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OPERATIONAL AND ENERGY PERFORMANCE OF 250 kW DOUBLE WHEELED VERSUS RUBBER HALF-TRACKED TRACTORS IN THE SOYBEAN SOWING

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KEYWORDS

slippage, operating speed, hourly fuel consumption.

ABSTRACT

The technological innovation in agriculture seeks to improve the performance of mechanized assemblies and, currently, rubber half-tracks are a valuable solution for agricultural tractors, combining traction performance and less soil compaction. The objective of the experiment was to evaluate the operational and energy performance of double wheeled versus rubber half-tracked agricultural tractors in the soybean sowing. The experiment was conducted in a strip-plot design with a double factorial arrangement (2×3). The first factor consisted of a tractor with double wheels on the front and rear axles versus a tractor with single wheels on the front axle and rubber half-tracks on the rear axle, while the second factor consisted of three different gears, with five replications, totaling 30 experimental units. The collected data were subjected to analysis of variance and, when significant, to the Tukey test. The sowing operation carried out with the half-tracked tractor was the most efficient in most of the analyzed parameters, allowing higher operational and energy efficiency in the soybean sowing.

INTRODUCTION

Several researchers have studied the use of tracks for locomotion of large vehicles in the past decades, especially steel tracks (Rabbani et al., 2011), not taking into account modern construction projects and the new technologies embedded in current agricultural machines.

The tire has stood out since the discovery of rubber due to its high versatility and practicality in the agricultural environment, being improved over the years, while tracks have been used little in agricultural operations due to its complexity (Molari et al., 2012). Because of compaction problems and the need for great traction performance, the agricultural tractor has been following the constant modernization of the field, mainly regarding architecture and components (Renius 1994; Lankenau et al., 2019).

Currently, the use of rubber tracks in agriculture has gradually increased, unlike the iron tracks, promoting less compaction and higher traction performance (Molari et al., 2015), but with higher cost compared to the tire. One way to minimize the cost and maintain the highest operational performance is the use of track only on the part that promotes traction, as we can observe in the new concepts of combines and tractors that have been released in Brazil.

The slippage index, which is closely related to the wheels, is among the various parameters that can be analyzed in the performance of the agricultural tractor. About 20 to 55% of the available power of a tractor can be lost in the process of interaction between the wheels and the soil surface, as demonstrated by Burt et al. (1983).

A slippage index higher than 15% can provide intensive soil degradation, interfering with the operating speed and the hourly fuel consumption. These parameters act directly or indirectly in the operational and energy performance of agricultural tractors, affecting the power and efficiency in the drawbar, specific fuel consumption, and engine thermal efficiency, thus lacking experiments to determine the most efficient drive wheel during the field operation (Smerda & Cupera, 2010; Moitzi et al., 2013; Battiato & Diserens, 2017; Janulevičius et al., 2018; Lopes et al., 2019; Oiole et al., 2019).

This study aimed to evaluate the operational and energy performance of double wheeled versus rubber half-tracked agricultural tractors in the soybean sowing operation.

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MATERIAL AND METHODS

The experiment was carried out at the Schlatter Group farm, located in Espigão do Leste, MT, Brazil, on an Oxisol covered with sunn hemp straw after the knife roller operation in the soybean sowing.

The experiment was conducted in a strip-plot design (Ferreira, 2018), with a double factorial arrangement (2×3). The first factor consisted of a tractor with double wheels on the front and rear axles (Figure 1A) versus a tractor with single wheels on the front axle and rubber half-tracks on the rear axle (Figure 1B). The second factor consisted of three different gears chosen based on the American Society of Agricultural Biological Engineers – ASABE D497.7 (2011) standard, namely: gear 5 (GA), gear 6 (GB), and gear 7 (GC), corresponding to theoretical speeds of 1.62, 1.86, and 2.17 m s^{-1}, or 5.83, 6.69, and 7.80 km h^{-1}, respectively, according to the operator's manual.

FIGURE 1. Tractors used in the experiment; (A) tractor equipped with wheels on the front and rear axles and (B) tractor equipped with single wheels on the front axle and half-track on the rear axle. Espigão do Leste, MT, Brazil, 2019.

Each treatment had five replications, totaling 30 experimental units, with each strip measuring 200 m in length. The tractors used in the experiment were a 2018 New Holland T8 385 with 2,800 hours and a 2019 New Holland T8 410 SmartTrax with 71 hours, both with a nominal power of 250 kW (340 hp), according to ISO14396 at 1970 RPM, and extra power (EPM)[2] of 300 kW, auxiliary front-wheel drive (FWD) and Full PowerShift (18×4) transmission.

