Performance of agricultural tractor with and without automatic transmission and engine rotation management[1]

Desempenho do trator agrícola com e sem gerenciamento automático da transmissão e rotação do motor

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HIGHLIGHTS:
Electronic gear selection and autonomous engine rotation management bring benefits to tractor driving.
The electronic management responded positively to the increase in the traction load.
The use of electronic management software should be more widespread among farmers and researchers.

ABSTRACT: The introduction of new technologies on board of agricultural machinery is constant, for greater energy performance and operational efficiency. Recently, electronic management systems have been able to automatically perform engine gear selection and rotation, aiming at lower hourly fuel consumption. The objective of the experiment was to evaluate the energy and operational efficiency of an agricultural tractor with automatic management of transmission and engine rotation, subjected to traction of different loads. The experiment was conducted in a randomized block design, in 50-m-long strips with two factors: the automatic management system of transmission and engine rotation (with and without) and three different loads applied on the drawbar, with four repetitions. The collected data were subjected to analysis of variance and to Tukey test. The automatic management system of transmission and engine rotation promoted 20% reduction in wheel slip, 10% increase in operating speed and 28% savings in fuel consumption.

Key words: gear, gearbox, productivity management software

RESUMO: A introdução de novas tecnologias a bordo das máquinas agrícolas é constante, para maior desempenho energético e eficiência operacional. Recentemente, sistemas de gerenciamento eletrônico são capazes de realizar a seleção da marcha e rotação do motor automaticamente, visando o menor consumo horário de combustível. O objetivo do experimento foi avaliar a eficiência energética e operacional do trator agrícola com gerenciamento automático da transmissão e rotação do motor, submetido a tração de diferentes cargas. O experimento foi conduzido no delineamento de blocos casualizado, em faixas de 50 m, com dois fatores: o sistema de gerenciamento automático da transmissão e rotação do motor (com e sem) e três cargas diferentes aplicadas na barra de tração, com quatro repetições. Os dados coletados foram submetidos a análise de variância e ao teste de Tukey. O sistema de gerenciamento automático da transmissão e rotação do motor proporcionou redução de 20% no patinamento, aumento de 10% na velocidade operacional e economia de 28% no consumo horário de combustível.

Palavras-chave: marcha, caixa de câmbio, Software de gestão da produtividade

Introduction

The agricultural tractor has been undergoing the constant modernization of the field, being increasingly independent of the operator, due to the new technologies of integrated communication (Fountas et al., 2015), promoting flexibility in traditional operation, ease in the tasks and pulling implements of different sizes.

Onboard systems for transmission and engine rotation management are constituted of hardware, which stores and executes customized software (Jha et al., 2019) in order to increase the economic return by reducing fuel consumption, which may interfere with the operational performance of agricultural tractors and production costs (Guerrieri et al., 2016).

The variation and maintenance of engine rotation, operating speed and wheel slip influence the quality of the task performed, the power requirement and the traction efficiency of the agricultural machinery (Rinaldi et al., 2016; Battiato & Diserens, 2017), hence affecting the specific fuel consumption and thermal efficiency of the engine (Farias et al., 2017).

Although many authors have evaluated different types of gear shifting regime, mainly with mechanically or automatically actuated gears, most studies were conducted with a pre-established engine rotation and there are no specific experiments with variation in the gears near the engine rotation from a target speed chosen on the display (Jasper et al., 2016).

The objective of the experiment was to evaluate the operational and energy performance of an agricultural tractor under the automatic management regime of transmission and engine rotation, when subjected to the traction of different loads.

Material and Methods

The experiment was carried out at Canguiri Farm, municipality of Pinhais, PR, Brazil (latitude 25° 24' 38" S and longitude 49° 09' 05" W) with a mean altitude of 920 m, on concrete pavement, according to the standards of the American Society of Agricultural Engineers - ASABE EP 496.3 (ASAE, 2015).

The experiment was conducted in a randomized block design with two factors: the automatic management system of transmission and engine rotation (with and without) and different loads applied on the drawbar, through the 'comboio' method (Mialhe, 1996). The automatic management was allocated in strips and the loads on drawbar in plots (40, 75, 110 kN), which totaled six treatments. For each treatment, four replicates were performed, totaling 24 experimental units, with 50 meters length each.

The experiment used a Case IH tractor, Magnum 340 model, nominal power of 250 kW and extra power electronic management of 275 kW, with auxiliary front wheel drive - AFWD, Full PowerShift transmission (18 x 4) and automatic productivity management (APM) system. The APM software program acts on the electronic transmission manager, automatically selecting the ratio of transmission (gears) and engine rotation according to the loads of transmission.

