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Tractor perfomance as a function of speed and seeder's tire inflation pressure

Desempenho de trator em função da velocidade e da pressão de inflação dos pneus da semeadora

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ABSTRACT

The performance of agricultural tractors under field conditions results from the interaction between tire and wheel affected by displacement speed. This work was developed to assess the performance of an agricultural tractor under different seeder's tire inflation pressure (518; 483 and 414kPa) and in two different gears providing speeds of 3.0 and 6.0km h^{-1}. The experiment was performed at Jaboticabal Campus of São Paulo State University (UNESP). The experimental design used was entirely randomized in a 2-factor factorial design (3x2) with four replications. The draft force was influenced by the gear as well as by the required power; however, tire inflation pressure in the seeder did not change these parameters. Also, fuel consumption was influenced only by the tractor gear. Energy consumption was greater as speed increased, caused by gear shifting. The displacement speed was greater for the 518kPa pressure due to a lesser slippage in the seeder under this pressure. Tractor slippage did not change.

Key words: *no-tillage system, fuel consumption, slippage.*

RESUMO

O desempenho de tratores agrícolas em condições de campo resulta da interação entre pneu e rodado, influenciado pela velocidade de deslocamento. O objetivo deste trabalho foi avaliar o desempenho de um trator agrícola sob diferentes pressões de inflação dos pneus da semeadora (518, 483, and 414kPa) e em duas marchas que proporcionaram velocidades de 3,0 e 6,0km h^{-1}. O experimento foi realizado no campus de Jaboticabal da Universidade Estadual Paulista (UNESP). O delineamento experimental utilizado foi fatorial inteiramente casualizado (3x2), com quatro repetições. A força de tração foi influenciada pela marcha e pela potência exigida; no entanto, a pressão de inflação do pneu da semeadora não alterou esses parâmetros. Além disso, o consumo de combustível foi influenciado apenas pela marcha do trator. O consumo de energia foi maior com o aumento da velocidade, ocasionada pela mudança de marcha. A velocidade de deslocamento foi maior para a pressão de 518kPa, em razão da menor patinagem da semeadora promovida por essa pressão. A patinagem do trator não foi alterada pelos fatores testados.

Palavras-chave: *sistema plantio direto, consumo de combustível, patinagem.*

INTRODUCTION

Tire inflation pressure has a direct influence on the performance of an agricultural tractor. An experiment assessing four levels of tire inflation pressure when moving on non-mobilized soil concluded that the speed, slippage and power parameters on the traction bar are influenced by pressure but do not follow a behavior pattern (YANAI et al., 1999).

Low tire pressure in agricultural tractors is an alternative to minimize compaction and increase traction efficiency, and wheel slippage is one of the

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factors that has the greatest influence on the traction ability of agricultural tractors (LOPES & LANÇAS, 2000).

The performance of a 62.7kW (86,5hp) agricultural tractor coupled with a dynamometric car with a breaking action of up to 60kN was investigated by YANAI & LANÇAS (2001). The tractor underwent different inflation pressures of 165kPa, 138kPa and 83kPa in the rear tires. Wheel slippage was lower (5.6%) and the displacement speed of the tractor-seeder system was greater when lower pressure was used. Traction bar power increased with inflation pressure, with an 83kPa pressure resulting from 49.3kW, due to the lower power required at the lower pressure. Fuel consumption (17.9L h^{-1}) was also lower at this tire inflation pressure.

Assessing the performance of the tractor-seeder combination in a dystrophic, clayey Oxisol, under no tillage, as a function of two displacement speeds in the 75.8kW (103hp) tractor, SILVA & BENEZ (2001) concluded that when speed changes, draft power is not influenced. On the other hand, the power required by the tractor was increased in 67% when speed changed from 5.0km h^{-1} to 8.2km h^{-1}. When considering tractor slippage in this operation, the authors could see that speed does not interfere with slippage, but increasing draft force results in greater slippage, which in turn causes speed to decrease.