The double wheeled tractor was set with 480/70R34 Goodyear radial tires at the front, with internal and external pressures of 110 kPa (16 Psi) and 97 kPa (14 Psi), respectively, and 710/70R42 Goodyear radial tires at the rear, with internal and external pressures of 83 kPa (12 Psi) and 69 kPa (10 Psi), respectively.

The half-tracked tractor was set with 650/60R34 Michelin AXIOBIB radial single tires at the front, with a pressure of 97 kPa (14 Psi), and SmartTrax tracks at the rear, with dimensions of 0.76 meters (30 inches) wide and 6.7 meters (264 inches) long. It is a triangular frame and a central drive wheel mounted directly on the transmission shaft, where it transfers the movement to the rubber track with internal teeth. The set features two belt-tensioning wheels on the ends and intermediate rollers in the center of the lower part of the track to distribute the load on the ground.

The difference in the position of the front wheels relation to the rear wheels in the configurations of double wheels and half-tracks were 1.62 and 1.40%, respectively, when the FWD was activated. The static masses on the tractor axles were determined using a CELMI CM-1002 scale with four platforms.

The double wheeled tractor had a 40% hydraulic ballast in the internal front wheel and internal and external rear wheel. Eleven 45-kg suitcase-type weights were added to the front, while two 227-kg wheel weights plus two 91-kg wheel weights were added to the rear, resulting in 16,865 kg of total mass, distributed 40% on the front axle and 60% on the rear axle. The half-tracked tractor used no hydraulic ballast, but 22 45-kg suitcase-type weights were used in the front as metallic ballast, totaling a mass of 17,035 kg, distributed 36.9% on the front axle and 63.1% on the rear axle. The mass to power ratio[3] was 67.46 kg kW^{-1} (49.60 kg hp^{-1}) in the double wheeled tractor and 68.14 kg kW^{-1} (50.10 kg hp^{-1}) in the half-tracked tractor.

A John Deere 2130 seed-cum-fertilizer drill (30 rows with 0.45 m spacing) was mounted in tandem and coupled to the drawbar. The seed drill was set with straw cutting discs of 18 inches in diameter (0.46 m) and double discs (0.41 m in diameter) to open the fertilizer and seed furrows, which were adjusted to depths of 0.08 and 0.04 m, respectively.

The seed-cum-fertilizer drill was set to deposit 60 kg ha^{-1} of triple superphosphate (41% P_2O_5 + 7% Ca) and 330,000 soybean seeds of the variety TMG 2378 IPRO per hectare. The fertilizer boxes were filled before conducting each experiment, the first in the morning (T8 SmartTrax) and the second in the afternoon (T8 385).

The tractors had the engine speed adjusted to 1970 RPM during the experiment, with the FWD activated and full fuel tank. The instrumentation described below was connected to the data acquisition system made on a printed circuit board, with a 1-Hz acquisition frequency (Jasper et al., 2016).

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[2] EPM – System that automatically manages the power distribution in the tractor according to the loads of transmission, hydraulic system, and power take-off. It was not activated during the experiment, being monitored on the panel.

[3] Considering a nominal power of 250 kW (340 hp).

The tractor operating speed (OS) was measured using a Vansco 740030A radar speed sensor, as a function of the number of emitted pulses, being previously calibrated. The transmission ratio was obtained using a Victor DM6236P digital tachometer.

Slippage was determined based on the engine speed and the tractor travel speed with the seed-cum-fertilizer drill under the working position (loaded) and transport position (not loaded), according to [eq. (1)].

$$\text{SLIP} = \left(1 - \frac{\text{SL x EW}}{SW\ x\ EL}\right) \text{x } 100 \tag{1}$$

Where:

SLIP is the wheel slippage (%);

SL is the tractor speed with load ($m\ s^{-1}$);

SW is the tractor speed without load ($m\ s^{-1}$);

EL is the engine speed with load (RPM), and

EW is the engine speed without load (RPM).

The hourly fuel consumption (HFC) was measured using two Flowmate OVAL M-III LSF 41L0-M2 flowmeters, which were installed in the tractor fuel supply system (inlet and return to the tank). The consumption was given by the difference in the number of pulses emitted by the flowmeters, being then converted into volume considering the frequency of 1 mL per pulse.

The drawbar force (DBF) was measured using a properly calibrated Berman load cell, with a capacity of 300 kN, a sensitivity of 2.0+0.002 Mv V^{-1}, and an accuracy of 0.01 kN, installed in the drawbar coupled to the tractor.

