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THE IMPACT OF AGRICULTURAL VEHICLES ROLLING SYSTEM ON SOIL

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ABSTRACT - The paper establishes the value of the average pressure at the contact surface level between the soil and the tires of the following vehicles and trailers: the U-650 and Valtra T-190 tractors, the 2RB5AT and 7RBAT trailers and the large dump capability Iveco Trakker 8x4. The wheel-ground pressure is determined as the report between wheel corresponding weight and the contact surface area with soil. This area was obtained by calculation, using 12 types of equations established by different authors. In this paper, we used the average of the 12 versions, both for the wheel-soil surface and for the wheel-ground pressure. It was found that the lowest wheel-ground pressures are recorded for the Valtra U-650 and T-190 tractors (63,535 ... 142,821 kPa) and the highest in the case of the 7RBAT and 2RB5AT trailers and the Iveco Trakker 8x4 dump (432,692. .. 623,414 kPa), the maximum imposed limit by agricultural requirements being 100 kPa. Regarding the tractors, the exceeding of the imposed limit (100 kPa) is recorded for all the wheels of the Valtra T-190 tractor and only for the front wheels of the U-650 tractor. These excesses are quite small (10 ... 42 kPa), so practically will not affect soil properties. For the trailers and dump, the wheel-ground pressure is 4,3 ... 6,2 times higher the upper limit imposed for agricultural soil, 100 kPa. These high pressures don't affect the asphalt or concrete roads, but will adversely alter the physical properties of agricultural soils.

Key words : Soil compaction; Road system; Tractors.

REZUMAT - Impactul sistemelor de rulare ale unor autovehicule din agricultură asupra solului. În cadrul acestei lucrări s-a stabilit valoarea presiunii medii, care ia naştere la nivelul suprafeței de contact dintre sol şi anvelopele cu care sunt echipate următoarele autovehicule şi remorci: tractoarele U-650 şi Valtra T-190, remorcile 2RB5AT şi 7RBAT şi autobasculanta de mare capacitate Iveco Trakker 8x4. Presiunea roții pe sol s-a determinat ca raport între sarcina repartizată pe roată şi suprafața de contact a acesteia cu solul. Această suprafață s-a obținut prin calcul, folosindu-se 12 variante de ecuații, stabilite de diferiți autori. În lucrare s-a utilizat media celor 12 variante, atât pentru suprafața de contact a roții cu solul, cât şi pentru presiunea roții pe sol. S-a constatat că valorile cele mai mici ale presiunii roții pe sol s-au înregistrat la tractoarele U-650 şi Valtra T-190 (63,5 ... 142,8 kPa), iar cele mai mari, în cazul remorcilor 2RB5AT şi

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7RBAT şi la autobasculanta Iveco Trakker 8x4 (432,7 ... 623,4 kPa), limita maximă impusă de cerinţele agrotehnice fiind de 100 kPa. În cazul tractoarelor, depăşirea limitei impuse (100 kPa) s-a înregistrat la toate roţile pentru tractorul Valtra T-190 şi numai la roţile din faţă la tractorul U-650. Aceste depăşiri sunt destul de mici (10 ... 42 kPa), astfel că, practic, nu vor fi influenţate proprietăţile solului. La remorci şi autobasculantă însă, presiunea roţilor pe sol a fost de 4,3 ... 6,2 ori mai mare decât limita maximă impusă pentru solurile agricole, de 100 kPa. Aceste presiuni mari nu afectează drumurile asfaltate sau betonate, însă vor modifica în sens negativ proprietăţile fizice ale solurilor agricole.

Cuvinte cheie : tasarea solului; sistem de rulare; tractoare.

INTRODUCTION

Using tractors (and other vehicles) increasingly heavy, with small wheels contact surface with ground, makes the pressure on soil to be large, 200 ... 1800 kPa. The soil structure elements specific strength does not exceed 100 kPa, but the most common values are 20... 60 kPa. As a result, on the wheels traces, at 30...50 cm depth and distances of about for times larger than the wheels width, the soil is compacted, consequence of deformation and fracture of its structure elements.

