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Evaluation of changes in traction properties of driving tyres on soil covered with turf

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Summary. The study presents the results of tests concerning the traction properties of driving tyres with radial and diagonal design on soil covered with turf differing by composition of plant species. It was shown that composition of plant species on the tested grounds had an effect on the traction forces and rolling resistance of tested tyres. Tyre 11.2R24 was characterised by greater pulling forces compared with tyre 9.5-24. However, no effect of the various compositions of species in the soil on the value of tractive efficiency was proven. Tyre 9.5-24 had higher demand for pulling power and power lost on wheel slip compared with tyre 11.2R24.

Key words: tractive abilities, driving tyre, power balance, soil covered with turf.

INTRODUCTION

Farming activities are connected with the operation of technical equipment on various types of soil. The characteristic properties of a given soil determine the tractive abilities of the vehicle, that is, the possibility of moving on it without considerable losses. Most farming work is carried out on deformable grounds which should transfer regular forces resulting from the weight of the vehicle and static forces connected with the applied driving torque of the wheel and the shear strength of the soil [9]. Deformable soils also include soil covered with turf. The research on turf conducted thus far concerns mainly its reaction to intensive utilisation. Changes are shown in the aboveground parts of plants, their root systems and soil environment [4, 14].

It should be stated that the mechanical and traction properties of turf are poorly recognized fields of research [5, 7, 12]. Many publications refer to arable soils. Traction forces are analysed, slip of driving wheels is measured, an energy balance of the driving wheel – soil system is conducted. Many publications refer to the negative effect of tractors on soil. In order to minimize unfavourable changes in soil while maintaining tractive efficiency, structural and operating parameters of tyres are chosen [6, 10, 15, 17, 18]. The specific character of soil covered with turf presented in publications indicates a considerable amount of organic matter covering the soil and the presence of root system of plants. This may have an effect on the tractive abilities of a farming tractor interacting with it. It is also worthwhile adding that tractors working on meadows and pastures in most cases are not equipped with special "grass" type tyres. Use of conventional driving tyres involves the possibility of damaging plants and the appearance of ruts which are the result of considerable unit pressures [13]. However, if usage of these tyres is so common and replacement of them with special tyres is connected with additional costs, the question arises whether other technical solutions limiting the unfavourable phenomena mentioned above are possible? Can such a solution be the replacement of driving tyres of diagonal design with tyres of radial design? The advantages of using these are broadly described in the literature [11, 16].

OBJECTIVE, SUBJECT MATTER AND METHODOLOGY OF TESTS

The analysis of issues connected with traction of farming tractors was the reason for which the research was undertaken, the objective of which was to:

1. Evaluate changes in tractive properties taking into account such parameters as traction forces, efficiency and rolling resistance for tyres of different designs.
2. Analysis of the tractive properties of tested tyres on turf with different composition of plant species.
3. Determination and comparison of the values of power for wheels equipped with the tested tyres for the assumed field conditions.

The research was conducted in autumn 2011 in four sites of the Agricultural Experimental Institute in Swojec within the Wrocław University of Environmental and Life Sciences. The soil on which the research was conducted was proper alluvial soil made of strong sandy loan. In site I and II a mixture of meadow plants, and in site III and IV a mixture of pasture plants were sown. Composition of species and percentage share of individual mixtures are presented in Table 1.

Table 1. Composition of species and percentage share of sown mixtures

Name of species	Variety	Share [%]
Meadow mixture		
Perennial ryegrass	*Licampo*	30
Meadow fescue	*Limosa*	20
Timothy grass	*Lischka*	10
Red clover	*Nike*	20
White clover	*Hula*	10
Smooth meadow grass	*Bila*	10
Pasture mixture		
Italian ryegrass	*Livictory*	15
English ryegrass	*Licampo*	45
Meadow fescue	*Limosa*	20
Timothy grass	*Lischka*	20

In site I and II, the standard of seed sowing was equal to 30 kg/ha, and in sites III and IV 40 kg/ha was used. No mineral fertilization was used, no pasturage of animals was carried out in the pasture sites. Directly before performance of traction tests, the sites were mowed at the height of 0.07 m and measurements characterizing the condition of the soil i.e. compactness of soil and maximum shear stresses were conducted, soil moisture was also determined.