The power available in the drawbar was obtained as a function of force and speed, according to [eq. (2)].

$$\text{DBP} = \text{DBF x OS} \tag{2}$$

Where:

DBP is the drawbar power (kW);

DBF is the drawbar force (kN), and

OS is the operating speed ($m\ s^{-1}$).

The diesel oil density was corrected through the temperatures obtained by a type K thermocouple, previously registered at the fuel inlet and outlet on the flow meter, according to [eq. (3)].

$$\text{D} = (844.14 - 0.53) \text{ x T} \tag{3}$$

Where:

D is the diesel density ($g\ L^{-1}$);

T is the diesel temperature (°C), and

844.14 and 0.53 are parameters of the density regression.

The hourly consumption based on mass was determined using [eq. (4)].

$$\text{HCM} = \left(\frac{\text{HFC } (844.14 - 0.53 \text{ x T})}{1000}\right) \tag{4}$$

Where:

HCM is the mass-based hourly fuel consumption ($g\ h^{-1}$);

HFC is the volume-based hourly fuel consumption ($L\ h^{-1}$), and

1000 is the conversion factor.

The specific fuel consumption was determined considering the mass-based hourly consumption due to the drawbar power, according to [eq. (5)].

$$\text{SFC} = \left(\frac{\text{HCM}}{\text{DBP}}\right) \tag{5}$$

Where:

SFC is the specific fuel consumption ($g\ kW\ h^{-1}$), and

DBP is the drawbar power (kW).

The drawbar efficiency was determined from the power available on the drawbar and the tractor engine[4], according to [eq. (6)].

$$\text{DBE} = \left(\frac{\text{DBP}}{\text{EP}}\right) \text{x } 100 \tag{6}$$

Where:

DBE is the drawbar efficiency (%);

DBP is the drawbar power (kW), and

EP is the engine power (kW).

The engine thermal efficiency was obtained through the specific consumption and lower fuel calorific power, according to [eq. (7)] (Farias et al., 2017).

$$\text{ETE} = \left(\frac{3600}{\text{SFC x LCP}}\right) \tag{7}$$

Where:

ETE is the engine thermal efficiency (%), and

LCP is the lower calorific power (42,295 $MJ\ kg^{-1}$).

The engine load (EL) was determined by the technology embedded in the tractor, using torque meters present at the flywheel output and on the rear axle, being monitored through the IntelliView IV monitor using the Precision Land Management (PLM) software package.

The collected data were subjected to normality (Shapiro-Wilk) and homogeneity (Brown-Forsythe) tests. Subsequently, the data were subjected to analysis of variance and, when significant, to the Tukey test, using the software Sigmaplot 14.

RESULTS AND DISCUSSION

Tables 1 and 2 show the results of the analysis of variance and the test of means for the analyzed variables. The coefficient of variation in all analyzed variables was categorized as stable, according to the Ferreira (2018) classification.

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[4] Considering a nominal power of 250 kW.

TABLE 1. Summary of analysis of variance and test of means.

Wheelset (W)	SLIP (%)	ES (RPM)	HFC (L h^{-1})	DBF (kN)	OS (m s^{-1})
WHEEL	10.13 A	1,866 B	60.00 A	74.46	1.59 B
HALF-TRACK	2.60 B	1,952 A	54.51 B	72.08	1.87 A
Gear (G)					
GA	6.10	1,943 A	54.19 C	73.16	1.52 C
GB	6.50	1,928 B	56.37 B	75.58	1.74 B
GC	6.50	1,855 C	61.21 A	71.08	1.94 A
F-test					
W	3,192.25**	165.32**	266.76**	1.42^{NS}	1,569.55**
G	0.681^{NS}	165.58**	56.47**	1.83^{NS}	638.77**
W × G	49.14**	65.79**	94.43**	3.20^{NS}	17.64**
Coefficient of Variation (%)					
W	5.74	0.95	1.61	7.48	1.12
G	13.90	0.61	2.64	7.19	1.51
W × G	10.73	0.76	1.96	7.70	1.29
Normality					
SW	0.031	0.897	0.160	0.204	0.530
Homogeneity					
BF	0.304	0.998	0.988	0.480	0.398

Parameters: wheelset slippage (SLIP), engine speed (ES), hourly fuel consumption (HFC), drawbar force (DBF), and operating speed (OS). Means followed by the same uppercase letter in the column do not differ from each other for each factor by the Tukey test ($P<0.05$). F-test of analysis of variance: NS – not significant; * ($P<0.05$) and ** ($P<0.01$). CV: coefficient of variation. Shapiro-Wilk Normality Test: $SW \leq 0.05$ – data abnormality; $SW > 0.05$ – data normality. Brown-Forsythe variance homogeneity test: $BF \leq 0.05$ – heterogeneous variances; $BF > 0.05$ – homogeneous variances.

