MODELING OF THE RUNNING SYSTEM PRESSURE ON THE SOIL DEPENDING ON THE STRUCTURAL PARAMETERS OF THE TRACTORS
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МОДЕЛЮВАННЯ ТИСКУ ХОДОВОЇ СИСТЕМИ НА ГРУНТ В ЗАЛЕЖНОСТІ ВІД КОНСТРУКТИВНИХ ПАРАМЕТРОВ ТРАКТОРІВ

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ABSTRACT
The article defines the influence of the traction resistance of the machine-tractor unit working tool on the weight distribution of the tractor along the running system axles. Depending on the type of field work, the resistance force of tools aggregated with a tractor has a different value, accordingly, the tractor has a different weight distribution along the axles and, thus, different ground pressure. An increase in pressure on the soil leads to additional costs for tillage, and in the future to a decrease in agricultural production efficiency. The article presents a mathematical model for determining the reactions of the soil, and, accordingly, the pressure of tractor engines on the ground, depending on the structural parameters of the tractor, its adequacy estimation, and an example of calculating the weight distribution along the tractor axles.

РЕЗЮМЕ
У статті визначено вплив тягового опору робочого знаряддя машинно-тракторного агрегату на розподіл ваги трактора по осям ходової системи. У залежності від виду польових робіт, сила опору знарядь, що агрегатуються із трактором має різне значення, а відповідно і трактор має різний розподіл ваги по осям та відповідно різний тиск на ґрунт. Збільшення тиску на ґрунт призводить до додаткових витрат на обробіток ґрунту, а у подальшому і до зменшення ефективності аграрного виробництва. У роботі представлена математична модель для визначення реакцій ґрунту, а відповідно і тиску тракторних рушіїв на ґрунт в залежності від конструкційних параметрів трактора, оцінена її адекватність, приведений приклад розрахунку розподілу ваги по осям трактора.

INTRODUCTION
During fieldwork, tractor wheels interact with the fertile soil layer. As a result of the force interaction, the phenomena of soil deformation and compaction are observed *(Golub et al, 2021; Mileusnić et al, 2022)*. Therefore, biological processes in the soil are disrupted *(Keller et al, 2022)*, which leads to a decrease in field crop yields *(Nawaz et al, 2012; Mueller et al., 2010)*.

Taking into account the existing trends towards increasing the productivity of machine-tractor units, as a result of an increase in the traction force and weight of tractors, there is an increase in the negative impact of running systems on the ground *(Keller et al, 2019; Mileusnić et al, 2022)*. In this regard, the problem of minimizing soil compaction is relevant for agricultural production.

The problem of soil compaction is one of the key ones for tractor developers. One of the most effective ways to solve the problem of reducing pressure on the ground is to increase the contact area of running systems with the ground, through the use of double wheels, specially designed tires and specially designed structures of running systems *(Keller et al, 2004; Shaheb et al, 2021; Molari et al, 2012)*.

To ensure the implementation of tractor traction power, it is necessary to provide a certain coupling weight in the contact area of running systems with the ground *(Golub et al, 2017)*. An increase in the resistance of aggregates and tools that are aggregated with the tractor leads to a decrease in pressure on the ground of the front wheels and an increase in pressure on the ground of the rear wheels, which is especially noticeable when working with mounted working machines *(Bauer et al, 2022)*.

It is well known that the most common weight distribution of tractors is as follows: classic row wheel tractor – 60% on the rear axle and 40% on the front axle; articulated frame tractor – 55% on the front axle and

45% on the rear axle; crawler tractor – 60% on the front and 40% on the rear axle. Regardless of the weight distribution of the wheeled tractor along the axles, the ground pressure of the front axle is 10-15% greater than that of the rear axle. The crawler tractor presses on the ground with the front part at a pressure that is 30% greater than the pressure of the tractor rear part.

In the results of field studies regarding ground pressure on wheeled running systems *(Ardvidson and Keller, 2014)*, it is noted that the John Deere tractor on paired wheels in a static state creates pressure at a depth of 15 cm – 150 kPa for the front axle and 145 kPa for the rear; and at a depth of 30 cm – 80 kPa for the front axle and 70 kPa for the rear. However, in this paper there are no dependences of pressure on the soil, taking into account the resistance of tillage or other tools.

Experimental studies of changes in the soil response from changes in the traction load on the hook of a wheeled tractor *(Polcar et al, 2017)* showed that with the traction resistance of the working tool in the range from 55 kPa to 70 kPa, there is a decrease in the pressure on the ground of the front axle and an increase in the pressure of the rear axle by an amount of 6 to 8 %. Similar results of pressure redistribution between the axles of wheeled running systems in the presence of traction load from a working machine are noted in studies *(Patil, 2015; Renčín et al, 2017)*. Analysis of completed studies *(Polcar et al, 2017; Patil, 2015; Renčín et al, 2017)* allows concluding that if there is a traction resistance of a working machine on the tractor hook, the front axle of the tractor is unloaded and the load of the rear axle increases.

