ISSN 2359-6562 (ONLINE) 2359-6562 (CD-ROM)

REDUÇÃO DO CONSUMO DE COMBUSTÍVEL COM O USO DE ESTRATÉGIA DE CONDUÇÃO EM TRATOR AGRÍCOLA*

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**Article extracted from the first author's dissertation.*

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RESUMO: O consumo de combustível demandado de um trator é um dos fatores que impacta diretamente nos custos de produção da atividade agrícola. Este trabalho teve como objetivo avaliar distintos modos de condução do trator agrícola, buscando reduzir o consumo de combustível e otimizar seu desempenho em tração. O delineamento experimental foi de blocos ao acaso com seis tratamentos, constituído da combinação dos fatores, marcha de trabalho (L5, L6 e H2) e rotação do motor (1800 e 2000 rpm), com quatro repetições. As variáveis analisadas foram: velocidade de deslocamento, força de tração, eficiência em tração, consumo horário e específico de combustível, potência na barra de tração e patinamento das rodas motrizes. Os resultados indicaram que, ao utilizar a estratégia de marcha para cima e rotação do motor para baixo, obteve-se menor consumo horário de combustível. Ao manter a velocidade de deslocamento e reduzir a rotação do motor, ocorreu redução de até 12% no consumo horário. Esta estratégia não influenciou nos resultados das outras variáveis (consumo específico de combustível, patinamento e potência na barra de tração). Pela correlação linear de Pearson, a velocidade de deslocamento é um dos principais fatores que interferem nas condições de desempenho em tração do trator.

Palavras-chaves: rotação do motor, consumo horário de combustível, eficiência em tração.

REDUCTION OF FUEL CONSUMPTION USING THE DRIVING STRATEGY OF THE AGRICULTURAL TRACTOR

ABSTRACT: The fuel consumption demanded by a tractor is one of the factors that directly impacts the production costs of agricultural activity. This work aimed to evaluate different driving modes of agricultural tractors, with the goal of reducing fuel consumption and optimizing traction performance. The experimental design was randomized blocks with six treatments, consisting of a combination of factors, working gear (L5, L6 and H2) and engine speed (1800 and 2000 rpm), with four replications. The displacement speed, traction force, traction efficiency, time and specific fuel, drawbar power and slippage of the drive wheels were monitored. The results indicated that when the gear-up and engine-speed-down strategies were used, lower fuel consumption was obtained. By maintaining the displacement speed and reducing the engine speed, there was a reduction of up to 12% in the hourly consumption. This strategy did not influence the results of the other variables (specific fuel consumption, slippage and drawbar power). According to Pearson's linear dynamics, the displacement speed is one of the main factors that interferes with traction performance conditions.

Keywords: engine speed, hourly fuel consumption, traction efficiency

Recebido em 18/11/2022 e aprovado para publicação em 08/02/2023
DOI: http://dx.doi.org/10.17224/EnergAgric.2023v38n1p36-46

1 INTRODUCTION

Agricultural mechanization plays a fundamental role in the modernization of activities and the efficiency of agricultural systems, increasing operational capacity (ALBIERO *et al.*, 2019) and enabling better use of the cultivation windows of agricultural crops, which can contribute to an increase in production. For the 2022/2023 harvest, Brazil's cultivation area is estimated at approximately 72 million hectares, with 301 million tons of grains produced for summer crops and 11 million tons for winter crops, with an estimated area of 3 million hectares (GRÃOS VERÃO E INVERNO, 2022).

To make it possible to cultivate the entire agricultural area of the country, different agricultural machines are available to farmers. Among these, the tractor stands out, as it is considered a versatile machine and can be used in different ways on rural properties, one of the main methods being the ability to exert traction via the drawbar.

The energy consumed by agricultural machines to carry out the work comes from mineral diesel oil, the fuel most used in the sector, derived from petroleum and from a finite source. The increasing adjustments in the price of this input directly impact the production costs of agricultural activity. In this sense, it is important to evaluate the fuel consumption of agricultural machinery during activities. Agricultural mechanization corresponds to 20 to 28% of the total cost of production on agricultural property, depending on the crop used and the intensity of use of the machines (SILVA *et al.*, 2022).

