INFLUENCE OF INFLATION PRESSURE IN TIRES ON TRACTION RATIO 2WD AND 4WD DRIVING MODES OF TRACTOR

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Abstract. Cargo is transported not only on the roads but also at various field conditions. Tractors with trailers are mostly used on the field conditions. The tractor is loaded drawbar pull more when transporting a bigger cargo. On drawbar pull not only slippage of the tractor depends, but also vertical loads of the driving wheels of the tractor. It is recommended to decrease the inflation pressure in the tires in order to reduce slippage. The energy losses due to slippage can be significantly reduced by selecting the optimal inflation pressure in the tires. In order to properly select tractor trailers aggregates and choose 2WD or 4WD driving mode of the tractor suitable for the field conditions it is very important to predict the slippage value in advance. In such a case, traction ratio is usually used to predict slippage. The paper deals with the influence of the inflation pressure of the driving wheels on the traction ratio of the tractor. The drawbar pull influence of the vertical loads of the driving wheels of the tractor is analyzed. Also the slippage dependencies between the drawbar pull of the tractor and the traction ratio, when driving with 2WD and 4WD modes at various different inflation pressures in the tires, are presented.

Keywords: vertical load, slippage, drawbar pull, traction ratio.

Introduction

Wheeled tractors are used for a whole year in agriculture. There are three groups of operation modes of the tractor by specification of operations: operations on the fields, when the tractor is loaded by a big drawbar pull (ploughing, cultivation, sowing and etc.); operations at a big friction efficiency in high speed (transport operations); operations with the tractor when the driving wheels are loaded unproportionaly on the driving axles (operations with front loader and etc.) [1; 2].

There is currently deteriorating ecological situation associated with mineral fuel consumption in the world nowadays. Therefore, in 2011 the United States provided minimal requirements relating to the tractor efficiency increasing in transport operations, which have already come into force in 2017 [3].

Slippage of the tractor is one of the main energy-economic indicators of compounding tractors with aggregates. It is one of the main indicators performing the tire road surface interaction [4-7]. Slippage depends on the drawbar pull. It is researched, that with the increase of slippage the drawbar pull also increases. The maximal drawbar pull can be developed on 15-20 % slippage [4-8]. But due to the negative impact of slippage on the soil surface maximum slippage of wheeled tractor can be limited to 15 % [4]. The recommended value of slippage must be taken into account to compounding tractor aggregates. For example, on plowing operations the recommended value of slippage must be approximately 8-12 % [4; 5]. If the slippage is oversized or too low, energy waste increases.

The exploitation period of the tire, economical effect, and drawbar pull of the tractor depend on the air pressure in the tires. The air pressure in the tires must be increased on the road. The air pressure in the tires must be about 1.4-1.6 bar on the road in higher speed [9]. However, in the field conditions, as the softer surface of the road, the inflation pressure in the tires should be reduced, thus reduced slippage of the tractor and increased operating economy.

Scientists recommend decreasing the air pressure in tires to reduce slippage [9-15]. The tire customizers are developing tires as low pressure as possible in using. In addition, there are more popular inflation pressure changing systems in agriculture nowadays. Choosing the inflation pressure the recommended slippage values vertical loads of the driving wheel and the working speed in agricultural operations should be taken into account.

Before selecting the number of units and driven axles of field work, it is necessary to predict the tractor slippage. Traction ratio is used to predict slippage of the tractor [16; 17]. However, the mathematical expression of the traction ratio underestimate the air pressure in the tires. Tyre pressure has a significant influence on the tractor slippage.

Dealing with the drive wheel slippage adjustment possibilities and reaching optimal ecological-economic results at the same time it is needed to know the traction ratio dependencies on the inflation pressure in the tires, vertical load of the tires and drawbar pull developed on different soils type. Road surface physical and mechanical properties of the transport operation are always different, because the same cargo is transported from the field on the road and conversely, so the slippage dependencies need to be found experimentally.

Materials and methods

Dry stubble was selected (hardness in 5 cm depth was 0.40 MPa, soil moisture in 5 cm depth was 14 %) for investigations. For slippage dependency on drawbar pull tests at different inflation pressures in the tires of the tractor, the tractor "Case Farmall 115U" was used. The investigations were performed with turn off front driving wheels and blocked rear differential. Tractor drawbar pull was performed by pulling tractors "Zetor 10540" and "MTZ 82", which were connected on rigid link 80 cm above road surface. There was fitted a drawbar pull measurement sensor.