Studies of the pressure distribution of crawler running systems of modern tractors *(Keller et al, 2002; Arvidsson et al, 2011; Ardvidson and Keller, 2014)* have shown that in the presence of traction load on the hook in comparison with static load, the load is redistributed, while the front support rollers are unloaded and the load increases in the area of the running systems rear part. The authors *(Keller et al, 2002; Arvidsson et al, 2011)* noted that after appropriate ballasting of the tractor and reducing the height of the working machine attachment point, the maximum vertical load in the tractor rear part was reduced and, accordingly, increased in the front.

The presented research results for different tractors give an idea of the general trends in weight redistribution between the axles and allow stating that the existing traction resistance of the working machine causes a redistribution of tractor weight between the axles. To ensure uniform pressure on the ground and ensure the implementation of engine traction power, the tractor must have an appropriate weight distribution in the contact area of the running systems with the ground under dynamic load during field work. Taking into account the design features of tractors and a variety of working machines, the correct acquisition of machine and tractor units is a rather complex practical task that requires experimental research, taking into account the work in a certain agrotechnological environment.

Polcar et al. obtained a dependence for determining the change in soil response from changes in the load on the tractor hook *(Polcar et al, 2017)*. At the same time, the authors took into account the placement of vectors of tractor traction forces at wheels point of contact with the ground. Since the ground load distribution model is based on the sum of the moments of forces relative to the wheel point of contact with the ground, this arrangement of the traction force vectors excludes their influence on the ground and, in addition, the force applied at the wheel point of contact with the ground cannot be the driving force *(Golub et al, 2017)*.

Wang and Zoerb, (1989), considers the change in axle load during tractor movement. The obtained dependences indicate that the load on the tractor axle depends on the horizontal traction on the hook, the distance of the hook from the rear axle, the height of the hook placement, and the wheelbase of the tractor. The authors obtained a dependence for determining the weight of the tractor front part when driving with a load:

$$W_F = W_{SF} - \frac{D\ .\ y}{B} - \frac{D\ .\ x}{B}$$

Where W_F – weight of the tractor front part when driving with a load, kg; W_{SF} – weight of the tractor front part without load, kg; D – traction force on the tractor hook, N; y – distance from hook to wheel axis, m; x – hook height above the surface, m; B – tractor wheelbase, m.

From this relationship, it follows that the weight of the tractor front part decreases under the influence of the traction force on the tractor hook. The reduction in the weight of the tractor front part depends proportionally on the coordinates of the hook placement and inversely on the size of the wheelbase.

Kumar et al, (2013), presents a study of changes in the sliding coefficient of the drive wheel depending on the unit speed, the angle of the working bodies' position and the processing depth. The most significant influence on the tractor traction properties was exerted by the processing depth and the angle of the working bodies' position, in contrast to the movement speed. The authors also use a dependency to determine the weight of the tractor rear axle when driving with a load:

$$W_D = W_S + P\frac{H}{X} \quad (2)$$

Where W_D – weight of the tractor rear part when driving with a load, kg; W_S – weight of the tractor rear part without load, kg; P – thrust force on the hook, N; H – hook height above the surface, m; X – tractor wheelbase, m. From this connection, it also follows that the increase in the weight of the tractor rear part is directly proportional to the height of the hook placement above the surface and inversely proportional to the tractor wheelbase size.

The above dependencies do not take into account the influence on the weight distribution of the tractor along the axles of the application angle of the working machine resistance force, the radii of the tractor wheels, besides, the tractor traction force vector is applied at the contact point of the wheels with the ground *(Wang and Zoerb, 1989; Kumar et al, 2013)*. Also, these dependencies do not take into account the weight of the tractor ballast.

The performed analysis gives an understanding that during operation, the traction resistance of the working machine leads to a redistribution of the tractor weight along the axles of the running systems. Existing dependencies partially take into account the redistribution of tractor weight, but do not fully take into account the design features of the tractor and the effect of forces that occur during its movement. Therefore, the development of refined dependencies for determining tractor weight distribution along the axles of the running system, depending on the traction resistance of the working machine, is an important scientific task.

The purpose of this work is to obtain dependencies for determining tractor weight redistribution, taking into account the action of the working machine resistance forces during field work and the design parameters of the tractor, which will be suitable for determining the weight of the tractor front ballast.

MATERIALS AND METHODS

Determination of the dependence that connects the redistribution of tractor weight and traction resistance on the hook during fieldwork was performed based on the power analysis of the machine-tractor unit, taking into account tractor design features and the resistance force angle of the action.

To check the adequacy of the obtained dependence of the tractor weight redistribution on the action of traction resistance on the hook, a comparison of experimental and theoretical data on the effect of the front load weight on the maximum traction force that the tractor can develop on the hook was performed. The John Deere 7130 wheeled tractor was chosen for experimental research, the main design parameters of which are shown in table 1.

Table 1

Main design parameters of the John Deere 7130 tractor

Indicator	John Deere 7130
Weight, N	**47,000**
Wheelbase, m	**2.7**
Distance from the front wheel axis to the tractor weight application point, m	**1.832**
Front wheel radius, m	**0.6**
Rear wheel radius, m	**0.9**
Distance from the rear wheel axis to the hook, m	**1.1**
Hook installation height, m	**0.4**

During the research, the tractor was placed on a flat horizontal plane and fixed to prevent horizontal movement. Fixing from horizontal movement was carried out by means of a connecting link, which was rigidly fixed at one end, and attached to the load cell with the other, which was attached to the tractor hook. The connecting link together with the load cell formed the angle of action of the resistance force to moving the tractor. The load cell on the tractor hook measured the resistance to movement that occurred under the traction force action. The maximum traction force on the tractor hook was recorded at the moment when the load from the tractor weight on the front axle was absent and the wheels of the front axle were torn off from the support surface.