For measurement of soil compactness, a penetrologger made by Eijkelkamp, with conical penetrometer with vertical angle 60° and field of base 0.0001 m^2, was used. The additional accessory of this device was the Theta Probe ML2x by means of which soil moisture was measured. Measurement of maximum shear stress was performed using shear Vane H-60 made by Geonor with measurement range from 0 to 260 kPa.

For traction tests, tyres 9.5-24 and 11.2R24 were chosen which were fitted on a special measurement station [1]. The vertical load of the tested wheel was equal to 3300 N. During motion of the wheel, the values of pulling force, driving moment, theoretical and actual route of the tested wheel were registered. The obtained parameters allowed us to calculate the value of traction force, rolling resistance and tractive efficiency [Białczyk and others 2012]. The energy balance of the tested tyres was presented on the basis of calculated powers according to formulas 1-5:

$$N_k = N_H + N_f + N_\delta, \tag{1}$$

$$N_H = P_H \cdot v_R, \tag{2}$$

$$N_f = (P_T - P_H) \cdot v_R, \tag{3}$$

$$N_\delta = P_T \cdot \left(r_D - \frac{v_R}{\omega_T} \right) \cdot \omega_T, \tag{4}$$

$$\omega_T = \frac{v_T}{r_D}, \tag{5}$$

where:
Nk – power supplied to the wheel [W],
NH – pulling power [W],
Nf – power used to overcome rolling resistance [W],
Nδ – power lost on wheel slip [W],
PT- traction force [N],
PH- pulling force [N],
vR – actual route [m],
vT – theoretical route [m],
rD – dynamic radius of the wheel [m],
ωT – theoretic rotational speed of the tested wheel [s^{-1}].

TEST RESULTS

Table 2 presents the results of parameters characterizing the condition of the tested soils. Values of maximum shear stresses and soil compactness were read out for three depths of soil profile. Growth of the values of these parameters with measurement depth was concluded. In meadow sites (I and II), due to higher soil moisture (20%), lower values of the analysed parameters versus pasture sites were recorded (soil moisture 18%).

Table 2. Values of parameters of the tested soil

	Site I	Site II	Site III	Site IV
Maximum shear stresses [KPa]				
0.05 m	72	70	78	78
0.10 m	98	84	108	118
0.15 m	118	114	126	134
Compactness [MPa]				
0.05 m	2.16	2.15	2.57	2.42
0.10 m	2.95	3.10	3.42	3.76
0.15 m	3.11	3.28	3.33	3.68

Figure 1 presents mean values of traction forces and maximum tractive efficiency calculated for wheel slip within the range of 0-30%. Lower values of traction forces for tyre 9.5-24 were recorded. It is also characteristic that for this tyre no changes in this parameter within sites having the same composition of species were shown. Different standards of seed sowing did not have any effect on traction properties of this tyre. Tyre 11.2R24 made better use of turf properties which was reflected in the values of analysed parameters. Traction forces achieved different values in individual sites. The tractive efficiency of this tyre was characterized by lower dynamics of changes which may indicate low sensitivity of this tyre to varying field conditions.

The highest tractive efficiency was achieved by tyres 9.5-24 in pasture sites. The explanation of this situation can be found in figure 2 presenting pulling force and rolling resistance for the tested tyres. These two parameters are components of the traction force presented above. For this tyre, pulling force remained at a comparable level, and

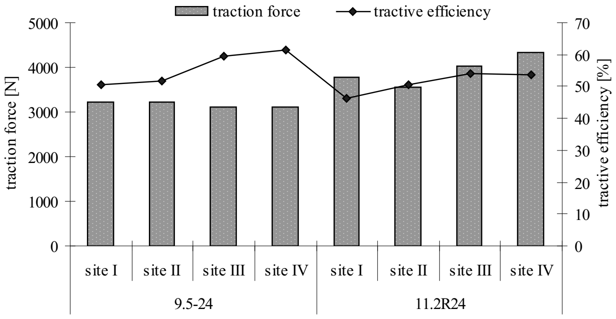

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Fig. 1. Values of traction forces and efficiency for the tested tyres

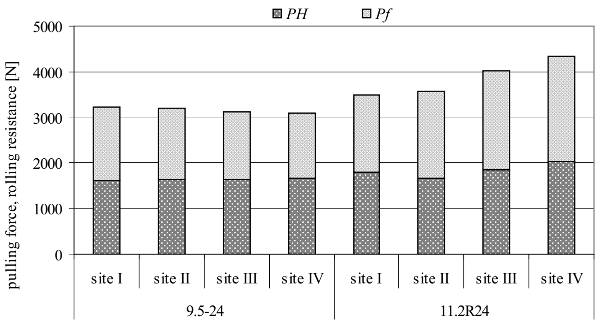

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Fig. 2. Values of pulling force and rolling resistance for the tested tyres

rolling resistance changed. Lower rolling resistance in sites 3 and 4 allowed us to obtain higher tractive efficiency. This allows us to conclude that in specific field conditions this tyre may achieve better tractive abilities.

