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ENERGY EFFICIENCY OF AGRICULTURAL TRACTORS EQUIPPED WITH CONTINUOUSLY VARIABLE AND FULL POWERSHIFT TRANSMISSION SYSTEMS

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KEYWORDS

fuel consumption, operational velocity, performance, power.

ABSTRACT

The efficiency of agricultural tractor transmission has been improved over the years, with new concepts such as Continuously Variable Transmission (CVT) and Full Powershift (FPS) evolving in advanced technologies. Both options seek to offer the farmer greater operational results with lower energy expenditure, necessitating studies to assess the effectiveness of these technologies and define the best choice for each purpose. The objective of this work was to evaluate the energy efficiency of two tractors equipped with CVT and FPS transmissions. For this, a strip experiment was conducted in a randomized block design, that analyzed, in addition to CVT and FPS transmissions, target velocities of 4, 6, 8 and 10 km h^{-1}. Operational energy performance parameters were evaluated, such as slippage index, engine rotation, operational velocity, fuel consumption, power available and efficiency on the drawbar, turbo pressure and temperatures of air intake and exhaust gas. Based on the results obtained, the tractor with FPS transmission was more energy efficient in most of the analyzed parameters, requiring 16.31% less in hourly fuel consumption, and providing 16.29% more in the traction bar yield, however, with lower operational velocity compared to the tractor with CVT transmission.

INTRODUCTION

In essence, agricultural tractors are designed to efficiently convert energy from fossil fuels into traction force, while towing and mounting implements in the most varied environments (Xia et al., 2020). In addition to promoting the proper burning of fuels, it is essential that the tractor power train transmits the energy to the driving wheels, an action for which the transmission is responsible, through a set of combinations that allow a variation of torque and speed (Park et al., 2016).

Currently, different types of transmission are offered in the global agricultural machinery market, especially tractor models with Continuously Variable Transmissions (CVT) and automated Full Powershift (FPS), which, according to Mattetti et al. (2019), also stand out in terms of efficiency factors. CVT transmission works through pumps and hydraulic components driven by the motor energy, in which gears combine hydraulic and mechanical force, allowing the infinitely variable activation of ratio ranges, resulting in high operational capacity and transmission efficiency (Rotella & Cammalleri, 2018). Automatic FPS transmission operates by adjusting the gears and rotation of the engine through the electronic manager, with the gear coupling carried out by an electro-hydraulic system, which limits the number of gears (Li et al., 2019).

The energy efficiency achieved by agricultural tractors is directly related to the efficiency parameters of the engines and how this energy is transmitted during traction, with an emphasis on the transmission architecture. Thus, a knowledge of transmission efficiency allows to estimate the losses of energy supplied through combustion during the execution of agricultural operations (Bietresato et al., 2012; Damanauskas & Janulevičius, 2015).

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The performance and quality of the agricultural operation are influenced by the operational velocity, which is related to the efficiency and the amount of power provided by the power train (Jasper et al., 2016). Moreover, the agricultural tractor must use the maximum engine power with the minimum fuel consumption, which increases proportionally with the increase in traction force and operational velocity (Damanauskas et al., 2019; Simikic et al., 2014).

Farias et al. (2017) evaluated the fuel consumption efficiency of a tractor equipped with CVT transmission, at different travel velocities and partial loads on the tractor's drawbar, and found that, in general, the specific fuel consumption decreased as partial loads and velocities were increased. Molari & Sedoni (2008), when evaluating the energy performance of a tractor equipped with FPS transmission in different operational conditions, found high energy losses in high gears, passive resistance and friction in the transmission together with the power absorbed by the hydraulic circuit in the neutral position.

Based on this, in this paper we evaluate the energy efficiency of two tractors equipped with CVT and FPS transmissions, subjected to traction effort at different target velocities.

MATERIAL AND METHODS

Experimental design

The research was conducted on a concrete surface, in an experimental area in Pinhais, PR, Brazil, according to ASAE (2011a). The banded experiment, conducted in a randomized block design, consisted of two tractors with CVT and FPS transmissions (T), allocated to plots, and the target velocities (v_T) in the subplots (4, 6, 8 and 10 km h^{-1}), resulting in eight treatments. For each treatment, five repetitions were performed, totalling 40 experimental units, in bands of 50-m length each.

The tractors evaluated in this research were the Case IH® models Magnum 380 and 340, with CVT and FPS transmissions, respectively; their technical specifications are shown in TABLE 1. The tractor with FPS transmission was equipped with automatic productivity management, which was kept activated during the tests, automatically selecting the gear ratio and engine rotation according to the transmission's load, the hydraulic system and the power take-off, maintaining the constant pressure of the clutch (Strapasson et al., 2020). Moreover, 40% of hydraulic ballast was added to all the tyres of both tractors, resulting in the static mass also shown in TABLE 1.

TABLE 1. Technical specifications of the tractors.

Tractor	Case IH Magnum 380		Case IH Magnum 340	
Transmission	CVT		FPS (18x4)	
Nominal power (kW/cv)*	283 / 380		250 / 340	
Traction type	4x2 AFWD**		4x2 AFWD**	
Anticipation index (%)	1.68		1.60	
Total static mass (kg)	21,171.34		18,631.23	
Power-mass ratio (N kW^{-1}/N cv^{-1})	733.59 / 546.32		730.85 / 537.39	
	Front-axle	Rear-axle	Front-axle	Rear-axle
Static mass distribution (%)	40	60	42	58
	Front tyres	Rear tyres	Front tyres	Rear tyres
Tyre type	Goodyear 480/70R34	Goodyear 710/70R42	Goodyear 480/70R34	Goodyear 710/70R42
Tyre pressure (kPa/psi)	96.50 / 14 (I)*** 82.74 / 12 (E)****	68.95 / 10 (I)*** 55.20 / 8 (E)****	96.50 / 14 (I)*** 82.74 / 12 (E)****	68.95 / 10 (I)*** 55.20 / 8 (E)****

*ISO TR14396; **AFWD – auxiliary front-wheel drive; ***I – internal wheelset; ****E – external wheelset.

