Operational and energy performance of the tractor-scarifier assembly: Tires, ballasting and soil cover

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ABSTRACT: The heights of tire claws, tractor ballasting and soil cover can influence the operational and energy performance of the tractor-scarifier assembly. The objective of this study was to analyze the operational and energy performance of the tractor-scarifier assembly as a function of the heights of the tire claws, ballasting and rolling surface. The experiment was conducted at the experimental area of the Fazenda Experimental do Vale do Curu of the Universidade Federal do Ceará in Pentecoste municipality, CE, Brazil. The experiment was carried out in a randomized block in a $2 \times 2 \times 2$ factorial arrangement with four repetitions. The treatments comprised two tire claw heights (T1-28% and T2-100%), two ballasts (B1-100% of solid and 75% liquid weights and B2 - 0% of solid and liquid weights), and two soil surfaces (S1 - soil with 4200 kg of straw ha^{-1} and S2 - mobilized soil). Worn tires provided a lower bar force (12.88 kN) and power requirement (20.06 kW) and a greater effective and operative field capacity of the tractor-scarifier assembly. The lowest slippage of the front wheels of the tractor was recorded for the worn tires (4.81%). For the rear wheels, slippages were found on the new tires (10.96%), and a higher speed of displacement was found for worn tires (5.54 km h^{-1}). Lower specific fuel consumption was found for the mobilized soil (534.68 g kWh^{-1}); furthermore, the hourly consumption of fuel and the consumption per area were not significantly affected by the treatments analyzed.

Key words: slipping wheel, power in the drawbar, rolling surface

Desempenho operacional e energético do conjunto trator-escarificador: Pneus, lastro e cobertura do solo

RESUMO: A altura das garras do pneu, o lastro do trator e a cobertura do solo podem influenciar o desempenho operacional e energético do conjunto trator-escarificador. O objetivo deste estudo foi analisar o desempenho operacional e energético do conjunto trator-escarificador, em função da altura das garras do pneu, do lastro e da superfície de rolamento. O experimento foi conduzido na área experimental da Fazenda Experimental do Vale do Curu, da Universidade Federal do Ceará, em Pentecoste, CE. O experimento foi conduzido em delineamento de blocos ao acaso, em arranjo fatorial $2 \times 2 \times 2$, com quatro repetições. Os tratamentos foram compostos por duas alturas de garras de pneu (P1-28% e P2-100%), duas lastragens (L1-100% de pesos sólidos e 75% líquidos e L2-0% de pesos sólidos e líquidos) e duas superfícies de solo (S1-solo com 4200 kg de palha ha^{-1} e S2-solo mobilizado). Os pneus desgastados proporcionaram menor exigência de força (12,88 kN) e potência na barra (20,06 kW) e maior capacidade de campo efetiva e operacional do conjunto trator-escarificador. Menor patinamento dos rodados dianteiro do trator foi registrado para pneu desgastado (4,81%). Para os rodados traseiros, o maior patinamento foi constatado para pneu novo (10,96%), e a maior velocidade de deslocamento foi constatada para pneu desgastado (5,54 km h^{-1}). Menor consumo específico de combustível foi constatado para solo mobilizado (534,68 g kWh^{-1}); além disso, o consumo horário de combustível e o consumo por área não foram afetados significativamente pelos tratamentos analisados.

Palavras-chave: patinamento dos rodados, potência na barra, superfície de rolamento

Introduction

Agricultural tractors allow farmers to cultivate extensive areas owing to their versatility during farming activities. These vehicles are responsible for a variety of mechanized tasks in agricultural areas, ranging from soil preparation, crop implantation and harvesting to transporting the production for commercialization (Taghavifar et al., 2015).

To break up compacted soil surface layers of the productive area in a minimum cultivation system, it is recommended to use a scarifier. Mazurana et al. (2011) observed that the mobilization promoted by scarification reduces soil density, mechanical resistance to penetration and increases water infiltration.

The soil compaction in agricultural areas can directly influence the performance of agricultural machines and implements, increasing in power demand for traction (Drescher et al., 2011).

Satisfactory operating performance in operations using a scarifier can reduce costs incurred by farmers and reduce machinery wear. In power transmission from the tractor engine to the drawbar, energy losses occur which, depending on the tractor operating conditions, can reach very compromising levels of power loss, presenting inadequate conditions for traction and causing excessive fuel consumption (Gabriel Filho et al., 2010).

