



ANALYSIS OF THE POWER TRANSMISSION IN THE TRACTOR WHEEL-FARMING GROUND SYSTEM

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ABSTRACT

The paper presents results of the research on the power transmission from the tractor wheel onto the grounds with different properties. The research was carried out in field conditions with the use of a stand aggregated with a farm tractor. Firstly, an initial evaluation of tractive properties was carried out by determination of the traction force and efficiency. In the fundamental part of the research values of the useful power (drawbar power), power lost to the rolling resistance and the power lost to the wheel slip were determined. A vertical load of a wheel, except for the ground type, was an additional factor. Based on the obtained results, it was proved that a wheel used on soil had higher values of the traction force but lower tractive efficiency in comparison to the values obtained on sod. Analysis of the power transmission proved that these differences result from higher power losses related to the rolling resistance of a wheel used on soil. Moreover, it was proved that the increase of the vertical wheel load favours the improvement of traction properties (increase in the tractive efficiency and the drawbar power shares) only in case of a wheel exploited on sod.

Introduction

In modern agriculture a large group of tractors may be defined as universal. These tractors can be employed both for field works on various types of agricultural grounds as well as for transport works. Traction properties variety results from such methods of exploitation. Losses of power may accompany transmission of traction power but proportions between those losses on particular grounds may differ. Losses of power may, on the other hand, have negative effects; on one hand these will be ecological effects (soil compaction) and on the other economic effects reflected in the increased fuel consumption by the tractor engine.

The tractive efficiency is used for description of the process of transferring the traction power from the tractor wheel to the ground. This parameter defines the relation of the effective power to the power supplied to a wheel (Bauer et al., 2013; Zoz et al., 2003). The tractive efficiency allows determination of the total size of losses in the wheel-ground system. However, it does not enable determination of the reasons of their formation. Such analysis

may be carried out with the use of assessment of the power transmission supplied to a wheel (Vantsevich, 2008; Żebrowski, 2010). This evaluation determines values of the useful power (drawbar power), power lost to the rolling resistance and the power lost to the wheel slip.

The research studies described in literature prove that better traction properties manifesting in higher values of the tractive efficiency are achieved generally on more compacted grounds (Jenane and Bashford, 2000; Senatore and Sandu, 2011; Zoz et al., 1999). A small number of papers pay attention to proportions between the component powers in the wheel – ground system and to indication of the prevailing type of losses at transferring the traction force. There are numerous papers, which indicate the impact of changes in vertical wheel load as a method for improvement of traction properties (Jun et al., 2004; Narang and Varshney, 2006; Taghavifar and Mardani, 2013) but changes in traction power and efficiency are not included in the power change.

Objective, object and conditions of research

Taking into consideration the facts presented above, research was undertaken whose objective was to evaluate the power flux at the transfer of the traction power from a wheel to the agricultural ground with different properties. Additionally, an assessment of the impact of the increased vertical load of a wheel on the changes of the power values was provided for.

The assumed traction properties were defined for a wheel equipped with a tyre 9.5-24. It was a bias-ply tube tyre with a traditional relief of a tread. Basic parameters of a tyre were presented in table 1. During the traction tests the pressure inside a tyre was 0.15 MPa. Two levels of the vertical load of 6110 N (623 kg) and 8060 N (822 kg) were applied. Both the level of pressure as well as the load did not exceed maximum values provided by the tyre producer.

Table 1
Parameters of a tyre used in tests

Internal diameter (mm)	Rim diameter (mm)	Total width (mm)	Tread height (mm)	Maximum load capacity (kg)	Maximum air pressure (MPa)
995	610	241	25	1120	0.25

Tests were carried out on two types of agricultural grounds, which were supposed to reflect, to some degree, a universal way of exploitation of agricultural tyres. Non-compacted soil (light clay) was the first ground. Meadow sod was the second one. Both grounds comprised experimental fields belonging to the Institute of Agricultural Engineering of the University of Life Sciences in Wrocław. Parameters of ground were set in table 2.

Table 2
Parameters of grounds

Ground	Moisture at the depth of 0.05 m (%)	Average compaction within the depth of 0-0.15 m (MPa)
Soil	12.3	0.82
Sod	21.0	1.75

Research methodology

Tests were carried out with the use of the stand presented in figure 1. The stand was aggregated with a farm tractor which allowed independence from external energy sources.

