Operational performance of an agricultural tractor under different tire inflation pressures in the subsoiling operation

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ABSTRACT

For the agricultural tractor's best performance, it must be correctly adapted to the job. Among other factors, the adequacy of tire inflation pressure is one of the most important and may influence the operation's efficiency and productivity. This study aimed to evaluate an agricultural tractor's operational performance with different tire inflation pressures in the subsoiling operation. The study was carried out in an experimental area of the Agricultural Machinery and Mechanization Laboratory of the experimental farm "Água Limpa," belonging to the University of Brasília. The experimental design used was in randomized blocks with the following values, 206.8 kPa (30 psi), 137.9 kPa (20 psi), and 68.9 kPa (10 psi), of inflation pressure for agricultural tractor tires. The mechanized set used was a tractor model TM7020 2WD MFWD pulling a subsoiler with five shanks, SPCR model, in a Latossolo Vermelho-Amarelo. The higher inflation pressure resulted in greater slippage, advance, hourly fuel consumption, and lower speed and operational field capacity.

Keywords: calibration, fuel consumption, slippage, tillage, operational performance.

Desempenho operacional de um trator agrícola sob diferentes pressões de inflação dos pneus na operação de subsolagem

RESUMO

Para o melhor desempenho do trator agrícola, é preciso que este esteja corretamente adequado ao trabalho. Dentre outros fatores, a adequação da pressão de inflação dos pneus é um dos mais importantes, podendo influenciar na eficiência e produtividade da operação. O objetivo do trabalho foi avaliar o desempenho operacional de um trator agrícola com diferentes pressões de inflação dos pneus na operação de subsolagem. O trabalho foi realizado em área experimental do Laboratório de máquinas e mecanização agrícola da Fazenda Experimental Água Limpa, pertencente à Universidade de Brasília. O delineamento experimental utilizado foi em blocos casualizados com os seguintes tratamentos: 206,8 kPa (30 psi), 137,9 kPa (20 psi) e 68,9 kPa (10 psi) de pressão de inflação dos pneus do trator agrícola. O conjunto mecanizado utilizado foi um trator modelo TM7020 4 x 2 TDA tracionando um subsolador com cinco hastes modelo SPCR, em Latossolo Vermelho-amarelo. A maior pressão de inflação resultou em maior patinagem, avanço e consumo horário de combustível, e menor velocidade e capacidade de campo operacional.

Palavras-chave: calibragem, consumo de combustível, patinagem, preparo do solo, rendimento operacional.

1. Introduction

The internal tire pressure directly affects the operating performance with an agricultural tractor. According to Misiewicz et al. (2015), adequate tire pressure provides dynamic balance to the tractor, higher tractive efficiency, and better contact of the tread with the ground. According to Spagnolo et al. (2012) and Jadoski et al. (2016), the combination of tire calibration pressure factors such as type of tires and ballast of the tractor can positively or negatively influence its slippage and kinematic advance, operational performance, tire life, and fuel consumption.

According to Biris et al. (2011), tires with low pressure suffer an exaggerated deflection in the carcass's central part, increasing the rolling resistance. High inflation pressures cause less tire adherence to the ground and accelerate wear, which occurs irregularly, especially in the rear tires.

As Mion et al. (2016) reported, the effects of incorrect inflation of tractor tires can be observed in the soil's physical aspects. The authors found in a study performed with inflation pressures in the rear tires of a farm tractor of 96.5, 124, 151, and 179 kPa, as well as a condition of loamy sand soil with 10.35% humidity, that the lowest pressure caused the lowest tension in the soil, demonstrating the relevance of reducing the pressure to decrease soil compaction to depths of 0.30 m. The highest pressures caused the largest deformations in the soil caused by reducing the tire-soil contact area. In the study, the authors cite that it is necessary to seek solutions to reduce working pressures to cause less superficial soil compaction due to vertical and horizontal tensions.

Feitosa et al. (2015) cite that not only the tire inflation pressure can be decisive to influence the physical aspects of the soil, but the constructive model, whether diagonal or radial, as well as the tire dimensions. The influence of internal pressures on the diagonal tires of the front and rear axles of an agricultural tractor of 83 and 86 kPa, 96 and 110 kPa, and 110 and 124 kPa, respectively, were evaluated, leading the authors to conclude that in Argissolo Vermelho-Amarelo, the application of pressures of 110 and 124 kPa on the front and rear tires caused the highest reduction in total soil porosity.

