ISSN: 1984-5529

Científica

Dracena, São Paulo, Brasil, v.50, 2022.

DOI: https://doi.org/10.15361/1984-5529.2022.v.50.1444

Traction performance of an agricultural tractor at different working speeds and surfaces

Desempenho em tração de um trator agrícola em diferentes velocidades de trabalho e superfícies

Alexandre RUSSINI[1]; Daniel Ciro de SOUZA[2]; Rogério Rodrigues de VARGAS[3]; Marcelo Silveira de FARIAS[4]; José Fernando SCHLOSSER[5]; Daniela HERZOG[6]

[1] Autor para correspondência, Doutor, Universidade Federal do Pampa, Campus Itaqui, Rua Joaquim de Sá Britto, S/N, CEP 97650-000, Itaqui/RSalexandrerussini@unipampa.edu.br
[2] Estudante do curso de Agronomia, Universidade Federal do Pampa,danielciro.aluno@unipampa.edu.br.
[3] Doutor, Universidade Federal do Pampa, rogeriovargas@unipampa.edu.br
[4] Doutor, Universidade Federal da Santa Maria,silveira_farias@hotmail.com
[5] Doutor, Universidade Federal de Santa Maria,josefernandoschlosser@gmail.com
[6] Doutoranda do Programa de Pós-graduação em Engenharia Agrícola, Universidade Federal de Santa Maria,dani_herzog@hotmail.com

Recebido em: 16-09-2021; Aceito em: 29-04-2022

Abstract

This research aimed to evaluate the traction performance of an agricultural tractor at different working speeds and surfaces. The experiment was carried out under a randomized block design, in a bifactorial scheme (5x2), resulting from the interaction of five speeds (2.98; 3.17; 3.53; 7.14 and 10.38 km h^{-1}) and two surfaces (firm soil with vegetation cover and pavement), with three repetitions. Data were collected using electronic instrumentation installed on the tractor. With the aid of a brake dynamometer, like a convoy, a load was imposed on the tractor's drawbar, corresponding to the maximum power on the drawbar, for each evaluated speed. The results indicated that the traction force, power and dynamic coefficient of traction were 1.49%, 13.09% and 2.04% higher, respectively, for the pavement surface in relation to the firm soil with vegetation cover. Specific fuel consumption was reduced by 6.95% for the pavement condition. It is concluded that the efficiency in transforming the engine power into traction power was 47.79% for firm soil with vegetation cover and 52.10% for the pavement surface, for the conditions in which the experiment was conducted.

Additional keywords: agricultural engineering; mechanization; traction efficiency.

Resumo

Este trabalho teve como objetivo avaliar o desempenho em tração de um trator agrícola em diferentes velocidades de trabalho e superfícies. O experimento foi conduzido sob delineamento experimental blocos ao acaso, em esquema bifatorial (5x2), proveniente da interação de cinco velocidades (2,98; 3,17; 3,53; 7,14 e 10,38 km h^{-1}) e duas superfícies (solo firme com cobertura vegetal e pista de concreto), com três repetições. Os dados foram coletados por meio de instrumentação eletrônica instalada no trator. Com auxílio de um freio dinamométrico, na forma de comboio, foi imposta carga à barra de tração do trator, correspondente à potência máxima na barra de tração, para cada velocidade avaliada. Os resultados indicaram que, a força de tração, a potência e o coeficiente dinâmico de tração foram superiores em 1,49%, 13,09% e 2,04%, respectivamente, para a superfície de concreto em relação ao solo firme com cobertura vegetal. O consumo específico de combustível foi reduzido em 6,95% para a condição de superfície de concreto. Conclui-se que, a eficiência na transformação da potência do motor em potência de tração foi de 47,79% para o solo firme com cobertura vegetal e de 52,10% para a superfície de concreto, de acordo com as condições em que o experimento foi conduzido.

Palavras-chave adicionais: engenharia agrícola; mecanização; eficiência em tração.

Introduction

The agricultural tractor performs different jobs on surfaces with little grip, usually mobilized soils or with vegetation cover, resulting in power losses in the drawbar and in the soil-tire interface due to the slip of the drive wheels (Gabriel Filho et al., 2004; Cortez et al., 2009; Fiorese et al., 2019). In addition, poor performance on the drawbar can also be caused by mass distribution over the wheel sets, tire and wheel characteristics, and mass transfer during agricultural operation (Gabriel Filho et al., 2004).

Thus, the tractor does not use all the power generated by the engine as traction force or traction power (Russini et al., 2018). Marquez (2012) states that, in most agricultural tractors, approximately 60% to 65% of the energy generated by the engine is effectively transformed into traction power. The estimated power loss for single-traction tractors and in different surface conditions range from 20% for concrete tracks at more than 53% for mobilized agricultural soils (Zoz, 1987; Gabriel Filho et al., 2010).