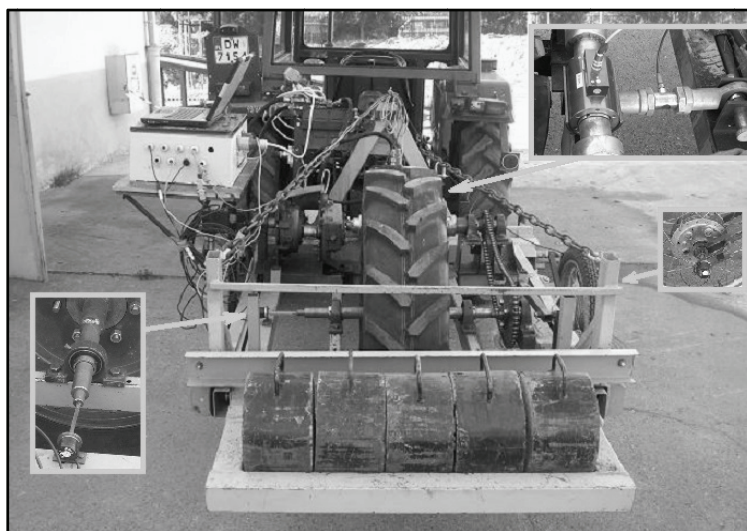


Figure 1. A general view of a stand for traction tests

The test consisted in transferring the torque from the power take-off shaft of a tractor to the tested wheel through a reduction gear. As a result, a translational motion of the stand was obtained. Traction parameters were being constantly measured during the crossing. Drawbar power was measured with a tensometrical sensor *TecSis* with the measurement precision of 40 N and within range of 0-20 kN. The torque was measured with the use of an induction torque measuring device *TecSis* (precision 1 Nm, the range 0-3000 Nm), whereas the speed was determined based on the angle of rotation measured by rotational encoders *MOK-40*. All data were registered by the electronic system cooperating with a computer. Each measurement was carried out in five repetitions.

Based on the obtained results, the values of a slip, the tractive efficiency and power, according to formulas 1-6 were determined.

$$\delta = 100 \cdot \left(1 - \frac{v_R}{v_T}\right) \quad (1)$$

$$\eta_T = \frac{P_u \cdot r_d}{M_O} \cdot (100 - \delta) \quad (2)$$

$$P_T = \frac{M_O}{r_d} \quad (3)$$

$$N_u = P_u \cdot v_R \quad (4)$$

$$N_f = (P_T - P_u) \cdot v_R \quad (5)$$

$$N_s = P_T \cdot (v_t - v_r) \quad (6)$$

where:

- δ – wheel slip, (%)
- v_R – real speed of a wheel, ($\text{m} \cdot \text{s}^{-1}$)
- v_T – theoretical speed of a wheel, ($\text{m} \cdot \text{s}^{-1}$)
- η_T – tractive efficiency, (%)
- P_u – pulling force, (N)
- r_d – dynamic radius of a wheel, (m)
- M_O – wheel torque, (Nm)
- P_T – traction force, (N)
- N_u – drawbar power, (W)
- N_f – power lost to the rolling resistance, (W)
- N_s – power lost to the slip, (W)

Research results

In order to carry out an initial assessment of traction properties of a wheel, traction force and tractive efficiency values were determined. Figure 2 presents mean values of the traction force (computed for a slip within the range of 0-30%) and the maximum values of tractive efficiency. It was determined that a wheel used on soil, had higher values of the traction force both at a lower and higher level of the vertical load; on sod these are by approx. 16% lower than on the non-sod soil. The obtained relations are different than in case of results presented in literature. Generally, higher values of traction force on weak-resistance ground were reported (Bashford et al., 1999; Jenane et al., 1996). Moreover, it was noted that the increase of the vertical load of a wheel results in the increase of the traction force – this tendency occurred on both grounds and is compliant to the results presented in literature (Gholkar et al., 2009; Jun et al., 2004).