Regarding the transport of agricultural crop harvested from the field, it is also achieved by means of transport designed for roads, and their rolling systems have aggressive action on the ground, whereas the wheels and tires that are fitted with are designed to travel on asphalt or concrete roads.

The indicator which expresses the rolling system aggressiveness on the soil is given by the average pressure achieved at tire-ground interface level. The literature indicates that soil properties are not altered if the average pressure at the contact surface level between the soil and the tire has values below 100 kPa.

MATERIAL AND METHOD

The paper establishes the value of the average pressure at the contact surface level between the soil and the tires of the following vehicles and trailers: the U-650 and Valtra T-190 tractors, the 2RB5AT and 7RBAT trailers and the large dump capability Iveco Trakker 8x4. The tire technical characteristics of the transport means mentioned above, are presented in *Table 1*.

The average pressure exerted on the tire-ground interface is determined as the report between wheel corresponding weight and the contact surface area with soil. In order to determine the ground contact surface area, several mathematical concepts have been developed.

It should be noted that mathematical models to calculate the relationship of the soil-wheel contact patch area, presented by different authors (researchers) can be empirical, semi-empirical and theoretical. In theoretical models, different geometric equations are used to calculate the contact surface of wheel with soil, e.g. known equations for determining the area of the circle, ellipse, square or rectangle. For empirical equation models, researchers use different empirical constants, obtained from a large number of experiments. The value of these constants varies depending on tire and soil characteristics.

Table 1 - **Tire characteristics of the transport means taken into the study**

Tire characteristics	U-650Tractor		ValtraT-190Tractor		2RB5T trailer	7RBAT trailer	Iveco Trakker 8x4
	front wheel	rear wheel	front wheel	rear wheel			
Exterior tire diameter, d (m)	0.850	1.600	1.400	1.800	0.9271	0.964	1.0755
Tire wheel width, b (m)	0.1651	0.3556	0.4293	0.5283	0.20955	0.2286	0.315
Unloaded wheel radius, r (m)	0.425	0.800	0.700	0.900	0.4635	0.482	0.5377
Loaded wheel radius, r_1(m)	0.385	0.720	0.665	0.875	0.4595	0.478	0.5337
Lugged wheel radius tread width, b_w (m)	0.145	0.320	0.410	0.500	0.1885	0.2057	0.2835
Wheel weight, G (kN)	6.227	11.500	17.210	17.063	18.1	25.5625	32.5
Tire air pressure, P (kPa)	216	89	160	160	600	600	750

Equations used to calculate the contact surface of wheel with soil

1. Equation determined by Komandi (1990) :

$$A = \frac{c \cdot W^{0,7} \cdot \sqrt{\frac{b}{d}}}{p_i^{0,45}}, (m^2), \text{ in which:}$$

A - tire contact patch area with the ground, m^2 ;
W- weight (force) of the wheel on the ground, kN;
b –tire wheel width, m;
d - exterior tire diameter, m;
p_i - tire air pressure chamber, kPa;
c - constant, depending on soil texture (0,30 ... 0,44, 0,31 was used).

2. Equation determined by Silversides and Sundberg (1989) :

$$A = \frac{0,90 \cdot W}{p_i}, (m^2), \text{ in which:}$$

A - tire contact patch area with the ground, m^2 ;
W - weight (force) of the wheel on the ground, kN;
p_i - tire air pressure chamber, kPa.

3. Equations determined by Grecenko (1995):

$$A = \pi \cdot \delta \cdot \sqrt{d \cdot b}, \quad (m^2),$$

$\delta = r - r_1$, in which:

δ- the amount by which the radius decreases wheel tire, due to its weight (force), (m);
r - unloaded wheel radius, which is down on the ground with a force equal to zero (m);
r_1 - loaded wheel radius, being ground down by its own weight (force) (m).