Fuel expenditure by agricultural tractors can be reduced by optimizing operational processes. According to Kim, Chung and Choi (2013), it is important to analyze the selection of gears during operation and engine rotation, as they can present different levels of fuel consumption, even when the same work is performed.

The use of different driving modes on tractors can be performed either manually, by the operator or automatically, in this case, with the use of continuously variable transmissions, which are equipped with a control system that can adjust the
transmission ratio and engine rotation so that it can work at a point that provides maximum fuel consumption efficiency under certain working conditions (RENIUS; RESCH, 2005).

Modern tractors are normally operated through independent management of the engine and transmission, a situation in which the operator changes the engine speed through the position of the accelerator and, in the transmission, by modifying the gear ratio, using gear levers (LINARES; CATALÁN; MÉNDES, 2006). By using different driving modes, it is possible to change the management of the engine and transmission so that a situation that provides a reduction in fuel consumption can be identified.

In the United States of America, this technique is called *"gear up and* throttle down", that is, "gar up and throttle down", which can be used in operations that do not require the maximum power of the tractor and consists of reducing engine speed and increasing working gear (GRISSO, 2020). This reduces engine speed and maintains travel speed while the work is being carried out.

Speed is a determining factor in achieving greater quality during field operations; thus, maintaining speed and changing the travel gear and engine rotation does not interfere with the quality of service or the operational capacity of the tractor. (PARK *et al.*, 2010). Moreover, reducing engine speed implies lower fuel consumption, as there is greater torque availability at lower speeds in addition to reducing the engine's frictional power. The efficiency of agricultural operations can be improved when the operational capacity is increased or fuel consumption is reduced, so the search for more efficient operations becomes one of the main concerns of farmers due to the high costs of fuel, labor and maintenance (KUMAR; PANDEY, 2015).

In studies carried out by Hunt (1995), maintaining the operating speed by reducing engine acceleration and gear shifting, it was possible to increase fuel use efficiency by up to 17%. In another work, developed by Silva *et al.* (2003) using one gear and four engine speeds, there was a 71% increase in fuel consumption from the lowest to the highest speed. Gotoh *et al.* (2010), using driving strategies, reported a reduction in fuel consumption ranging from 7--13%.

Within this proposal, this work aimed to evaluate different driving modes of the agricultural tractor, with the goal of reducing fuel consumption and optimizing its traction performance.

2 MATERIALS AND METHODS

The study was carried out at the Federal University of Santa Maria (UFSM) in an experimental area of the Department of Animal Science, with coordinates 29°43'30. 19"S and 53°44'12.08"W. An area 110 m long by 100 m wide with flat, very regular relief was selected at the site. The typical soil of the region is classified as sandy dystrophic Red--Yellow Argisol (EMBRAPA, 1999), belonging to the Santa Maria Mapping Unit, and according to Köppen's climate characterization (1931), it is humid subtropical.