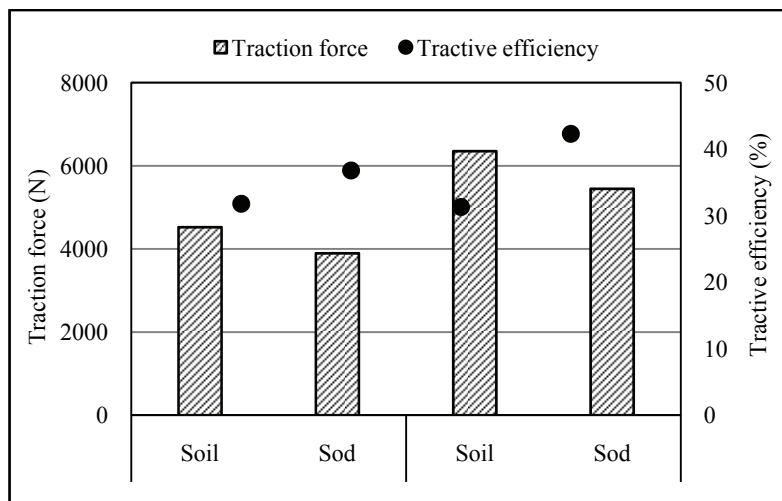


Figure 2. Mean traction force values and maximum tractive efficiency values

The analysis of the maximum values of the tractive efficiency showed that higher values of this parameter concerned a wheel used on sod. The increase in the efficiency value as a result of the increase in the vertical load was also reported on this ground (the increase was 15%). On soil, the efficiency value did not exceed 35%; the increase in the vertical load of a wheel caused a slight decrease in its value. Literature confirms the results concerning the tractive efficiency since many authors proved that on more compacted ground, values of the tractive efficiency are higher (Jenane et al., 1996; Senatore and Sandu, 2011, Zoz et al., 1999).

The presented differences in the traction force and tractive efficiency on different grounds may result from various values of power on wheels, thus analysis of the power flux seems reasonable. Figure 3 presents the courses of component powers subsequently for a lower and higher vertical load of a wheel. Based on the analysis of these courses one may state that the values of the drawbar power and power lost to the rolling resistance had high increments at a low slip (less than 3%). In case of a wheel used on soil, higher values of power lost to the rolling resistance were reported. At a slip exceeding 3%, the power slightly decreased, which might have been caused by the increase of soil compaction and in consequence a lower resistance of ground deformation. The analysis of the drawbar power course showed no clear differences in the shapes of these courses on particular grounds; in both cases after a slip of 3% was exceeded no significant changes of the value of this power were reported. Courses of power lost to the slip in all cases have a similar shape - the increase of the value of this power is proportional to the wheel slip growth. However, it should be emphasised that on the sod after exceeding the slip equal to 20% a certain increase of the growth rate of this power is reported. Certainly it is related to destruction of the sod structure and lower ability to counteract the slip.

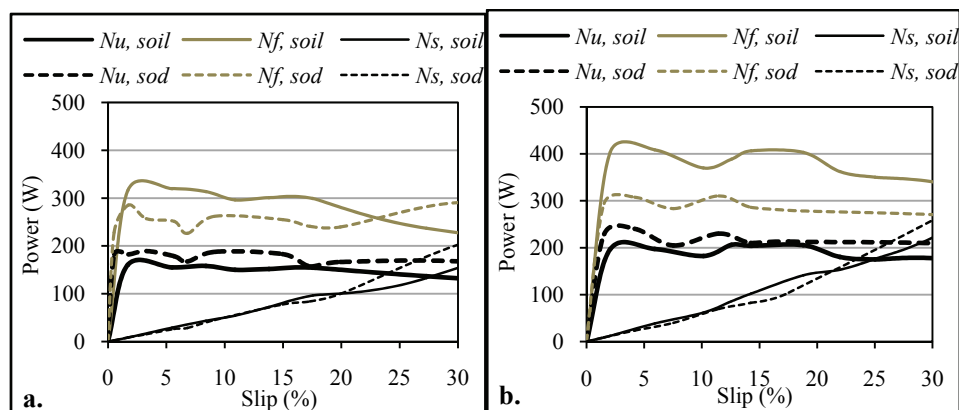


Figure 3. Courses of component powers as a function of a wheel slip: a – vertical load 6110 N, b – vertical load 8060 N; N_u – drawbar power, N_f – power lost to the rolling resistance, N_s – power lost to a slip

The nature of changes of the power values as a function of a slip is similar to the results presented in the papers by Materek (2004) and Materek and Pieczarka (2008). In other papers, authors indicated that the stabilization of the courses of drawbar power and the power lost on a slip occurred at higher slips than in case of these results (Bashford et al., 1999; Jenane et al., 1996; Wulfsohn and Way, 2009).