Another important factor in the scarification operation is the energy performance of operations involving crops. Compagnon et al. (2013) evaluated the performance of the tractor-scarifier assembly and concluded that the greater the depth of work of the scarifier, the greater the hourly and operational consumption of fuel.

The adequacy of the agricultural tractor can contribute to satisfactory scarification of the soil. The height of the tire claws, the solid and liquid tractor ballasting and the presence or absence of straw on the soil cover are factors that can influence the operational and energetic performance of the tractor-scarifier assembly. Therefore, the objective of this study was to evaluate the operational and energy performance of the tractor-scarifier assembly as a function of the height of the tire claws, type of ballasting and soil cover.

Material and Methods

The experiment was conducted at the Fazenda Experimental do Vale do Curu of the Universidade Federal do Ceará (UFC), which is located in the municipality of Pentecoste, CE state, Brazil, at 3° 49' S and 39° 20' W, and altitude of 46 m.

The climatic classification of the region, according to Köppen, is BSw'h' or semi-arid with irregular rainfall, with an average annual precipitation of 806.5 mm that is concentrated between January and April, an average temperature of 28 °C, and an average relative humidity of the air of around 73.8% (Alvares et al., 2014). The soil of the experimental area was classified as Alfisols with sandy loam texture.

The experimental design was randomized block design with a 2 × 2 × 2 factorial arrangement and four repetitions; thus, there were a total of 32 experimental units. The factors comprised two tire claw heights: T1-28% (worn tire) and

T2-100% (new tire); two ballasts: B1-100% and 75% of solid and liquid weights (with ballasts) and B2-0% of solid and liquid weights (without ballast); and two bearing surfaces: S1 - soil with an average of 4200 kg ha^{-1} of straw (soil with straw), and S2 - prepared soil (mobilized soil). Each plot was 3.5 m wide by 30 m long with total area was 105 m^2.

In the soil scarification process, the Marchesan® trawl scarifier model AST/MATIC 450 with a total mass of 1560 kg was used; it was configured with five spaces having a width of 0.45 m, narrow tips of 0.08 m, and as mooth cutting disc at the front of each rod and ripper roller. The depth of work was controlled by the scarifier tires using rings attached to the hydraulic pistons working at a depth of 0.28 m.

To draw the scarifier, a Valtra® tractor, model BM120 4x2 TDA (auxiliary front drive wheel), with a maximum capacity of 88.26 kW (120 HP) was used in the engine at a rotation of 2000 rpm with the front drive connected, which is suitable for trawling operations with a distribution of weight of 35% on the front axle and 65% on the rear. It was equipped with diagonal tires, a front axle with 14.9-24 R1 tires, and a rear axle with 18.4-34 R1 tires; furthermore, the inflation pressure was 12 and 16 psi (82.8 and 110.4 kPA), respectively, according to the manufacturer's recommendation.

To determine the force on the drawbar, the load cell generated signals were stored in the Quantum X MX804A HBM data acquisition system. The average force on the drawbar was obtained using Eq. 1.

$$F = \left(\frac{\sum Fi}{\sum n} \right) 0.0098 \qquad (1)$$

where:

F   - average force on the draw bar, kN;
Fi   - instantaneous traction force, kgf;
n   - number of recorded data points; and,
0.0098 - adequacy factor.

The average power in the drawbar was calculated as a function of the average traction force and the actual travel speed of the assembly.

The effective field capacity was obtained as a function of the working width of the scarifier, the travel speed and the unit conversion factor. The operational field capacity was obtained as a function of the work width of the implement, the travel speed and the efficiency of the operation, which was set as 75%.

The determination of the slipping was performed by counting the number of turns of the tractor wheel in the experimental plot tractioning the implement (with load) and with the implement suspended (without load) according to Eq. 2.

$$ST = \left[\frac{n^1 - n^0}{n^1} \right] 100 \qquad (2)$$

where:

ST   - slipping of tractor' wheels, %;
n^0 - number of turns of the wheels without a load; and,
n^1 - number of turns of the wheels with a load.

The volume of fuel consumed by the agricultural tractor during the course of the experiment in mL was measured using two Flowmate° oval flow meters, model Oval M-III and LSF 41, with a precision of 0.01 mL, which were installed in series at the entrance and at the return of the injection pump. The Eq. 3 was used to define the consumption in L h⁻¹.

$$HC = \left(\frac{q}{t}\right)3.6 \qquad (3)$$

where:

HC   - hourly fuel consumption, L h⁻¹;
q   - volume consumed in each plot, mL;
t   - time spent in the plot, s; and,
3.6 - unit conversion factor.

