normality (Shapiro-Wilk) and homogeneity (Bartlett), followed by the analysis of variance and the Tukey test to compare means.

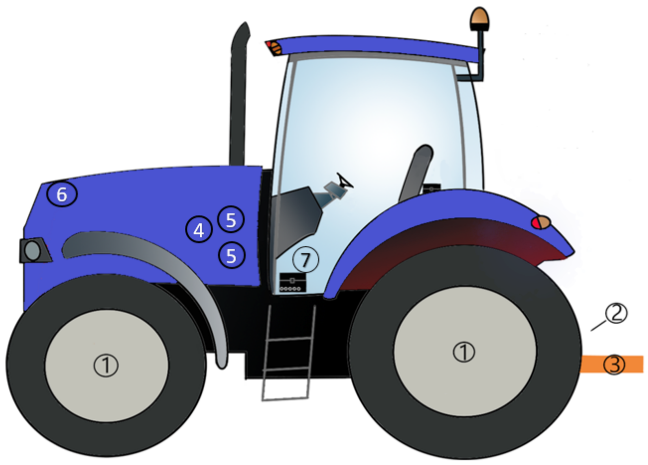

Figure 1. Position of the sensors: Encoders on the four wheels (1), Encoder on the power take-off (2), Load cell (3), Fuel temperature sensors (4), Input and output flow meters (5), Speed radar (6), Data acquisition system (7)

Results and Discussion

Tables 1 and 2 show the results of the analysis of variance and the means test. In most of the variables, the coefficients of variation presented absolute values classified as stable, according to the classification of Ferreira (2018), except for the SLP, which showed a coefficient of variation classified as moderately unstable, results that demonstrate adequate experimental care.

The results obtained in the mechanized assembly operation (tractor coupled to the intermediate disc harrow) in the MDBAs (39%/61% and 46%/54%) showed a significant difference for the following variables: DBF; DS; PDB; SFC; YDB; TEE; and DL. MDBA 39%/61%, with a greater mass on the rear axle of the tractor, which provided greater DBF, DS, PDB, and DL, consequently greater YDB and TEE, without statistically differentiating HCC and MRI, demonstrating the importance of the configuration of MDBA most suitable for the soil tillage operation performed.

The values of the variables HFC, DBF, DS, PDB, YDB, TEE, and DL increased significantly with the gears' increase,

Table 1. Means and synthesis of the analysis of variance of the variables wheel slip (SLP), engine rotation (ER), hourly fuel consumption (HFC), drawbar force (DBF), and displacement speed (DS)

Mass Distribution Between Axles (MDBA)	.SLP (%)	ER (RPM)	HFC (L h^{-1})	DBF (kN)	DS (m s^{-1})
39%/61%	8.01 a	1.880 a	18.18 a	21.10 a	7.12 a
46%54%	8.39 a	1.865 a	17.75 a	19.01 b	7.04 b
Gears (G)					
MA	7.45 a	1.862 a	15.64 c	19.08 b	5.70 c
MB	8.16 a	1.876 a	17.84 b	19.82 b	6.86 b
MC	9.01 a	1.879 a	20.42 a	21.29 a	8.68 a
F-test					
MDBA	2.22 ^{ns}	4.24 ^{ns}	1.22 ^{ns}	52.21 **	40.81 **
G	3.91 ^{ns}	5.11 ^{ns}	450.27 **	21.80 **	4.071.76 **
MDBA x G	16.94 **	4.57 ^{ns}	1.15 ^{ns}	5.34 *	4.98 ^{ns}
CV (%)					
MDBA	10.97	0.91	5.31	3.54	0.40
G	20.89	0.60	1.78	3.40	0.94
MDBA x G	9.88	0.68	2.29	1.50	1.07
Normality					
SW	0.315	0.997	0.998	0.697	0.999
Homogeneity					
B_0	0.669	0.159	0.851	0.990	0.662