The results showed that the configuration using a half-track at the rear (HALF-TRACK) had a statistical difference in all parameters analyzed in the experiment (SLIP, ES, HFC, OS, DBP, SFC, DBE, ETE, and EL), except for DBF, compared to the wheeled-tractor (WHEEL). The parameter DBF represents the transmission of the wheelset force that drives the tractor, available at the end of the drawbar, promoting traction. It shows the quality of the experiment, as both tractors performed the same traction force using the tested different gears.

The parameter SLIP in the factor WHEEL was slightly below the range recommended by the ASABE D496.3 (2011) standard, which recommends slippage indices from 11 to 13% for the mobilized surface, but it was 74.33% higher than the factor HALF-TRACK. Arvidsson et al. (2011) found similar results when evaluating an agricultural tractor equipped with different wheels (wheels and tracks).

The highest SLIP indices provide higher HFC and lower OS, directly interfering with the operational performance of the moto-mechanized set, as described by Molari et al. (2015) and Lopes et al. (2019). The variable SLIP showed no statistical difference regarding the tested gears.

The parameter OS was 17.61% higher in the factor HALF-TRACK than in the factor WHEEL, showing the efficiency of the half-track in the operation and, therefore, allowing a larger worked area in less time. Molari et al. (2012) obtained similar results, justifying the higher speed of the tracked tractor due to its lower SLIP indices.

The effective fieldwork capacity, determined by Mialhe (1996) as the product of the machine working width by the operating speed, reached values of 7.72 and 9.09 ha h^{-1} for the double wheeled and half-tracked tractor, respectively. Consequently, the effective efficiency was 18% higher for the half-tracked tractor.

The higher OS observed in the factor HALF-TRACK is directly and indirectly reflected in the parameters shown in Table 2, providing lower SFC and EL and higher DBP, DBE, and ETE. Therefore, this factor provided higher operational and energy efficiency, even requiring a high ES and 9.15% less HFC compared to the factor WHEEL. Molari et al. (2015) also found lower fuel consumption in a harrowing operation when comparing wheeled and rubber tracked tractors.

TABLE 2. Summary of analysis of variance and test of means.

Wheelset (W)	DBP (kW)	SFC (g kW h^{-1})	DBE (%)	ETE (%)	EL (%)
PNEU	118.40 B	436 A	47.35 B	19.69 B	109.73 A
MEIA-ESTEIRA	134.87 A	350 B	53.20 A	24.81 A	90.27 B
Gear (G)					
GA	110.75 B	420	43.97 B	20.72	90.50 B
GB	132.05 A	371	52.41 A	23.66	100.20 C
GC	137.11 A	387	54.44 A	22.37	109.30 A
F-test					
W	12.80*	42.02*	10.35*	36.71**	244.31**
G	18.04**	7.27^{NS}	18.27**	6.07^{NS}	110.72**
W × G	1.86^{NS}	10.38*	1.85^{NS}	7.06*	38.98**
Coefficient of Variation (%)					
W	9.96	9.22	9.90	10.40	3.41
G	8.22	7.55	8.17	8.52	2.83
W × G	9.11	8.27	9.05	9.40	2.59
Normality					
SW	0.093	0.264	0.094	0.377	0.964
Homogeneity					
BF	0.706	0.495	0.703	0.408	0.290

Parameters: drawbar power (DBP), specific fuel consumption (SFC), drawbar efficiency (DBE), engine thermal efficiency (ETE), and engine load (EL). Means followed by the same uppercase letter in the column do not differ from each other for each factor by the Tukey test ($P<0.05$). F-test of analysis of variance: NS – not significant; * ($P<0.05$) and ** ($P<0.01$). CV: coefficient of variation. Shapiro-Wilk Normality Test: SW ≤ 0.05 – data abnormality; SW > 0.05 – data normality. Brown-Forsythe variance homogeneity test: BF ≤ 0.05 – heterogeneous variances; BF > 0.05 – homogeneous variances.

The parameters HFC, OS, DBP, DBE, and EL increased as the used gear increased, whereas the parameter ES showed the opposite behavior. Martins et al. (2018) analyzed the energy optimization of agricultural tractors and found similar results to the parameters OS, DBP, and DBE. The high number of the selected gear provided a higher effective speed and, therefore, higher OS, DBP, DBE, and EL and hence higher HFC, reducing ES.