In addition to the power of the engine and the efficiency of the transmission system, the tractor can be characterized through its dimensions and its mass, which has decreased considerably making them increasingly dependent on ballast (Estrada et al., 2016). Consequently, the suitability of the tractor to work becomes an indispensable task since tractors of different powers may require different masses to perform the same work.

Therefore, the efficiency on the drawbar can be used to evaluate and/or compare tractors (Monteiro et al., 2013). By measuring the force on the drawbar, the tractor speed, and the power available on the drawbar, it is possible to detect which are the working conditions that offer greater or lesser efficiency for the mechanized assembly (Jasper et al., 2016). Also, the quantification of fuel consumption is another important aspect in the evaluation of traction performance and, consequently, performance in mechanized agricultural operations (Farias et al., 2019).

In this sense, this work aims to evaluate the traction performance of an agricultural tractor at different working speeds and surfaces.

Material and Methods

Tractor used in the study

We used the tractor TL 75E, of New Holland, equipped with FPT diesel cycle engine, model S 8000, with 1200 hours of use, four cylinders, displaced volume of 3908 cm^3, aspirated, and with mechanical fuel injection system. According to the manufacturer, it has a rated power of 57.41 kW (78 hp) at 2400 rpm and a maximum torque of 280 Nm at 1400 rpm, according to the SAE J1995 standard. The tractor was equipped with tires of the brand Goodyear type R2, diagonal construction, with the following dimensions: front 14.9-24 and rear 23.1-26. Internal pressure was calibrated at 137.9 kPa (20 psi) for the front and rear tires, as recommended by the manufacturer.

The total mass of the tractor was 4916 kg, with static distribution of 39% and 61% over the front and rear axles, respectively. The distribution was adjusted by changing the position of the metal masses and the hydraulic ballast volume, respecting the limit of 40% and 75% of the internal volume of the front and rear tires, respectively. The mass/power ratio was 85.62 kg kW^{-1} in order to obtain maximum traction capacity (Schlosser et al., 2005).

.

Field Experiment

The experiment was conducted at the Federal University of Pampa, Itaqui, located on the western border of the state of Rio Grande do Sul. According to the Köppen climatic classification, the climate is the subtropical Cfa type with hot summers and no defined dry season.

The tractor was subjected to two surface conditions, firm soil with vegetation cover and a pavement track, to determine traction performance.

The soil was classified as dystrophic Haplic Plinthosol (Santos et al., 2018) of textural class sandy clay loam, according to particle size analysis. The area was covered with vegetation composed predominantly of Annoni grass (Eragrostis plana Nees) at rest for two years. The average soil moisture was 0.0353 m^3 m^{-3} and 0.20 m deep.

The standard pavement track had the dimensions of 0.10 x 6.0 x 100.0 m, for height, width, and length, respectively. It was characterized by being completely flat and without imperfections, offering no restrictions for the movement of the convoy.

The tractor was coupled to the Scania mechanical truck, model 112 HW, with 280 kW (360 hp) of nominal power, 10-gear mechanical transmission forward and two reverse to apply the stress levels on the drawbar and determine traction performance. The braking system of the wheel sets of the truck was adapted to act as a dynamometric brake and impose constant loads to brake the tractor. The set (Figure 1) was arranged like a convoy, according to the methodology proposed by Mialhe (1996).

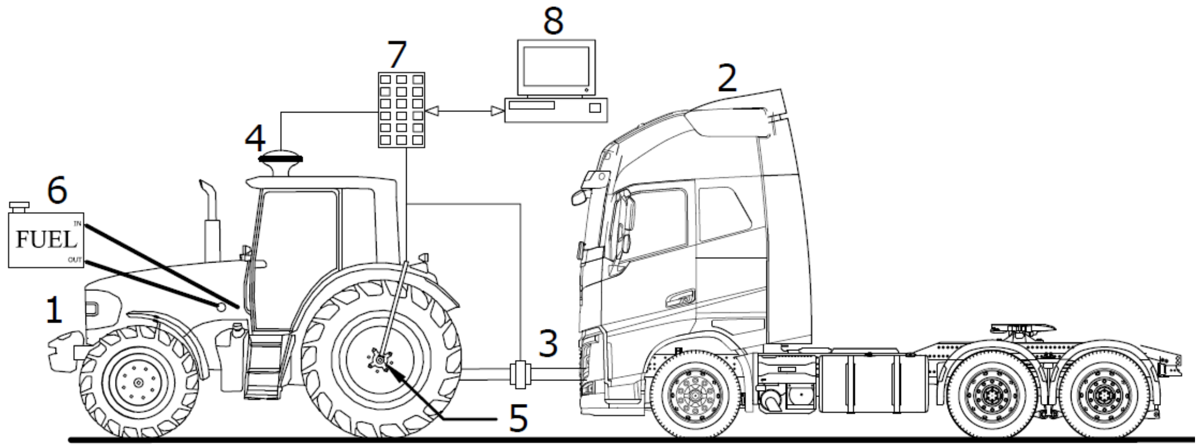

Figure 1 - Schematic representation of the experiment to obtain the parameters of traction performance (1. agricultural tractor, 2. dynamometer brake, 3. load cell, 4. GPS, 5. inductive sensor, 6. auxiliary fuel tank, 7. central for data acquisition, 8. software for data collection and analysis).

