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Energy efficiency of an agricultural tractor according to different driving modes and working speeds

Eficiência energética de um trator agrícola de acordo com diferentes modos de condução e velocidades de trabalho

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Abstract

The objective of this study is to evaluate the energy efficiency of an agricultural tractor according to driving modes (full throttle and shift up and throttle back) and working speeds (3.50 km h^{-1}, 6.70 km h^{-1} and 9.80 km h^{-1}) during a disc harrow operation. The experimental design was randomized blocks in a bi-factorial design (2x3) with three replications, totaling 18 experimental units. An agricultural tractor was used with a nominal power of 55 kW (75 hp) pulling a disc harrow. The evaluated variables were hourly, specific and operational fuel consumption, all recorded by electronic instrumentation installed in the tractor. The results indicate that the shift up and throttle back mode may be used as a rational driving strategy for agricultural tractors. Savings of up to 22.43% of fuel have been obtained in face of the full throttle mode normally used by farmers.

Additional keywords: driving strategy; mechanized field operation; specific fuel consumption.

Resumo

Objetivou-se avaliar a eficiência energética de um trator agrícola, em modos de condução (aceleração máxima e marcha longa e aceleração reduzida) e velocidades de trabalho (3,50 km h^{-1}, 6,70 km h^{-1} e 9,80 km h^{-1}), durante a operação de gradagem. O delineamento experimental utilizado foi o de blocos casualizados, em desenho bifatorial (2x3), com três repetições, totalizando 18 unidades experimentais. Utilizou-se um trator agrícola, com potência nominal de 55 kW (75 cv), tracionando uma grade niveladora. As variáveis avaliadas foram os consumos horário, específico e operacional de combustível, todas registradas por meio de instrumentação eletrônica instalada no trator. Os resultados indicam que o modo marcha longa e aceleração reduzida pode ser utilizado como uma estratégia racional de condução do trator agrícola, visto que foram obtidas economias de até 22,43% de combustível em relação ao modo aceleração máxima, normalmente utilizado pelos agricultores.

Palavras-chave adicionais: consumo específico de combustível; estratégia de condução; operação mecanizada de campo.

Introduction

Farmers should consider the way they drive farm tractors when buying them because it directly interferes with the consumption of biodiesel. Brazilian biodiesel (ANP, 2017) is composed of 92% of diesel oil of mineral origin, and the price is related to international financial variations, which affect the high prices of fuel in Brazil. In addition to the growing concern about environmentally clean and socially viable nature, there is pressure for a correct use of fossil fuels, which are responsible for the emission of polluting gases into the atmosphere (Frantz et al., 2014).

Considering that the cost of fuel in agricultural machinery operations has a significant impact on the total cost of agricultural mechanization (Montanha et al., 2011; Jasper & Silva, 2013), and those costs may reach up to 45% of the cost of a tractor (Siemens & Bowers, 1999), fuel consumption may be reduced by means of correct operating procedures. According to Toledo et al. (2010), mechanized agricultural operations must be planned rationally for an increased profitability in the field.

Soil preparation using plows, disc harrows, rotary hoes, subsoilers and scarifiers, although currently not used in cereal crops, replacing no-tillage and minimum cultivation, is widely performed for crops such as carrots, garlic, onions and potatoes (Júnior, 2012). The conventional tillage system is one of the activities with the highest energy costs for the grain production system (Sá et al., 2013). According to Peloia & Milan (2010), in terms of a potential for reducing production costs, agricultural mechanization may be considered as a main factor.

According to Montanha et al. (2011), fuel consumption of agricultural tractors is directly related to factors such as adequacy and condition of the tractor-equipment combination, depth of operation, soil type and condition, and total number of operations of the soil preparation process. Moreover, according to Kim et al. (2013), it is important to analyze the effects of gear selection during mechanized agricultural operations. Different fuel consumption can be obtained for a same type of work depending on the gear used (Gabriel Filho et al., 2010).