On the constant concern with the rational use of energy resources and the reduction of mechanized costs, Montanha et al. (2011) address that the fuel consumption demanded by the tractor-implement set can be optimized based on the suitability of the tires to work, since they have the function of displacing, balancing, directing and damping the set; for these reasons, the pressure used becomes an aspect of fundamental regulation, aiming at the operation performance and economy.

This study aimed to evaluate an agricultural tractor's operational performance with different tire inflation pressures in the subsoiling operation.

2. Material and Methods

The work was carried out at the Agricultural Machinery and Mechanization Laboratory of the experimental farm "Água Limpa" (Lamagri/FAL), belonging to the University of Brasília.

The area used is located on the geographical coordinates 15°57'00" S and 47°55'41" W, and an average altitude of 1109 m. The soil was classified by Papa et al. (2011) as Latossolo Vermelho-Amarelo (LVA) with a clay texture. The average water content in the soil during the experiment was 23%, obtained from six random samples of soil between the 0.0 - 0.3 m layers of the experimental area, submitted to the standard oven method (EMBRAPA, 2011). The average soil density was 0.096; 0.074 and 0.046 g cm-3 at depths of 0.0 - 0.1; 0.1 - 0.2, and 0.2 - 0.3, respectively, obtained from random samples by the volumetric ring method (EMBRAPA, 2011).

The average temperature of the day during the experiment was 22.7 °C. The area's history is with corn cultivation in a no-tillage system, with the soil covered by spontaneous vegetation and 8032.8 kg ha^{-1} of residual straw from the grain harvest.

The experimental design used was in randomized blocks with four repetitions per treatment, with the values 206.8 kPa (30 psi), 137.9 kPa (20 psi), and 68.9 kPa (10 psi) of inflation pressure of the four tires of the agricultural tractor. The pressure 137.9 kPa (20 psi) was adopted according to the tire manufacturer's technical recommendation, and the lower and higher pressures were established to simulate inadequate pressure and extreme use conditions in the field. The experimental plots were 80 m long and 5 m wide.

The mechanized set consisted of a Piccin subsoiler, model SPCR, equipped with five shanks spaced 0.4 m from each other, with tips 0.08 m wide, without wings, straw cutting discs of 0.46 m, a cutting roller, and 1550 kg in weight. The subsoiler worked with the shanks at a depth of 0.35 m, driven by the drawbar of a New Holland tractor, model TM7020 2WD MFWD, with 109.58 kW (149hp) of engine power, the total weight of 7125 kg, 2494 kg on the front axle and 4631 kg on the rear axle.

On the tractor's front axle, two diagonal tires of the Pirelli brand model TM95, type R1 were used, with measures 18.4-26, consisting of 12 tarps and claws 0.043 m high. Two Goodyear diagonal tires, model Dyna Torque II, type R1, with measures 20.8-38, 14 tarps, and 0.052 m high claws were employed on the rear axle. The four tires used 75% of the volume with liquid ballast.

The slippage index (P) of the rear wheels was determined according to the methodology described by Mialhe (1996), obtained by Equation 1.

$$P\,(\%) = \frac{SC - CC}{SC}\,x\,100$$

Where:

P: Slippage index (%)

CC: Number of turns of the rear wheels with tractive force on the drawbar (implement lowered).

SC: Number of turns of the rear wheels without traction force on the drawbar (implement lifted).

The kinematic advance index (A) of the front wheels was determined by Equation 2, according to the methodology described by Gameiro and Lanças (1996).

$$A\,(\%) = \frac{CT - ST}{ST}\,x\,100$$

Where:

A: Kinematic advance index (%)

CT: Number of turns of the front wheelset with the MFWD on

ST: Number of turns of the front wheelset with the MFWD off

Hourly fuel consumption (Hfc) was determined using the standard test tube methodology described by Sichocki et al. (2013). Two 1000 ml beakers, graduated in a 10 ml scale, were installed in the tractor's fuel supply system, one supplying diesel for the injection pump supply and the other receiving the nozzle return. At the entrance of each plot, the feeding beaker was filled with known volume, and at the end, subtracting the volumes of each beaker, consumption data were obtained and submitted to Equation 3 to determine the Hfc. The time required to travel within each plot was measured with a digital timer.

$$Hfc = \frac{Vi - Vr}{t}\,x\,3,6$$

Where

Hfc: Hourly fuel consumption (L h^{-1})

Vi: Volume of fuel consumed in the inlet beaker (L)

Vr: Volume of fuel consumed in the return beaker (L)

t: Time necessary to travel the plot (s)

3,6: Transformation constant

According to the methodology described by Mialhe (1974), the operational field capacity was determined, being used in equation 4.

$$Ofc = \frac{W\,.\,s}{10}\,x\,Ef$$

Where

Ofc: Operational field capacity (ha h^{-1})

W: Actual working width of the machine (m)

s: Working speed (km h^{-1})

Ef: Field efficiency expressed in decimal (75%)

The data obtained were subjected to variance analysis and the averages compared by Tukey's test at 5% significance, with the statistical software R, version 1.1.463.