The experiment consisted of five theoretical speeds (2.98 km h^{-1}, 3.17 km h^{-1}, 3.53 km h^{-1}, 7.14 km h^{-1}, and 10.38 km h^{-1}), which represent the main operating speeds in the field, calculated by mathematical equation 1, and obtained with the following working gears: 3rd group I; 1st group II; 2nd group II; 3rd group II, and 4rd group II; which correspond to the following transmission indices: 197.24, 185.53, 166.54, 82.37, and 56.64, respectively.

$$Vel = 3{,}6 \times \left(\frac{2\times\pi\times n\times RI}{60\times it}\right) \quad (1)$$

Where: Vel is the theoretical speed (km h^{-1}), π is the mathematical constant (3.141592...), n is the engine speed (rpm), RI is the tire radius index (0.760 m), and *it* is the transmission index.

The relations with the suspended rear wheels of the tractor were determined for each working gear, with the differential lock activated and a constant engine angular speed fixed at 2300 rpm. The revolutions in the center of the output axel of the final reduction of the transmission were read with a digital tachometer, and the gear ratio was obtained by the quotient between the engine rotation and the rotation measured on the axel.

Data acquisition

The tractor was equipped with electronic instrumentation to determine the response variables: traction force, working speed, slip of the drive wheels, and fuel consumption. Such instrumentation was composed of a logic processing core, consisting of Arduino microprocessor, capable of reading and storing data obtained by the sensors, every second.

The load cell of brand MK, model 5030, with a capacity of 50 kN, calibrated by the manufacturer, was used to determine the traction force. The actual working speed was obtained by a GPS signal receiver. The rotation of the rear wheels was measured using inductive sensors. Subsequently, the wheel speed was calculated as a function of its dynamic radius and slip (equation 2).

$$Pat = \left(\frac{V_R - V_{GPS}}{V_R}\right) \times 100 \quad (2)$$

Where: Pat is the slip of the drive wheels (%), V_R is the speed of the wheel (km h^{-1}) and V_{GPS} is the GPS speed (km h^{-1}).

The power developed in the drawbar was calculated by the quotient between the force obtained in the drawbar, measured by the load cell, and the actual working speed, according to mathematical equation 3.

$$P_{BT} = \left(\frac{Ft \times V_R}{3{,}6}\right) \quad (3)$$

Where: P_{BT} is the power on the drawbar (kW), Ft is the traction force (kN) and V_R is the actual working speed (km h^{-1}).

The dynamic traction coefficient, which according to Marquez (2012) represents how much of the mass of the tractor is effectively transformed into force on the drawbar, was calculated using mathematical equation 4.

$$\mu = \left(\frac{Ft}{Ma}\right) \quad (4)$$

In which: μ is the dynamic traction coefficient, Ft is the traction force (kN), and Ma is the adherent mass (kN).

The hourly fuel consumption was obtained manually, through an auxiliary reservoir connected to the fuel supply system of the agricultural tractor and isolated from the main tank (equation 5). The volume of the auxiliary reservoir was weighed on a scale measured before and after the end of each replicate, obtaining the mass of fuel consumed for each distance traveled.

$$Ch = \frac{\left(\frac{M_C}{T}\right)\times 3,6}{\sigma} \quad (5)$$

Where: Ch is the hourly fuel consumption (L h^{-1}), M_C is the mass of fuel consumed (g), T is the time spent in the distance traveled (s), and σ is the fuel density (kg L^{-1}).

The specific fuel consumption was determined by equation 6 based on the hourly fuel consumption.

$$Ce = \left(\frac{Ch}{P_{BT}}\right) \quad (6)$$

Where: Ce is the specific fuel consumption (g kW h^{-1}), Ch is the hourly fuel consumption (L h^{-1}), and P_{BT} is the power on the drawbar (kW).

The critical speed (equation 7) was determined considering the maximum power of the engine, the transmission efficiency, and the dynamic traction coefficient, which is related to the soil and work surface conditions (Márquez, 2012).

$$Vc = \frac{N \; x \; nt \; x \; 270}{M \; x \; Ca \; x \; 1{,}0} \quad (7)$$

Where: Vc is the critical speed (km h^{-1}), N is the engine power (cv), nt the transmission efficiency (0.87 a 0.93), M the tractor mass (kg), and Ca the dynamic traction coefficient (0.5 a 0.6).