The main technical data of the tractors used in the experiments are shown in Table 1.

Table 1

Technical data of tractors

Technical data	Case Farmall 115U	Zetor 10540	MTZ 82
Rated engine power, kW	83	78.3	58,82
Weight of the tractor, kg	4250	4336	3420
Wheelbase, mm	2350	2380	2450
Front tires	Michelin Multibib 340/65R24	16.9 – 14 R38	16.9R38
Rear tires	Michelin Multibib 540/65R34	12.4 – 28 TZ19	15.5R30
Weight of the front axle, kg	1990	1848	1221
Weight of the rear axle, kg	2260	2488	2449

During the investigations the distance was measured, which the rear wheels of the tractor drove in 10 revolutions during the experiments. Laser rangefinder Bosch PLR 50 was used to measure the distance. Measurement precision is 2 mm.

The coefficient of slippage of the tractor rear wheels during exploitation with 2WD driving wheels was calculated by equation:

$$\delta = \frac{s_{th} - s_a}{s_{th}} = \frac{s_{4\times2(F_t)} - s_{4\times2(F_t=0)}}{s_{4\times2(F_t)}}. \tag{1}$$

where s_{th} – the theoretical distance of the rear wheel travelling during 10 revolutions accordingly;
s_a – the actual distance of the rear wheel travel during 10 revolutions.

The coefficient of slippage of the tractor during exploitation with 4WD driving wheels was calculated by equation:

$$\delta = \frac{s_{th} - s_a}{s_{th}} = \frac{s_{4\times4(F_t)} - s_{4\times2(F_t=0)}}{s_{4\times4(F_t)}}. \tag{2}$$

The theoretical distance s_{th} was determined according to the American Society of Agricultural Engineers (ASAE) standard S296.2 as the distance travelled per revolution of the wheel when operating at the specified zero condition; $s_{4\times2(Ft)}$ – the distance, which drives the rear wheels in 10 rates when the tractor was loaded drawbar pull with 2WD driving wheels; $s_{4\times4(Ft)}$ – the distance, which drives the rear wheels in 10 rates when the tractor was loaded drawbar pull with 4WD driving wheels.

The traction ratio was calculated by the next equation:

$$\varphi_g = \frac{F_t}{G_v}, \tag{3}$$

where F_t – the drawbar pull of the tractor;
G_v – the vertical load of the driving wheels of the tractor.

Traction ratio is calculated by using rear wheel vertical load when the tractor drives with 4X2 driving wheels, traction ratio is calculated by using all vertical load of the tractor when the tractor drives with 4X4 driving wheels.

All investigations were performed on soil preparing for sowing and stubble, driving on the third diapason and second gear, on 1400 rpm engine speed with blocked rear differential.

The inflation pressures in the front and rear tires of the tractor were changed during the investigations. Pressures were selected respectively 80, 120, 140, 160, 200, 240 kPa for the investigations.

Vertical load of the wheels was determined on a flat area on the electronic axle weigher WPD-2. The tractor "Case Farmall 115 U" was affected on different loads of the drawbar pull. The measurement precision is 2 kg.

In order to obtain greater reliability and precision of the results, the tests were repeated three times.

Results and discussion

It is known that drawbar pull has influence on the vertical load of the driving wheels of the tractor.The results of the tractor "Case Farmall 115 U" vertical load on the rear wheel of the traction force are shown in Figure 1. The vertical load increases in proportion to the biggest load on the drawbar pull. Vertical load increases in proportion to the largest load on the drawbar pull by regression equation from Fig. 1:

$$G_v = 0.513F_t + 26.452, \tag{4}$$

where G_v –vertical load of the rear driving wheel;
F_t – drawbar pull.