The experiment was conducted using the train method, that is, the evaluated tractors pulled a third Case IH Steiger model tractor, which acted as a brake. Braking was performed by a pre-established gear, providing 103 kN as traction force, selected based on the ASAE (2011b) standard, which resulted in an available power of 198.5 kW (270 cv) in the drawbar. During the experiment, both tractors had AFWD activated and the fuel tank was also full.

Evaluated parameters

The tractors were fitted with sensors described below (FIGURE 1), connected to a data acquisition system, with a printed circuit board as described in Jasper et al. (2016).

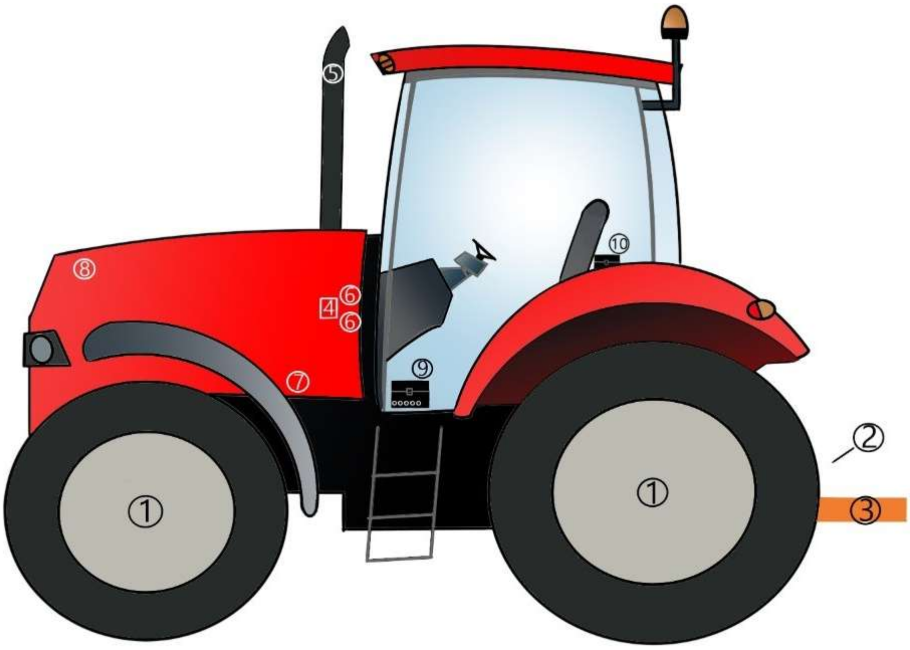


FIGURE 1. The following sensors are arranged in the following order: Encoders on the four wheelset (1), Encoder on the power take-off (2), Load cell (3), Inlet and outlet flowmeters (4), Exhaust temperature sensor (5), Sensors Temperature Sensor (6), Engine Oil Temperature Sensor (7), Cooling Air Temperature Sensor (8), Temperature Data Acquisition Box (9) and Central Data Acquisition Box (10).

The following operational energy performance parameters were evaluated: slippage index (S_I); engine rotation (E_R); hourly (FC_H) and specific (FC_S) fuel consumptions, and engine thermal efficiency (ET_η). The determination of these parameters are fully described in Strapasson et al. (2020). The operational velocity (v_O) was determined as a function of the number of pulses emitted by 740030A radar (Vansco Electronics LP Inc., Canada).

The turbo pressure (TP), force (DB_F), power available (DB_P) and efficiency (DB_η) on the drawbar, and air intake (I_T) and exhaust gas (E_T) temperatures, were determined according to Oiole et al. (2019). Furthermore, TP was measured using a MPX 5700DP piezoresistive pressure transducer model (Motorola Inc.) to assess the pressure at the tractor engine intake manifold during the tests; and I_T and E_T were measured during the test using type-K thermocouples placed at the air filter inlet, and exhaust, respectively.

The data collected from the described parameters were assessed by normality (SW – Shapiro-Wilk) and homogeneity of variance (BF – Brown-Forsythe). Given these premises, they were subjected to analysis of variance (ANOVA) to verify the effects of factors (T and v_T) and their interaction, through the statistical software SigmaPlot 12 (Systat Software Inc., CA, USA). When the F-test presented a significant probability value ($P<0.05$), the averages were compared using the Tukey test ($P<0.05$) for qualitative factors (T). The regression test was applied for quantitative factors (v_T and interaction), with models selected by the criterion with the highest determination coefficient (R^2) and significance ($p<0.05$) of the equation parameters. Furthermore, to facilitate the presentation and discussion of the results obtained, the data were separated into two datasets.

RESULTS AND DISCUSSION

TABLE 2 shows the synthesis results for the analyses of the first set of operational energy performance parameters, with no need to transform the means, denoting the normality (SW) and homogeneity of the variance residues (BW), except for the FC_H and v_O parameters, which showed heterogeneous behavior. Moreover, the coefficient of variation (C_V) in all parameters was categorized as “stable”, except for S_I, which was classified as “average dispersion” (Ferreira, 2018).