Experimental and statistical procedures

The experiment was conducted under a randomized block design, in a bifatorial scheme (5x2), from the combination of five work speeds and two surfaces, each treatment consisting of three replicates.

The data of force, power, dynamic traction coefficient, working speed, slip, hourly consumption, and specific fuel consumption were analyzed for normality (Lilliefors test). Therefore, all variables were subjected to analysis of variance (p≤0.05), and the means were adjusted by means of regression equations, using the Sisvar *software*, version 5.3 (Ferreira, 2011).

Results and Discussion

After submitting the results to the analysis of variance, it was verified that there was no interaction between the factors working speeds and surface for the analyzed variables (Table 1). However, there was a difference for the speed factor and the surface factor, and the variables drawbar power, slip, and hourly fuel consumption.

Table 1 - Summary of analysis of variance for the traction force (kN), drawbar power (kW), slip (%), dynamic coefficient of traction, hourly (L h^{-1}) and specific (g kW h^{-1}) fuel consumption.

Sources of variation	Degrees of Freedom	Means square					
		Traction Force (kN)	Drawbar Power (kW)	Slip (%)	Dynamic Coefficient	Specific Consumption (g kW h^{-1})	Hourly Consumption (L h^{-1})
Suface (S)	1	0.96	67.35*	594.08*	0.00056	6304.02	3.47*
Velocity (V)	4	409.10*	46.73*	201.69*	0.18*	3623.26	3.86*
S x V	4	7.74	1.99	24.67	0.0034	389.93	0.65
Residue	18	4.46	5.24	24.95	0.0019	2165.76	0.44
Fc (S x V)	-	1.74	0.38	0.99	1.79	0.18	1.46
CV (%)	-	9.09	9.41	32.45	9.13	11.56	5.63

*Differ statistically (ρ≤0.05).

Individually, the working speed factor presented a difference for the variables force and dynamic traction coefficient. In relation to the coefficient of variation (CV), according to Pimentel Gomes (2009), the parameters analyzed are considered low, with the exception of the slip that presents CV of 32.45%, classified as medium.

There was a reduction in traction force due to the increase in the working speed, for both surfaces studied (Figures 2a and 2b). The mean reduction of traction force, considering the gap between the lowest and highest speeds evaluated, was 32.14% for the firm soil with vegetation cover and 57.19% for the pavement track.

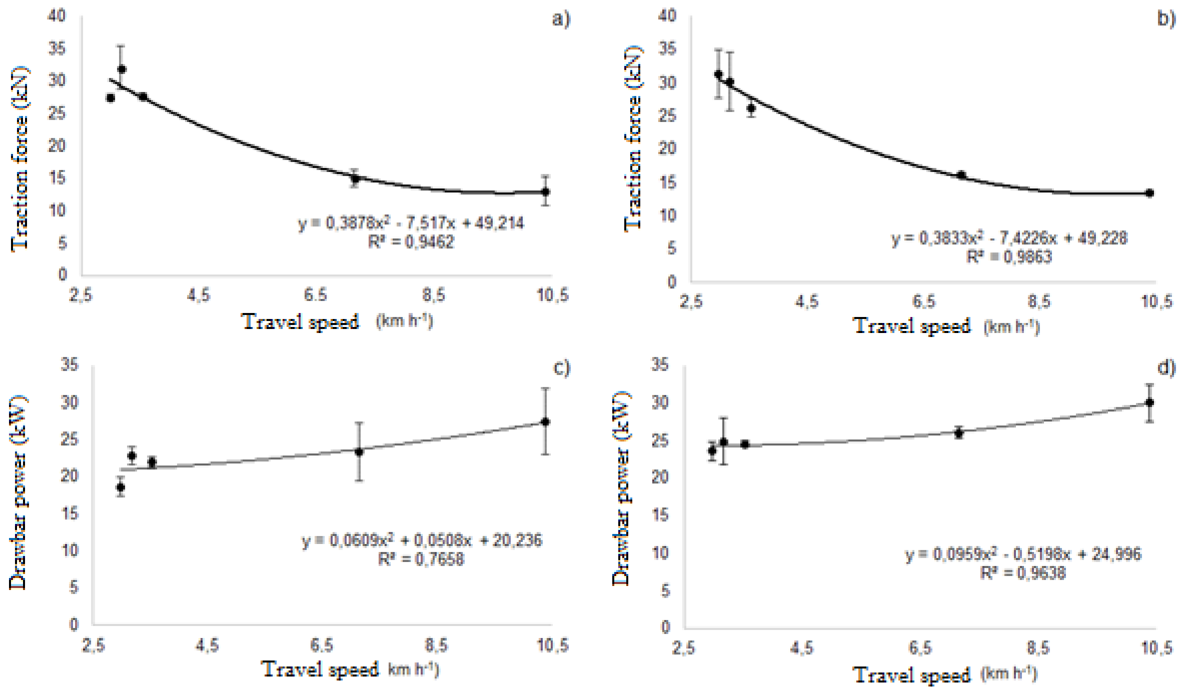

Figure 2 - Traction force (kN) on firm soil with vegetation cover (a), and on the pavement (b); and drawbar power (kW) on firm soil with vegetation cover (c), and on the pavement (d), as a function of the travel speed (km h^{-1}).