4. ö $A = c_1 \cdot d \cdot b$, (m^2), in which:

c_1 - a constant, depending on tire and soil characteristics (0,175 ... 0, 270, 0,270 was used)

5. Equations determined by Krik (1969):

$A = 8 \cdot \delta \cdot h$, ($m^2$), in which:

$h = 0,77 \cdot b^{0,89}$, (m), established by Liasko (1994):

h - the tire height section, m.

6. $A = 5,3 \cdot h^2 \cdot \delta \cdot \left(\frac{p_i}{W} \cdot d \cdot b \right)^{0,8}$, ($m^2$)

7. Equation determined by Pillai and Fielding (1986) :

$A = 1,85 \cdot \delta^{\frac{2}{3}} \cdot b \cdot r^{\frac{1}{3}}$, ($m^2$)

8. Equation determined by Godbole (1993):

$A = \pi \cdot \delta \cdot \sqrt{d \cdot h}$, ($m^2$), in which:

h = b, and

$\delta = h \cdot 0,67 \cdot \left(\frac{p_i \cdot d \cdot b}{W} \right)^{-0,8}$, (m).

9. Equation determined by Dwyer (1984) :

$A = \frac{W}{G}$, (m^2), in which:

$G = \frac{W}{b \cdot d} \cdot \sqrt{\frac{h}{\delta}} \cdot \left(1 + \frac{b}{2 \cdot d} \right)$, (kPa), in which:

G - indicate the pressure of the wheel on the ground, kPa;

$h = 0,77 \cdot b^{0,89}$,

$\delta = r - r_1$;

10. Equation determined by Ziani and Biarez (1990) :

$A = \frac{\pi}{4} \cdot b_c \cdot l_c$, ($m^2$), in which:

$b_c = 2 \cdot \sqrt{z \cdot (2 \cdot r_b - z)}$, (m)

$l_c = 2 \cdot \sqrt{z \cdot (2 \cdot r - z)}$, (m)

$z = 0,147r$, and $r_b = \frac{b}{2}$

b_c - width of the wheel contact patch with the ground, m;

Lc - length of the wheel contact patch with soil, m;

z - wheel sinking into the ground or wheel traces depth, m;

r_b - transverse radius of the tire, m;

11. Equation determined by Febo (1987) :

$A = \frac{\pi}{4} \cdot b_c \cdot l_c$, ($m^2$), in which:

$b_c = b_w \cdot \left(1 - \exp^{-k \cdot \delta} \right)$, (m)

$l_c = 2 \cdot \sqrt{d} \cdot \delta^j$, (m)

$\delta = r - r_1$, (m)

b_w - lugged tire tread width, m;

k - empirical constant, depending on the characteristics of the tire (18 ... 33, used 33),

j - empirical constant depending on the characteristics of the tire (0,40 ... 0,44, 0,41 was used).

12. Equation determined by Söhne (1969) :

$A = 2 \cdot b \cdot \sqrt{d \cdot z}$, ($m^2$).

The equation used to calculate the average pressure exerted by the wheel on the ground

$p_m = \frac{G}{A}$, (kPa), in which:

p_m – the average pressure exerted by the wheel on the ground, kPa

G – weight (force) of the wheel, kN

A – the area of the tire-soil contact patch aria, m^2.

RESULTS AND DISCUSSION

In each of the tire wheel categories,the wheel-ground contact area was calculated for all the 12 versions of the surface equation (the 12 equations presented above). For each tire wheel categories, it was determined the average tire–soil contact area (the 12 versions average).

Also, according to the effective tire-ground surface contact area and to the corresponding weight on each wheel, for each of the tire wheel categories, the tire ground pressure was calculated for all 12 versions of the surface equation. For each tire wheel categories, it was determined the average pressure exerted on the ground (the 12 versions average).