TABLE 2. Synthesis of the analysis of variance and the test of means for the evaluated operational energy performance parameters (Set I).

Analysis		Parameters					
		S_I (%)	E_R (rpm)	FC_H (L h^{-1})	DB_F (kN)	v_O (km h^{-1})	DB_P (kW)
	SW	0.650	0.277	0.726	0.138	0.319	0.805
	BF	0.917	0.735	0.042	0.892	0.033	0.500
-test	T	52.42**	7,703.01**	2,143.81**	9.86*	30.89**	119.67**
	v_T	15.99**	3,715.75**	303.89**	1.07^{NS}	5,095.75**	903.41**
	T x v_T	0.56^{NS}	1,255.78**	29.28**	7.06**	5.13*	9.07**
v (%)	T	13.06	0.45	1.21	2.84	1.81	1.94
	v_T	15.32	0.40	4.76	3.95	1.49	3.44
	T x v_T	16.66	0.37	5.90	2.86	1.69	2.52
lean test	380 CVT	2.38 b	1,548 b	46.89 a	68.03 b	7.13 a	129.62 b
	340 FPS	3.22 a	1,756 a	39.24 b	69.97 a	6.61 b	138.60 a

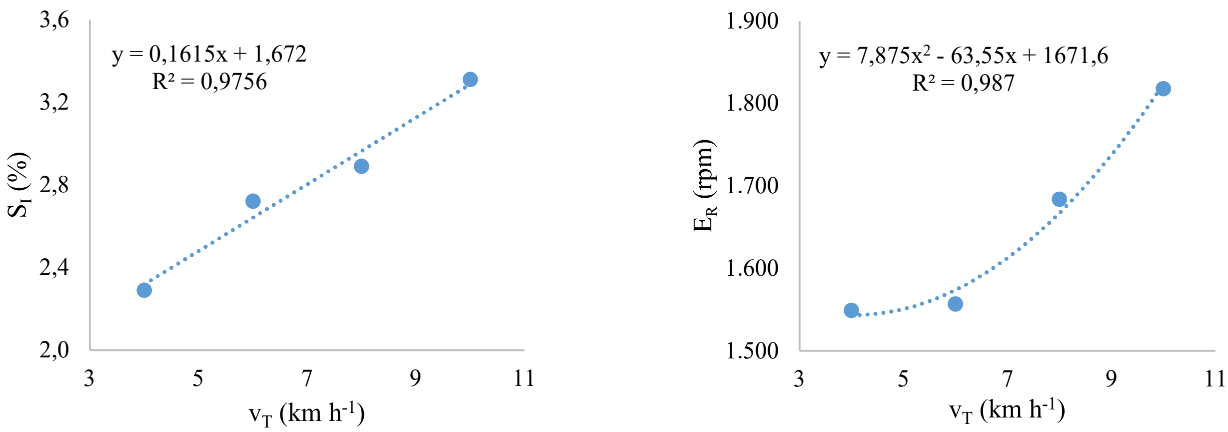
Values with different letters in a column are significantly different (P<0.05). F-test: NS – not significant; * – P<0.05; ** – P<0.01. Shapiro-Wilk normality test: SW ≤0.05 – abnormal data; SW >0.05 – data normality. Brown-Forsythe homogeneity test: BW ≤0.05 – heterogeneous variances; BW >0.05 – homogeneous variances. C_V – coefficient of variation; S_I – slippage index; E_R – engine rotation; FC_H – hourly fuel consumption; DB_F – force on the drawbar; v_O – operational velocity; DB_P – power on the drawbar; T – transmission factor; v_T – target velocity factor; 380 CVT – tractor with CVT transmission; 340 FPS – tractor with FPS transmission.

The results obtained for both tractors in the slip were below the range recommended by ASAE (2011a), which recommends 4 to 8% when operated on a concrete surface. The 340 FPS slipped 0.84% more than the 380 CVT, therefore requiring greater engine rotation (13.4%) (TABLE 2). This can be explained by the fact that the S_I is delimited in an ideal range, with minimum values representing overload in the power train and maximum values indicating energy expenditure generated by the greater surface-tyre interaction (Battiato & Diserens, 2017).

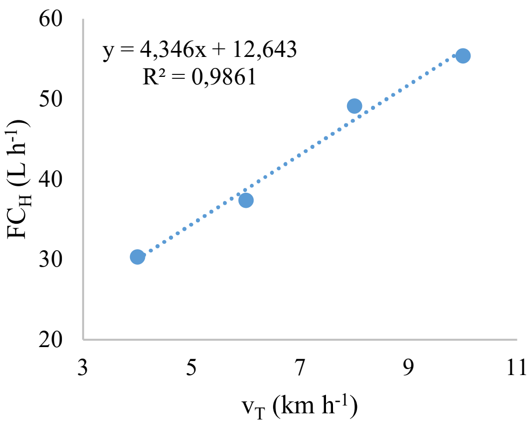
The tractor with CVT transmission consumed 16.3% more fuel per hour compared to the 340 FPS transmission (TABLE 2). The operation of the CVT system occurs through the hydraulic force provided by an auxiliary pump, demanding greater power consumption from the engine, which results in a greater energy expenditure to reach the target velocity, even at lower engine rotation (Qu et al., 2019). Furthermore, the highest consumption, even in smaller E_R, was provided by the electronic management of the CVT transmission in relation to FPS, which does not take into account only the E_R, but also the necessary load for the activation of the aforementioned hydraulic pump.