Additionally, the average traction strength did not differ for the surfaces, being 1.49% higher at the pavement surface in relation to the firm soil with vegetation cover, for all the evaluated speeds (Table 2). Simultaneously, the dynamic traction coefficient had a performance similar to that of the traction force, decreasing with the increase in speed.

Table 2 - Tractor performance parameters (traction force (kN), drawbar power (kW), slip (%), dynamic coefficient of traction, hourly (L h^{-1}) and specific (g kW h^{-1}) fuel consumption) at the different surfaces evaluated.

Surface	Performance Parameters					
	Traction Force (kN)	Drawbar Power (kW)	Slip (%)	Dynamic Coefficient	Hourly Consumption (L h^{-1})	Specific Consumption (g kW h^{-1})
Firm Soil	23.07^a	22.83^a	19.84^a	0.48^a	11.47^a	417.19^a
Pavement	23.42^a	25.82^b	10.94^b	0.49^a	12.15^b	388.20^a

*Means followed by the same letter in the column do not differ by the Tukey test at 5% error probability.

The reduction of the traction dynamic coefficient in relation to the increase in velocity was 52.63% on firm soil and 52.63% on the pavement surface (Figures 3c and 3d). As the velocity increases, the torque produced in the drive wheels and, consequently, the slip decreases, increasing the traction force until reaching the critical speed (Russini et al., 2018).

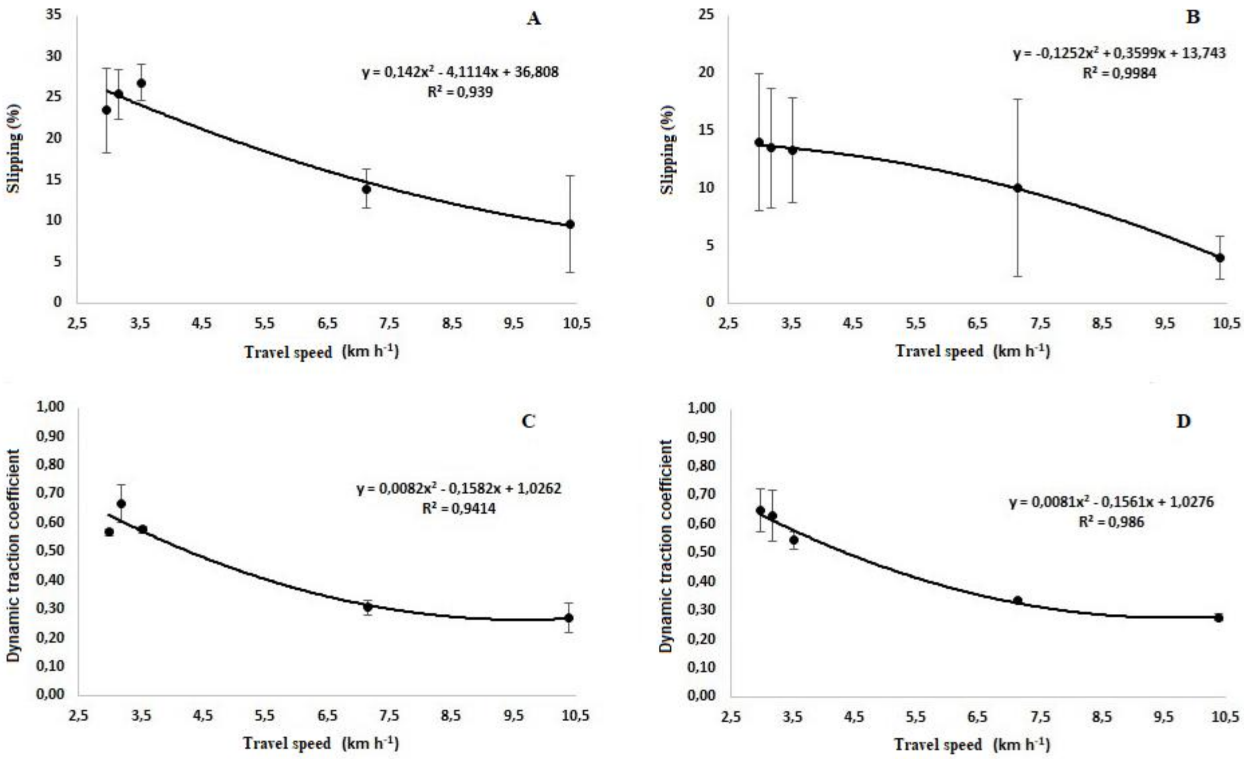

Figure 3 - Slipping (%) on firm soil with vegetation cover (a), and on the pavement (b); and dynamic traction coefficient on firm soil with vegetation cover (c), and on the pavement (d), as a function of the travel speed (km h^{-1}).