A decrease in the fuel consumption per area (6.2L ha^{-1}) and a increase in the force on the traction bar (8.6kN), engine power (19.5kW) and effective field capacity (2.2ha h^{-1}) as speed increases was observed by MAHL et al. (2004) for a 88.3kW (120cv) tractor.

Working with clayey Oxisol under no tillage and assessed the specific use of energy per area (kWh ha^{-1}) in the seeding operation, which was obtained as a function of the power on the traction bar (kW) and the effective time required to work one hectare (h ha^{-1}), MARQUES & BENEZ (2000) concluded that the consumption of energy in direct planting was 6.3kWh ha^{-1}, even when modifying mechanical and chemical handling of soil cover before seeding.

This work was developed to assess the performance of an agricultural tractor under different seeder's tire inflation pressure and in two displacement speeds.

MATERIAL AND METHODS

The experiment was performed at Sao Paulo State University (UNESP), Jaboticabal Campus, in the state of Sao Paulo, Brazil, and was conducted by Laboratory of Machines and Agricultural Mechanization (LAMMA). The experimental area is located at the geodesic coordinates 21º15' southward latitude and 48º18' westward longitude, with a mean altitude of 570m occupying an area of approximately 1.5ha under a no tillage system. The experimental design was entirely randomized in the factorial design (3x2) with 4 replications, with three tire inflation pressures in the driving wheel of the seeder (518, 483, and 414kPa) and two gears (G1: 3.0km h^{-1}, G2: 6.0km h^{-1}). The plots were 25m long and 3.6m wide with a 15m interval between plots for maneuvering.

The soil at the experiment site is classified by EMBRAPA (1999) as a oxisoil, with clayey texture (55%), containing sand (20%) and silt (25%), A moderate vitreous kaolinitic soil under a Aw climate type according to Köppen classification, i.e., tropical wet and dry.

The tractor used was a 4x2 with front wheel assist drive (FWAD), 73.6kW (100hp) engine power with 2000 engine revolutions, with a 5,400kg mass (40% front and 60% rear), 14.9-24 R1 front tires with a perimeter of 3.8m and inflation pressure of 18psi (124kPa), and 23.1-26 R1 rear tires with a perimeter of 4.9m and inflation pressure of 22psi (152kPa).

A PST Plus Marchesan precision seeder-fertilizer was utilized, with four sowing rows and 18" (45.7cm) cutting discs, a fertilizer-laying furrowing rod with a 2.7cm thick pointer, 1.0cm thick rod, cutting disc-rod distance of 12cm, a height-length relation of the pointer (H/L) of 1.06, an angle of incidence of 20º, and a staggered 16" (40.6cm) double disc for seed deposition. The machine had a horizontal disc seed distributor with 28 holes. Fertilizer distribution was done using a helicoidal mechanism. Firestone T – 615 tires were used in the seeder. The tire dimensions are 6.50-16 LT with 10 radial belts holding a maximum load of 518kPa (75psi).

In order to gauge the time for each plot a data collection system was used, as described by FURLANI et al. (2005), using a Campbell Scientific, Inc. micrologger CR23X with an internal timer calibrated to hundredths of seconds. The data was then transferred via cable to a conventional microcomputer through a specific program (PC 208W 3.2 - Datalogger Support Software) where electronic spreadsheets were built.

Draft force was obtained by means of a 10,000kgf load cell manufactured by M. Shimizu, model TF 400, with a usable temperature ranging from -20 to 80ºC and a recommended feed ranging from 10 to 12Vcc. To measure fuel consumption, a prototype built and described by LOPES et al. (2003) was used and automatically turned on by data collection system with a 1mL accuracy. Fuel temperature was obtained using equipment provided by S&E Instrumentos de Testes e Medições LTDA, model SSRP-C ME 6446/02 PT100, with an accuracy of 0.01ºC.