To exemplify, the model calculation results are presented in detail for the two categories of the U-650 tractor tire wheel.

The U-650 tractor front wheel

The wheel-ground contact area (*Fig. 1*) varied depending upon the version of equation used for calculating, from 0,0181 m^2 (version 6) to 0,0761 m^2 (version 12). The contact surface of the wheel with the ground is 320,4 % higher for version 12 compared to version 6 (it is 4,2 times higher). It is estimated that the difference between the two extreme options (6 and 12) is too great. The average of the 12 variants is 0,0430 m^2.

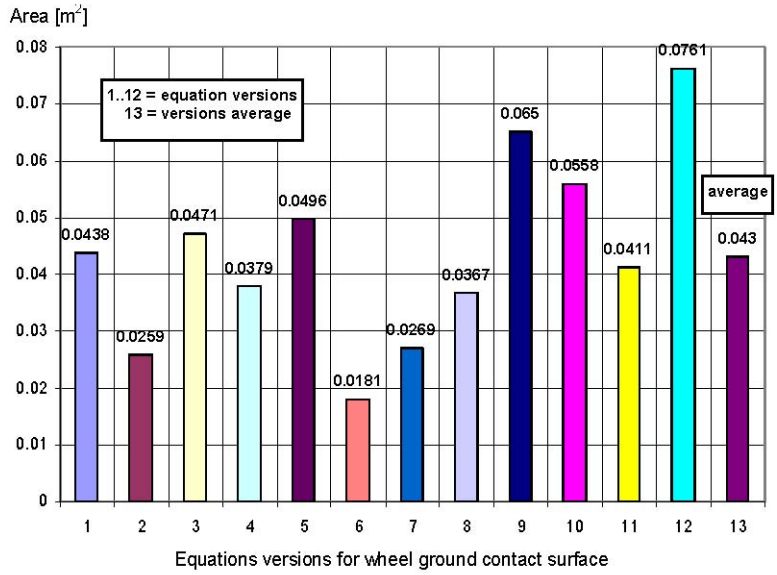

Figure 1 - Wheel-soil contact surface for different kinds of equations regarding this area (the U-650 tractor, front wheel)

The average pressure exerted by the wheel on the soil (*Fig. 2*) varied, depending upon the version of the equation used to calculate the wheel contact area with the ground, between 81,835 kPa (version 12) to 344,745 kPa (version 6). The average pressure exerted by the wheel on the ground is 321,3 % higher for version 6 compared to version 12 (it is 4,21 times higher). The average value of the 12 variants is 142,821 kPa. We believe that the difference between the two extreme options (12 and 6) is high. Regarding media variants, it exceeds with 42,821 kPa the 100 kPa maximum permissible pressure value of agro requirements. Requirement is met only by versions 9 and 12.

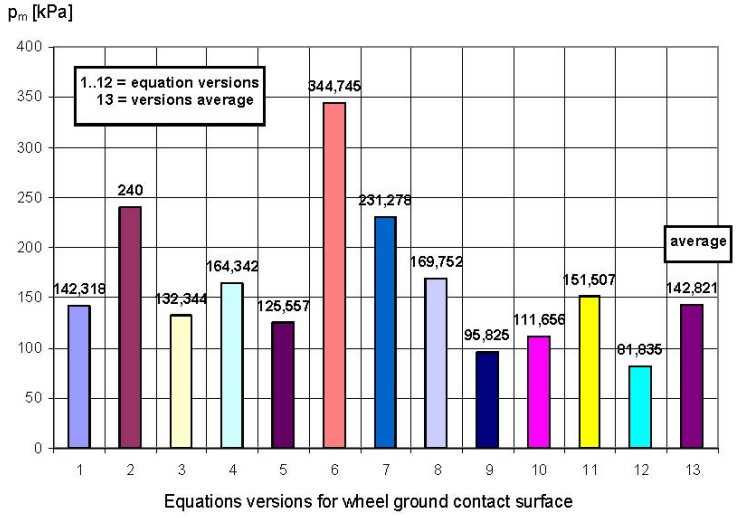

Figure 2 - The average pressure exerted by the wheel on the ground for different versions of wheel-ground surfaces equations (the U-650 tractor, front wheel)