The slip of the driving wheels on the pavement surface at a speed of 7.14 km h^{-1} (Figure 3b) presented the highest standard deviation, changing the shapes of the estimated functions. This fact is due to the loss of adhesion of the wheels and surface, causing higher values of slip. Furthermore, the low average slip at higher speeds is due to the high mass of the tractor and speeds higher than the critical velocity. This is defined as the minimum working speed of the tractor to use the maximum power produced by the engine in relation to its mass. The calculated critical speed was 6.42 km h^{-1}, considering a dynamic traction coefficient of 0.6 and transmission efficiency of 90%.

The slipping of the driving wheels differed between the evaluated surfaces (Table 2). On average, slip was 44.85% lower on the pavement surface in relation to the firm soil (Figures 3a and 3b), reflecting a 2.09% increase in the dynamic traction coefficient. The slip was 19.84% higher on the firm soil with vegetation cover than indicated by ASABE EP496.3 (2011), which establishes slip values between 8 and 10%, for firm soils.

It can be inferred that the vegetation cover interferes with the soil-tire interaction, increasing the slip rates. According to Neujahr and Schlosser (2001), slipping between 5 and 20% provides greater traction efficiencies. In addition, high levels of dry matter on the soil surface tend to increase slip rates and, consequently, reduce traction efficiency (Gabriel Filho et al., 2010).

The power developed in the drawbar increased due to the increase in the working speed on both surfaces, although it presented a reduction in the traction force (Figures 2c and 2d). This is due to the traction power being calculated by the product of the force developed by the speed (Zoz & Grisso, 2003). Also, the power in the drawbar depends on the soil conditions and power available in the tractor engine (Marquez, 2012).

The maximum drawbar powers differed between the evaluated surfaces (Table 2). The efficiency transforming engine power into traction power was 47.79% for the firm soil with vegetation cover and 52.10% for the pavement surface. These data are lower than those recommended by ASAE D497.4 (1999), which mentions efficiencies of 77% for firm soils and 87% for paved surfaces.

This fact can be explained by the high mass/power ratio of the analyzed tractor. The excess mass results in greater rolling resistance, causing a reduction in engine rotation and the actual working speed, especially on the pavement track, due to the high contact of the wheels with the surface. Marquez (2012) states that the power in the drawbar is conditioned to the ballast used and the suitability of the tires to the type of soil to be worked.

Hourly fuel consumption was approximately 5.52% higher in the condition of pavement track in relation to firm soil (Table 2). This is due to the higher traction effort developed on this surface and the lower slipping, reflecting in greater traction power.

Hourly fuel consumption is a linear function of traction power (Howard et al., 2013). Farias et al. (2018) state that fuel consumption increases according to increments in speed and load applied to the drawbar, which is consistant with the data obtained in this work (Figure 4c). Additionally, fuel consumption varies according to its type, density, and viscosity, in addition to the load applied to the tractor engine (ASAE, 2006).

The specific fuel consumption was reduced by 13.24% for the firm soil condition and by 12.50% for the pavement surface, as the speed increased (Figures 4a and 4b). The specific fuel consumption helps in the evaluation of engine efficiency, that is, the work that can be produced from one gram of fuel, regardless of the power available in the engine (Marquez, 2012).