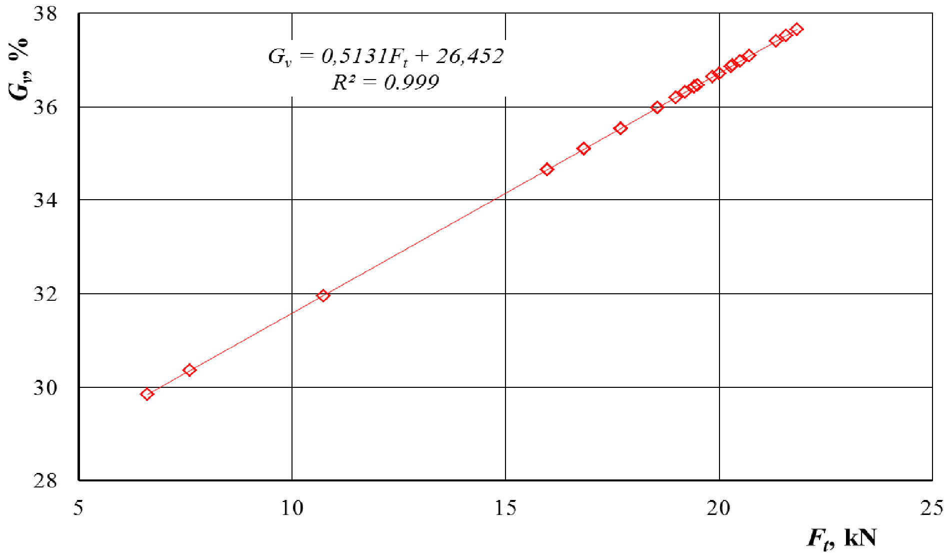

Fig. 1. **Tractor "Case Farmall 115U" vertical load of rear wheels G_v dependency on drawbar pull F_t**

Increasing the load (drawbar pull) of the tractor, the rear wheel vertical load increases proportionally. When the tractor is loaded 6.2 kN of drawbar pull, the vertical rear wheel load was 29.7 kN, and at 22.3 kN of drawbar pull, vertical load was 37.8 kN respectively (Fig. 1).

Tractor slippage depends on the drawbar pull. Slippage of the tractor "Case Farmall 115U" dependencies on drawbar pull are shown at different inflation pressure in the tractor tires during exploitation on stubble with 4X2 driving wheels in Fig. 2. The inflation pressure in the rear tires during the investigations was 80; 120; 160; 200; 240 kPa. Tractor slippage also depends on the weight distribution (weight transfer effect) to the driving wheels; therefore, the vertical load dependence on drawbar pull is shown in the same graph.

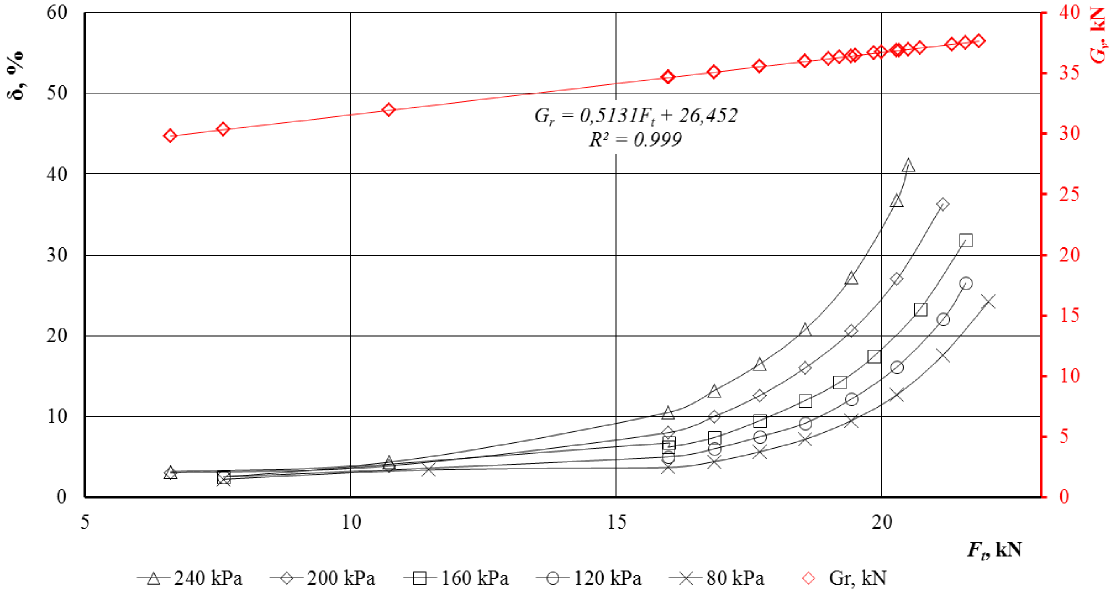

Fig. 2. **Slippage of rear driving wheel dependence on drawbar pull driving with the tractor "Case Farmall 115U" 4X2 driving wheels on stubble at different inflation pressure in tires: 80; 120; 160; 200; 240 kPa. Vertical load of rear wheels G_v dependence on drawbar pull F_t**