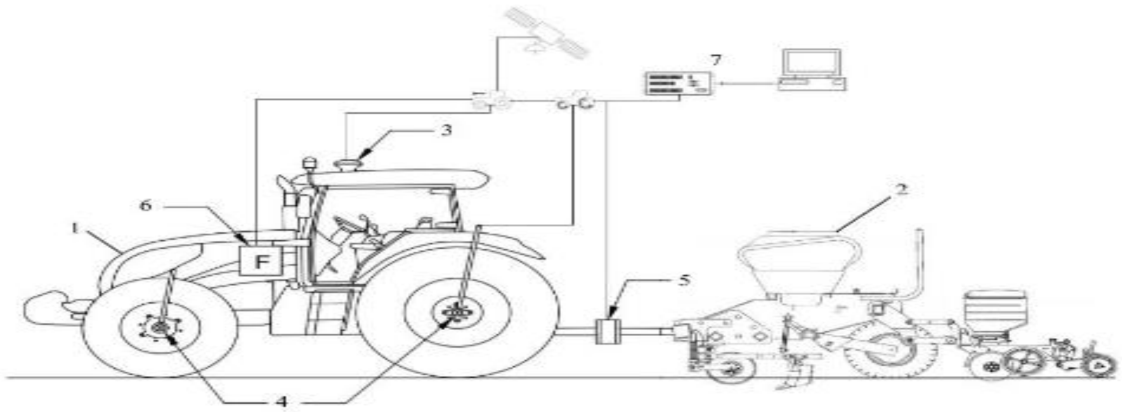
In the experiment, a Massey Ferguson tractor, model MF 6711, with an auxiliary front–wheel drive, a diesel cycle engine (AGCO Power brand, model 44WC3), *a turbointercooler* with four cylinders, and a displaced internal volume of 4,400 cm³, with a maximum power of 74 kW at 1806 rpm and a maximum torque of 431 Nm at 1402 rpm, was used. To collect this information, the tractor was previously subjected to a dynamometric test.

The tractor has a total mass with ballast of 25.77 kN (6,460 kgf), with a static mass distribution of 40.7% on the front axle and 59.3% on the rear axle. According to Strapasson Neto *et al.* (2021), this is a static distribution that provides maximum traction performance. The tractor was equipped with type R1 tires from the Goodyear brand, Dyna torque II 12-ply model, with measurements of 14.9--26 on the front wheels, and type R1 tires from the Goodyear brand, Dyna torque III, 12 ply, with measurements of 23.1--30 on rear wheels. The tractor always works with the auxiliary front-wheel drive and differential lock mechanism activated.

To apply a load to the tractor's drawbar, simulating the sowing operation, a Massey Ferguson seeder, model MF 509, 8 rows with a rod-type furrow system, with a working depth of 0.10 m and mass, was used. constant.

To collect the data, electronic instrumentation was used (Figure 1), which is capable of simultaneously and instantly collecting data on travel speed, traction force, hourly fuel consumption and rotation of the driving wheels, with a frequency of 1 Hertz, storing them in a *datalogger* suitable for mechanized activities and scientific research, developed by Rosa (2019).

Figure 1. Schematic representation of the tractor + seeder mechanized set with electronic instrumentation



Source: Farias *et al.* (2020)
Legend: 1 – Tractor, 2 – seeder, 3 – actual working speed, 4 – slipping of the driving wheels, 5 – force on the drawbar, 6 – fuel consumption, 7 – data storage center.

The traction force was obtained through a load cell positioned between the tractor and the seeder via a retractable traction bar, where the force demanded was measured in mV, which generated electrical pulses according to the intensity of the effort needed. . The theoretical speed of the wheelsets was obtained via sprockets with 32 teeth each, coupled to an extender and fixed to the front and rear wheelsets of the tractor, and an inductive sensor was placed on each sprocket to detect the passage of the gear teeth. gear by the sensor, according to the rotation speed. The real speed of the tractor was obtained by a satellite signal receiver (GNSS). To estimate the theoretical speed, Equation (1) was used:

$$Vroda = \frac{(Freq\ x\ \ Per\ x\ 3{,}6)}{n} \quad (1)$$

where:
Vwheel: Wheel speed (km.h $^{-1}$);
Freq: Frequency captured by the sensor (Hz);
Per: Wheel perimeter (m);
n: Number of teeth on the sprocket.

Hourly fuel consumption was measured via an Oval M III flowmeter, model LSF 41, which generates a certain number of pulses according to the volume of fuel that passes through it, which was calculated via Equation 2:

$$CH = Pul\ x\ 3{,}6 \quad (2)$$

where:
CH: Fuel consumption (L h $^{-1}$);
Pul: Pulses generated by the flowmeter.