The automatic managements of the transmission and engine rotation were performed simultaneously, by the APM software,

from the theoretical speed selected on the display, which in this experiment was 2.22 m s^{-1} (8.00 km h^{-1}).

In the evaluation without the activation of the automatic transmission and engine rotation system, the gear number eight was selected at an engine rotation of 2000 rpm, resulting in speed close to 2.35 m s^{-1} (8.46 km h^{-1}).

The tractor used in the experiment was mounted with double wheels, Goodyear brand, 480/70R34 on the front with pressures of 96.5 and 82.7 kPa for the internal and external wheels, respectively, and 710/70R42 on the rear with pressures of 68.9 and 55.2 kPa, for the internal and external wheels, respectively.

The advance rate of the front wheel compared to the rear was 1.60%, when the AFWD was activated. The static masses on the tractor axles were determined with a CELMI scale, CM-1002 model, composed of four pads. 40% of water was added in all tires (internal and external), as well as 810 kg of metallic ballast at the front and 2270 kg at the rear, available in a total mass of 18,625 kg distributed as 42% on the front axle and 58% on the rear axle.

In the 'comboio' method, the brake tractor consisted of a Case IH tractor, Steiger 370 model, with 275 kW of nominal power, 16 x 2 Full PowerShift transmission, equipped with 710/70R42 front and rear double wheels, to provide loads of 40, 75 and 110 kN on the tractor pull bar evaluated in the experiment. The brake tractor was driven at a slower speed than the tractor tested (changing the engine speed and transmission gears), affecting the load on the drawbar, allowing variation of up to 5% in desired loads. The loads on the drawbar were chosen based on the ASABE 497.7 (ASAE, 2011) standard, considering a 4 x 2 tractor and concrete surface.

The tractor was instrumented with the sensors described below, connected to the data acquisition system (DAS), with a printed circuit board (Jasper et al., 2016). Acquisition frequency was one hertz, with values stored directly on the hard disk.

Wheel slip was measured using encoders from Autonics brand, E100S model. Engine rotation was determined from the power takeoff, also obtained by Autonics E100S encoder. The transmission ratio between engine rotation and power takeoff was obtained by means of a Victor digital tachometer, DM6236P model.

Hourly fuel consumption (HFC) was measured by Flowmate OVAL MIII - LSF 45 flowmeters, installed in the tractor fuel supply system (inlet and return to tank). Drawbar force (DBF) was measured using Bermann load cell, with a capacity of 300 kN, sensitivity of 2.0+0.002 mV/V and accuracy of 0.01 kN, installed on the drawbar coupled to the tractor.

The operating speed (OS) was determined by a Vansco radar, 740030A model. The power available on the drawbar was determined through Eq. 1.

$$DBP = (DBF \cdot OS) \qquad (1)$$

where:
DBP - drawbar power, kW;
DBF - mean drawbar force, kN; and,
OS - operating speed, m s^{-1}.

The diesel oil density function presented in Eq. 2 was obtained in laboratory according the NBR 7148 (ABNT, 2013). Diesel oil density was corrected through the temperatures obtained by type-K thermocouple, being previously recorded at the fuel inlet in the flowmeter and at the outlet.

$$D = 844.14 + (-0.53\ T) \qquad (2)$$

where:

D - diesel oil density, g L^{-1};
T - diesel oil temperature, °C; and,
844.14 and 0.53 - density regression parameters.

Hourly fuel consumption on mass basis was determined by Eq. 3.

$$HFCm = (HFCv \cdot D) \qquad (3)$$

where:

HFCm - hourly fuel consumption on mass basis, kg h^{-1}; and,
HFCv - hourly fuel consumption on volume basis, L h^{-1};

Specific fuel consumption was obtained according to Eq. 4.

$$SFC = \left(\frac{HFCm}{DBP}\right) \qquad (4)$$

where:

SFC - specific fuel consumption, g kW h^{-1}; and,
DBP - drawbar power, kW.

Drawbar efficiency was calculated as a function of drawbar power and engine power, by Eq. 5, according to Gabriel Filho et al. (2010).

$$DBE = \left(\frac{DBP}{EP}\right)100 \qquad (5)$$

where:

DBE - drawbar efficiency, %;
DBP - drawbar power, kW; and,
EP   - engine power, kW.

Based on the specific consumption and lower heating value of the fuel, the engine thermal efficiency was determined using Eq. 6, according to Farias et al. (2017).

$$ETE = \left(\frac{3600}{SFC \cdot LHV}\right) \qquad (6)$$

where:

ETE - engine thermal efficiency, %; and,
LHV - lower heating value, 42.295 kcal kg^{-1}.