To gauge real speed a radar unit was used on the right side of the tractor, RVS II type, forming a 45º angle with the ground. To assess driving wheel slippage in the tractor, pulse-generating sensors (model GIDP 60 12v) were used, placed at the center of each wheel. These sensors convert rotational movements and linear displacement into electric pulses, generating 60 pulses per rotation of the tractor wheel. For seeder slippage, the same sensors were used coupled with the gear shift boxes which receive the rotational movement of the tires. The seeder's wheel slippage was calculated considering the transmission chain.

To calculate the total power on the traction bar demanded by the tractor in the seeding operation was used the equation: *BP=DF v*, where, *BP* is the power on the traction bar (kW); *DF* is the mean draft force on the bar (kN); and *v* is the real displacement speed (m s^{-1}). For the power per row, the *BP* value was divided by the number of rows of the seeder, while the peak power was calculated using the highest force value in the plot.

The theoretical field capacity (*Tfc*) was obtained through the relation between real displacement speed and real sowing width (obtained by tape measuring): $Tfc = \frac{Rmw \;\; v}{10}$, where, *Tfc* is the theoretical field capacity (ha h^{-1}); *Rmw* is the real working width of the implement (m); *v* is the real displacement speed (km h^{-1}); and 10 is the conversion factor to ha h^{-1}.The effective time (*Eft*) was obtained by the inverse of *Tfc*.

Wheels slippage was calculated by: $Sl = \left(1 - \frac{NPL}{NPNL}\right)100$, where, *Sl* is the slippage (%); *NPL* is the number of pulses in the wheel, with the tractor operating with load on the traction bar, and *NPNL* is the number of pulses in the wheel, with the tractor operating with no load on the traction bar.

The energy consumption per worked area was provided as described by SIQUEIRA & GAMERO (2000): *Ca=BP Eft*, where, *Ca* is the energy consumption per worked area (kWh ha^{-1}), *BP* is the power on the traction bar (kW), and *Eft* is the effective time (h ha^{-1}).

To calculate the fuel consumption per hour: $Ch = \frac{C \;\; 3.6}{t}$, where, *Ch* is the consumption per hour (L h^{-1}); *C* is the consumed volume (mL); *t* is the travel time in the plot (s); and 3.6 is the conversion factor. The operational fuel consumption was calculated by: $Oc = \frac{Ch}{Tfc}$, where, *Oc* is the operational consumption (L ha^{-1}); *Ch* is the consumption per hour (L h^{-1}); and *Tfc* is the theoretical field capacity (ha h^{-1}). And the ponderal fuel consumption: $Pfc = \frac{Chv \;\; FD}{1000}$, where, *Pfc* is the ponderal consumption, (kg h^{-1}), *FD* is the fuel density (g L^{-1}) and the regression equation (FD=851,04-0,6970 T), where *T* is the fuel temperature (ºC), obtained by GROTTA (2003), with R^2 of 0,97, and *1000* is the conversion factor.

Finally, the specific fuel consumption was calculated: $SC = \frac{FD \;\; C}{P}$, where, *SC* is the specific consumption (g kWh^{-1}); *FD* is the fuel density (g L^{-1}); *C* is the consumption per hour (L h^{-1}); and *BP* is the power (kW).

The data obtained were analysed and submitted to analysis of variance. When the F test value was significant with a 5% probability, the Tukey Test was also done to compare the means (PIMENTEL-GOMES, 1987).

RESULTS AND DISCUSSION

The draft force on the bar and the power required (Table 1) were not affected by tire inflation pressure in the seeder, contrary to assumption. However, the gears to which the tractor was submitted and which caused theoretical speeds of 3.0 and 6.0km h^{-1} influenced both the total draft force and the draft force per row on the bar. The peak draft force (Table 1) was influenced by both factors, and the higher inflation pressure demanded less force due to its easy displacement over the terrain; gears affected peak draft force due to higher speed. Peak power was influenced by increased speed due to the gear used. Energy consumption, as a function of the consumed power on the bar, was also affected by the gears, but not by seeder's tire inflation pressure (Table 1).