From the data obtained on traction force and real speed of travel, the power on the traction bar was determined via Equation 3:

$$PBT = \frac{FT\ .Vr}{3{,}6} \quad (3)$$

where:
PBT: Drawbar power (kW);
FT: Traction force on the bar (kN);
Vr: Actual travel speed (km h $^{-1}$).

With data on the hourly fuel consumption, fuel density and drawbar power, the specific consumption is obtained according to Equation (4):

$$CE = \frac{CH \times \rho \times 1000}{PBT} \quad (4)$$

where:
EC: Specific consumption (g kWh $^{-1}$);
CH: Hourly fuel consumption (L h $^{-1}$);
ρ: Fuel density (0.875 kg L $^{-1}$);
PBT: Drawbar power (kW).

To obtain the slippage of the driving wheels, data on the speed of the driving wheels and the speed of the tractor were used, according to Equation 5:

$$\delta = \left[1 - \left(\frac{Vr}{Vt}\right)\right] . 100 \quad (5)$$

where:
δ: Skating (%);
Vr: real tractor speed (km.h $^{-1}$);
Vt: Wheel speed (km.h $^{-1}$).

With the power data on the drawbar and power supplied by the engine, the traction efficiency of the tractor was obtained according to Equation (6):

$$ET = \frac{PBT}{Nm} \quad (6)$$

where:
ET: Traction efficiency;
PBT: Drawbar power (kW);
Nm: Power supplied by the engine (kW).

The treatments consisted of a combination of working gear and engine speed, totaling six treatments (Table 1). The engine speeds were defined to compare two working conditions, the first at 2000 rpm, which is traditionally used by users, and the second at 1800 rpm, which is considered reduced. To define the gears used, the gears that provided the closest travel speeds and the best traction condition of the implement were selected, corresponding to the gears L5, L6 and H2. To choose the combinations, a previous experiment was carried out with all the tractor's gears, which were capable of pulling the seeder.

The tractor transmission ratio (it) for the gears at the peripheral engine speeds used was also determined. The rotation of the rear wheel axle was determined with a digital tachometer. The transmission ratio is determined by dividing the engine rotation by the rotation obtained in the wheelset, and the results are available in Table 1.

Table 1. Treatments used in the experiment

Order	March	Engine revolutions	Treatment	it
1	L5	1800	L5 1800	171.43
2	L5	2000	L5 2000	190.48
3	H2	1800	H2 1800	160.71
4	H2	2000	H2 2000	178.57
5	L6	1800	L6 1800	139.53
6	L6	2000	L6 2000	155.04

Source: The author

The chosen experimental design was a randomized block design with four replications. The dependent variables analyzed were speed (km h $^{-1}$), hourly fuel consumption (L h $^{-1}$), specific fuel consumption (g kWh $^{-1}$), traction force (kN), slippage (%), traction bar power (kW) and traction efficiency (%).

The data were subjected to tests of normality and homogeneity of residual variances and additivity of the statistical model, and subsequently, analysis of variance was used at a 5% probability of error. On the basis of data that differed from each other, the Scott–Knott test was performed to compare means. To identify the statistical relationships between the variables, Pearson's linear correlation was used. Data analysis was performed via the RStudio statistical program.

3 RESULTS AND DISCUSSION

According to Table 2, the results of the comparison of means can be verified via the Scott–Knott test at a 5% probability of error for the analyzed variables.

Table 2. Comparison of Scott–Knott means for the variables speed (km h $^{-1}$), CH – Hourly consumption (L h $^{-1}$), CE – Specific consumption (g kW h $^{-1}$), FT – Traction force (kN), δ - Slippage (%), PBT - drawbar power (kW) and ET - traction efficiency.