In TABLE 2, the force exerted on the drawbar was slightly higher for the 340 FPS (2.9%), which may have been provided by the higher S_I, indicating an increase in the tyre-surface interaction, providing notable growth in the traction on the drawbar (Battiato & Diserens, 2017). Also, in TABLE 2, the 380 CVT expressed a 7.9% higher v_O, corroborating Bietresato et al. (2012), who also obtained a higher operational speed with a tractor equipped with this type of transmission in relation to a tractor with automatic transmission. And finally, the power available on the drawbar was 6.9% higher for the 340 FPS tractor, a result that can be explained by the higher DB_F compared to the 380 CVT.

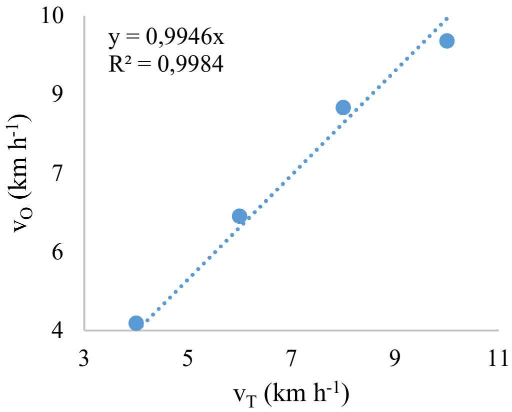
Analyzing the effect of the target velocities on the parameters evaluated so far, linear behaviours were observed for S_I, FC_H, v_O and DB_P, and quadratic for E_R, with R^2>0.97 in all cases (FIGURE 2).



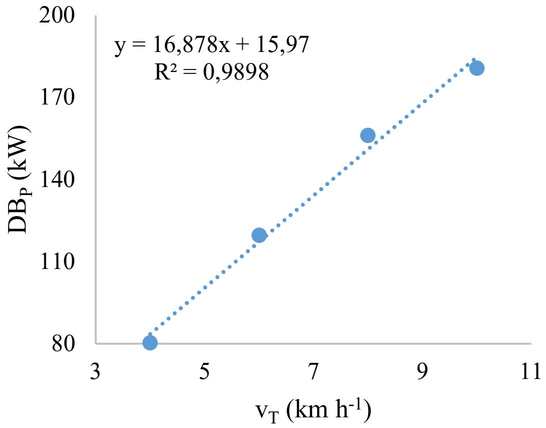
(a) (b)



(c)



(d)



(e)

FIGURE 2. Regression analysis for the isolated target velocity (v_T) factor in the parameters: (a) slippage index (S_I); (b) engine rotation (E_R); (c) hourly fuel consumption (FC_H); (d) operational velocity (v_O); and, (e) power on the drawbar (DB_P).

According to the generated equation in FIGURE 2a, an increase of 0.16% in slip is observed with an increase of 1 km h^{-1}, added to the 1.67% necessary for the system to minimize overload on the transmission components. It can be explained by the slippage index being influenced by the selected ballast and target velocity (Monteiro et al., 2011). Regarding the equation for the engine rotation in FIGURE 2b, it is observed that the lowest rotation of 1,544 rpm occurred at the target speed of 4 km h^{-1}, considering that the performance of the automatic productivity management in the transmission, in order to reach the target velocity, influenced the engine rotation (Strapasson et al., 2020). For hourly fuel consumption, there was an increasing trend of 4.34 L h^{-1} every 1 km h^{-1}, added to the 12.64 L h^{-1} required for the maintenance of the power train components (FIGURE 2c). This increase in FH_C is due to the selection of high gears to result in a higher effective speed, and, consequently, to increase fuel consumption (Martins et al., 2018).

By the equation presented in FIGURE 2d for the operational velocity, it is possible to reach 99.46% of the desired velocity due to the slippage of the driving wheels and the occurrence of alternations in the loading moments on the engine. This situation occurs because the traction component is related to the torque transmission performance of the wheel to the drawbar, in addition to v_O being given by the wheels spinning, corroborating with Vantsevich (2007). For the power in the drawbar, the equation obtained allows an increase of 16.87 kW to be observed, added to the 15.97 kW results of the product of the traction force by the displacement velocity (FIGURE 2e), which can be explained by the greater applied target velocity providing an increase in the performance of power in the drawbar; a similar result was also reported by Gabriel Filho et al. (2010).

Due to the significant interactions observed between v_T and types of transmission shown in TABLE 2, it was possible to generate equations capable of representing them (FIGURE 3).