A different situation occurred for tyre 11.2R24, whose larger surface of contact with the base enabled it to achieve greater pulling forces, however the values of rolling resistance were (apart from site 1) higher than the generated pulling force. The obtained results are compliant with those received by Wulfsohn and others [19], who proved that design of the tyre had an effect on achieved tractive efficiency, and diagonal tyre had worse tractive abilities.

Figure 3 presented progresses of individual powers in the function of slip for wheel with tyre 9.5-24 in the tested sites. Detailed analysis of the power balance presented in this way allowed us to show what part of supplied power is used for pulling force and what part is lost on rolling resistance and wheel slip. It can be clearly concluded from the presented progresses that the character of changes in analysed powers is comparable for individual sites. Fast growth of power supplied to the wheel (*Nk*) was connected with overcoming initial resistance to motion, and then this power was stabilized and oscillated within the range of 300-450 W, except for site 4 where proportional growth of its value in line with wheel slip is observed. In this site, a higher standard of seed sowing was used which resulted in higher thickness of turf coverage. If this condition is combined with higher values of strength parameters in this site, it can be assumed that the tyre of diagonal design caused more difficult immersion of tread projections as a result of which power lost on wheel slip increased with pulling power maintained at a comparable level.

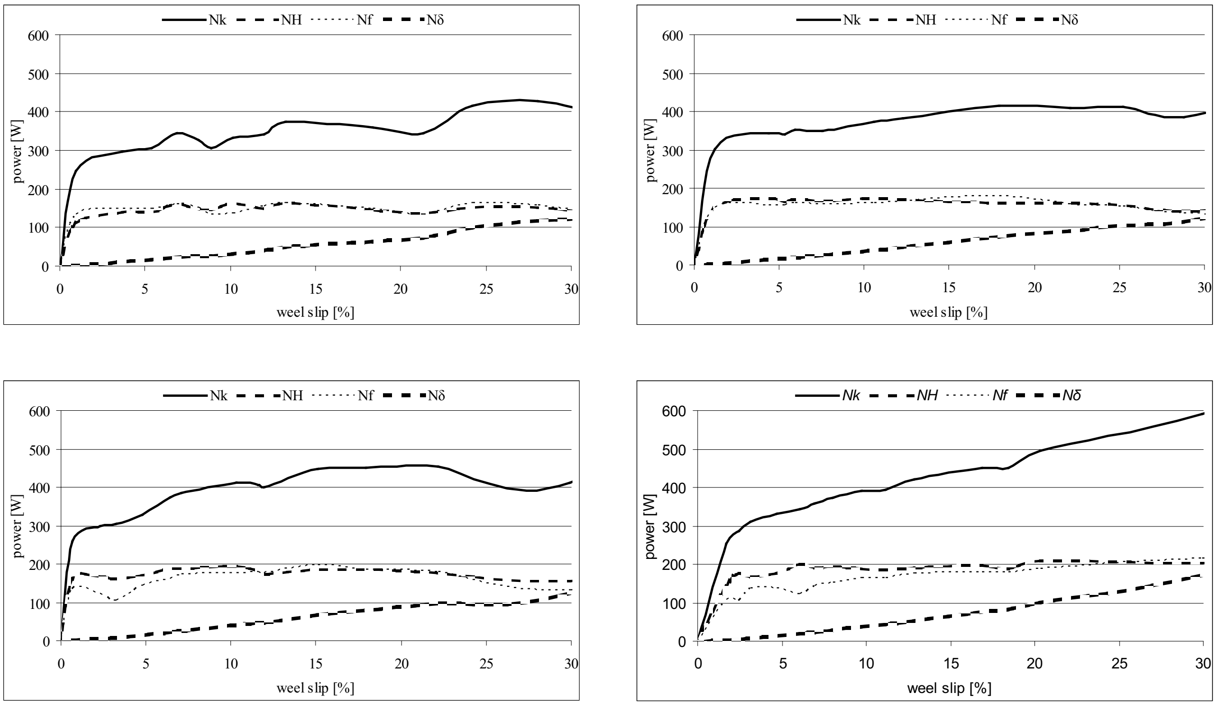

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Fig. 3. Progresses of power in the function of slip for tyre 9.5-24: a – site I, b – site II, c – site III, d – site IV