The specific fuel consumption was determined as shown in Eq. 4.

$$SC = \frac{HC\ d}{F} \qquad (4)$$

where:

SC   - specific fuel consumption, g kWh⁻¹;
HC   - hourly fuel consumption, L h⁻¹;
d   - fuel density, 835 g L⁻¹; and,
F   - force in the draw bar, kW.

After obtaining the fuel consumption (g kWh⁻¹), the consumption in L ha⁻¹ was calculated (Eq. 5).

$$C_A = \frac{HC}{EFC} \qquad (5)$$

where:

C_A - fuel consumption per area, L ha⁻¹;
HC   - hourly fuel consumption, L h⁻¹; and,
EFC - effective field capacity, ha h⁻¹.

The travel speed of the tractor-scarifier assembly was determined by dividing the length of the plot (30 m) by time acquired using a digital timer that was turned on and off according to the tractor's front wheel drive laterally to the stakes delimiting the plots.

For statistical analysis of the data, the software Assistat version 7.7 beta ° was used. The data were submitted to the normality test using the coefficients of asymmetry and kurtosis according to Mesquita et al. (2003). After verifying the normality, the analysis of variance was performed, and when the data were significant, the Tukey test was used at $p \leq 0.05$ for the comparison of means.

Results and Discussion

Table 1 shows the analysis of variance and the mean values obtained for the following variables: force in the drawbar, power in the drawbar, effective field capacity and operational field capacity for the tire, ballasting and surface treatments.

For force in the drawbar (F), significant difference ($p \leq 0.05$) was observed between the means for the tire and surface factors; furthermore, new tires and mobilized soil presented greater force demands when compared to the other factors.

These results may be related to the greater height of the new tire claws that have less flat tread that allows for smaller contact area of the wheel with the soil, therefore favoring a greater demand of force in the drawbar of the tractor. Significant interaction between the factors tire and ballasting was observed for the force in the drawbar (Figure 1).

Table 1. Mean and F values obtained for force in the drawbar (F), power in the drawbar (P), effective field capacity (EFC) and operational field capacity (OFC)

Source of variation		F (kN)	P (kW)	EFC (ha h⁻¹)	OFC (ha h⁻¹)
Tire (T)	T1 - Worn tire	12.88 b	20.06 b	1.25 a	0.93 a
	T2 - New tire	14.59 a	21.39 a	1.18 b	0.88 b
Ballasting (B)	B1 -With ballast	13.87 a	21.22 a	1.23 a	0.92 a
	B2 - Without ballast	13.61 a	20.23 b	1.19 b	0.89 b
Surface (S)	S1 - Soil with straw	12.98 b	19.59 b	1.22 a	0.91 a
	S2 - Mobilized soil	14.49 a	21.86 a	1.20 a	0.90 a
F-value	T	43.61**	11.43*	37.19*	37.19 *
	B	1.10ns	6.35*	8.70*	8.70 *
	S	34.08**	33.10*	3.91ns	3.91 ns
	T x B	5.21*	4.09ns	0.03ns	0.03 ns
	T x S	1.36ns	2.79ns	4.06ns	4.06 ns
	B x S	2.53ns	1.88ns	0.31ns	0.31 ns
	T x B x S	2.02ns	1.90ns	0.29ns	0.29 ns
CV (%)		5.32	5.38	2.54	2.54

Means followed by the same letter in the columns for the same source of variation do not differ according to Tukey test, at $p \leq 0.05$; *- Significant ($p \leq 0.05$); ns - Not significant; CV - Coefficient of variation
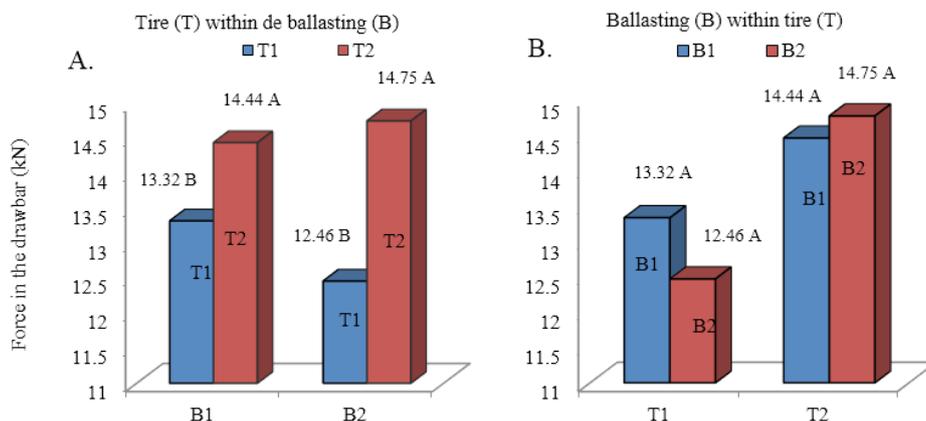
T1 - Worn tire; T2 - New tire; B1 - With ballast; B2 - Without ballast; Means followed by the same letter in the bars do not differ according to Tukey test at $p \leq 0.05$