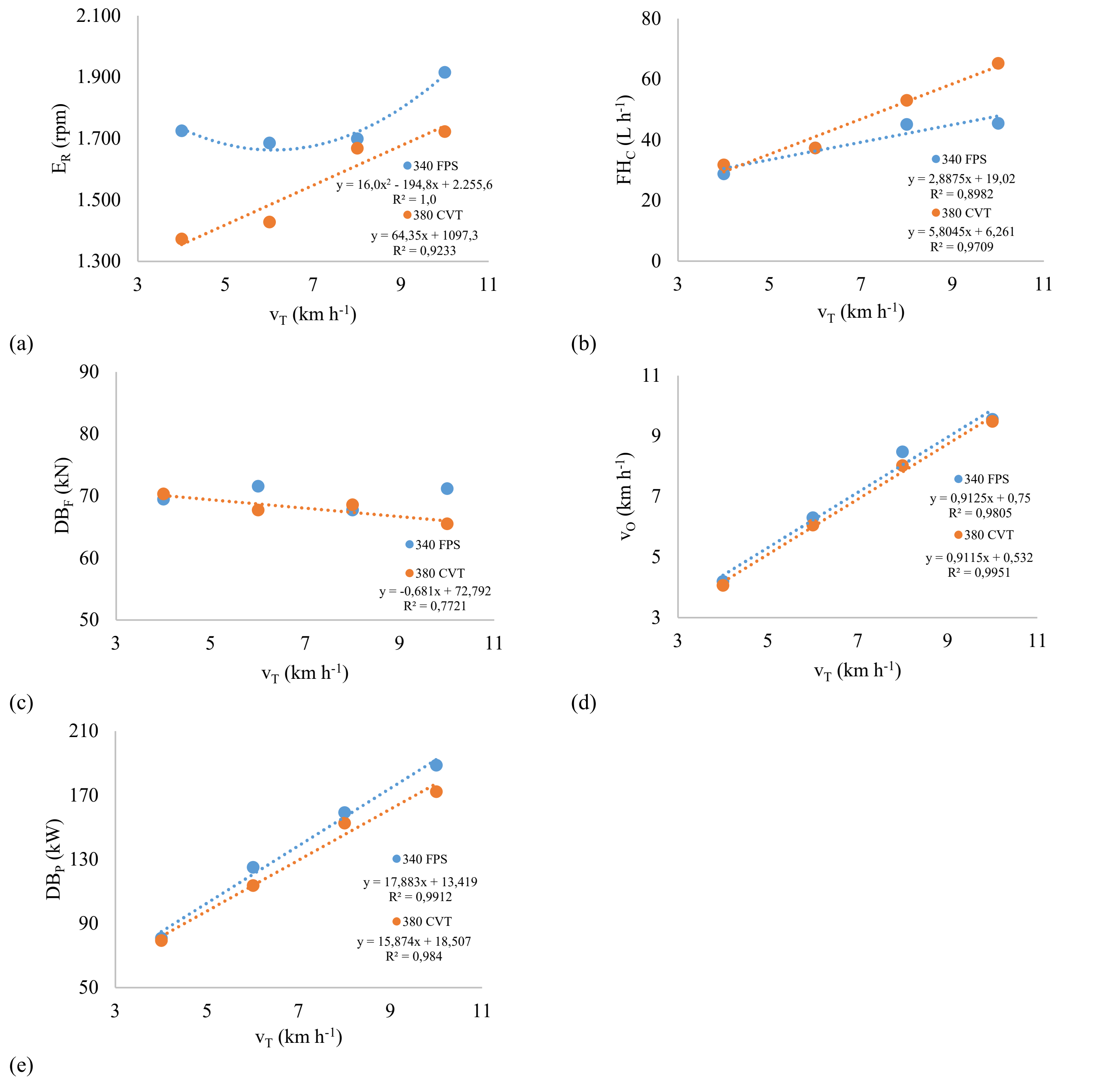


FIGURE 3. Regression analysis of the interaction transmissions (340 FPS and 380 CVT) and target velocity (v_T) in the parameters: (a) engine rotation (E_R); (b) hourly fuel consumption (FC_H); (c) force on the drawbar (DB_F); (d) operational velocity (v_O); and (e) power on the drawbar (DB_P).

For the engine rotation, it is noted that the 380 CVT and 340 FPS presented linear and quadratic equations with the increase in v_T, respectively (FIGURE 3a). It is also observed that for the 340 FPS it reaches the minimum E_R (1,662 RPM), the v_T will be 6 km h^{-1}, in addition to presenting an E_R higher than that of the 380 CVT in all evaluated v_T, corroborating with Piros & Farkas (2012).

Hourly fuel consumption was similar at the lowest speeds for both transmissions, however, for the two highest v_T, the 340 FPS demanded an average of 22.60% (-13.83 L h^{-1}) less fuel than the 380 CVT, demonstrating its energy advantage (FIGURE 3b). This result corroborates the postulate by Mayet et al. (2019) that conventional CVT technology is not yet competitive due to its relatively lower efficiency compared to other transmission models. For the force on the drawbar, there was no trend for the 340 FPS that can be explained mathematically (FIGURE 3c). On the other hand, for the 380 CVT, there was a decreasing behaviour for the DB_F as a function of v_T, corroborating with Lopes et al. (2010) when describing that the DB_F is related to the traction force and v_O, since at lower v_O there is a greater traction force.

The operational velocity on both tractors showed similar behaviour, with a slight average advantage of 3.27% for the 340 FPS compared to the 380 CVT (FIGURE 3d). In addition, the interaction between DB_P and target speeds also demonstrates an advantage for the 340 FPS tractor, which was, on average, 6.44% higher for all v_T, with a greater distance from the 380 CVT at higher velocities (FIGURE 3e).

TABLE 3 shows the synthesis results for the analyses of the second set of operational energy performance parameters, which also did not show the need to transform the means. With the exception of the E_T parameter, the others showed normal variance residues (SW). For homogeneity of the variance residues (BF), the parameters PT and I_T showed heterogeneous behaviour. Moreover, all C_V are categorized as "stable" (Ferreira, 2018).

TABLE 3. Synthesis of the analysis of variance and the test of means for the evaluated operational energy performance parameters (Set II).