When performing experimental studies, the weight of the front ballast load was changed from 0 to 4 kN in increments of 0.5 kN. When applying the torque to the tractor wheels, the separation moment of the front axle from the horizontal surface and the value of the traction resistance indicator on the load cell were simultaneously recorded. For each value of the ballast load weight, the maximum traction resistance was measured in threefold repetition. The equipment that was used during the research is shown in Fig. 1.

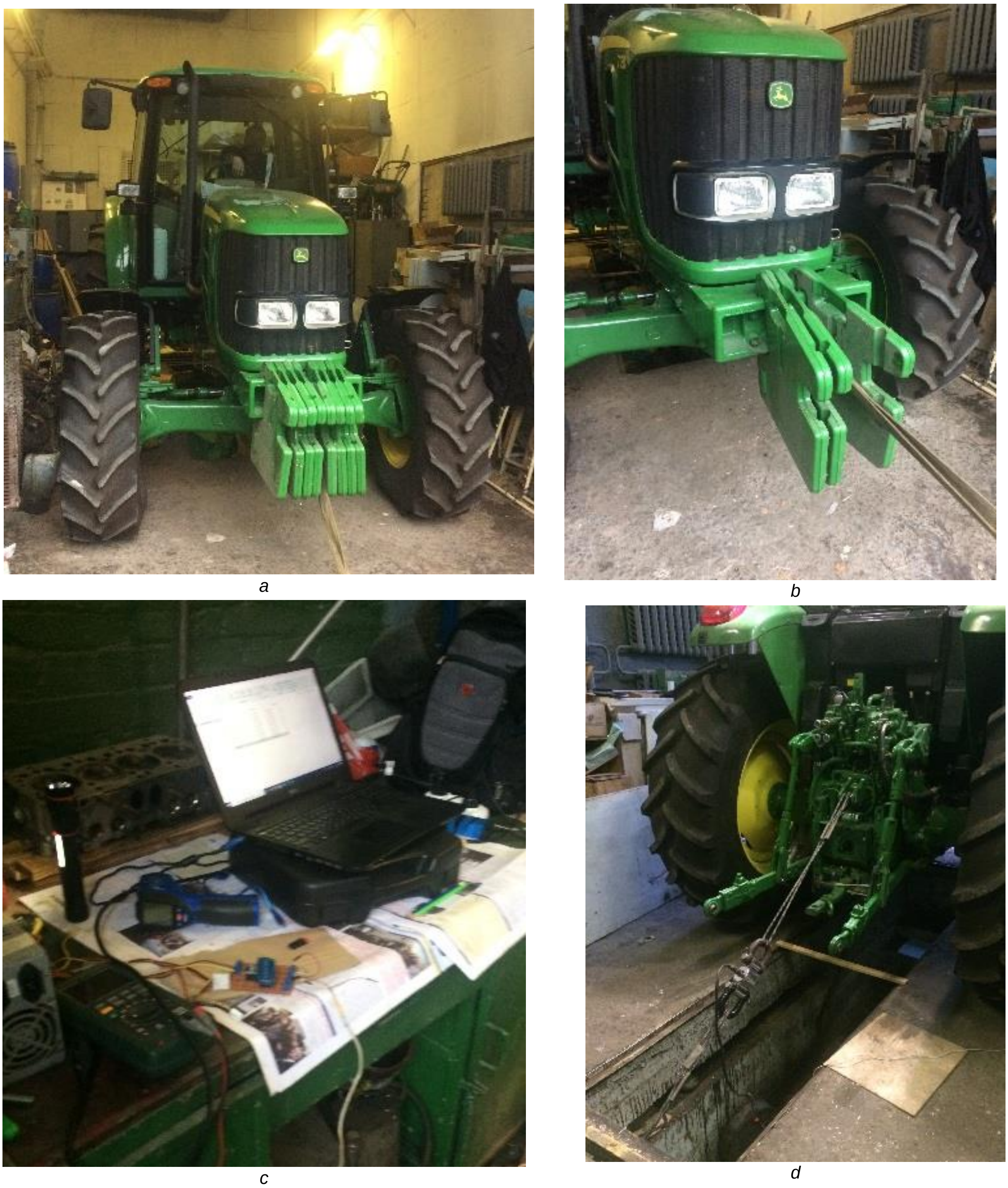

Fig. 1 - Equipment used in conducting experimental studies

a – tractor with front load; b – change in the weight of the front load; c – traction load locking system; d – sensor with cables for measuring traction load

When moving evenly from the tractor side, the following factors affect the ground: the weight of the tractor G, the weight of the front G_{FL} and rear G_{BL} load, the resistance of the tool F_{TR}, the traction on the front F_{TF} and rear F_{TB} wheel. This scheme was supplemented with countermeasures from the soil to the front R_F and rear R_B axles. The design diagram of the tractor used during the research is shown in Fig. 2.