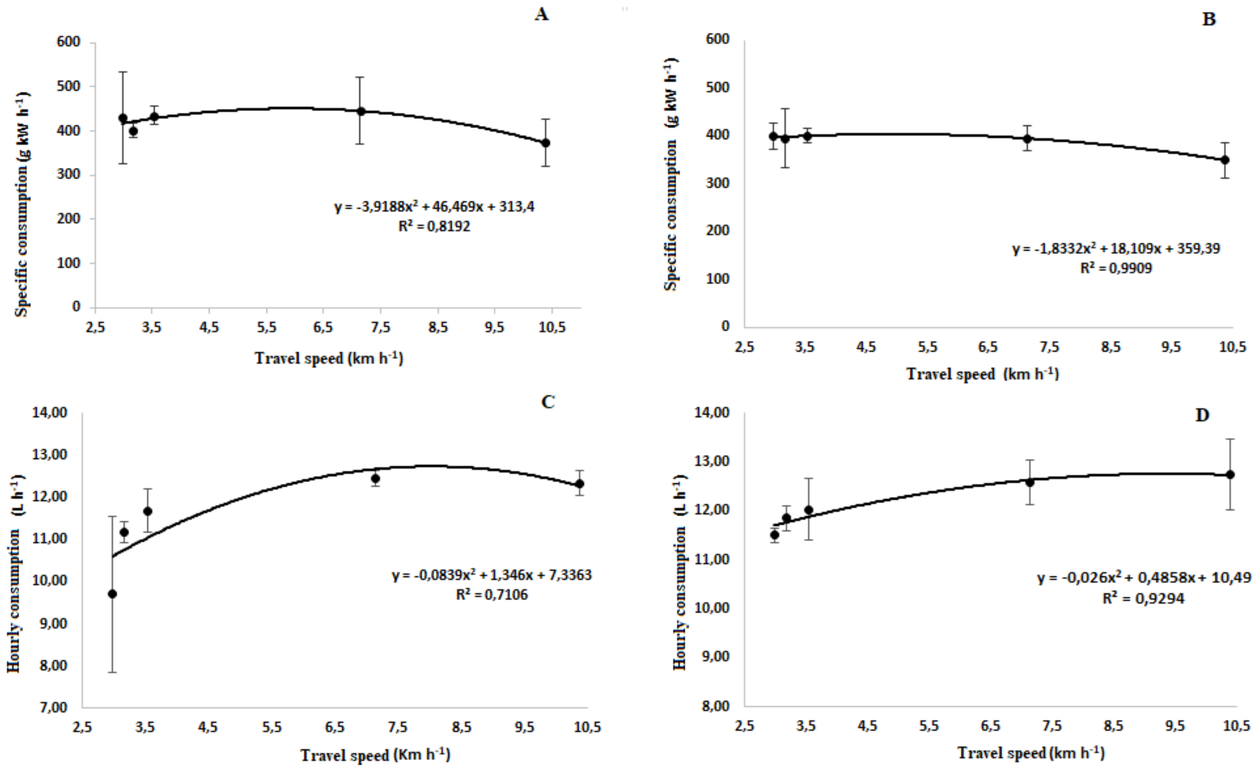

Figure 4 - Specific fuel consumption (g kW h^{-1}) on firm soil with vegetation cover (a), and on the pavement (b); and hourly fuel consumption (L h^{-1}) on firm soil with vegetation cover (c), and on the pavement (d), as a function of the travel speed (km h^{-1}).

It is also noteworthy that the working gear factor has a significant influence on the specific fuel consumption since it decreases as the working speed increases (Lopes et al., 2003; Farias et al., 2019). However, there is a limit in relation to the dynamic traction coefficient, that is, the traction force for the adherent mass ratio, for each selected gear ratio.

Conclusions

The traction force, power, and dynamic traction coefficient were 1.49%, 13.09% and 2.04% higher on the pavement surface when compared to the firm soil with vegetation cover, respectively, and the specific fuel consumption was reduced by 6.95% for the pavement surface condition.

The efficiency in the transformation of engine power into traction power was obtained at the lowest working speed, being inferior on firm soil with vegetation cover (47.79%) when compared to the concrete surface (52.10%), according to the conditions in which the experiment was conducted.

Acknowledgements

To the Federal University of Pampa - Unipampa, Itaqui campus, for the provision of the structure and equipment necessary to conduct this research.

References

ASAE (1999). American Society of Agricultural Engineers. ASAE D497.4: Standards engineering practices data, St Joseph:359-366.

ASAE (2006). American Society of Agricultural Engineers. ASAE D497.5: Agricultural Machinery Management, St Joseph:343-349.

ASABE (2011). American Society of Agricultural and Biological Engineers. ASABE EP496.3: Agriculturalmachinery management, St Joseph:7p.

Cortez, J.W., Furlani, C.E.A., Vigna, G.P., Borsatto, E.A., & Silva, R.P. (2009). Desempenho do trator agrícola no manejo da cultura de cobertura e pressão de inflação do pneu da semeadora. *EngenhariaAgrícola,* 29 (1): 72-80. https://doi.org/10.1590/S0100-69162009000100008

Estrada, J.S., Schlosser, J.F., Farias, M.S., Martini, A.T., Santos, G.O. (2016). Mass of agricultural tractors available in the Brazilian market. *Ciência Rural,* 46 (8): 1390-1394. https://doi.org/10.1590/0103-8478cr20150853

Farias, M.S., Schlosser, J.F., Russini, A., Negri, G.M., Casali, L. (2018). Agricultural tractor performance with different wheel and tires configurations. *Científica,* 47 (1): 15-20. https://doi.org/10.15361/1984-5529.2019v47n1p15-20

Farias, M.S., Schlosser, J.F., Linares, P., Bertollo, G.M., & Martini, A.T. (2019). Reduction of fuel consumption using driving strategy in agricultural tractor. *Revista Brasileira de Engenharia Agrícola e Ambiental,* 23 (2): 144-149. https://doi.org/10.1590/1807-1929/agriambi.v23n2p144-149