The collected data were subjected to Anderson-Darling normality tests and, if the value obtained rejected the normal distribution, it was transformed through the Box-Cox. Subsequently, the analysis of variance and Tukey test were performed using the program SigmaPlot 14.

RESULTS AND DISCUSSION

Table 1 presents the results of the ANOVA and the means comparison test for the variables analyzed, as well as the coefficient of variation and normality test. The coefficient of variation for all parameters was classified as stable, according to the classification of Ferreira (2018).

It was verified that, when activated in the tractor, the automatic management system of the transmission and engine rotation caused statistical difference in the variables (SLP, ER, HFCv, DBF, OS, SFC and ETE) when compared to its non-activation, with no difference in the variables DBP and DBE. Regarding the loads tested, the variables analyzed (SLP, DBF, DBP, DBE and ETE) showed significantly higher absolute values, as the pulled load increased.

Table 1. Summary of the analysis of variance and means comparison test

Factors	SLP	ER[1]	HFCv	DBF[1]	OS	DBP	SFC	DBE	ETE[1]
AD									
Tabulated	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99
Calculated	0.46[N]	1.53[A]	0.42[N]	1.24[A]	0.98[N]	0.96[N]	0.96[N]	0.26[N]	1.47[A]
Box-Cox		0.31[N]		0.57[N]					0.24[N]
F test									
EM	29.47**	205.62**	263.42**	11.38*	602.95**	6.02[NS]	73.23**	6.01[NS]	15.72*
TL	109.32**	1.27[NS]	89.08**	70.98**	2.090.95**	744.88**	74.64**	744.24**	62.31*
EM x TL	0.10[NS]	84.34**	4.21[NS]	2.98[NS]	35.26**	37.10**	4.37[NS]	37.08**	2.42[NS]
CV − %									
EM	10.10	1.04	4.82	2.81	1.03	3.22	8.59	3.22	10.95
TL	11.67	0.73	6.73	3.97	0.61	3.91	7.96	3.92	8.66
EM x TL	14.43	1.04	7.85	2.51	0.81	2.33	8.59	2.33	6.37
Electronic management − EM									
	%	rpm	L h^{-1}	kN	m s^{-1}	kW	g kW h^{-1}	%	%
Without APM	3.82 a	1.916 a	50.53 a	74.85 a	1.99 b	145.33	297 a	62.16	28.73 b
With APM	3.05 b	1.750 b	36.61 b	70.27 b	2.21 a	150.09	220 b	64.19	41.04 a
Tested Loads − TL (kN)									
40	2.11 c	1.836	33.13 c	40.78 c	2.22 a	89.92 c	302 a	38.46 c	27.53 b
75	3.16 b	1.845	52.52 a	68.73 b	2.21 a	151.98 b	287 a	65.00 b	29.82 b
110	5.03 a	1.818	45.06 b	108.21 a	1.86 b	201.24 a	186 b	86.07 a	47.32 a

SLP - Wheel slip; ER - Engine rotation; HFCv - Hourly fuel consumption; DBF - Drawbar force; OS - Operating speed; DBP - Drawbar power; SFC - Specific fuel consumption; DBE - Drawbar efficiency; ETE - Engine thermal efficiency; APM – Automatic productivity management system; 1 - Transformed value (Box-Cox) for ANOVA; In each column, for each factor, means followed by the same lowercase letter do not differ by Tukey test (p ≤ 0.05); ns, *, ** - Not significant, and significant at p ≤ 0.05 and p ≤ 0.01 by F test, respectively;. CV - Coefficient of variation; AD - Anderson-Darling Normality Test (p ≤ 0.01): N - Normality; A - Abnormality

The results obtained for SLP in both factors were below the range from 4 to 8% on concrete surface recommended by ASABE D496.3 (ASAE, 2011). These results were possibly influenced by the surface in contact with the tire, ballast and type of tire, as explained by Monteiro et al. (2009) and by Battiato & Diserens (2017).

Higher SLP when the APM is not activated can be explained by the higher ER, since the concrete track, ballast and tires were the same. Therefore, the higher ER when the APM was not activated caused the higher wheel rotation, leading to lower grip of the tire with the concrete surface, hence increasing SLP.

SLP was 20% lower when APM was activated, promoting a 10% increment in OS compared to the non-activation of APM, variables that directly or indirectly interfere in the operational performance of the agricultural tractor, as explained by Battiato & Diserens (2017) and Mamkagh (2019).