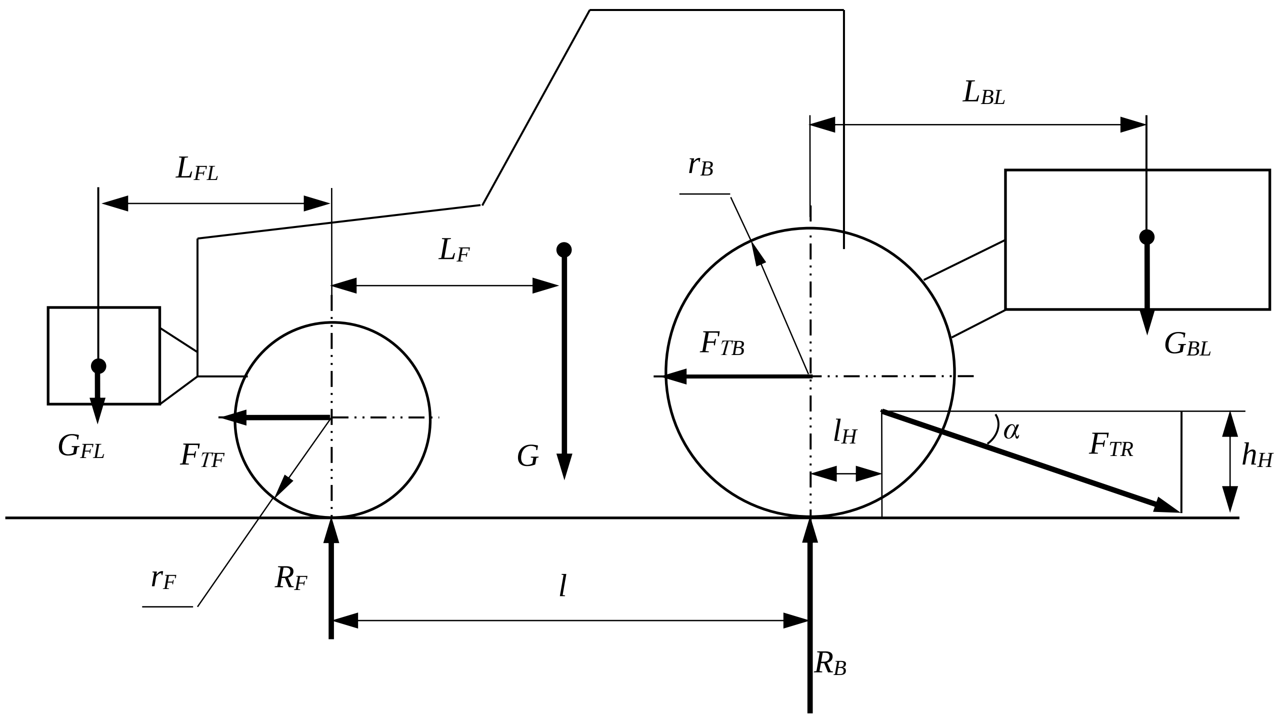

Fig. 2 - Calculation scheme of a wheeled tractor

G – tractor total weight, kN; G_{FL}, G_{BL} – weight of the front and rear loads, kN, respectively; l – distance between tractor wheel axles (tractor base), m; l_F – distance from the front wheel axis to the tractor weight application point, m; l_{FL}, – distance from the front wheel axis to front load center of gravity, m; l_{BL} – distance from the rear wheel axis to rear load center of gravity, m; r_F, r_B – radius of the tractor front and rear wheels, respectively, m; l_H – distance from the rear wheel axis to the hook, m; h_H – hook installation height, m; R_F, R_B – reaction at the tractor front and rear wheels contact point with the ground, kN; F_{TF}, F_{TB} – traction force on the tractor front and rear wheels, respectively, kN; F_{TR} – resistance force of the tillage tool, kN; α – resistance force action angle, rad.

When performing theoretical calculations, the values of the tractor parameters were taken in accordance with those at which experimental studies were performed (Table 1).

RESULTS

By reducing the action of the tractor weight and loads $G = G_{FL} + G_F + G_B + G_{BL}$ to one point and taking into account the distance from the front wheel axis to the application point of the tractor weight l_F, based on the moments from the action of the tractor components weight $G_{FL}(l_{FL} + l_F) + G_F l_F = G_B(l - l_F) + G_{BL}(l_{BL} + l - l_F)$ we will get:

$$l_F = \frac{G_B l - G_{FL} l_{FL} + G_{BL}(l_{BL} + l)}{G_{FL} + G_F + G_B + G_{BL}} \tag{1}$$

In the absence of rear, front, and both loads, this distance will be:

$$l_F^B = \frac{G_B l - G_{FL} l_{FL}}{G_{FL} + G_F + G_B}; \; l_F^F = \frac{G_B l + G_{BL}(l_{BL} + l)}{G_F + G_B + G_{BL}}; \; l_F^{BF} = \frac{G_B l}{G_F + G_B} \tag{2}$$

Where G_F, G_B – part of the tractor weight transmitted to the front and rear axles of the tractor, kN.