Ferreira, D.F. (2011). Sisvar A computer statistical analysis system. *Ciência e Agrotecnologia,* 35 (6): 1039-1042. https://doi.org/10.1590/S1413-70542011000600001

Fiorese, D.A., Machado, T.M., Zandonadi, R.S., Araujo, R.F.A., Ricardo, G.F.S., & Schimitt, J. (2019). Desempenho de um trator agrícola em operações de preparo de solo no estado de Mato Grosso. *Nativa,* 7 (3): 288-295. https://doi.org/10.31413/nativa.v7i3.7554

Gabriel Filho, A., Silva, S.L., Modolo, A.J., & Silveira, J.C.M. (2004). Desempenho de um trator operando em solo com diferentes tipos de cobertura vegetal. *Engenharia Agrícola*, 24 (3): 781-789. https://doi.org/10.1590/S0100-69162004000300032

Gabriel Filho, A., Lanças, K.P., Leite, F., Acosta, J.J.B., & Jesuino, P.R. (2010). Desempenho de trator agrícola em três superfícies de solo e quatro velocidades de deslocamento. *Revista Brasileira de EngenhariaAgrícola e Ambiental,* 14 (3): 333-339. https://doi.org/10.1590/S1415-43662010000300015

Howard, C.N., Kocher, M.F., Hoy, R.M., & Blankenship, E.F. (2013). Testing the fuel efficiency of tractors with continuously variable and standard geared transmissions. *Transactions of the ASABE,* 56 (3): 869-879. https://doi.org/10.13031/trans.56.10222

Jasper, S.P., Bueno, L.S.R., Laskoski, M., Langhinotti, C.W., & Parize, G.L. (2016). Desempenho do trator de 157 kW na condição manual e automático de gerenciamento de marchas. *Revista Scientia Agraria,* 17 (3): 55-60. https://doi.org/10.5380/rsa.v17i3.50998

Lopes, A., Lanças, K.P., Furlani, C.E.A., Nagaoka, A.K., Castro Neto, P., & Grotta, D.C.C. (2003). Consumo de combustível de um trator em função do tipo de pneu, da lastragem e da velocidade de trabalho. *Revista Brasileira de Engenharia Agrícola e Ambiental,* 7 (2): 382-386. https://doi.org/10.1590/S1415-43662003000200033

Márquez, L. (2012). *Tractores agrícolas: Tecnologías y utilización*. Espanha: B&H Grupo Editorial. 844p.

Mialhe, L.G. (1996). *Máquinas agrícolas: ensaio e certificação*. Piracicaba: CNPq-PADCT/TIB-FEALQ. 722p.

Monteiro, L.A., Albiero, D., Souza, F.H., Melo, R.P., & Cordeiro, I.M. (2013). Rendimento na barra de tração de um trator agrícola com diferentes relações peso potência. *Revista Ciência Agronômica*, 44 (1): 70-75. https://doi.org/10.1590/S1806-66902013000100009

Neujahr, E.B., & Schlosser, J.F. (2001). Comportamento de pneus agrícolas radiais e diagonais em relação à tração. *Engenharia Agrícola*, 21 (2): 180-189. http://www.ufrrj.br/institutos/it/deng/varella/Downloads/IT154_motores_e_tratores/Literatura/patinagem_1.pdf

Pimentel, G.F. (2009). Curso de estatística experimental. Piracicaba: Fundação de Estudos Agrários Luiz de Queiroz. 45p.

Russini, A., Schlosser, J.F., Farias, M.S. (2018). Estimation of the traction power of agricultural tractors from dynamometric tests. *Ciência Rural,* 48 (4): 1-7. https://doi.org/10.1590/0103-8478cr20170532

Santos, H.G., Jacomine, P.K.T., Anjos, L.H.C., Oliveira, V.A., Lumbreras, S.J., Coelho, M.R., Almeida, J.A., Araújo Filho, J.C., Oliveira, J.B., Cunha, T.J.F. (2018). *Sistema Brasileiro de Classificação de Solos*. 5.ed. Rio de Janeiro: Embrapa Solos. 355p. https://www.embrapa.br/busca-de-publicacoes/-/publicacao/1094003/sistema-brasileiro-de-classificacao-de-solos

Schlosser, J.F., Debiasi, H., Willes, J.A., & Machado, O.D.C. (2005). Análise comparativa do peso específico dos tratores agrícolas fabricados no Brasil e seus efeitos sobre a seleção e uso. *Ciência Rural* 35 (1): 92-97. https://doi.org/10.1590/S0103-84782005000100014

Zoz, F.M. (1987). Predicting tractor field performance (updated). St. Joseph: ASAE Paper n.871623. 12p.

Zoz, F.M., & Grisso, R.D. (2003). Traction and tractor performance. Louisville: ASAE. 46p. http://www.esalq.usp.br/departamentos/leb/disciplinas/Molin/leb5004/Material_para_leitura/Traction_Tractor_Performance.pdf