In each column, for each factor, means followed by the same lowercase letter do not differ by Tukey's test (p ≤ 0.05); F test of analysis of variance (ANOVA): ns, *, ** - Not significant, significant at p ≤ 0.05 and p ≤ 0.01, respectively; Shapiro-Wilk Normality Test: SW ≤ 0.05 - Data abnormality; SW > 0.05 - Normality in the data; Bartlett's homogeneity test of variances: B0 ≤ 0.05 - Heterogeneous variances; B0 > 0.05 - Homogeneous variances; CV - Coefficient of variation

Table 2. Means and synthesis of the analysis of variance of the variables power in the drawbar (PDB), specific fuel consumption (SFC), yield in the drawbar (YDB), the thermal efficiency of the engine (TEE), and dynamic load (DL)

Mass Distribution Between Axles (MDBA)	PDB (kW)	SFC (g kW h^{-1})	YDB (%)	TEE (%)	DL (kN)
39%/61%	42.10 a	376 b	42.74 a	22.91 a	49.61 a
46%54%	37.44 b	413 a	38.01 b	20.89 b	44.18 b
Gears (M)					
MA	30.21 c	441 a	30.67 c	19.34 c	46.71 b
MB	37.77 b	402 b	38.34 b	21.20 b	46.85 b
MC	51.33 a	339 c	52.11 a	25.17 a	47.12 a
F-test					
MDBA	80.43 **	25.74 **	80.74 **	20.05 *	10.250.91 **
G	840.71 **	372.82 **	840.57 **	419.47 **	21.80 **
MDBA x G	11.41 **	0.33 ^{ns}	11.40 **	0.41 ^{ns}	5.34 *
CV (%)					
MDBA	3.20	4.46	3.20	5.04	0.28
G	2.63	1.91	2.63	1.88	0.27
MDBA x G	1.74	2.80	1.74	3.22	0.12
Normality					
SW	0.373	0.755	0.373	0.826	0.697
Homogeneity					
B_0	0.669	0.159	0.851	0.990	0.662

In each column, for each factor, means followed by the same lowercase letter do not differ by Tukey's test (p ≤ 0.05); F test of analysis of variance (ANOVA): ns, *, ** - Not significant, significant at p ≤ 0.05 and p ≤ 0.01, respectively; Shapiro-Wilk Normality Test: SW ≤ 0.05 - Data abnormality; SW > 0.05 - Normality in the data; Bartlett's homogeneity test of variances: B0 ≤ 0.05 - Heterogeneous variances; B0 > 0.05 - Homogeneous variances; CV - Coefficient of variation providing greater speed of displacement from MA, MB to MC, respectively, diverging only the CPB that was lower. Lopes et al. (2019), by increasing the displacement speed, also found lower specific fuel consumption, explained by the increase in PDB, provided by the higher DBF and RV (Simikic et al., 2014).

There was no significant difference for SLP in the different MDBA and gears used, and the values found are within the range recommended by ASABE D496.3 (ASABE, 2011), which recommends slippage between 8 and 10% on firm ground. SLP values similar to those reported by Gabriel Filho et al. (2010), who evaluated the tractor's slippage by pulling a load on a surface of uncovered firm soil.

In the ER variable, there is no significant difference in the MDBA (Table 1), remaining constant, even with the increase in DBF (MC gear). The HFC also did not differ in the compared MDBA, being explained due to ER and SLP because they do not differ significantly, corroborating Mamkagh et al. (2018) and Janulevičius et al. (2019). However, there was a significant difference in the different gear shifts, resulting from the other gear ratios (McLaughlin et al., 2019).

The reduction in RV in MDBA 46%/54% can be explained by Brixius (1987), who mentions the speed of displacement of the mechanized set being the product of the wheelset's angular speed versus the effective radius. The angular speed of the agricultural wheels did not differ between the MDBA since there was no significant difference between SLP and the ER; therefore, the greater load on the front axle provided by the MDBA 46%/54% reduced the effective radius of the front wheel.

The higher YDB is justified by the DBF and PDB variables being higher in MDBA 39%/61% when pulling the grid, promoted by the higher RV in MDBA 39%/61%. In the different marches, the YDB was higher as the number and group of gears increased, due to these promoting greater DS and DBF, directly increasing YDB.