From Fig. 2, the sum of the moments of forces acting on the MTA relative to the wheels points of contact with the ground will be:

$$T_F = R_B l - G l_F + F_{TF} r_F + F_{TB} r_B - F_{TR} h_H \cos\alpha - F_{TR}(l_H + l) sin\alpha = 0 \tag{3}$$

$$T_B = -R_F l + G(l - l_F) + F_{TF} r_F + F_{TB} r_B - F_{TR} h_H \cos\alpha - F_{TR} l_H sin\alpha = 0 \tag{4}$$

Where:

T_F, T_B – the total moment of forces acting on the MTA relative to the front and rear wheels contact point with the ground, respectively, kN m.

The distribution of the traction forces of the front and rear wheels is determined according to the distribution of the tractor weight between the front and rear axles by the expressions: $F_{TF} = \frac{G_F}{G} F_T = k_{TF} F_T$ and

$F_{TB} = \frac{G_B}{G} F_T = k_{TB} F_T$, and taking that the total traction force of the tractor as $F_T = F_{TR} cos\alpha$, the soil reactions to the rear and front axles will have the value:

$$R_B = [Gl_F - k_{TF}F_{TR}r_F cos\alpha - k_{TB}F_{TR}r_B cos\alpha + F_{TR}h_H \cos\alpha + F_{TR}(l_H + l)sin\alpha]l^{-1}; \quad (5)$$

$$R_F = [G(l - l_F) + k_{TF}F_{TR}r_F cos\alpha + k_{TB}F_{TR}r_B cos\alpha - F_{TR}h_H \cos\alpha - F_{TR}l_H sin\alpha]l^{-1}, \quad (6)$$

or:

$$R_B = \left[Gl_F - F_{TR}\left((k_{TF}r_F + k_{TB}r_B - h_H)\cos\alpha - (l_H + l)sin\alpha\right)\right]l^{-1}; \quad (7)$$

$$R_F = \left[G(l - l_F) + F_{TR}\left((k_{TF}r_F + k_{TB}r_B - h_H)\cos\alpha - l_H sin\alpha\right)\right]l^{-1}, \quad (8)$$

Where k_{TF}, k_{TB} – coefficients of distribution of the tractor total weight between the front and rear axles, respectively, rel. un.

For a crawler tractor that is driven only from the rear axle, using the reaction equations for the wheeled tractor (7) and (8), the soil reaction equations for the front and rear of the crawler tractor will look like:

$$R_B = \left[Gl_F - F_{TR}\left((r_C - h_H)\cos\alpha - (l_H + l)sin\alpha\right)\right]l^{-1}; \quad (9)$$

$$R_F = \left[G(l - l_F) + F_{TR}\left((r_C - h_H)\cos\alpha - l_H sin\alpha\right)\right]l^{-1}, \quad (10)$$

Where r_C – radius of the rear drive sprocket of the tractor track, m.

At critical action angles of the drag force (α = 0° and α = 90°) and different conditions of mutual placement of the hook relative to the wheels, the ground reactions to the front and rear axles will have the values shown in table 2.

Table 2

Values of soil reactions to the front and rear axles of the tractor with the same radii of the front and rear wheels ($r_F = r_B = r_W$)

α = 0°, $r_W = h_H$	α = 0°, $r_W > h_H$
$R_B = G\frac{l_F}{l}$; $R_F = G\frac{l - l_F}{l}$	$R_B = G\frac{l_F}{l} - F_{TR}\frac{r_W - h_H}{l}$; $R_F = G\frac{l - l_F}{l} + F_{TR}\frac{r_W - h_H}{l}$
α = 0°, $r_W < h_H$	α = 90°, $r_W = h_H$; $r_W > h_H$; $r_W < h_H$
$R_B = G\frac{l_F}{l} + F_{TR}\frac{h_H - r_W}{l}$; $R_F = G\frac{l - l_F}{l} - F_{TR}\frac{h_H - r_W}{l}$	$R_B = G\frac{l_F}{l} + F_{TR}\frac{l_H + l}{l}$; $R_F = G\frac{l - l_F}{l} - F_{TR}\frac{l_H}{l}$

From the above formulas, it is possible to draw several conclusions: at zero action angle of the resistance force on the tractor hook, the pressure forces of the wheels on the ground do not depend on the resistance force on the tractor hook, but depend only on the distribution of the tractor weight between the axles; if the tractor hook is installed above the wheel axles, then with an increase in the resistance force on the tractor hook, the pressure force of the front wheels on the ground decreases (the tractor can turn around the rear axle), and the pressure force of the rear wheels increases; if the tractor hook is installed below the wheel axles, then when the drag force on the tractor hook increases, the pressure force of the front wheels on the ground, on the contrary, increases, and the pressure force of the rear wheels decreases.