The U-650 tractor rear wheel

The contact surface of the wheel with the ground (*Fig. 3*) varied from 0,1070 m^2 (option 1) to 0,3080 m^2 (version 12). The contact surface of the wheel with the ground is 188 % higher for version 12 compared to version 1 (it is 2,88 times higher). It can be said that the difference between the two extreme options (1 and 12) is quite large. The average of the 12 variants is 0,1810 m^2.

The wheel average pressure exerted on the ground (*Fig. 4*) has different values, ranging from 37,277 kPa (version 12) to 107,313 kPa (version 1). The average pressure exerted by the wheel on the ground is 187,9 % higher for version 1 compared to version 12 (it is 2,879 times higher). The average of all 12 variants is 63,535 kPa. It appears that the difference between the two extreme options (12 and 1) is quite large. It should be pointed out that the

average of the 12 variants is less than the maximum admissible of 100 kPa. Moreover, 10 version of the wheel average pressure on the ground is below the maximum limit imposed, and for the other two variants (1 and 7) the limit exceeded is insignificant, especially in version 7. Comparing the average values , leads to the conclusion that the rear wheels of the tractor U-650 average ground pressure is much lower than the front wheels value (63,535 kPa to 142,821 kPa).

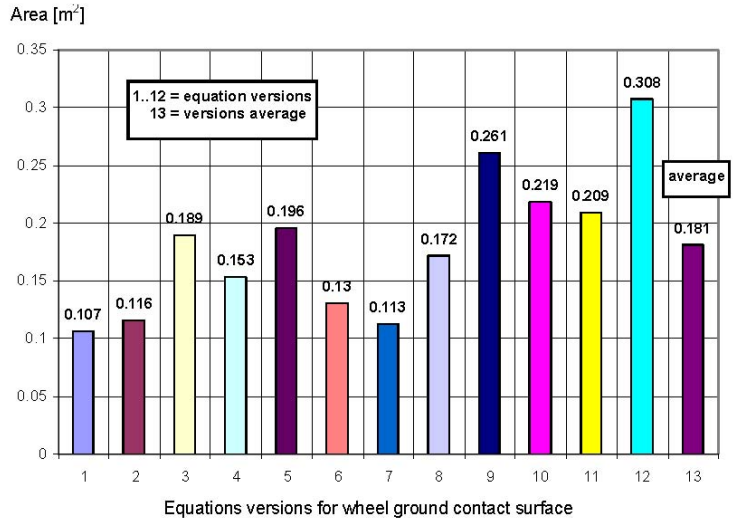

Figure 3 - Wheel-soil contact surface for different kinds of equations regarding this area (the U-650 tractor, rear wheel)

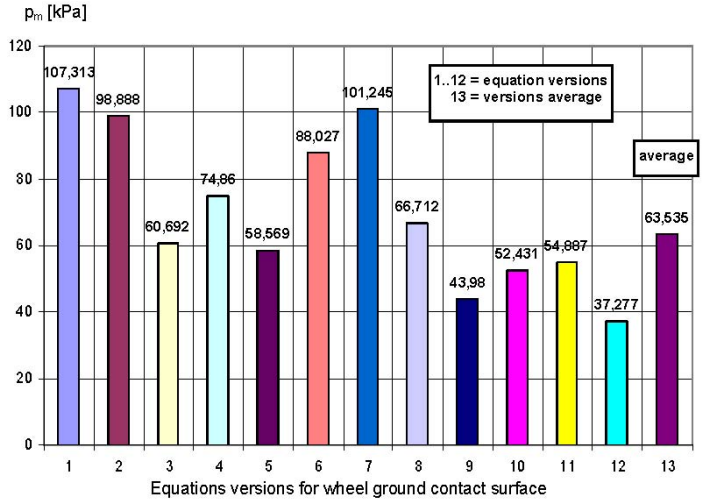

Figure 4 - The average pressure exerted by the wheel on the ground for different versions of wheel-ground surfaces equations (the U-650 tractor, rear wheel)