As shown in Figure 2, when the tractor loaded on a low drawbar pull (F_t < 15 kN) slippage of the tractor less depends on the inflation pressure in the driving wheels. At 80 kPa of inflation pressure, maximal slippage of the tractor is equal to 5.8 %, and by increasing the inflation pressure from 80 to 240 kPa, slippage of the tractor increases to 9 %. When the tractor is loaded 15 kN of drawbar pull, slippage of the tractor is equal 12.2 and 5.2 %, when the pressure in the rear tires is 240 and 180 kPa, respectively. And when the tractor is loaded 20 kN drawbar pull, slippage increases to 34.5 % when the pressure in the rear tires is 240 kPa and 12.2 %, when the pressure in the rear tires is 80 kPa.

At 15 kN drawbar pull the tractor slips 26 % less, when the inflation pressure is reduced from 240 to 80 kPa respectively. In higher loads, when the drabar pull is equal 20 kN, the tractor slips 56 % less, reducing the inflation pressure in the driving wheels from 240 to 80 kPa driving with the tractor 4X2 driving wheels in stubble.

Knowing the driving wheel vertical loads and developed drawbar pull by using dependencies from the first and second picture slippage dependencies of the traction ratio at different inflation pressure in the rear wheels are created (Fig. 3).

At low traction ratio ($\varphi < 0.35$) slippage of the tractor is small: between 3.4-4.3 % (Fig. 3) by changing the inflation pressure in the tires.

Operating with the tractor at higher loads, when the traction ratio is 0.45 slippage of the tractor is equal to 10.5 %, when the inflation pressure in the tractor rear tires is 240 kPa and 6.2 %, when the inflation pressure in the rear tires is 80 kPa. When the traction ratio is 0.50 slippage of the tractor is equal to 17.7 %, when the inflation pressure in the rear tires is 240 kPa and 6.2 %, when the inflation pressure in the rear tires is 80 kPa. When the traction ratio is 0.55, the tractor slips 36.8 %, when the inflation pressure in the rear tires is 240 kPa, the tractor slips 12.7 %, when the inflation pressure in the rear tires is 80 kPa (Fig. 3).

As shown in Fig. 3, tractor slippage decreases in 32 % by reducing the inflation pressure in the driving wheel tires from 240 to 80 kPa, when the traction ratio is equal 0.4. At 0.55 of traction ratio, slippage of the tractor decreases in 64 % by reducing the inflation pressure in the driving wheels from 240 to 80 kPa.

The inflation pressure in the tires of the tractor has influence on the performance during exploitation with 4x4 driving wheels. Therefore, in order to reach the optimal economical-ecological indicators it is necessary to adjust the inflation pressure in the tires properly.

During operation with 4X4 wheel drive the total weight of the tractor with hitched horizontally flexible link on the aggregate is consistent and equal 47.64 kN.

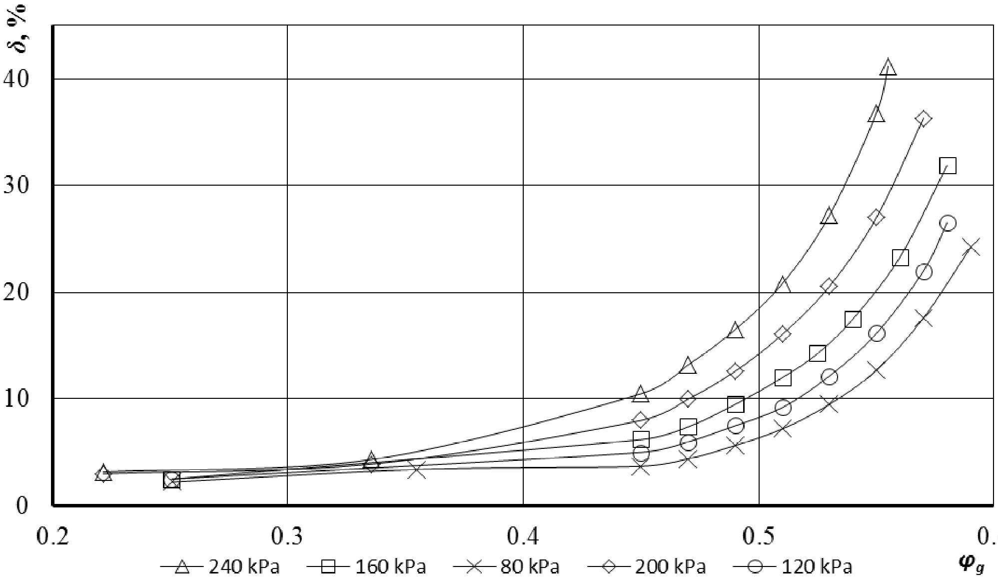

Fig. 3. **Slippage dependence on traction ratio driving with the tractor "Case Farmall 115U" 4X2 driving wheels on stubble at different inflation pressure in front and rear tires: 80; 120; 160; 200; 240 kPa**