3. Results and Discussion

The results from the variance analysis for the investigated variables are shown in Table 1 and demonstrate significance for all variables. Slippage (P), kinematic advance (A), operating speed (V), and operational field capacity (Ofc) have a significance level of 1% probability of error, and hourly fuel consumption (Hfc) exhibits a significance of 5% probability of error.

The slippage (P) and advance (A) results are shown in Figure 1 and indicate that the wheels' inflation pressures differed by the variable.

The lowest inflation pressure showed a slippage of 10.58%, an index 21.5, and 34.1% lower than those seen in intermediate and higher pressures. As suggested by Godinho Júnior et al. (2017), slippage at the highest inflation pressure can be considered outside the acceptable efficiency limit for firm soils, considered ideal from 10 to 15% by the authors.

The result can be understood, according to Santos et al. (2016). They found a linear increase of 0.053% in slippage by increasing a pressure unit (kPa) in the tires when studied an agricultural tractor with different tire inflation pressures in tillage operation. That slippage should be due to the occurrence of a smaller area of contact between the tire's tread and the ground, causing less grip and traction, thus increasing slippage.

The result of less slippage with lower inflation pressure corroborates that verified by Janulevicius et al. (2019). They found that slippage was reduced by 11% when the tire pressure was reduced from 240 to 80 kPa when working with different inflation pressures on an agricultural tractor's tires.

It is observed that when the inflation pressure of the front tires increases, the rate of kinematic advance increases. At the lowest pressure (68.9 kPa), the advance was 1.49%, 49.1, and 68.8% less than at 137.9 and 206.8 kPa, respectively. The result is possibly due to the association between an increase in the rolling radius and a smaller area of wheel-to-ground contact when the pressure is higher and to the requirement for traction force on the drawbar by the subsoiler, described by Feitosa et al. (2015).

The slippage result differs from that obtained by Feitosa et al. (2015) when comparing three inflation pressures in an agricultural tractor's rear wheels, 96, 110, and 124 kPa. The author identified that these values did not significantly affect the wheelset slippage, obtaining an average of 1%. The low value obtained and the divergence with the current work are due to the tractor used by the authors was not subjected to efforts on the drawbar.

The kinematic advance is substantially increased by the increase in the wheelsets' inflation pressure, being higher (4.78%) at 206.8 kPa. The result is in line with Leite et al. (2017), who detected an increase of 0.026%

in the slip index for each unit of pressure added to the tires at the same speed, justified by the increase in the rolling radius of the tires.

According to Janulevicius et al. (2017), with the reduction of the wheelsets' inflation pressure, there is a reduction of its rolling radius; thus, the front wheels acquire greater rotation than the rear wheels, increasing the kinematic advance. However, the result obtained at the highest pressure is between 1 and 5%, limits described by Feitosa et al. (2015) as being suitable for the agricultural tractor's good performance, if the slippage does not exceed 20%.

The wheels' inflation pressures have relevance to the variables shown in Figure 2 since they reflect the influence of the results of Figure 1 on the wheel rolling, traction efficiency, and energy efficiency of the tractor. The results reveal that excessive pressure induces greater slippage (Figure 1) due to the wheels' larger rolling radius, the smaller contact area, and the wheel-to-ground adhesion. Thus, energy efficiency is hindered by the increase in fuel consumption for improper rotation of wheelsets and the loss of travel speed. If impaired the speed of an implement, the operational field capacity will be reduced.

Table 1. Analysis of variance for the studied variables according to the pressure of the tire inflation of the agricultural tractor.

Variable	Anova				
	SI	A	Hfc	OS	Ofc
F-test	100.65	591.26*	7.72	66.84*	74.47*
CV (%)	4.08	4.42	4.98	3.20	3.05
MSD	1.07	0.26	2.74	0.30	0.05
SE	0.273	0.067	0.69	0.078	0.013
SD	0.564	0.135	1.38	0.156	0.026

P: slippage; A: advance; Hfc: hourly fuel consumption; V: operational speed; Ofc: operational field capacity. * Significant at the 5% level of error probability. ** Significant at the level of 1% probability of error. CV: coefficient of variation; MSD: minimum significant difference; SE: standard error of the average; SD: standard deviation.