The calculation of the wheel-soil contact surface (the 12 contact area equations versions plus the average of these versions) and wheel-ground pressure (12 versions plus their average) was carried out for all the other types of wheels with tires, using the methodology applied to the U-650 tractor wheels (front and rear). For all wheels it was found, as in U-650 tractor wheels, that the difference between extreme alternatives is large, both for the wheel-ground contact surface and for wheel pressure on soil. Therefore, we considered that the interpretation of results obtained should be made solely by the average of 12 variants.

It is worth mentioning that the researches regarding the wheel-soil contact surface and the wheel pressure exerted on the ground were determined for eight categories of tire wheels: U-650 tractor(front and rear wheels), Valtra T-190 tractor (front and rear wheels), the 2RB5AT and 7RBAT trailers and the large dump capability Iveco Trakker 8x4 (P_1 and P_2 axle, P_3 and P_4 axle).

In *Fig. 5* are presented the results regarding the wheel-soil contact surface (the 12 equations versions average for tire contact patch area with the ground) for all the eight categories of tire wheels.

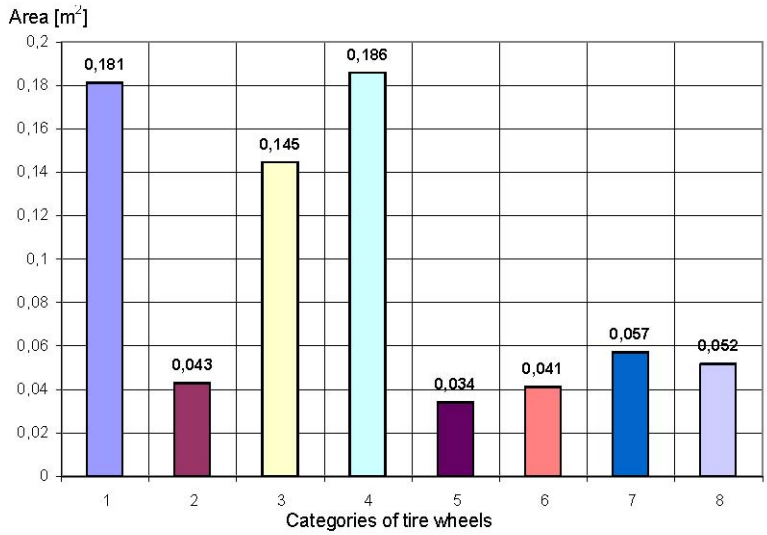

Figure 5 - **Average wheel-soil contact patch area:** *1* – U-650 tractor (rear wheel); *2* –U-650 tractor (front wheel); *3* – Valtra T-190 tractor (front wheel); *4* – Valtra T-190 tractor (rear wheel); *5* – 5 tonnes 2RB5AT trailer (wheel); *6* – 7 tonnes 7RBAT trailer (wheel); *7* – large dump capability Iveco Trakker 8x4 P_1 and P_2 axle (wheel); *8* – large dump capability Iveco Trakker 8x4 P_3 and P_4 axle (wheel).