To check the obtained dependences (7 and 8) by conducting experimental studies, from the reaction equation of the front wheels, in the absence of a rear load, it is necessary to determine the conditions under which the pressure of the front wheels on the ground will be absent ($R_F = 0$):

$$R_F = \left[G(l - l_F) + F_{TR}\left((k_{TF}r_F + k_{TB}r_B - h_H)\cos\alpha - l_H sin\alpha\right)\right]l^{-1} = 0. \quad (9)$$

Therefore, the value of the resistance force at which this condition will be met is:

$$F_{TR} = -\frac{G(l - l_F)}{(k_{TF}r_F + k_{TB}r_B - h_H)\cos\alpha - l_H sin\alpha} = -\frac{(G_{FL} + G_F + G_B + G_{BL})\left(l - \frac{G_B l - G_{FL}l_{FL} + G_{BL}(l_{BL}+l)}{G_{FL}+G_F+G_B+G_{BL}}\right)}{(k_{TF}r_F + k_{TB}r_B - h_H)\cos\alpha - l_H sin\alpha} =$$

$$= -\frac{G_{FL}l + G_F l + G_B l + G_{BL}l - G_B l + G_{FL}l_{FL} - G_{BL}(l_{BL}+l)}{(k_{TF}r_F + k_{TB}r_B - h_H)\cos\alpha - l_H sin\alpha} = -\frac{(G_{FL}+G_F)l + G_{FL}l_{FL} - G_{BL}l_{BL}}{(k_{TF}r_F + k_{TB}r_B - h_H)\cos\alpha - l_H sin\alpha} \quad (10)$$

The drag forces at which the pressure of the front wheels on the ground will be absent in the absence of rear, front and both loads, respectively, will be:

$$F_{TR}^{B} = -\frac{(G_{FL}+G_F)l + G_{FL}l_{FL}}{(k_{TF}r_F + k_{TB}r_B - h_H)\cos\alpha - l_H sin\alpha}; \; F_{TR}^{F} = -\frac{G_F l - G_{BL}l_{BL}}{(k_{TF}r_F + k_{TB}r_B - h_H)\cos\alpha - l_H sin\alpha}; \; F_{TR}^{BF} = -\frac{G_F l}{(k_{TF}r_F + k_{TB}r_B - h_H)\cos\alpha - l_H sin\alpha} \quad (11)$$

To check the adequacy of the obtained theoretical dependence (10), a comparison of theoretical and experimental data was performed. As a result of comparative studies, experimental and calculated graphical dependences of the effect of the front ballast load weight on the value of traction resistance on the tractor hook were obtained (Fig. 3).

Studies have shown that when the front ballast weight of the tractor changes in the range from 0 to 4kN, the maximum traction force of the tractor increases by 34.8 %. It should be noted a proportional increase in the maximum traction force with an increase in the mass of the ballast load. The index of determination of the calculated values and experimental data of changes in the traction force on the hook from changes in the weight of the front ballast load is calculated according to the method of *Dospehov, (1985)* and is $\eta^2 = 0.74$.

The specified value of the index of determination allows asserting the adequacy of the obtained calculated dependence (10) on experimental data, and also allows recommending the obtained models (7) and (8) for modeling the influence of tractor traction resistance on the weight redistribution between the axles of running systems when performing machine and tractor units of field work.

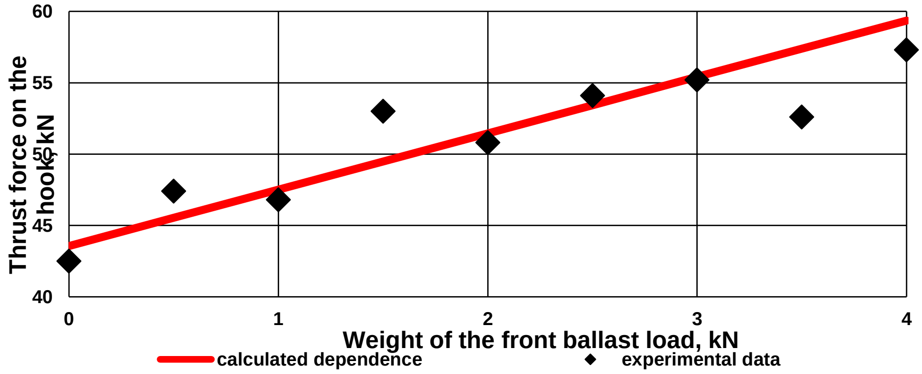

Fig. 3 - Dependence of the traction resistance of the tractor hook on the weight of the front ballast load

Expressions (7) and (8) were used to calculate the dependence of soil reactions (or ground pressure forces) on the front and rear axles as a function of the drag force action angle for the John Deere 7130 tractor when working with a Lemken five-body plow with a resistance of 30,000 N. The weight distribution of the tractor was as follows: the front axle was 15,118 N, the rear axle was 31,882 N. The calculation results are shown in Fig. 4.

Analysis of Fig 4 shows that the addition of a front load weighing 4 kN with a traction resistance of the working machine of 30 kN leads to a decrease in the load on the rear axle by 4.8% and an increase in the load on the front axle – by 29.7% with zero value of the resistance force action angle of the working machine. An increase in the resistance force action angle of the working machine from 0 to 15 degrees with the specified traction resistance leads to an increase in the load of the rear axle by 19.2% and a decrease in the load of the front axle – by 11.9%. Adding a 4 kg front load with a drag force angle of 15 degrees, reduces the load on the rear axle by 3.9% and increases the load on the front axle by 37.7%.