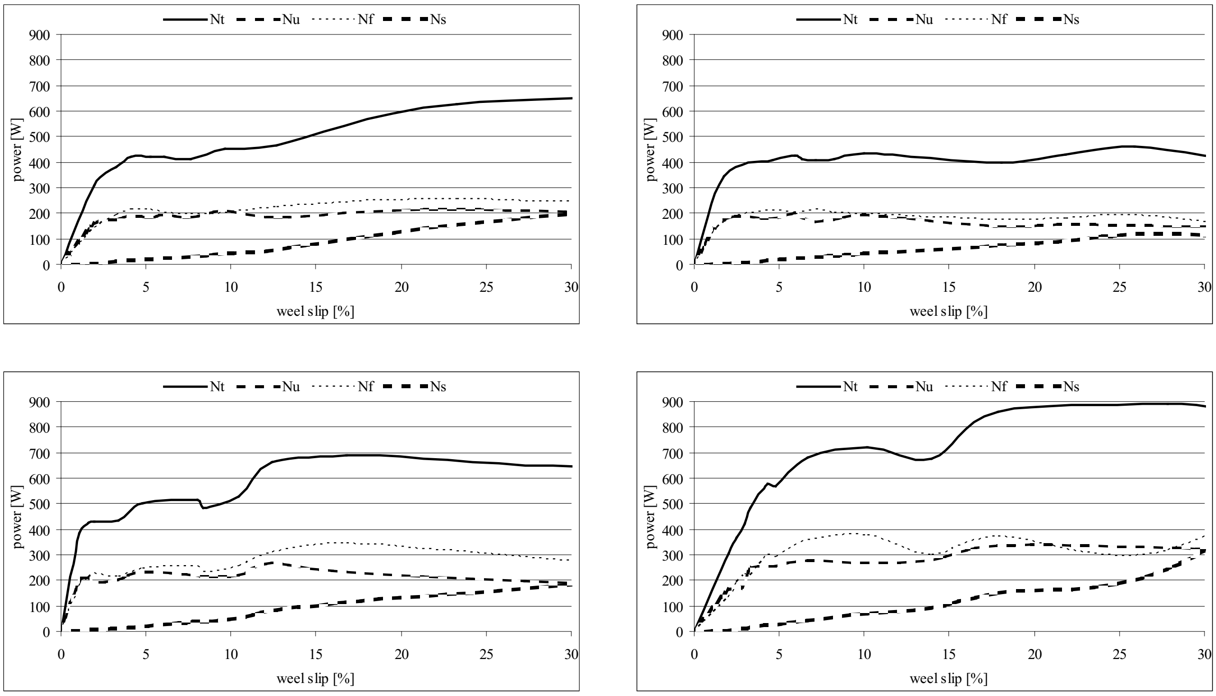

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Fig. 4. Progresses of power in the function of slip for tyre 11.2R24: a – site I, b – site II, c – site III, d – site IV

Figure 4 presents progresses of individual powers in the function of slip for the wheel equipped with tyre 11.2R24 in the tested sites. The analysed tyre showed higher demand for supplied power if compared with tyre 9.5-24 which allowed increased pulling power. The power needed to overcome rolling resistance also increased. As already mentioned above, the radial tyre better reflects existing field conditions which for sites 1 and 2 allows pulling properties comparable with sites 3 and 4 to be obtained at lower energy expense. This was probably connected with a higher adhesion coefficient for this tyre which was proven also in a study by Gee-Glough and others [8].

Presentation of the above progresses allowed evaluation of the range of changes in the analysed values, however in order to analyse the share of individual powers in total power supplied to the wheel, their percentage share was presented in figure 5. Tyre 9.5-24 showed higher demand for pulling force apparent especially in sites 3 and 4. However, it was not directly reflected in the generated pulling force which in each of the analysed sites had a lower value compared with the pulling force obtained by the radial tyre. Power lost on slip of this tyre in sites 1 and 2 also grew which was probably connected with the presence of white and red clover forming a considerable part of the organic matter reducing the adhesion of this tyre.