The chart presented above shows that the contact surface of wheel with soil ranges from 0,0340 m^2 (5 tonnes 2RB5AT trailer,) to 0,1860 m^2 (rear wheel of the Valtra T-190 tractor). A high value of the wheel-ground surface contact is also recorded for the rear wheel of the U-650 tractor. Also,the Valtra T-190 tractor front wheel has a quite large contact surface with the ground. High values of the wheel contact surface with soil may cause pressure reduction on it. For the front wheel of the U-650 tractor, for the trailers (2RB5AT, 7RBAT) and for the large dump capability Iveco Trakker 8x4, wheel-soil contact surface is small, which may lead to increased pressure on the ground.

The obtained results regarding wheel pressure on the ground (the 12 versions average for the wheel-ground contact area) for all types of wheels with tires are shown in the chart of *Fig. 6*.

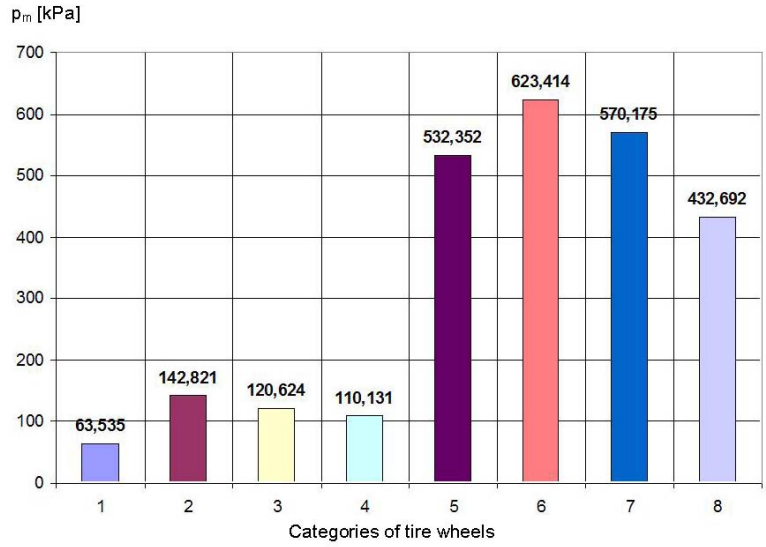

Figure 6 - **Average wheel-soil pressure:**
1 – U-650 tractor (rear wheel); *2* – U-650 tractor (front wheel);
3 – Valtra T-190 tractor (front wheel); *4* – Valtra T-190 tractor (rear wheel);
5 – 5 tonnes 2RB5AT trailer (wheel); *6* – 7 tonnes 7RBAT trailer (wheel);
7 – large dump capability Iveco Trakker 8x4 P_1 and P_2 axle (wheel);
8 – large dump capability Iveco Trakker 8x4 P_3 and P_4 axle (wheel).

It was established that the wheel-ground pressure varies very wide, from 63,535 kPa (rear wheel of the U-650 tractor) to 623,414 kPa (the 7 tonnes 7RBAT trailer wheel). The lowest values of wheel pressure on soil are registered for the U-650 and Valtra T-190 tractors, and the largest, for trailers (2RB5AT and 7RBAT) and Iveco Trakker 8x4 dump.

The U-650 tractor situation is different for the two types of wheels.

At the rear wheels is a very good situation, the wheel ground pressure is only 63,535 kPa (the lowest of all types of wheels pressures achieved in the study). This pressure is below the limit required by agricultural requirements (100 kPa). For the front wheels of the tractor U-650 the average ground pressure is higher (142,821 kPa), exceeding the imposed limit. However, it is estimated that the overrunning is not too high to consistently affect the soil characteristics.

For the Valtra T-190 tractor, as for the U-650 tractor, the average pressure on the ground is higher for the front wheels, compared to the rear wheels (120,624 kPa at the front wheel and 110,131 kPa at the rear one) . For both types of wheels, the average pressure on the ground exceeds the required maximum of 100 kPa, but the excess is quite small, especially at the rear wheels, so practically the soil characteristics are not affected. It can be said that for the two agricultural tractors, U-650 and Valtra T-190, the wheels pressure on the ground is acceptable, practically not affecting soil properties.