Suitable tractor driving strategies may reduce production costs. Driving strategies are joint forms of managing the engine and transmission aiming to reduce fuel consumption, thus achieving a greater efficiency in the use of diesel (Howard et al., 2013). Grisso et al. (2014) described this technique as “Gear Up and Throttle Down”. According to the authors, this is a fuel-saving practice that could be optimized when demands on drawbar loads are less than 75% of the rated power.

Due to the need for a greater energy efficiency in the use of agricultural tractors, the objective here is to evaluate the energy efficiency of an agricultural tractor according to driving modes (full throttle and shift up and throttle back) and working speeds (3.50 km h^{-1}, 6.70 km h^{-1} and 9.80 km h^{-1}).

Material and methods

The field experiment was conducted in a sandy Dystrophic Red Argisol located in the state of Rio Grande do Sul. The climate is Cfa, according to the classification of Köppen & Geiger (1928). The annual average temperature is 19.2 °C, and the average annual rainfall is 1,708 mm, well distributed throughout the year (Maluf, 2000).

The experimental area was the production sector of a University. Soil is fallow, with predominance of grass species of a relief considered flat, with a slope of 2º. Before the installation of the experiment, the area was harrowed using an intermediate disc with 16 disks, 26 inches in diameter, at a depth of 0.20 m, and part of the vegetation cover was eliminated. The tests occurred in a soil water content of 0.16 kg kg^{-1}.

In the experiment, we used a Massey Ferguson tractor, model MF 4275, with a MWM diesel engine, 1,339 hours of use, four-stroke model A4-4.1, four cylinders, displaced volume of 4,100 cm^3 and natural aspiration. According to the manufacturer, its nominal power is 55 kW (75 hp) at 2,200 rpm. The mechanical engine was a Delphi rotary fuel injection pump. The biodiesel fuel used in the experiment was acquired from the local automotive supply network, with a specific mass of 873 kg m^{-3} at 20 ºC.

The tractor had a total weight of 4,030 kgf (39.52 kN), with a static mass distribution of 58% on the rear axle and 42% on the front axle. Weighing was carried out using a portable Toledo weight balance, model BPV-830, equipped with a set of six platforms, with a capacity of 294.20 kN (30,000 kgf). The tires were Pirelli PD 22 18.4-30 R-1 rear diagonal tires with 75% hydraulic pressure and 110.32 kPa (16 Psi) of internal pressure, and Goodyear Dyna Torque II 12.4-24 R-1 diagonal front tires without water and internal pressure of 165.47 kPa (24 Psi). In addition, it had eight front counterweights of 35 kgf, totaling 280 kgf. The kinematic advance of the tractor was 1.048, within the range of values recommended by Linares et al. (2006), which should be between 1.01 and 1.05.

The tractor's drawbar, coupled to a GNDL lightweight disc harrow, had 32 discs (20" x 3.50 mm) spaced 175 mm, totaling a working width of 2.55 m and total weight of 730 kgf (7.16 kN). According to information provided by the manufacturer, the power requirement of the engine is 75 to 85 hp, which sets the harmony of the mechanized assembly. The angle of attack of the harrow discs was 17.64º, following calculation of the horizontal angle of attack of agricultural disc harrows, as proposed by Stolf et al. (2010).

In function of engine speed and gear ratio of each gear, the 3rd gear (2nd RB - second gear, Reduced and Low gearboxes), the 5th gear (3rd RB - third gear, Reduced and Low gearbox) and the 7th gear (1st DB - first gear, Direct and Low gearboxes) were used, which, for a 2,000 rpm engine speed, corresponded to the working speeds of 3.50 km h^{-1}, 6.70 km h^{-1} and 9.80 km h^{-1}, respectively. A speed variation of 3-10 km h^{-1} was proposed to contemplate the wide diversity of agricultural operations carried out in the field.