Table 1 - Summary of the variance analysis and the means test for the following variables: draft force (DF), draft force per row, peak draft force, power, power per row, peak power and energy consumption (Ec).

Factors	DF (kN)	DF per row (kN row^{-1})	Peak DF (kN)	Power (kW)	Power per row (kW row^{-1})	Peak Power (kW)	Ec (kWh ha^{-1})
Pressure							
518kPa	15.6 a	3.9 a	18.6 b	20.9 a	5.2 a	24.9 a	12.0 a
483kPa	15.9 a	4.0 a	19.8 ab	20.4 a	5.1 a	25.3 a	12.2 a
414kPa	16.7 a	4.2 a	20.5 a	22.2 a	5.5 a	27.2 a	12.9 a
Gear							
G1 (3km h^{-1})	15.4 b	3.9 b	18.7 b	14.3 b	3.6 b	17.3 b	11.9 b
G2 (6km h^{-1})	16.8 a	4.2 a	20.6 a	28.0 a	7.0 a	34.3 a	12.8 a
F Test							
Pressure (P)	2.4 ns	2.4 ns	3.7 *	2.7 ns	2.7 ns	2.5 ns	2.7 ns
Gear (G)	8.8 *	8.8 *	10.2 *	446 *	446 *	387 *	8.4 *
P x G	0.1 ns	0.1 ns	0.1 ns	0.2 ns	0.2 ns	0.4 ns	0.5 ns
V.C. (%)	6.9	6.9	7.3	7.5	7.5	8.2	6.2

ns: non-significant (P>0.05); *: significant (P<0.05); V.C.: variation coefficient.

Peak force affected by speed is in agreement with MAHL et al. (2004), who also observed the fact, and is in disagreement with SILVA & BENEZ (2001), who concluded that when speed changes, draft force is not influenced by it. In energy consumption, values were higher when compared to MARQUES & BENEZ (2000), where an energy consumption of 6.3kWh ha^{-1} was observed in no tillage.

The real displacement speed was very close to that established by the tractor operation manual, and as expected it differed for the proposed gears. It is important to observe that tire inflation pressures in the seeder changed the real displacement speed, as shown in table 2.

An increase in speed caused an increase in force, as opposed to what has been concluded by SILVA & BENEZ (2001). According to them, when speed changes, draft force should remain constant. It is possible that due to a difference of 50% in the displacement speed between gears, this fact may have caused the force to increase, and so should be that large differences in speed tend to change draft force on the bar. Also was observed that the total power and the power per row were modified by the gears, due to an increase in speed, since power is the result of force and displacement speed. The increase of 50% in speed causes a 95% increase in power and this fact was also seen by MAHL et al. (2004) in which increased speed causes great power demand by the tractor during seeding.

When analyzing tractor slippage, tire inflation pressure in the seeder and the displacement speed do not change this parameter. Seeder slippage was not influenced by gears used in the tractor, which resulted in different displacement speeds. However, the tire inflation pressure factor in the seeder showed that, at a higher pressure (518kPa), there is less slippage (2%), and this fact results in greater speed (Table 2).

The fact that pressures change speed indicates that when there is an increased pressure (75psi) the tractor-seeder system is able to achieve greater speed, since there is a connection between this and how much easier it is to overcome obstacles when the tire is filled up. In addition, it decreases ground-tire contact. This fact disagrees with YANAI & LANÇAS (2001) in a study about the performance of an agricultural tractor with different tire inflation pressures, where they observed that the displacement speed of the combination was greater (8.2km h^{-1}) when using the lower pressure.

Tractor slippage was not affected by tested parameters. This fact was studied by SILVA & BENEZ (2001) who assessed the performance of the tractor-seeder combination in a oxisol under no tillage as a function of the two displacement speeds of the tractor. They concluded that tractor slippage in this operation does not change because of speed, but that draft force results in increased slippage, which, in turn, causes a

Table 2 - Summary of the variance analysis and means test for the following variables: speed, theoretical field capacity (*Tfc*), tractor slippage and seeder slippage.