Unlike the two types of tractors, in the case of the trailers (2RB5AT and 7RBAT) and Iveco Trakker 8x4 dump, the situation is different. For these vehicles, the wheel pressure on the ground is much higher. The biggest pressure on soil is recorded for the 7 tonnes 7RBAT trailer wheels (623,414 kPa), which is 6,2 times higher than the imposed limit on agricultural soils (100 kPa).

Clearly, it is also a great pressure on the ground for the other categories of wheels: the 5 tonnes trailer 2RB5AT (532,352 kPa), the Iveco Trakker 8x4 dump axle P1 and P2 (570,175 kPa), the Iveco Trakker 8x4 dump axle P3 and P4 (432,692 kPa). Within these three wheels categories, the average pressure on ground is 4,3 ... 5,7 times higher than upper limit imposed.

It should be noted that the 7RBAT and 2RB5AT trailers and the Iveco Trakker 8x4 dump are designed for transports on asphalt or concrete roads. Traveling with these vehicles on such roads,the wheels contact surface is not affected by the high pressure of the wheel. The rolling of such vehicles on ground will adversely affect the soil physical properties.

CONCLUSIONS

For each wheel support, both wheel-soil contact surface and wheel-ground pressure were calculated in 12 versions (variants of equations for determining the area of wheel contact with the ground). In all wheels categories it was found that the difference between extreme versions is large, both for the wheel-ground contact surface and for wheel-ground pressure. Therefore, we considered that the interpretation of obtained results should be made solely by the average of the 12 versions.

Regarding the Valtra T-190 tractor wheels (front wheels and rear wheels) and the U-650 tractor rear-

wheels, the wheel-soil contact surfaces has high values (0,1450 ... 0,1860 m^2), which may lead to decrease pressure to the ground.

For the front wheels of the U-650 tractor, the trailers (7RBAT and 2RB5AT) and the Iveco Trakker 8x4 dump, the wheel-soil contact surface is low (0,0340 ... 0,0570 m^2), which may lead to increasing pressure to the ground.

The lowest wheel-ground pressures are recorded for the Valtra T-190 and U-650 tractors (63,535 ... 142,821 kPa) and the highest in the case of the 7RBAT and 2RB5AT trailers and the Iveco Trakker 8x4 dump (432,692. .. 623,414 kPa).

For the U-650 tractor rear wheels, the pressure on the ground is only 63,535 kPa, well below the maximum required by the agricultural requirements (100 kPa). In exchange, for the front wheels of the tractor average pressure on the ground is higher (142,821 kPa), exceeding the limit imposed. However, it is estimated that the overrunning is not too high to consistently affect the soil characteristics.

The average wheel-soil pressure of the Valtra T-190 tractor is 110,131 kPa for the rear wheels and 120,624 kPa for the front wheels, both exceeding the 100 kPa imposed limit. It should be pointed out that the excess is quite small, especially for the rear wheels, so basically will not alter the soil properties.

Regarding the trailers (2RB5AT and 7RBAT) and the Iveco Trakker 8x4 dump, the situation changes radically from that of the U-650 and Valtra T-190 tractors.The trailers and dump wheels-ground pressure has much higher values (wheel-ground pressure is 4,3 ... 6,2 times higher the upper limit imposed for agricultural soil, 100 kPa), amounting to 623,414 kPa for the 7RBAT trailer. These high pressures don't affect the asphalt or concrete roads, but will adversely alter the physical properties of agricultural soils.

We consider it is necessary to reduce pressure on the ground, primarily for the front wheels of the U-650 tractor, but also for front and rear wheels of the Valtra T-190 tractor, in order not to exceed the maximum imposed limit of 100 kPa. One solution is to decrease associated weight of the tractor or of the front or rear wheels axle. Another solution, easier to apply, is to increase the diameter of the wheels. We believe that the most easily applied solution can be the increasing of tire wheel width.

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