Slippage of the tractor "Case Farmall 115U" dependencies on drawbar pull at different inflation pressure in the tractor tires during exploitation on stubble with 4X4 driving wheels are shown in Fig. 4. The inflation pressure in the front and rear tires during the investigations was respectively: 80 and 80; 120 and 120; 160 and 160; 200 and 200; 240 and 240 kPa.

At low loads of the tractor, when the drawbar pull was less than 14 kN, the slippage of the tractor was small and varied from 6.7 to 5.1 %, when the inflation pressure was 240 and 80 kPa in the driving wheels respectively.

At higher loads the inflation pressure in the tractor tires has a much greater influence on the tractor's slippage. At 15 kN of drawbar pull, slippage of the tractor was 7.0 and 4 %, when the inflation pressure in the tires was respectively 240 and 80 kPa. At 20 kN of drawbar pull, slippage of the tractor was 15.1 and 6.3 %, and with increased load up to 23.5 kN the tractor slippage was 31.87 and 9.6 %, respectively, when the inflation pressure in the front and rear tires was 240 kPa and 80 kPa, respectively (Fig. 4).

Thus, slippage can be reduced up to 23.9 % by reducing the inflation pressure in the front and rear driving wheels from 240 to 80 kPa. At higher loads the inflation pressure in the tires has higher influence: at 15 kN of drawbar pull slippage can be reduced up to 42.9 %, at 20 kN of drawbar pull slippage can be reduced up to 58.2 % and at 23.5 % of drawbar pull slippage can be reduced to 69.9 % by reduction of the inflation pressure in the driving wheels from 240 kPa to 80 kPa respectively during exploitation with 4X4 driving wheels of the tractor "Case Farmall 115U".

Compounding various tractor aggregates for transport operations in the field conditions with 4X4 driving wheels, a very important task is slippage prediction in advance. Traction ratio is also used for slippage prediction. In this case the traction ratio is calculated by basing the total vertical weight and developed drawbar pull of the tractor during exploitation with 4X4 driving wheels.

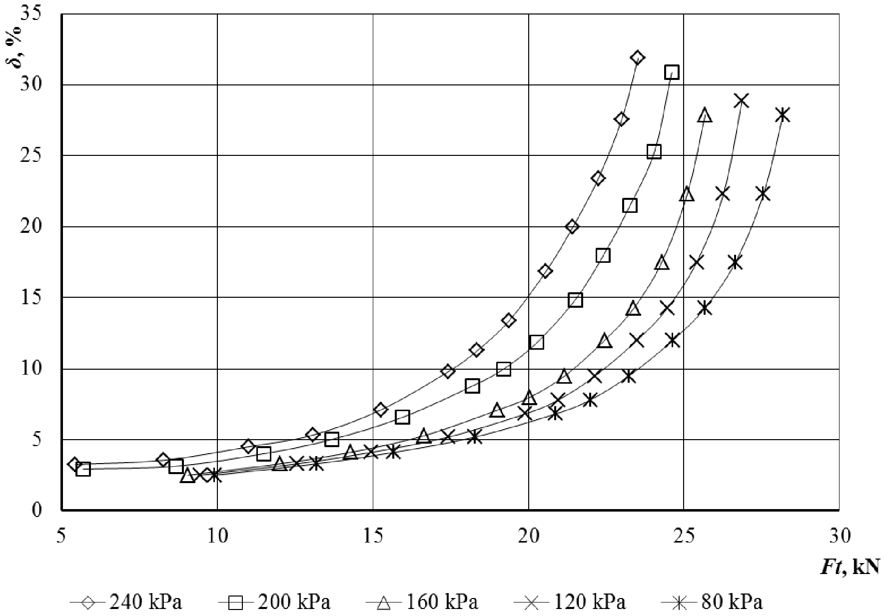

Fig. 4. **Slippage of the tractor „Case Farmall 115U" dependence on drawbar pull driving with 4X4 driving wheels on stubble at different inflation pressure in front and rear tires: 80 and 80; 120 and 120; 160 and 160; 200 and 200; 240 and 240 kPa**

There are shown slippage dependencies on the traction ratio at different inflation pressure in the front and rear driving wheels during exploitation with 4X4 driving wheels. Inflation pressure in the front and rear tires during the investigations was respectively: 80 and 80; 120 and 120; 160 and 160; 200 and 200; 240 and 240 kPa.