Analysis		Parameters					
		DB_η (%)	FC_S (g kW h^{-1})	ET_η (%)	TP (kPa)	I_T (°C)	E_T (°C)
	SW	0.199	0.520	0.534	0.191	0.985	0.062
	BF	0.523	0.521	0.259	0.049	0.026	0.929
-test	T	850.94**	993.94**	740.63**	0.307^{NS}	1,540.50**	259.01**
	v_T	898.76**	34.26**	33.72**	295.02**	572.22**	721.96**
	T x v_T	21.08**	18.62**	33.33**	26.07**	870.88**	77.67**
$_V$ (%)	T	1.92	2.07	2.57	2.80	1.93	5.72
	v_T	3.47	6.05	6.19	4.23	0.90	1.51
	T x v_T	2.76	5.38	5.18	2.24	1.02	4.31
lean test	380 CVT	46.50 B	310 A	27.73 B	83.81 A	27.04 B	183.52 B
	340 FPS	55.55 A	252 B	34.62 A	82.83 A	34.30 A	246.04 A

Values with different letters in a column are significantly different (P<0.05). F-test: NS – not significant; * – P<0.05; ** – P<0.01. Shapiro-Wilk normality test: SW ≤0.05 – abnormal data; SW >0.05 – data normality. Brown-Forsythe homogeneity test: BW ≤0.05 – heterogeneous variances; BW >0.05 – homogeneous variances. C_V – coefficient of variation; DB_η – drawbar efficiency; FC_S – specific fuel consumption; ET_η – engine thermal efficiency; TP – turbo pressure; I_T – intake air temperature; E_T – exhaust gas temperature; T – transmission factor; v_T – target velocity factor; 380 CVT – tractor with CVT transmission; 340 FPS – tractor with FPS transmission.

TABLE 3 shows that the tractor equipped with FPS transmission provided 9.05% more of the energy provided by the engine (i.e. DB_η), even with less power. This parameter highlights the efficiency of this transmission system in relation to CVT, due to the greater capacity to transfer the available energy to the wheelsets. The efficiency of these transmission mechanisms is directly related to the energy demanded for its operation and the losses generated, considering that the CVT mechanism requires an auxiliary pump for its operation. Molari & Sedoni (2008) point out that the factors gear speed, lubrication regime, transmission material and oil temperature directly influence power losses and, therefore, the efficiency.

The smallest FH_C and the greatest capacity to transfer available energy (DB_η) of the 340 FPS, express the most efficient use of the fuel demanded, resulting in a lower specific fuel consumption. Also, the 380 CVT required 58 g (23.02%) more fuel to generate the energy equivalent to the 340 FPS, indicating less efficiency in converting fuel to work, as explained by Mayet et al. (2019). Furthermore, due to this lower FC_S, it can also be seen in TABLE 3 that the 380 CVT presented 6.89% less in the use of energy in the engine (i.e. ET_η). The high energy efficiency of the 340 FPS compared to the 380 CVT demonstrates greater use of the calorific value of fossil fuels, an essential factor for the development of sustainable agriculture (Bietresato et al., 2015).

And finally, the highest exhaust gas temperature for the 340 FPS was provided by the highest expressed E_R, as reported and explained by Bietresato et al. (2015). In addition, this factor was also higher due to the higher air intake temperature observed in the engine, which was increased due to the variation in air temperature (i.e., uncontrollable factors), as well as the higher DB_P and DB_η expressed, with greater power requirements for traction, which generated greater engine effort and, consequently, increased E_T (Castellanelli et al., 2008).

Analyzing the isolated effect of v_T on the second set of parameters evaluated, we observe the linear behaviour for DB_η and TP (R^2>0.96 – FIGURE 4a,d) and quadratic for FC_S, ET_η, I_T and E_T (R^2>0.88 – FIGURE 4b,c,e,f).