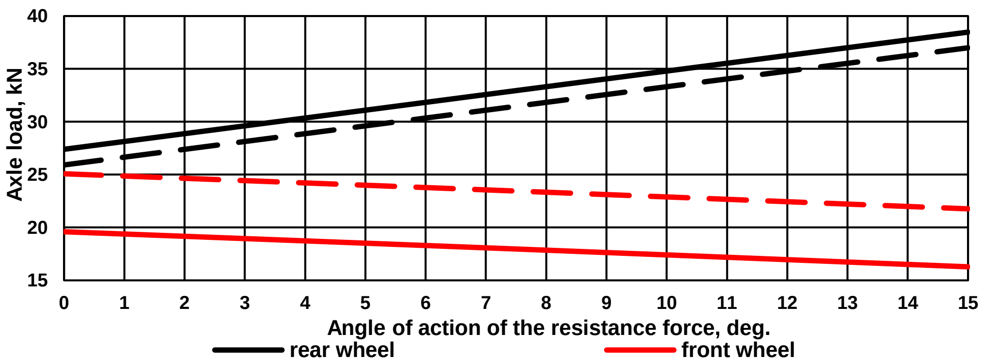

Fig. 4 - Dependence of soil reactions (or ground pressure forces) on the front and rear axles depending on the drag force action angle in the presence of a front load weighing 4 kN and without it

Expressions (9) and (10) were used to calculate the dependence of soil reactions (or ground pressure forces) on the front and rear axles as a function of the drag force action angle for the Challenger MT 845C crawler tractor when working with a Lemken seven-body mounted plow with a resistance of 45,000.

The weight distribution of the tractor was as follows: the front axle was 113,865 N, the rear axle was 75,904 N. The wheelbase of the tractor was 3 m, the radius of the front and rear sprockets was 0.47 m and 0.775 m. The calculation results are shown in Fig. 5 and 6.

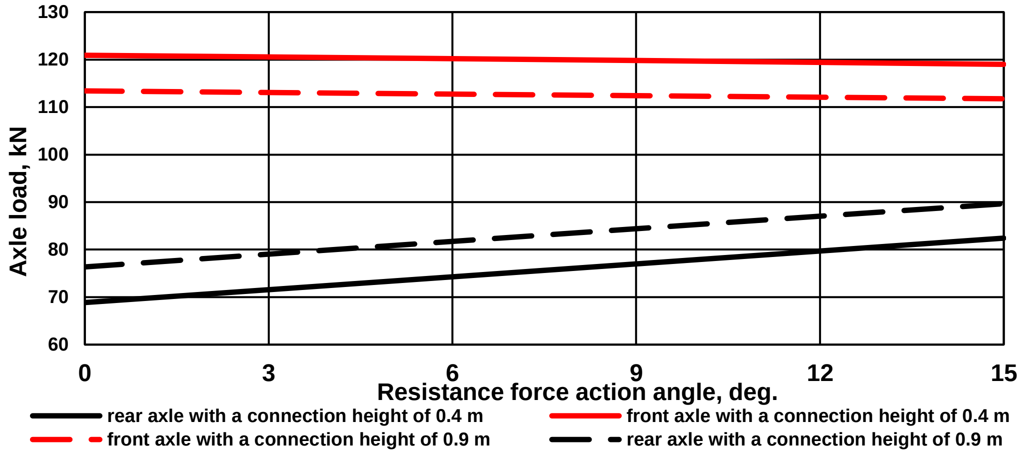

Fig. 5 - Dependence of soil reactions (or ground pressure forces) on the front and rear of the crawler tractor, depending on the drag force action angle and the height of the plow connection

Analysis of the obtained dependencies shown in Fig. 5 demonstrates that for a crawler tractor, when the connection height of the working machine increases, there is an increase in the load on the track rear part and unloading of the track front part. With a traction resistance of the working machine of 45 kN and an angle of action of resistance forces of 0 deg., an increase in the connection height of the working machine from 0.4 to 0.9 m, there is an increase in the load on the rear of the track by 10.9% and unloading by 6.2% of the front of the track. An increase in the drag force action angle of the working machine from 0 to 15 degrees at the specified traction resistance leads to an increase in the load on the rear part of the track by 19.7% and a decrease in the load on the front part of the track by 1.6%. At the same time, there is a slight decrease in the influence of the attachment height of the working machine on the load change. Thus, when the resistance angle of the working machine is 15 degrees, increasing the mounting height from 0.4 to 0.9 m leads to an 8.8% increase in the load on the rear of the track and unloading by 6.1% of the front of the track.

The dependencies shown in Fig. 6 demonstrate the influence of the working machine resistance angle and the height of its connection on the change in the ratio between the load on the front and rear axles of the Challenger MT 845C crawler tractor. The analysis of the obtained dependencies allows stating that by increasing the height of the working machine connection with a traction resistance of 45 kN, it is possible to reduce the ratio between loads between the front and rear axles in the range from 13.2% to 15.43%. It should be noted that a higher value of reducing the ratio corresponds to the resistance force action angle of the working machine at 0 degrees. With an increase in the working machine resistance angle, there is a decrease in the ratio between the loads on the front and rear axles. Thus, an increase in the action angle of the working machine resistance from 0 to 15 at the connection height of the working machine 0.4 m leads to a decrease in the ratio between the loads on the front and rear axles by 17.71%, and by 15.54% at the connection height of 0.9 m. In general, the analysis shows that by increasing the connection height and the action angle of the working machine resistance force, it is possible to reduce the ratio between the loads on the axles from 1.75 to 1.25 rel. units. The results show that due to the change in the connection height of the working machine, it is possible to slightly change the weight balance between the front and rear parts of the track, and by changing the action angle of the working unit resistance, it is possible to significantly load the rear part of the track.