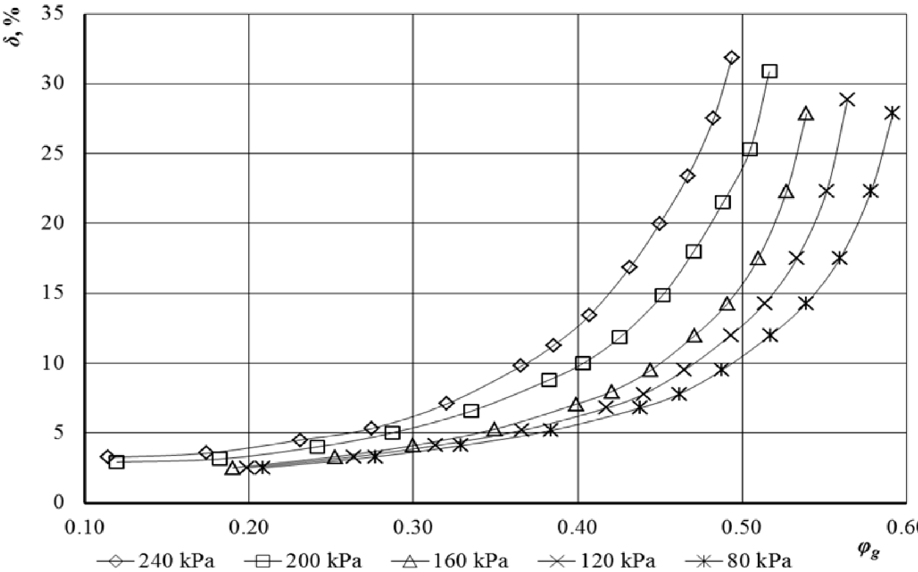

Fig. 5. **Slippage of the tractor „Case Farmall 115U" dependence on traction ratio driving with 4X4 driving wheels on stubble at different inflation pressure in front and rear tires: 80 and 80; 120 and 120; 160 and 160; 200 and 200; 240 and 240 kPa**

At low traction ratio ($\varphi < 0.35$) the slippage of tractor is small: up to 4.6-8.4 % (Fig. 5) by changing the inflation pressure in the tires.

Operating with the tractor at higher loads (when the traction ratio is equal 0.4) slippage of the tractor is equal to 13.1 %, when the inflation pressure in the tractor's rear tires is 240 kPa and 6.2 %, when the inflation pressure in the rear tires is 80 kPa. When the traction ratio is 0.45, slippage of the tractor is equal to 19.6 %, when the inflation pressure in the rear tires is 240 kPa and 7.5 % when the inflation pressure in the rear tires is 80 kPa. When the traction ratio is 0.48, the tractor slips 27.5 % when the inflation pressure in the rear tires is 240 kPa and 9.5 %, when the inflation pressure in the rear tires is 80 kPa (Fig. 3).

As shown in Fig. 5, slippage of the tractor decreases in 61,73 % by reducing the inflation pressure in the driving wheels from 240 to 80 kPa driving with the tractor „Case Farmall 115U“ with 4X4 driving wheels in stubble, when the traction ratio is equal to 0.45. At 0.48 of traction ratio, slippage of the tractor decreases in 64.5 % by reducing the inflation pressure in the driving wheels from 240 to 80 kPa.

In both cases slippage of the tractor “Case Farmall 115U” could be significantly reduced by reducing the inflation pressure in the driving wheels from 240 to 80 kPa. Driving with 4X2 driving wheels slippage could be reduced up to 69.9 %, and driving with 4X4 driving wheels could be reduced up to 64.5 %, respectively.

As it can be seen from the field tests, inflation pressure in the driving wheels has a significant influence on slippage prediction of the tractor. Therefore, further investigations are necessary in the future that will estimated the regression equitation, applying of which should predict the influence of the inflation pressure in the driving wheels to the traction ratio, by which slippage of the tractor in advance could be precisely predicted.