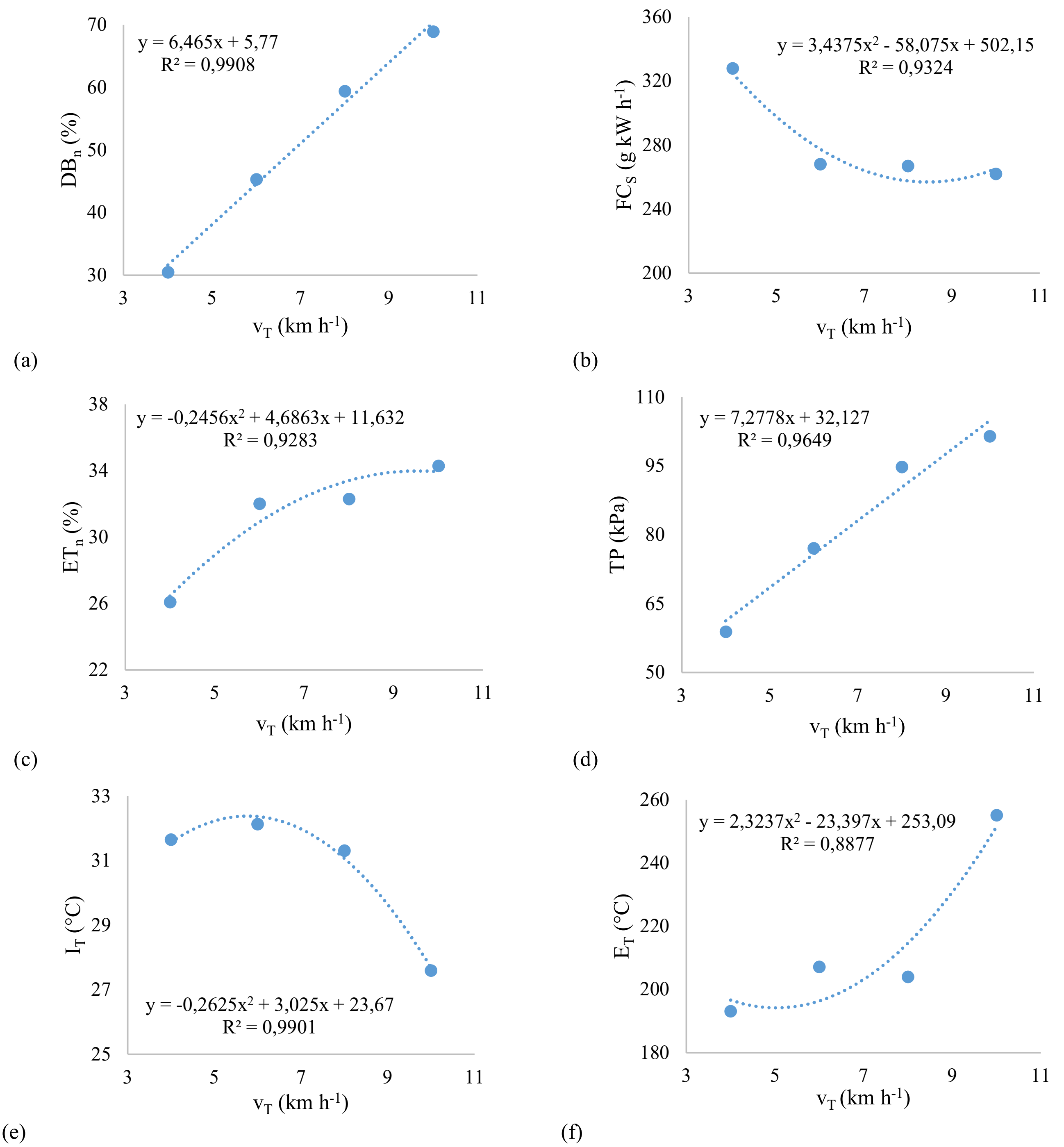


FIGURE 4. Regression analysis for the isolated target velocity (v_T) factor in the parameters: (a) drawbar performance (DB_η); (b) specific fuel consumption (FC_S); (c) engine thermal efficiency (ET_η); (d) turbo pressure (TP); (e) intake air temperature (I_T); and, (f) exhaust gas temperature (E_T).

FIGURE 4a shows an increase of 6.46% in the drawbar efficiency with an increase of 1 km h^{-1}, added to 5.77% due to the travel velocity and the ratio weight-power of the tractor. According to Monteiro et al. (2013), this can be explained by DB_η varying according to the magnitude of the torque that the motor-transmission set is capable of applying to the wheelset. According to the equation generated in FIGURE 4b, the lowest FC_S (256.86 g kW h^{-1}) occurred at v_T=8.45 km h^{-1}. Low values of specific fuel consumption in higher v_T mean simultaneous optimization of engine performance, efficiency in traction and the suitability of the implement to the energy supply. Regarding the thermal efficiency of the engine, the highest value (33.98%) occurred at v_T=9.54 km h^{-1}, since, when employing rotations close to the maximum torque and high v_T, the engine reaches the higher range of TE_M, which favours the reduction of fuel consumption (Serrano et al., 2007).

Regarding the intake air and exhaust gas temperatures of the engine, by equations generated in FIGURES. 4e and 4f, maximum and minimum values of 32.4 and 194.19 °C were obtained at v_T of 5.76 and 5.03 km h^{-1}, respectively. Because the pressure in the intake manifold and the mass flow of gases through the compressor are increased at higher v_T, it reflects in the air-fuel ratio and the fraction of the exhaust gases (Zhang et al., 2013). Furthermore, higher speeds require an increase in injected fuel, resulting in an increase in the enthalpy of the gases released in the exhaust (Giakoumis, 2016).

As with the first set of parameters, equations were generated through the significant interactions shown in TABLE 3 between v_T and the types of transmission (FIGURE 5).