Taking into account the trends in the development of modern crawler tractors, which have a sufficiently large power and a specific weight distribution between the front and rear of the track, manufacturers should develop recommendations in advance on how and with what working units of their machines can work to reduce the negative impact on the soil. To load the crawler tractor, it was chosen a swing mounted unit with a resistance of 45 kN, but it was not possible to ensure the same weight distribution between the front and rear parts of the track when working with it. As a rule, powerful tracked vehicles work with wide-range trailed or semi-trailed working units. However, when working with such units, the connection height and the action angle of the working machine resistance either do not change, or change in a rather insignificant range.

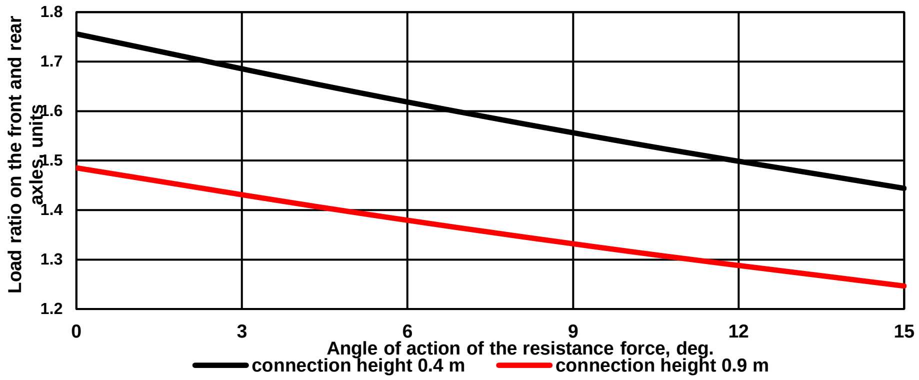

Fig. 6 - Dependence of the load ratio on the front and rear axles depending on the action angle of the resistance force and the height of the plow connection

The obtained dependencies give an understanding of the redistribution of weight between the tractor axles when performing technological operations, allow modeling the influence of structural and technological parameters of machine and tractor units on the distribution of weight between the axles of running systems, predict the further impact of running systems on the fertile soil layer and achieve minimum sliding values of running systems due to the redistribution of tractor weight.

The obtained research results allow checking the efficiency of completing tractors with a working machine, as well as checking the effectiveness of design solutions in the development of new tractors at the design stage.

Further development of the obtained dependencies application will be aimed at solving the consistency issues of the design and parameters of the working machine and tractor to ensure minimal negative impact on the soil. When conducting further research, it is advisable to improve the obtained mathematical model by finding out the influence of the agrotechnological environment properties and driving modes on the weight distribution of the tractor. Also, based on the obtained data, it is advisable to implement an automatic control system for the weight distribution of the tractor when performing technological operations.

CONCLUSIONS

✓ According to the research, the weight distribution of the tractor along the running system axles is established depending on the action angle of the working machine resistance force and its traction resistance. The obtained mathematical model allows, based on the height of the trailer hook installation, the action angle of the working machine resistance force, tractor wheelbase, ballast load mass, the distribution of the tractor weight in a static position, the traction resistance of the working machine, determining the weight distribution of the tractor along the running system axles. The obtained dependence makes it possible to simulate the influence of these factors on the contact load in the running systems contact zone with the soil to minimize the harmful impact on it.

✓ Modeling of the effect of the front ballast load value on the traction force showed that an increase in the front ballast load by 8.5% of the weight of a wheeled tractor leads to an increase by 34.8% of the maximum possible traction force on the tractor hook.

✓ It was established that for a wheeled tractor with a working machine traction resistance of 30 kN, the presence of a front load weighing 4 kN leads to a decrease in the load on the rear axle by 4.8% and an increase in the load on the front axle by 29.7%. An increase in the action angle of the working machine drag force from 0 to 15 degrees with a traction resistance of 30 kN leads to an increase in the load of the rear axle by 19.2% and a decrease in the load of the front axle by 11.9%. The obtained results make it possible to adjust the machine and tractor unit during field work in order to reduce the negative impact of running systems on the soil.

✓ The results of research on the weight distribution of a tracked tractor showed that the use of a mounted tillage tool with a traction resistance of 45kN, as well as design settings, do not allow equalizing the weight distribution between the front and rear parts of the track. According to the simulation performed, when the connection height of the working machine changes from 0.4 to 0.9 m, the load on the rear part of the track increases by 10.88% and the front part of the track is unloaded by 6.2%. By increasing the action angle of the working machine drag force from 0 to 15 degrees, it is possible to increase the load of the track rear part by 19.6% and reduce the load of the track front part by 1.6%. Increasing the connection height of the working machine allows balancing the weight between the front and rear of the track. By changing the action angle of the working unit resistance, one can significantly load the track rear part. Analysis of the weight distribution of a tracked tractor indicates the need at the design stage to coordinate its power with the parameters of the working machines with which it will work.

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