In order to equalize the same pre-defined working speeds (3.50, 6.70 and 9.80 km h^{-1}), we chose a lower engine speed (1,600 rpm), but longer working gears: the 4th gear (2nd RA - second gear, Reduced and High gear), the 6th gear (3rd RA - third gear - Reduced and High gear) and the 8th gear (1st DA – first gear, Direct and High gear). Thus, two modes of tractor driving were characterized: full throttle (FT), and shift up and throttle back (SUTB). The schematic representation of the engine speeds and gears used in the experiment is shown in Figure 1. Thus, for statistical analyses, a two-factor experiment was considered, in which the factors were tractor driving modes (FT and SUTB) and working speeds (3.50, 6.70 and 9.80 km h^{-1}), in completely randomized blocks with three replicates, totaling 18 experimental units.

In order to quantify the hourly fuel consumption, an Oval M-III flowmeter, model LSF 41, composed of two gears was used. One of them had a magnet that sensitizes an inductive sensor at each turn (1 mL of dislocated volume) generating a pulse converted and stored in a Campbell Scientific, CR1000, data logger. Information was recorded continuously over a two-second period. Since only one flowmeter was used, the fuel from the pump and the injector nozzles did not return to the tank, but rather, through a connection made after the flowmeter, forced to be consumed by the engine, no longer passing through the flowmeter.

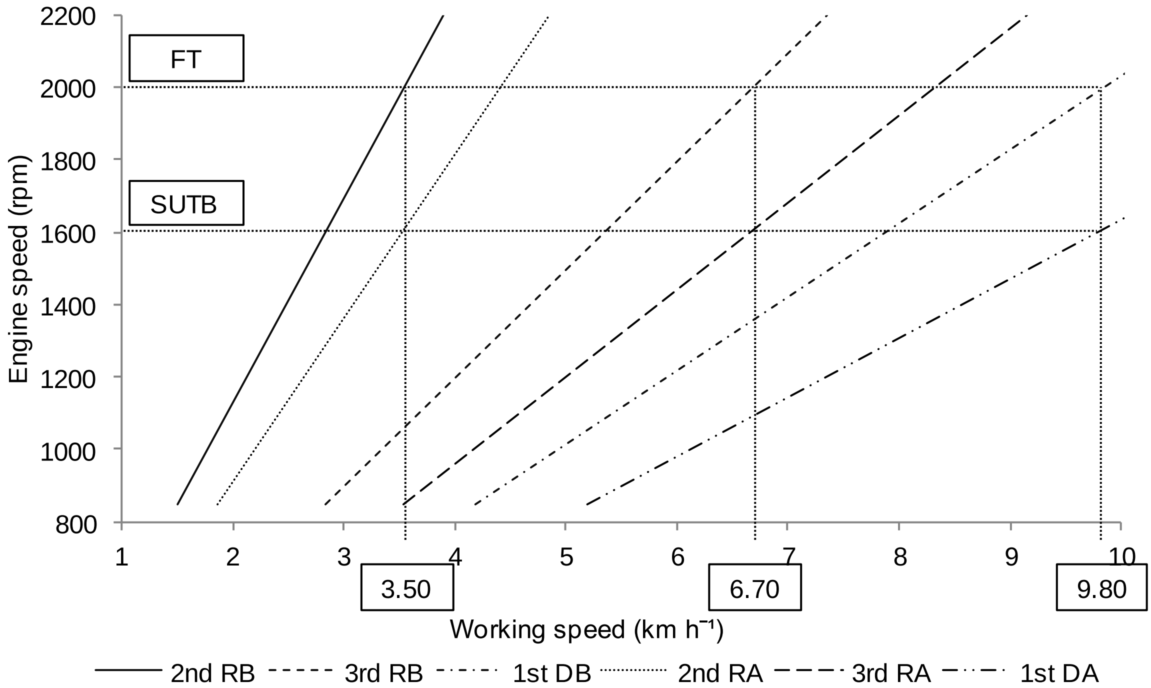

Figure 1 - Engine speeds and work gears used that configure full throttle (FT) and sift up and throttle back (SUTB) driving modes, as well as working speeds, for the MF 4275 tractor (Massey Ferguson, Canoas, Brazil).