Figure 1. Graphs of the interactions of tire within ballasting (A) and ballasting within tire (B) for variable force in the drawbar

For the interaction tire (T) within each ballasting situation (B), it was observed that for both ballast conditions, a greater demand of force on the drawbar was observed when working with a new tire. Al-Suhaibani & Ghaly (2010), evaluating the performance of the tractor-scarifier assembly, observed that when the travel speed increased, the demand for traction force followed the same trend.

Regarding the power in the drawbar, significant differences ($p \leq 0.05$) of the means of the factors tire, ballasting and surface were observed. The new tire with ballast and mobilized soil required more power in the tractor's drawbar (Table 1). Monteiro et al. (2013) observed similar results when performing the energy evaluation of a 4x2 TDA tractor as a function of net ballasting; furthermore, greater power values were observed when the ballasting increased.

There were significant differences ($p \leq 0.05$) in the means of the tire and ballasting values for the variable effective field capacity. The greatest value was observed for the worn tire. Regarding the ballasting, the greatest field capacity value was observed for the condition with ballast.

Studying the operational field capacity, the greatest average was observed for the worn tire with ballast. This was probably owing to the better tire-soil contact area and the larger mass of the tractor, which increased the travel speed and, consequently, the operational field capacity. Lopes et al. (2005) evaluating the performance of a tractor in a soil classified as Oxisols observed that the field capacity was lower when working without net ballasting, corroborating with the results obtained in the present study.

Table 2 shows the results of the analysis of variance for the variables slipping of the front and rear wheels and speed.

Greater average slipping values for the front wheels (SFW) were observed in new tires without ballasting ($p \leq 0.05$). It is possible that these results may be related to the fact that a new tire has less flat claws when compared to a worn tire, which has flat claws, and the absence of ballasting promotes a smaller surface of contact of the wheel with the soil, favoring the slipping. Some of the slipping values fell outside the range recommended by the ASAE (2003), which is between 8 and 10% for firm soil.

When the slipping of the rear wheel (SRW) was evaluated, significant differences were observed for tire, ballasting and surface, with values between 6.94 and 10.96%. Furtado Júnior (2013) emphasized that high slipping rates in agricultural operations lead to reduced traction efficiency and consequent unnecessary fuel consumption.

The travel speed was significantly affected by the state of the tires and ballasting ($p \leq 0.05$), with greater average speed values attributed to the worn tire with ballasting. Gabriel Filho et al. (2010), working with a John Deere® 6600 tractor with TDA driven, observed that the gradual increase in tractor speed from 3.5 to 6.0 km h⁻¹ did not affect the wheel slipping, which contradicts the results presented herein.

Table 3 shows the results of analysis of variance for the values obtained for fuel consumption per hour, specific consumption and consumption per area for the tire, ballast and surface factors.

No differences were observed in the hourly fuel consumption ($p > 0.05$) due to tire claws, ballasting and bearing surface, showing that those field conditions were not extreme enough to increase fuel consumption.

In a study conducted by Monteiro et al. (2011) with a tractor equipped with radial tires and diagonal tires, three ballasting conditions (0, 40 and 75% of water) on in three surface conditions of dystrophic Ultisols (solid ground surface and mobilized soil at travel speeds 4, 5 and 7 km h⁻¹) pointed to significant differences in the hourly consumption of fuel. When working in mobilized soil with 0% ballasting, the authors obtained higher average hourly fuel consumption, contrary to the data presented in the present study, which probably did not show significant differences for hourly fuel consumption because different travel speeds were not tested.

The specific fuel consumption was greater when operating on soil with straw ($p \leq 0.05$). This occurred probably because the surface with the straw demanded a greater reduction in energy efficiency when compared with mobilized soil.