Factors	Speed (km h^{-1})	*Tfc* (ha h^{-1})	Tractor slippage (%)	Seeder slippage (%)
Pressure (kPa)				
518	4.8 a	1.71 a	7.2 a	2.0 b
483	4.5 b	1.63 b	7.9 a	5.7 a
414	4.7 ab	1.69 ab	8.1 a	5.5 a
Gear				
G1 (3km h^{-1})	3.3 b	1.2 b	8.2 a	4.5 a
G2 (6km h^{-1})	6.0 a	2.2 a	7.3 a	4.3 a
F Test				
Pressure (P)	4.9 *	5.1 *	0.3 ns	4.8 *
Gear (G)	2157 *	2181 *	0.8 ns	0.1 ns
P x G	0.1 ns	0.1 ns	3.4 ns	0.5 ns
V.C. (%)	3.0	3.0	30.3	60.0

ns: non-significant (P>0.05); *: significant (P<0.05); V.C.: variation coefficient.

decreased speed. This is not proven by this experiment, because even when increasing force by 9% (Table 1), tractor slippage did not change.

In the seeder, slippage was affected at the highest pressure, with a decrease in slippage and an increase in speed. Lesser slippage can be related to a filled-up tire overcoming obstacles more easily, even when were considered that the rolling resistance is greater with an increased pressure. This is because it is easier to sink in a soil when the contact area is smaller for the same seeder mass. At lower pressures tire-ground contact area is greater, and so the greatest slippage occurs (5.6%) due to the difficulty in overcoming friction. In these conditions, the seeder tire is further dragged over the area.

In table 3 the fuel consumption was affected only by the working gear, which resulted in different displacement speeds and different required power. The volumetric and ponderal fuel consumption per hour were then greater for G2 while the specific consumption and the consumption per area were lower for the same gear.

Results for fuel consumption agree with MAHL et al. (2004) and FURLANI et al. (2008) where a lower consumption occurs at greater speeds. In the other hand, YANAI & LANÇAS (2001), observed that volumetric fuel consumption per hour decreases with an increase in pressure. This was not seen in this experiment, since the seeder tires had very little influence on the tractor's traction feature.

Table 3 - Summary of the variance analysis and means test for the following variables: volumetric (*Ch*) and ponderal (*Pfc*) fuel consumption per hour, fuel consumption per area (*Ca*) and specific fuel consumption (*SC*).

Factors	*Ch* (L h^{-1})	*Pfc* (kg h^{-1})	*Ca* (L ha^{-1})	*SC* (g kWh^{-1})
Pressure (kPa)				
518	9.7 a	8.2 a	5.8 a	412.3 a
483	10.3 a	8.7 a	6.8 a	477.4 a
414	10.0 a	8.4 a	6.1 a	402.1 a
Gear				
G1 (3km h^{-1})	8.6 b	7.3 b	7.2 a	518.8 a
G2 (6km h^{-1})	11.4 a	9.6 a	5.2 b	342.4 b
F Test				
Pressure (P)	0.2 ns	0.3 ns	0.9 ns	0.9 ns
Gear (G)	17.5 *	15.8 *	10.6 *	12.9 *
P x G	1.1 ns	1.1 ns	1.0 ns	1.0 ns
V.C. (%)	16.1	16.4	23.4	27.9

ns: non-significant (P>0.05); *: significant (P<0.05); V.C.: variation coefficient.

CONCLUSION

An increase in the peak force at the lowest inflation pressure did not have any influence on the peak power. Energy consumption was greater at a 6.0km h^{-1} speed, which also caused an increase in the volumetric and ponderal consumption per hour and a decrease in the specific and per-area consumption. The 518kPa pressure in the seeder's driving wheel provided greater speed and lesser slippage. Second gear (6.0km h^{-1}) provided greater theoretical field capacity but also a greater total power.

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