Figure 1. Slippage and kinematic advance (%) at different tire inflation pressures.
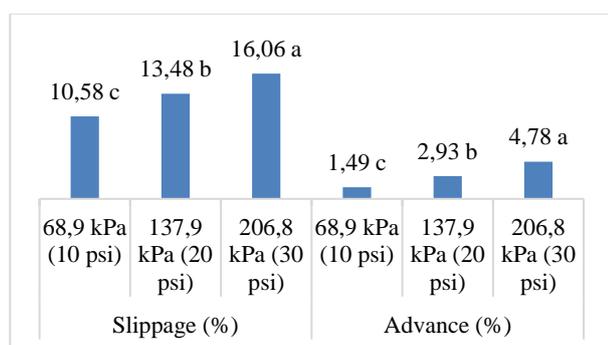
Means followed by the same lowercase letter do not differ from each other by the Tukey test at the 5% level of significance.

Figure 2. Hourly fuel consumption (Hfc), operational speed (V), and operational field capacity (Ofc).

Means followed by the same lowercase letter do not differ from each other by the Tukey test at the 5% level of significance.

The lowest hourly fuel consumption (Hfc), 25.67 L h^{-1}, was obtained by the 68.9 kPa inflation pressure of the wheelsets, whose slippage and the kinematic advance was lower (Figure 1). Due to the lower slippage and advance, the Hfc of the lowest pressure was 10.1 and 12.4% lower than the values corresponding to 68.9 kPa and 137.9 kPa, respectively. Between 137.9 and 206.8 kPa, Hfc did not differ significantly, although slippage and advance did diverge.

The result corroborates that found by Montanha et al. (2011), who studied two tire inflation pressures, 124 and 242 kPa, and found that, at the lowest pressure, there was a 3% reduction in hourly fuel consumption. However, it differs from that found by Mamkagh (2018), when verifying that the fuel economy increased from 7.3% to 11.4% by increasing the tire inflation pressure from 110 to 159 kPa.

The operating speed (V) was reduced by 15.3 and 23.3% from the highest pressure (206.8 kPa) to 137.9 and 68.9 kPa, respectively. The lower speed of the highest pressure, 4.19 km h-1, occurred due to the greater slippage and the wheelsets' kinematic advance, which delayed the fluent movement of the mechanized set. In this context, Rosca et al. (2014) describe that the tires' pressure is directly related to the operational speed that the tractor-implement set can develop. This is due to the tire's contact and adherence to the soil surface, which may be greater or lesser and may vary according to the inflation pressure used. However, the discussion is different from that described by Amorim et al. (2019) when they tested a tractor-seeder set with two tire inflation pressures and did not find an operational speed variation. The result is possibly the consequence of the lower traction force required by the seed drill compared to the subsoiler.

Directly dependent on operational speed, the operational field capacity (Ofc) was lower, 0.75 ha h^{-1}, at the highest tire inflation pressure, whose speed was lower. The context discussed for understanding the lower

speed results is synchronous to the Ofc obtained and agrees with Taghavifar and Mardani (2014). They describe the loss of operational speed due to greater slippage of the wheels when the power provided by the tractor is reduced from 20 to 55%. Similarly, Simões et al. (2011) detected the loss of subsoiling Ofc when, in a gentle slope, the tractor suffers greater slippage due to the greater traction effort, with reduced travel speed and increased fuel consumption.

Damanauskas et al. (2015) state that adding ballast (load) to the tractor and reducing the tire inflation pressure are possible measures to be adopted to decrease the wheelset slip index, increase speed, and Ofc. However, the authors mention that these actions can increase fuel consumption, as verified in the results presented in Figure 2. Evaluating four inflation pressures of the wheels and different ballast masses of the tractor, Damanauskas et al. (2015) found that the condition of higher pressure (240 kPa) without ballast provided greater slippage (13.5%) and lower Ofc (1.36 ha h^{-1}) concerning the condition of lower pressure (100 kPa) with greater ballast mass, with values of 6.6% for slippage and 1.46 ha h^{-1} for Ofc.

4. Conclusions

Given the conditions of the current work, it can be understood that the higher inflation pressure of the tractor tires provokes less subsoiling operational productivity, higher hourly fuel consumption, slippage, and the kinematic advance of the tractor wheels.

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