TREAT	SPEED	CH	CE	FT	δ	PBT	ET
L5 1800	5.54c	20.39b	347.43 a	32,218 a	16.99 to	49.98b	0.67b
L5 2000	6.16b	21.40 to	331.66b	32,504 a	8.69c	55.25 to	0.74 to
H2 1800	6.26b	20.58 a	315.99b	32,334 a	11.16b	56.05 to	0.75 to
H2 2000	6.24b	20.77 a	322.15b	32,150 to	7.64c	55.56 to	0.75 to
L6 1800	6.40 b	18.82c	324.74b	28.483b	7.64c	50.48 a	0.68b
L6 2000	7.09 to	20.77 a	330.74b	27.276c	8.80c	54.43 a	0.73 to
CV (%)	5.87	4.39	2.69	2.55	12.97	5.38	5.38

Means followed by the same letter in the same column do not differ from each other according to the Scott–Knott test at 5%.

Source: The author.

When the average test for the speed variable was analyzed, the highest value occurred in gear L6 at 2000 rpm, precisely because it is the gear that has the lowest transmission ratio among those used in the experiment (Table 1), resulting in the highest speed of the tractor. Compared with the L5 2000 rpm treatment, the L5 1800 rpm treatment presented a lower displacement, precisely because of the difference between the engine rotations of these treatments, with the latter having a greater rotation, resulting in an increase in the displacement speed. In the L5 2000 rpm, H2 1800 rpm, H2 2000 rpm and L6 1800 rpm treatments, there was no significant difference in this variable. The behavior between travel speeds, which are related to the working gear, has already been predicted because, precisely, by increasing the tractor's gear speed, the travel speed increases (AMORIM *et al.*, 2019).

For the variable hourly fuel consumption (CH) (Table 2), the L5 2000 rpm and L6 2000 rpm treatments presented higher levels of consumption, with values of 21.40 and 20.77 L h $^{-1,}$ respectively, but did not differ from those of the H2 1800 rpm and H2 2000 rpm treatments. The lowest fuel consumption was observed for the L6 1800 rpm treatment, with 18.82 L h $^{-1}$. When comparing the L5 1800 rpm and L5 2000 rpm treatments and the L6 1800 rpm and L6 2000 rpm treatments, which were performed with the same gear but with an increase in the engine's angular speed, the consumption increased by 5% and 9%, respectively.

The lowest fuel consumption was observed in the treatments with the lowest speeds, i.e., L6 1800 rpm and L5 1800 rpm. The lower speed in Diesel cycle engines achieves greater efficiency because of the greater capacity to admit oxygen (oxidizer), longer time to complete the combustion cycle and lower friction between the dynamic and static components of the engine (MÁRQUEZ, 2012).

The highest specific fuel consumption (CE) occurred in the L5 1800 rpm treatment, with 347.43 g kW h $^{-1}$, whereas for the other treatments, there was no difference (Table 1). This behavior of the results is related to the power on the drawbar, which is considered for calculating the specific fuel consumption.

Although there was no difference between the treatments, the lowest specific consumption was observed for the H2 1800 rpm treatment, with 315.99 g kW h $^{-1}$. A lower specific fuel consumption means that there is greater optimization of engine performance, traction efficiency and suitability of the implement to the tractor (LYNE; BURT; MEIRING, 1984).

For the variable traction force (FT), the highest values were observed in the L5 1800 rpm, L5 2000 rpm, H2 1800 rpm and H2 2000 rpm treatments, with values of 32.22, 32.50, 32.33 and 32.15 kN, respectively, and these treatments did not differ from each other (Table 3). This may be associated with little variation in displacement speed in these treatments, and because the experimental area was flat, the required traction force presented similar values.

The treatment that showed the greatest difference was the L6 2000 rpm treatment with 27.28 kN, which could also be related to the variation in displacement speed between these treatments, which was 7.09 km h^{-1}, with a reduction in traction force with increasing speed. Similar results were reported by Furlani *et al.* (2007), where an increase in travel speed results in a reduction in traction force.

For driving wheel slippage (δ), the highest rate of 16.99% was found in the L5 1800 rpm treatment (Table 3). This may be associated with the tractor's travel speed. Furlani *et al.* (2007) reported a higher value with a lower tractor travel speed. For the H2 1800 rpm treatment, the slippage rate was 11.16%, and the ideal rate in soils without mobilization should be between 8 and 10% (ASAE, 2003).