Figure 4 presents the list of mean values of power computed for the entire analyse-range of a slip. The graph shows that the wheel exploited on sod achieved higher values of effective power than on soil. Differences in values of this power for the lower and higher vertical load were respectively 21 W (14%) and 38 W (20%). Opposite tendency was reported in case of the power lost on the rolling resistance – at both levels of a vertical load, higher values of this power concerned a wheel exploited on soil. Certainly it was related to a lower compaction of this ground and consequently to a higher tendency to vertical deformation. Literature confirms this phenomenon. It proves that better traction properties concern grounds which are more compacted (Jenane and Bashford, 2000; Senatore and Sandu, 2011; Zoz, 2003).

At both levels of a vertical load, higher values of the total power were reported on non-compacted soil, which means that this ground demands more supplied power. The increase of the vertical load results in the increase of each component powers on both grounds, but a higher increase of the total power (by 30%) occurred on soil.

The values of total power on particular grounds were varied, thus it seems reasonable to present percentage participation of component powers in the total power (fig. 5). Regardless the size of the vertical load, a higher participation of the drawbar power was reported for a wheel exploited on sod. A lower participation of power lost to the rolling resistance also occurred on this ground. At a lower vertical load, a higher participation of power lost to the slip was proved for a wheel utilized on sod. After the load was increased, participation of losses related to a slip on both grounds was similar.

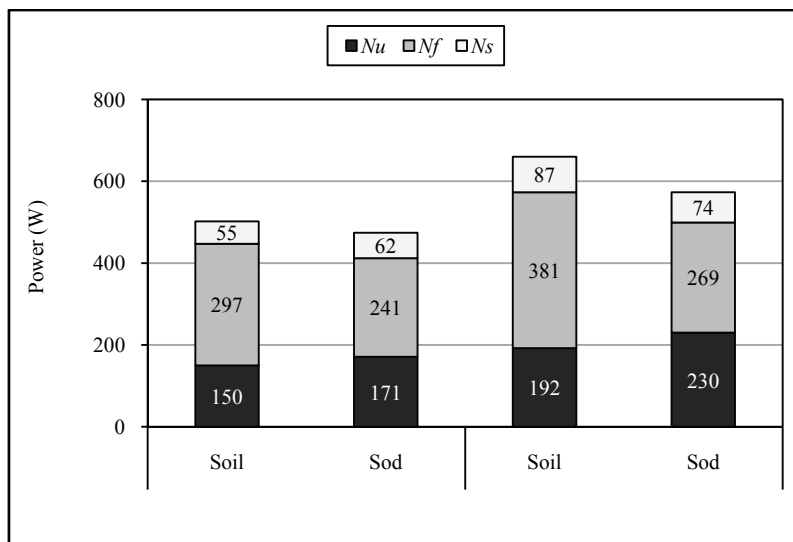


Figure 4. Mean values of component powers for the range of a slip 0-30% (symbols as in figure 3)

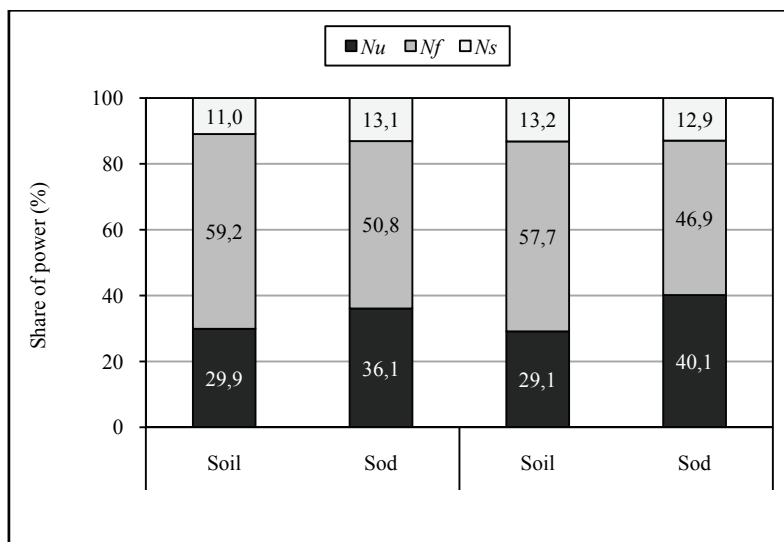


Figure 5. Total power structure (symbols as in figure 3)

Loading a wheel on soil resulted in a slight decrease of the drawbar power share, and on sod it grew by 11%. Therefore, the increase of the vertical load of a wheel may be recognized as an effective method of improving traction properties on sod. Such a relation complies with the results presented by other researchers – it was proved that the increase of the vertical load improves traction properties, but better effects are reported on more compacted grounds (Gholkar et al., 2009; Jun et al., 2004; Narang and Varshney, 2006; Taghavifar and Mardani, 2013).