From the hourly and available power consumption data on the drawbar, known by means of an Alfa calibrated load cell, model 5T, with capacity for 50 kN (5,000 kgf), the values for specific fuel consumption were represented by equation 1.

$$SFC = \frac{Hc \times \rho \times 1000}{N_{DB}} \quad (1)$$

Wherein: SFC is the specific fuel consumption (g kWh^{-1}), Hc is the hourly fuel consumption (L h^{-1}), ρ is the relative fuel density (0.875 kg L^{-1}), and N_{DB} is the power on the drawbar (kW).

Operational fuel consumption was determined by the relation between hourly fuel consumption and effective field capacity, according to Mialhe (1974). The effective field capacity was determined by the relation between the useful area of the plot and the time spent in the course of the plot.

Data (hourly, specific and operational fuel consumption) were submitted to analysis of variance (ANOVA), to Tukey test for comparison of means and, in case of an interaction between factors, a polynomial regression analysis at a 5% significance.

Results and discussion

After obtaining the ANOVA for hourly, specific and operational fuel consumption, we verified that the three variables presented a difference (Table 1). To facilitate the visualization and analysis of the results, the data and tendency curves were plotted for the parameters evaluated.

Table 1 - Summary of the analysis of variation for the hourly (L h^{-1}), specific (g kW^{-1} h^{-1}) and operational (L ha^{-1}) fuel consumption parameters.

Causes of variation	Mean squares		
	Hourly fuel consumption	Specific fuel consumption	Operational fuel consumption
Mode (M)	11.60	59635.61	4.22
Speed (S)	26.88	148947.58	5.33
M x S	0.24*	11608.16*	0.28*
Residue	0.07	1110.84	0.07
CV (%)	3.56	4.91	4.69

*Differ statistically (ρ≤0.05).

Hourly fuel consumption

The hourly fuel consumption values were higher using the FT driving mode for all working speeds evaluated when compared to the SUTB mode (Table 2). By analyzing Figure 2a, it can be observed that the increase in the hourly fuel consumption in relation to the speed of operation obtained the same tendency as reported for the ASAE (2006) standard, i.e., a linear tendency.

Upon studying speed and loads imposed on the engine, Janulevicius et al. (2013) achieved significant reductions in fuel consumption. In order to be more profitable, when the required engine power is less than 80% of its rated power, its speed must not exceed 80% of the nominal power. In this study, the SUTB driving mode may be used as a tractor driving strategy, since it is able to provide savings at the range of 15-25% of fuel consumption per hour compared to the FT mode (Table 2).

Table 2 - Energy efficiency parameters (hourly, specific and operational fuel consumption) in different engine speed for the three evaluated travel speeds.

	(a)2nd RB and 2nd RA	(b)3rd RB and 3rd RA	(c)1st DB and 1st DA
	3.50 km h^{-1}	6.70 km h^{-1}	9.80 km h^{-1}
	Hourly fuel consumption (L h^{-1})*		
SUTB**	4.67a	6.73a	8.55a
FT**	6.02b	8.14b	10.61b
Mean	5.34	7.43	9.58
CV (%)	13.86	10.60	12.34
	Specific fuel consumption (g kWh^{-1})		
SUTB	757.00a	549.98a	558.24a
FT	963.86b	657.00b	589.72a
Mean	860.43	603.49	573.98
CV (%)	13.29	11.01	6.31
	Operational fuel consumption (L ha^{-1})		
SUTB	5.97a	4.79a	4.65a
FT	7.44b	5.56b	5.33b
Mean	6.70	5.17	4.99
CV (%)	12.53	8.44	10.17

(a) 2nd RB and 2nd RA - second gear, Reduced and Low gearboxes and second gear, Reduced and High gear; (b) 3rd RB and 3rd RA - third gear, Reduced and Low gearbox and third gear - Reduced and High gear; (c) 1st DB and 1st DA - first gear, Direct and Low gearboxes and first gear, Direct and High gear; * Means followed by the same letter in the column do not differ by the Tukey test at 5% error probability; ** Full throttle (FT) and shift up and throttle back (SUTB).