For the variable drawbar power (PBT), the highest values were obtained for the L5 2000 rpm, L6 1800 rpm, L6 2000 rpm, H2 1800 rpm and H2 2000 rpm treatments, with 55.25, 50.48, 54.43, 56.05 and 55.56 kW, respectively, but these values did not differ from each other. The lowest power was recorded in the L5 1800 rpm treatment, with 49.98 kW. The drawbar power to be obtained considers the parameters of traction force and travel speed, as demonstrated in Equation 3. In this sense, the highest values for this variable are related to treatments with the highest tractor travel speed. A study conducted by Silveira *et al.* (2013) revealed that with increasing travel speed, the power demand on the tractor drawbar increased.

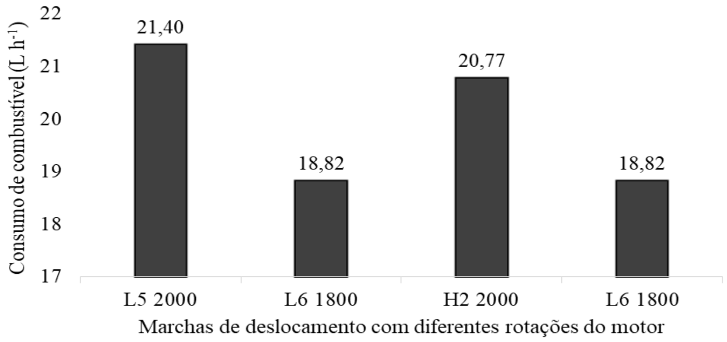
For traction efficiency (ET), the highest values were obtained in the L5 2000 rpm, L6 2000 rpm, H2 1800 rpm and H2 2000 rpm treatments, with values of 0.74, 0.73, 0.75 and 0.75, respectively. These values are not different from each other. These higher values may be associated with the tractor slipping conditions. A study conducted by Fiorese *et al.* (2019) reported the highest efficiencies of 0.76 and 0.73 in subsoiling and harrowing operations, respectively, with slippage rates between 8% and 10%.

The lowest traction efficiency value of 0.67 was obtained for the L5 1800 rpm treatment because of greater slippage. For the L6 treatment, 1800 rpm was 0.68, an effect related to the lower power on the drawbar that was developed in this treatment, to obtain traction efficiency, the relationship between the power on the drawbar and the power provided by the engine, as shown in Equation 6.

In another way of analyzing the results obtained, treatments can be compared according to the same travel speed, with reduced working gear and high engine speed and vice versa, as proposed by Grisso (2020). The treatments that provided this analysis were the alternatives proposed in the comparison of L5 2000 rpm with L6 1800 rpm and H2 2000 rpm with L6 1800 rpm.

For the hourly fuel consumption (Figure 2), as the working gear increased from L5 to L6, reducing the engine speed from 2000 rpm to 1800 rpm, the hourly consumption decreased by 12%. For another comparison, the reduction in consumption was 9.4%, increasing the gear from H2 to L6 and reducing the engine speed.

Figure 2. Hourly fuel consumption at the same travel speed but with different gears and engine speeds.

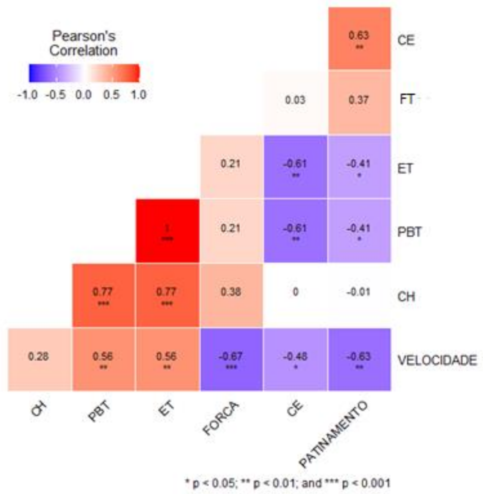


Source: The author

In a study conducted by Silveira *et al.* (2013) using different engine speeds for the same travel speed, variations of 7--44% in hourly fuel consumption were found, from the lowest to the highest speed. Miranda, Oliveira and Nunes (2000), using two peripheral engine speeds (1800 rpm and 2000 rpm), reported an increase of 12.9% in the hourly fuel consumption when the tractor was driven at the highest speed.