The lower ER and SLP directly affect the HFCv (Janulevicius & Damanauskas, 2015), which was 28% lower compared to the non-activation of APM. Li et al. (2019) also found lower fuel consumption when they obtained lower engine rotation, studying transmission of agricultural tractor, and Damanauskas & Janulevicius et al. (2015) obtained increased slippage, which led to an increase in fuel consumption. For the different loads pulled, there was no statistical difference in ER.

In relation to DBF, its value was higher when APM was not activated, despite the higher SLP, which can be explained by the higher ER, agreeing with the results obtained by Battiato & Diserens (2017) and disagreeing with the results of Russini et al. (2018), who observed an increase in SLP leading to a reduction in DBF.

DBP did not differ statistically when APM was activated, for being constituted by OS multiplied by DBF, so OS was higher when APM was used, but it was compensated by the higher DBF when APM was not activated. DBE reflects the behavior of DBP; therefore, it also showed no statistical difference with the activation or not of APM.

As DBP did not differ, the higher SFC when APM was not activated can be explained by the higher HFCv and lower OS expressed in this factor. Gabriel Filho et al. (2010) also obtained lower SFC values at higher operating speeds when analyzing an agricultural tractor. Thus, ETE was 40% higher when APM was activated, compared to its non-activation, hence leading to higher energy efficiency, as described by Peça et al. (2010).

By analyzing the different loads pulled, it can be noted that the variables OS, SFC and ETE did not differ statistically for the loads of 40 and 75 kN. The lowest OS at the load of 110 kN can be explained by the higher DBF, being 62.31 and 36.48% higher than the values for 30 and 75 kN, respectively, requiring greater pull force, which would be available on the axle in the form of torque for the wheel to develop higher OS. Similar results were obtained by Jasper et al. (2016), analyzing agricultural tractor with manual and automatic gear management.

As for the fact that SFC did not differed at both loads (40 and 75 kN) and was lower at the highest load, it can be explained by the higher HFCv at the load of 75 kN to maintain higher OS and by the lower DBP at the load of 40 kN, compensating the variables that constitute the SFC. The absence of difference in ETE at the lowest loads can also be explained in the same way, as it is given as a function of SFC, being lower at 40 and 75 kN and higher at 110 kN.

The higher values of DBP and DBE observed when the load increased can be explained by the increase in DBF. The variables ER, OS, DBP and DBE were significantly affected by the interaction between the factors analyzed, and the interactions were decomposed in Table 2.

By analyzing the interactions, it was possible to note that ER and OS were higher when the APM was not activated at the loads of 40 and 75 kN and lower at the load of 110 kN. As the load increased, the APM promoted an increase in ER seeking to maintain the OS, which explains the higher ER at the load of 110 kN, different from the fixed rotation (without APM), triggering torque reserve, decreasing ER and OS due to the increase in the engine load, promoted by the higher load pulled.

At loads of 40 and 75 kN, when APM was not activated, there were higher values of DBP and DBE, variables that suffered interference from the higher ER and OS expressed in this factor. However, at the load of 110 kN, there was a reduction in engine rotation, reducing OS and hence promoting lower DBP and DBE. When APM was activated, the software program increased ER through the management and could maintain higher OS, consequently higher DBP and DBE, demonstrating its efficiency in the pulling of higher loads.

Table 2. Summary of interactions between electronic management (EM) and loads for the analyzed variables

EM	Tested loads (kN)		
	40	75	110
Engine rotation - ER (rpm)			
Without APM	2,000 aA	1,992 aA	1,756 bB
With APM	1,672 bB	1,699 bB	1,880 aA
Operating speed – OS (m s⁻¹)			
Without APM	2.34 aA	2.35 aA	1.79 bB
With APM	2.11 bA	2.07 bA	1.93 aB
Drawbar power – DBP (kW)			
Without APM	96.03 aA	159.59 aB	195.59 bC
With APM	83.81 bA	144.36 bB	206.88 aC
Drawbar efficiency – DBE (%)			
Without APM	41.07 aC	68.25 aB	83.65 bA
With APM	35.84 bC	61.74 bB	88.48 aA

Means followed by the same letters, uppercase in the rows and lowercase in the columns, do not differ by Tukey test (p ≤ 0.05); APM – Automatic productivity management system

Conclusions

1. The automatic transmission and engine rotation management system promoted 20% reduction in slippage, 10% increase in operating speed and 28% saving in hourly fuel consumption, hence leading to lower specific consumption and higher thermal efficiency of the engine, not affecting the tractor's pulling capacity.

2. As for the loads pulled, due to the higher engine rotation when the automatic productivity management system (APM) was not used, there was higher operating speed at the lowest load. At the highest load when the APM was used, the engine rotation was automatically increased, enabling higher speed.

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