The parameter DBP is the product between DBF and OS and because DBF showed no statistical difference, this variation can be explained by the higher operating speed by the half-tracked tractor (Molari et al., 2015), directly reflecting on the lower SFC, which represents how efficiently the used fuel is actually being turned into work. Thus, higher ETE was observed, with higher energy efficiency in the factor HALF-TRACK. The parameters SFC and ETE showed no difference regarding the different gears.

The lower DBE in the factor WHEEL is explained by the lower DBP, thus demonstrating less use of engine power in the drawbar. Thus, the half-tracked tractor allows the traction of higher loads compared to the double wheeled tractor, showing its operational efficiency, as described by Monteiro et al. (2013). The parameter EL also demonstrates the use of engine power, but in an inverse way to DBE, demonstrating the demand for engine power on the rear axle. The double wheeled tractor demanded more engine power on the axle during its operation.

The parameters SLIP, ES, HFC, OS, SFC, ETE, and EL showed interaction, which was sliced in Table 3.

TABLE 3. Data on the interaction between the factors wheelset and gears.

Slippage (%)				Engine speed (RPM)			
Wheelset	Gear			Wheelset	Gear		
	GA	GB	GC		GA	GB	GC
WHEEL	12.00 Aa	9.20Ab	9.20 Ab	WHEEL	1.928 Ba	1.901 Bb	1.770 Bc
HALF-TRACK	1.00 Bb	3.00 Ba	3.80 Ba	HALF-TRACK	1.958 Aa	1.956 Aa	1.941 Aa
Hourly fuel consumption (L h^{-1})				Operating speed (m s^{-1})			
Wheelset	Gear			Wheelset	Gear		
	GA	GB	GC		GA	GB	GC
WHEEL	59.76 Aa	60.12 Aa	60.12 Ba	WHEEL	1.40 Bc	1.62 Bb	1.76 Ba
HALF-TRACK	48.61 Bc	52.61 Bb	62.30 Aa	HALF-TRACK	1.64 Ac	1.87 Ab	2.11 Aa
Specific fuel consumption (g kW h^{-1})				Engine thermal efficiency (%)			
Wheelset	Gear			Wheelset	Gear		
	GA	GB	GC		GA	GB	GC
WHEEL	481 Aa	434 Aab	392 Ab	WHEEL	17.71 Bb	19.61 Bb	21.75 Aa
HALF-TRACK	360 Bab	307 Bb	382 Ba	HALF-TRACK	23.72 Ab	27.71 Aa	23.00 Ab

Engine load (%)			
Wheelset	Wheelset		
	GA	GB	GC
WHEEL	104.00 Ab	112.00 Aa	113.20 Aa
HALF-TRACK	77.00 Bc	88.40 Bb	105.40 Ba

Means followed by different uppercase letters in the rows and lowercase letters in the columns differ by the Tukey test (P<0.05).

The interactions between the wheelset and the tested gears showed that the parameter SLIP was higher in the factor WHEEL for all gears. It can be explained by the higher contact area of the half-track with the ground, presenting a tension distribution on the ground higher than that of the wheel (Arvidsson et al. 2011), optimizing the wheel-ground interaction (Bürger & Böttinger 2018). This parameter provided a lower OS regardless of the selected gears, as observed by Molari et al. (2015).

The parameter HFC was higher in the factor WHEEL for GA and GB, and lower for GC. This behavior can be explained by a decrease in the ES that occurred in this gear. The ES remained lower in the different gears of this factor, being slightly lower in GA and GB, and more distant in the GC than the registered in the factor HALF-TRACK.

The parameter SFC reflects the behavior of OS and HFC, being higher in the factor WHEEL in GA and GB, and slightly higher in GC, thus providing that ETE in GC does not present a statistical difference between the analyzed factors, and superiority in the gears GA and GB for the factor HALF-TRACK. The engine load in the factor WHEEL was higher in all tested gears, requiring higher engine power on the rear axle compared to the half-tracked tractor.

CONCLUSIONS

The results obtained from the comparison between the wheelset of tractors in the sowing operation demonstrated that the half-tracked tractor at the rear slipped 74.33% less, providing higher operating speed, power, and efficiency on the drawbar and engine thermal efficiency, expressing lower engine load and 9.15% less hourly fuel consumption, even requiring higher engine speed.

The double-wheeled tractor showed a lower value in the parameters evaluated under most of the used gears, being more efficient only in the highest gear, with the lowest hourly fuel consumption.

Therefore, most of the analyzed parameters showed a higher operational and energy performance of the half-tracked tractor, providing an effective efficiency 18% higher and enabling the traction of higher loads than the double wheeled tractor. Thus, new experiments using different agricultural implements under different field conditions are necessary.

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