Pearson's linear correlation (Figure 3) demonstrates the relationships between the studied variables, regardless of the treatment used, which can positively or negatively influence the correlated response variable.

Figure 3. Pearson correlation for the variables speed (km h $^{-1}$), CH – hourly consumption (L h $^{-1}$), CE – specific consumption (g kW h $^{-1}$), FT - traction force (kN), δ - slippage (%), PBT - drawbar power (kW) and ET - traction efficiency.



Source: The author

The slipping of the driving wheels is positively correlated with specific fuel consumption (CE); that is, as slippage increases, there is an increase in specific fuel consumption by the tractor. Wheel slipping occurs due to several factors, the main factor being the traction effort required to pull certain equipment, which consequently reduces the speed of the tractor. Cortez *et al.* (2005) reported that, in soil preparation and soybean sowing operations, a lower travel speed provided the highest specific fuel consumption of the agricultural tractor.

The traction efficiency (ET) has a significant and negative association with driving wheel slippage and specific fuel consumption as the traction efficiency increases and slippage decreases. Gabriel Filho *et al.* (2004), evaluating the performance of tractors in different types of vegetation cover, reported a relationship similar to that demonstrated for these variables, where less slippage increased traction efficiency. Likewise, while traction efficiency tends to increase its indices, it provides a reduction in specific fuel consumption, as the tractor presents fewer losses during the traction process, thus becoming more efficient (NEUJAHR; SCHLOSSER, 2001).

The variable drawbar power (PBT) also has a negative and significant association with slippage and specific fuel consumption; as the value of the first variable increases, it tends to decrease. The power on the drawbar demonstrates how much of the engine's power is reaching the drawbar and thus provides the tractor's greater capacity to pull implements, which tends to require greater traction demand.

The power on the drawbar is a product of multiplying the travel speed by the traction force, as shown in Equation 3; therefore, any factor that influences these requirements interferes with the development of power on the drawbar. In this sense, the increase in slippage leads to a decrease in travel speed, which in turn reduces the power at the drawbar.

The reduction in specific fuel consumption, related to the increase in drawbar power, may be associated with travel speed, as previously described. To obtain the specific consumption, in addition to the fuel density data and hourly consumption, it also considers the bar power values, as shown in Equation (4), which means that the higher the value is, the lower the specific fuel consumption. Traction efficiency showed a high positive and significant correlation with drawbar power because these variables are dependent on each other.

Hourly fuel consumption (CH) was positively correlated with the drawbar power and traction efficiency. For the first variable, this may occur because the power on the drawbar is dependent on the traction force exerted by the tractor; with greater force demands, the hourly fuel consumption tends to be greater. This can also be related to the second variable; to obtain traction efficiency, the power developed in the traction bar is considered.

The travel speed had the highest number of correlations with the other variables analyzed, as increasing speed tends to reduce the traction force, specific fuel consumption and slipping of the driving wheels. The drawbar power and traction efficiency increase with increasing tractor speed.

4 CONCLUSIONS

According to the results obtained, it can be concluded that:

i. Maintaining the same travel speed and reducing the engine's angular speed results in lower hourly fuel consumption.
ii. In the proposal to gear up and rev down as a strategy to reduce fuel consumption, there is a reduction of up to 12% in hourly consumption.
iii. The use of driving strategies did not influence the specific fuel consumption, slippage or drawbar power variables.
iv. Pearson's linear correlation demonstrates that travel speed is one of the main factors affecting the tractor's performance conditions.

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