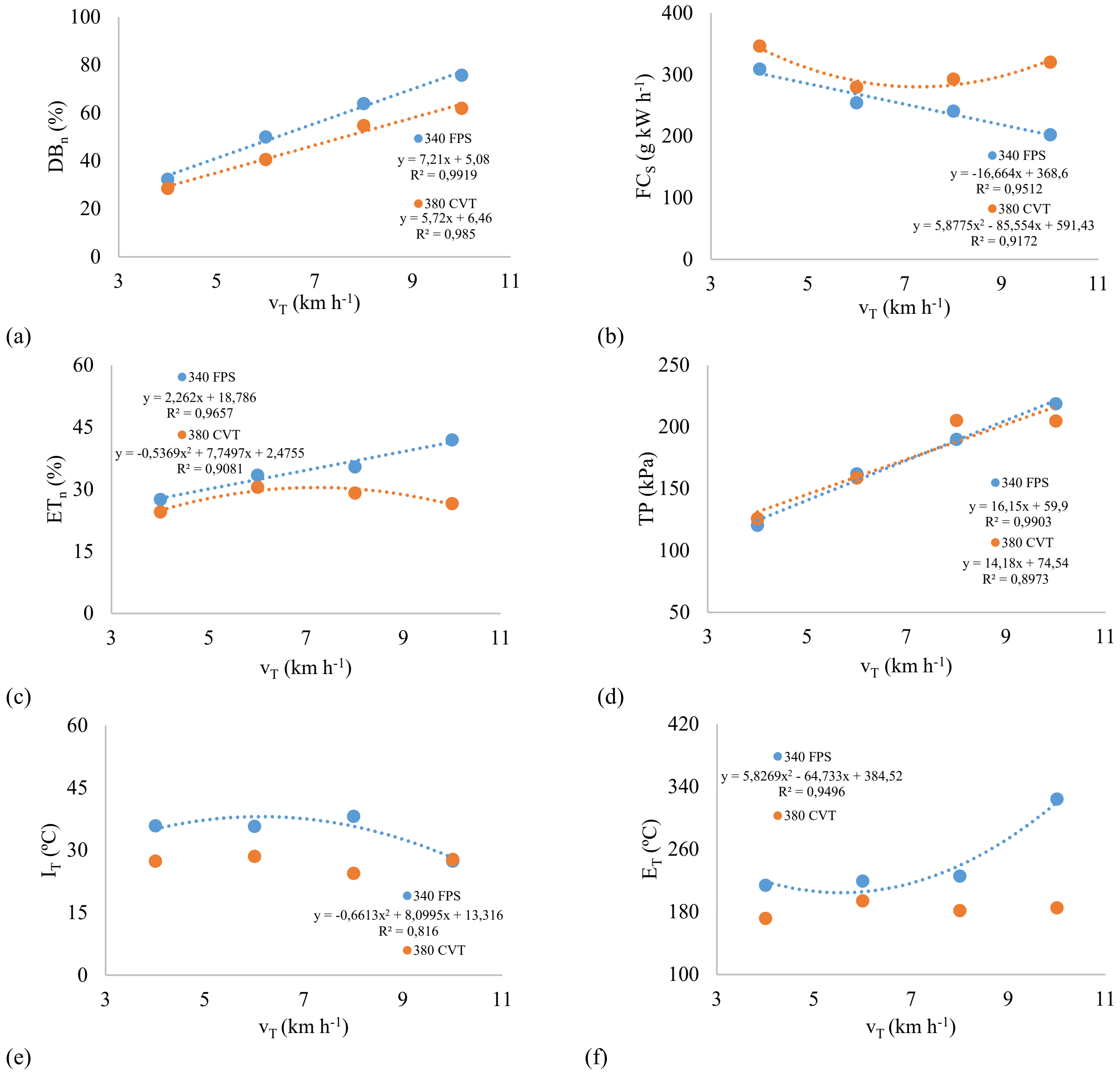


FIGURE 5. Regression analysis of the interaction transmissions (340 FPS and 380 CVT) and target velocity (v_T) in the parameters: (a) drawbar efficiency (DB_η); (b) specific fuel consumption (FC_S); (c) engine thermal efficiency (ET_η); (d) turbo pressure (TP); (e) intake air temperature (I_T); and, (f) exhaust gas temperature (E_T).

The drawbar efficiency showed a positive linear trend with an increase in v_T for both transmissions types (R^2>0.98 – FIGURE 5a). The 340 FPS had the highest DB_η in all v_{Ts}, which was increased by 1.31 times more with an increase in velocity by 1 km h^{-1}, showing greater efficiency in transferring the energy provided by the engine to the wheelsets. On the other hand, the lowest DB_η observed on the 380 CVT can be attributed to the energy demand of the additional hydraulic pump for its operation.

With the increase in v_T, the FC_S showed linear and quadratic trends for the 340 FPS and 380 CVT, respectively (R^2>0.91 – FIGURE 5b). The tractor equipped with FPS transmission had lower FC_S, reducing 16.66 g kW h^{-1} with an increase of 1 km h^{-1}, providing greater efficiency at higher target velocities. On the other hand, the 380 CVT had the lowest FC_S (280.09 g kW h^{-1}) at v_T=7.27 km h^{-1}. Therefore, since the 340 FPS requires less fuel to produce the same energy, a higher ET_η is observed compared to the 380 CVT, which is higher in all evaluated v_T (FIGURE 5c). This greater efficiency of use is evidenced mainly at the highest v_T, due to the 380 CVT tractor having a maximum ET_η (28.27%) at v_T=5.21 km h^{-1}, which is 2.29% lower than the 340 FPS. The behaviour of this parameter on the 340 FPS tractor showed a linear trend with an increase of 2.26 times with an increase of 1 km h^{-1} as well.

The linear increase in the turbo pressure shown in FIGURE 5d, for both transmission systems, showed an average variation of 9.55 kPa between them, due to the need to increase the supply of air volume to meet the ratio between air and fuel on the engine cylinders. The adjustment of the pressure and volume of compressed air is provided by changing the geometry of the turbine rotor vanes, which takes into account the engine speed and load condition (Feneley et al., 2017; Giakoumis & Tziolas, 2018).

The engine's air intake temperature at v_T of 4, 6 and 8 km h^{-1} was, on average, 9.82 ºC lower for the 380 CVT factor, and similar at v_T=10 km h^{-1} compared to the 340 FPS (FIGURE 5e). As previously mentioned, this can be explained by the variation of the air temperature in the environment during the course of the experiment, since the temperature was collected at the entrance of the air filter in both cases.

Analyzing FIGURE 5f, the 340 FPS showed a higher exhaust gas temperature at all v_T compared to the 380 CVT, which can be explained by the higher E_R and torque obtained by the 340 FPS, plus the higher air intake temperature of the motor, as previously shown in FIGURE 5e (Bietresato et al., 2015). According to Macor & Rossetti (2011), the energy expenditure observed in the 380 CVT tractor, in relation to the 340 FPS, is due to the double energy conversion that occurred in the transmission's hydraulic branch. However, tractors equipped with hydromechanical transmissions provide part of the power through a mechanical path, which is considered more efficient, and partly by a CVT, therefore conditioning greater durability of the components due to the smoothing of gear changes.

CONCLUSIONS

The tractor with FPS transmission was more energy efficient in most of the analyzed parameters, requiring less in hourly fuel consumption, and providing more in the traction bar yield, however, with lower operational velocity in relation to the tractor with CVT transmission.

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