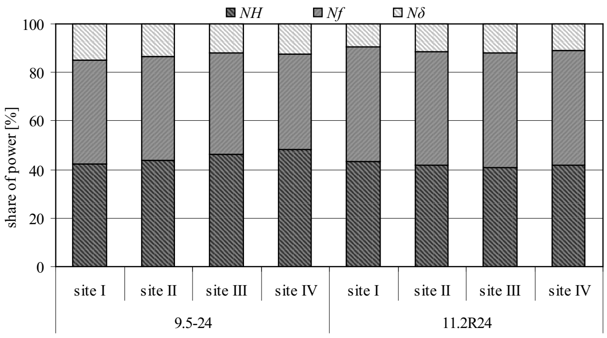

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Fig. 5. Percentage share of individual powers in total power

In spite of lower demand for pulling power, tyre 11.2R24 was able to generate higher pulling abilities which, however, took place at the expense of a greater share of power lost on rolling resistance. However, this was compensated for by lesser demand for power lost on wheel slip.

Based on the obtained results, multi-factor analysis of variance at the significance level $\alpha = 0.05$ was performed using the Statistica 9.0 package. Different botanical composition of the soil and the type of tyre used have an effect on generation of traction forces with different values. The tested tyres also showed different rolling resistance and tractive efficiency. However, no effect of soil on the value of achieved tractive efficiencies was proven (table 3).

Table 3. Results of statistical analysis (F – test value, p – probability)

Factor	Dependent variable					
	Traction force		Rolling resistance		Tractive efficiency	
	F	p	F	p	F	p
Soil	12,304	<0,0001	10,968	<0,0001	0,530	0,6613
Tyre	41,008	<0,0001	50,212	<0,0001	39,850	<0,0001

source: own study

The results of statistical analysis presented in table 4 allowed it to be proved that both the type of soil and type of tyre used have an effect on total power supplied to the wheel. Different demand for pulling power, power of rolling resistance and power lost on slip were also shown.

Table 4. Results of statistical analysis (F – test value, p – probability)

Factor	Dependent variable							
	Total power		Pulling power		Power lost on Rolling resistance		Power lost on slip	
	F	p	F	p	F	P	F	P
Soil	21,232	<0,0001	27,619	<0,0001	14,336	<0,0001	10,949	<0,0001
Tyre	49,257	<0,0001	28,508	<0,0001	58,405	<0,0001	26,281	<0,0001

source: own source

CONCLUSIONS

1. In the tested sites, the analysed tyres generated traction forces with different values. The completed analysis of components of these forces allowed us to conclude that tyre 11.2R24 showed better pulling abilities, but growth of rolling resistance occurred which resulted in lower tractive efficiency for this tyre.
2. No effect of species-related composition of soil on the tractive efficiency of the tested tyres was shown. Tyre 11.2R24 achieved different pulling forces on turf with the same species-related composition but different seed sowing standards. Due to considerable stiffness resulting from its diagonal design, tyre 9.5-24 achieved pulling forces with comparable values.
3. Tyre 9.5-24 showed higher demand for pulling power which was not directly reflected in growth of pulling forces because higher losses of power on wheel slip occurred. Tyre 11.2R24 lost more power on rolling resistance, but its radial design allowed better use of the strength properties of the soil by reducing wheel slip power.

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OCENA ZMIAN WŁAŚCIWOŚCI TRAKCYJNYCH OPON NAPĘDOWYCH NA PODŁOŻACH ZADARNIONYCH

Streszczenie. W pracy przedstawiono wyniki badań dotyczących właściwości trakcyjnych opon napędowych konstrukcji radialnej i diagonalnej na podłożach zadarnionych różniących się składem gatunkowym roślin. Dokonana analiza sił trakcyjnych oraz oporów przetaczania, wykazała wpływ składu gatunkowego roślin badanych podłoży na zdolności trakcyjne opony 11.2R24, która ponadto cechowała się wyższymi siłami uciągu w porównaniu do opony 9.5-24. Nie wykazano natomiast wpływu odmiennego składu podłoża na wartość sprawności trakcyjnej. Opona 9.5-24 wykazywała większe zapotrzebowanie na moc uciągu oraz moc traconą na poślizg koła w porównaniu do opony 11.2R24.

Słowa kluczowe: zdolności trakcyjne, opona napędowa, bilans mocy, podłoże zadarnione