Tractor slippage is influenced by many factors. Some of the factors related to the soil physical and mechanical properties are very different. Therefore, in each case slippage of the tractor is different [1;4;9;10;13;14].

Conclusions

1. Increasing the drawbar pull from 6.2 to 22.3 kN, vertical rear load increases from 29.7 to 37.8 kN, but vertical load of the tractor is constantly 47.64 kN.
2. Slippage is 69.9 % less by reducing the inflation pressure in the tires from 240 to 80 kPa operating with the tractor “Case Farmall 115 U” with 4X2 driving wheels, when the traction ratio is equal to 0.55.
3. Slippage is 64.5 % less by reducing the inflation pressure in the tires from 240 to 80 kPa operating with the tractor “Case Farmall 115 U” with 4X4 driving wheels, when the traction ratio is equal to 0.48.
4. Inflation pressure in the driving wheels has a major influence on slippage prediction of the tractor. Therefore, in order to predict slippage of the tractor during traction operations it is necessary to take into account the inflation pressure in the tires of the driving wheels.

References

1. Lacour S., Burgun C., Perilhon C., Descombes G., Doyen V. A model to assess tractor operational efficiency from bench test data. Journal of Terramechanics 54, 2014, pp. 1-18.
2. Janulevičius A., Pupinis G., Kurkauskas V. How driving wheels of front-loaded tractor interact with the terrain depending on tire pressures. Journal of Terramechanics 53, 2014, pp. 48-92.
3. Delgado O., Lutsey N., Advanced Tractor-Trailer Efficiency Technology Potential in The 2020-2030 Timeframe, white paper, 2015. 61 p.
4. Lee J W., Kim J. S. Kim K. U. S. Computer simulations to maximise fuel efficiency and work performance of agricultural tractors in rotovating and ploughing operations, Biosystems Engineering 142, 2016, pp. 1-11.
5. Molari, G., Bellentani, L., Guarnieri, A., Walker, M., Sedoni, E. Performance of an agricultural tractor fitted with rubber tracks. Biosystems engineering 111, 2012, pp. 57-63.
6. Jun H., Kishimoto T., Way T. R., Tauinguhi T. Three direction contact stress distributions for a pneumatic tractor tire in soft soil, Transaction of the ASAE, Vol 41, No 5, 1998, pp. 1237-1242.
7. Grečenko A, Prikner P. Tire rating based on soil compaction capacity. Journal of Terramechanics 52, 2014, pp. 77-92.
8. Porteš P., Bauer F., Čupera J. Laboratory-experimental verification of calculation of force effects in tractor’s three-point hitch acting on driving wheels. Soil & Tillage Research 128, 2013, pp. 81-90.

9. Janulevičius A., Giedra K. The slippage of the driving wheels of a tractor in a cultivated soil and stubble. Transport 24(1), 2009, pp. 14-20
10. Kolator B. Bialobrzevski I., A simulation model of 2WD tractor performance, Computers and Electronics in Agriculture 76(2), 2011, pp. 231-239.
11. Karkee M. Steward B. L., Parameter estimation and validation of a tractor and single axle towed implement dynamic system model, Computers and Electronics in Agriculture 77(2), 2011, pp. 135-146.
12. Žuraulis V, Levulytė L Sokolovskij E. The impact of road roughness on the duration of contact between a vehicle wheel and road surface. Transport 29 (4), 2014, pp. 431-439.
13. Taghavifar H, Mardani A. Evaluating the effect of tire parameters on required drawbar pull energy model using adaptive neuro-fuzzy inference system. Energy 85, 2015, pp.586–593.
14. Pranav P. K., Pandey K. P. Computer simulation of ballast management for agricultural tractors, Journal of Terramechanics 45(6), 2008, pp. 193-200.
15. Damanauskas V., Janulevičius A. Differences in tractor performance parameters between single-wheel 4WD and dual-wheel 2WD driving systems. Journal of Terramechanics 60, 2015, pp. 63-73.
16. Lyasko M. I. How to calculate the effect of soil conditions on thrust performance, Journal of Terramechanics, 47, 2010, pp. 423-445.
17. Taghavifar H., Mardani A. On the modeling of energy efficiency indices of agricultural tractor driving wheels applying adaptive neuro-fuzzy inference system, Journal of Terramechanics 47, 2014, pp. 37-47.