Specific fuel consumption

The specific fuel consumption was higher at 2,000 rpm for the speeds 3.50 and 6.70 km h^{-1}, not differing from 1,600 rpm only for the speed 9.80 km h^{-1} (Table 2). We observed, through the behavior of regression curves shown in Figure 2b, a decline in specific fuel consumption with an increase in travel speed, but this difference decreases as the speed reaches 9.80 km h^{-1}.

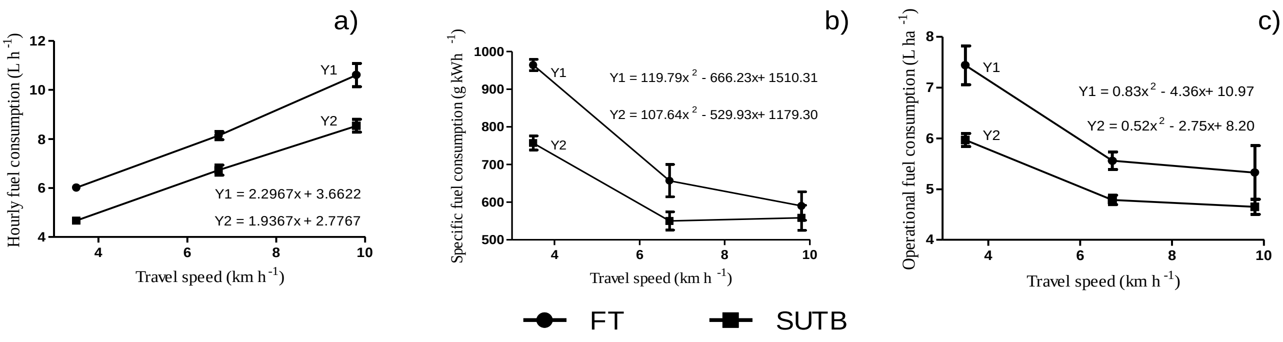

Figure 2 - (a) Hourly; (b) specific and (c) operational fuel consumption regarding the driving modes applied to the tractor for three travel speeds (3.50, 6.70 and 9.80 km h^{-1}). FT – Full throttle; SUTB – Shift up and throttle back.

Evaluating the fuel consumption of a tractor in function of speed of work, Lopes et al. (2003) observed that an increasing speed reduced specific fuel consumption. Proper selection and correct use are of fundamental interest to reduce the energy demand of farm machinery (Jasper & Silva, 2013). Results of this study suggest rational use of agricultural tractors, when greater efficiency in the use of fuels is sought.

Operational fuel consumption

Values of operational fuel consumption were higher when using the FT driving mode in relation to the SUTB for the three speeds evaluated (Table 2). In addition, it can be observed that the operational consumption had a similar behavior as the specific fuel consumption, with a marked reduction in the transition from the speed 3.50 km h^{-1} to the speed 6.70 km h^{-1} (Figure 2c).

Thinking about the use, cost and environmental impact of mechanized agricultural operations, fuel economy becomes the main objective to achieve a maximum economic efficiency. The increase in the working speed contributes to the reduction in the operational fuel consumption (Almeida et al., 2010). The results show that, at smaller engine speeds and longer working gears, fuel economy is achieved.

Conclusions

Shift up and throttle back mode may be used as a rational driving strategy for agricultural tractors. Savings of up to 22.43% of fuel are obtained in relation to the full throttle mode normally used by farmers.

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