The obtained results were statistically analysed with the use of *Statistica 10.0*. A two – way ANOVA was carried out on the significance level of $\alpha=0.05$. Results of the analysis were presented in table 3.

Table 3
Results of statistical analysis

Factor	Parameter	Tractive efficiency	Traction force	Drawbarpower	Power lost to the rolling resistance	Power lost to the slip
Vertical load of a wheel	<i>F</i>	63.154	236.33	63.032	80.684	0.728
	<i>p</i>	0.00002*	<0.00001*	0.00002*	0.00001*	0.41558
Groundtype	<i>F</i>	6.847	1123.4	188.721	35.648	39.165
	<i>p</i>	0.02796*	<0.00001*	<0.00001*	0.00021*	0.00015*

*data marked are statistically significant on the significance level of $\alpha=0.05$

Pursuant to the statistical analysis results a significant impact of the ground type on all analysed traction parameters was reported. In case of the second factor (vertical loads of a wheel) no vital impact on the values of traction power lost to the slip was confirmed.

Conclusions

Based on the obtained research results, the following conclusions were formulated:

1. The wheel used on sod had higher values of the tractive efficiency and a lower traction force in comparison to the wheel used on a non-compacted soil. On both grounds, the increase of the traction force and tractive efficiency as a result of the increment of the vertical load of the wheel was proved.
2. Higher values of the drawbar power and its shares were related to the wheel used on sod. The increase of the vertical load of the wheel resulted in the growth of the drawbar power value on both grounds. Only on sod, the increase of the drawbar power share was reported after increasing the vertical load which proves that this method of improving traction properties is effective only on more compact grounds.
3. The wheel exploited on soil has higher values (and shares) of the power lost to the rolling resistance than on sod. Moreover, a higher increment of the values and shares of power lost to the rolling resistance as a result of increasing the vertical load of a wheel was reported.
4. A higher value of the total power (higher demand for power) was reported for the wheel exploited on a non-compacted soil. An increase of the vertical load of the wheel on both grounds resulted in the growth of the total power value but a higher increase occurred on soil.

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ANALIZA STRUMIENIA MOCY W UKŁADZIE KOŁO CIĄGNIKA – PODŁOŻA ROLNICZE

Streszczenie. W pracy przedstawiono wyniki badań dotyczące transmisji mocy z koła ciągnika rolniczego na podłoża o różnych właściwościach. Badania przeprowadzono w warunkach polowych z wykorzystaniem stanowiska badawczego agregatowanego z ciągnikiem rolniczym. W pierwszej kolejności dokonano wstępnej oceny właściwości trakcyjnych poprzez wyznaczenie siły trakcyjnej i sprawności trakcyjnej. W zasadniczej części badań wyznaczono wartości mocy użytecznej (uciągu), mocy traconej na opór przetaczania oraz mocy traconej na poślizg koła. Dodatkowym czynnikiem, oprócz rodzaju podłoża, było obciążenie pionowe koła. Na podstawie uzyskanych wyników wykazano, że koło eksploatowane na glebie odznaczało się wyższymi wartościami siły trakcyjnej lecz niższą sprawnością trakcyjną w porównaniu do wartości uzyskiwanych na darni. Analiza strumienia mocy wykazała, że przyczyną tych różnic były większe straty mocy związanej z oporem przetaczania koła eksploatowanego na glebie. Ponadto wykazano, że zwiększanie pionowego obciążenia koła sprzyja poprawie właściwości trakcyjnych (wzrost sprawności trakcyjnej i udziału mocy uciągu) jedynie w przypadku koła eksploatowanego na darni.

Słowa kluczowe: ciągnik, opona, sprawność trakcyjna, poślizg, opór przetaczania, moc