These results differ from those observed by Lopes et al. (2005), who evaluated the performance of a 4x2 TDA agricultural tractor with a maximum power of 89 kW (121cv)

Table 2. Mean and F values of slipping of the front (SFW) and rear (SRW) wheels and speed

Source of variation		SFW	SRW	Speed
		(%)		(km h⁻¹)
Tire (T)	T1 - Worn tire	4.81 b	6.94 b	5.54 a
	T2 - New tire	8.08 a	10.96 a	5.25 b
Ballasting (B)	B1 - With ballast	5.41 b	8.05 b	5.45 a
	B2 - Without ballast	7.48 a	9.84 a	5.33 b
Surface (S)	S1 - Soil with straw	6.17 a	8.48 b	5.45 a
	S2 - Mobilized soil	6.73 a	9.42 a	5.35 a
F-value	T	125.14*	174.44*	37.19*
	B	50.01*	34.52*	8.70*
	S	3.62ⁿˢ	9.61*	3.91ⁿˢ
	T × B	0.01ⁿˢ	0.03ⁿˢ	0.03ⁿˢ
	T × S	0.18ⁿˢ	0.19ⁿˢ	4.06ⁿˢ
	B × S	0.01ⁿˢ	2.13ⁿˢ	0.31ⁿˢ
	T × B × S	0.33ⁿˢ	0.06ⁿˢ	0.29ⁿˢ
CV (%)		12.85	9.62	2.54

Means followed by the same letter in the columns for the same source of variation do not differ according to Tukey test, at $p \leq 0.05$; *- Significant ($p \leq 0.05$); ns - Not significant; CV - Coefficient of variation

Table 3. Mean and F values of hourly fuel consumption per hour (HC), specific fuel consumption (SC) and consumption per area (CA)

Source of variation		HC	SC	CA
		(L h⁻¹)	(g kW h⁻¹)	(L ha⁻¹)
Tire (T)	T1 - Worn tire	14.06 a	588.43 a	11.14 a
	T2 - New tire	14.15 a	555.33 a	11.94 a
Ballasting (B)	B1 - With ballast	14.45 a	572.56 a	11.67 a
	B2 - Without ballast	13.76 a	571.19 a	11.42 a
Surface (S)	S1 - Soil with straw	14.44 a	609.07 a	11.81 a
	S2 - Mobilized soil	13.77 a	534.68 b	11.28 a
F-value	T	0.04ⁿˢ	2.51ⁿˢ	3.77ⁿˢ
	B	2.27ⁿˢ	0.004ⁿˢ	0.36ⁿˢ
	S	2.15ⁿˢ	12.70*	1.62ⁿˢ
	T × B	0.76ⁿˢ	0.12ⁿˢ	0.76ⁿˢ
	T × S	0.15ⁿˢ	2.99ⁿˢ	0.01ⁿˢ
	B × S	3.07ⁿˢ	0.07ⁿˢ	1.98ⁿˢ
	T × B × S	0.42ⁿˢ	0.59ⁿˢ	0.36ⁿˢ
CV (%)		9.20	10.32	10.17

Means followed by the same letter in the columns for the same source of variation do not differ according to Tukey test, at $p \leq 0.05$; *- Significant ($p \leq 0.05$); ns - Not significant; CV - Coefficient of variation

and a pulling straw scarifier equipped with seven inclined straight rods with 7 cm wide tips, in which the lowest consumption was observed when the tires were 75% full of water.

No difference in the fuel consumption per area was observed among treatments ($p > 0.05$), disagreeing with the results obtained by Santos et al. (2016), who worked with three depths (0.15, 0.30 and 0.40 m) and two ballasting situations (with and without ballasting) in soil preparation with a scarifier and observed significant differences in the fuel consumption per area, with a greater value at 0.40 m depth.

Conclusions

1. Worn tires give the tractor-scarifier assembly a lower bar force (12.88 kN), power requirement (20.06 kW) and greater effective and operational field capacity.

2. The lowest slippage of the front wheels of the tractor was recorded for worn tires (4.81%); furthermore, for the rear wheels, slippages were found for new tires (10.96%) and a higher speed of displacement was found for worn tires (5.54 km h^{-1}).

3. Lower specific fuel consumption was found for the mobilized soil (534.68 g kWh^{-1}). Furthermore, the hourly consumption of fuel and consumption per area was not significantly affected by the treatments analyzed.

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