The highest rates of thermal efficiency of the engine (TEE) were achieved with the MDBA of 39%/61%, with the tractor moving in the MC gear. In this condition, the engine expressed maximum efficiency in transforming thermal energy into work (Farias et al., 2017) compared to the other gears.

The DC was higher in MDBA 39%/61% due to the distribution providing greater load on the rear axle, which promoted greater interaction between tractor-soil, affecting the traction performance, reflecting in greater DBF, corroborating results obtained by Battiato & Diserens (2017).

The MA gear use provided less HFC, RV, PDB, YDB, and greater CPB, not differing from MB gear in DBF and DL variables. The lower consumption (SFC) for MB compared to MA can be explained by the higher PDB (Jasper et al., 2016) produced by MB, provided by DS and DBF, which were lower than the MC, variables which promoted lower TEE (Lopes et al., 2019), in both gears (MA and MB).

Higher DBF, DS, PDB, YDB, TEE, DL, and lower CPB were observed in the MC gear, which promoted greater energy performance of the mechanized set, resulting in an increase of 34.33% and 23.04% in the displacement speed (DS), concerning the MA and MB gears. However, the HFC increased by 23.41% and 12.63% in the MA and MB gears, respectively.

The interaction between the two factors evaluated was significant for SLP, DBF, PDB, YDB, and DL, with the interactions unfolding in Table 3. It is observed that in the MA gait, the SLP was lower in the MDBA 46%/54%, the greatest mass on the front axle at the lowest displacement speed resulted in the lowest SLP values.

DBF was higher in MDBA 39%/61%, which provided greater mass in the tractor's rear axle, as justified by Yanai et al. (1999); the increase in mass on the rear axle of the agricultural tractor allows better use of its mass, allowing greater adherence of the rear wheels to the surfaces, and therefore providing greater force in the drawbar (DBF), differing within the staggering gears (MA, MB, and MC).

The YDB demonstrates the use of the engine power in the drawbar, considering the DS and DBF that the tractor is pulling. The DS did not present any interaction between the parameters analyzed; therefore, this fact is explained by the tractor in the MDBA 39%/61% show greater mass in the rear axle, hence greater DL, consequently, traction greater DBF, as described by Lankenau et al. (2018), thus promoting greater PDB that directly provides greater YDB, justifying the results found in the configuration 46%/54% in the MA, MB, and MC gears had been lower.

Table 3. Means of the variables slippage, gears, and dynamic load according to the mass distribution between axles (MDBA) and gears

MDBA	Gears (G)		
	MA	MB	MC
	Slippage - .SLP (%)		
39%/61%	6.43 bB	7.78 aB	9.83 aA
46%/54%	8.47 aA	8.53 aA	8.18 aB
	Drawbar force - DBF (kN)		
39%/61%	19.63 aC	20.74 aB	22.62 aA
46%54%	18.19 bC	18.89 bB	19.96 bA
	Power in the drawbar - PDB (kW)		
39%/61%	31.70 aC	40.11 aB	54.48 aA
46%54%	28.71 bC	35.43 bB	48.18 bA
	Yield in the drawbar - YDB (%)		
39%/61%	32.19 aC	40.72 aB	55.31 aA
46%54%	29.15 bC	35.97 bB	48.91 bA
	Dynamic load - DL (kN)		
39%/61%	49.40 aC	49.54 aB	49.89 aA
46%54%	44.03 bC	44.16 bB	44.35 bA

MA - A gear; MB - B gear; MC - C gear; Means followed by different uppercase letters in the rows and lowercase letters in the columns differ by the Tukey test at $p \leq 0.05$

Conclusions

1. Tractor performance can be altered by distributing masses between tractor axles (MDBA) and displacement speed in operations with equipment coupled to the drawbar and with intermediate power demand.

2. The ideal condition that maximizes the tractor's performance in conditions equivalent to this experiment is that of MDBA 39/61% with gear that provides speed close to 10 km h^{-1}.

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