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INVESTIGATION OF THE INFLUENCE OF PERMANENT TRAFFIC LANE PROPERTIES ON ROLLING OF BRIDGE AGRICULTURAL EQUIPMENT WHEELS

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Movement of bridge agricultural equipment along the permanent traffic lanes is characterised by significant energy costs for overcoming the rolling resistance forces. Until now, the movement process of bridge agricultural equipment wheels along the compacted soil of permanent traffic lanes has been paid only a little attention. It has been established that the physical and mechanical properties of soil lanes significantly affect the energy consumption necessary for overcoming the rolling resistance of forces of bridge agricultural equipment wheels. Considering the range of possible changes in these properties, the coefficient of rolling resistance of equipment wheels varies from 0.06 to 0.1, which is 66%. In order to reduce the rolling resistance coefficient of equipment wheels when moving along the permanent traffic lanes, the surface needs to be undeformable. When moving along such a solid and dense supporting surface, the wheel rolling resistance is lowest.

Keywords: traffic lanes; resistance; movement; soil; physical and mechanical properties of soil

When using agricultural machinery with different working widths, majority of fertile soil (approx. 75%) is subjected to unfavourable impacts of the tractor and machinery wheels (Barwicki et al., 2012; Chen et al., 2010; Isbisteret al. 2013; Galambošová et al., 2020). Controlled traffic farming confines all machinery loads to the least possible area of permanent traffic lanes. Moreover, it provides a wide range of benefits, e.g. greater rainfall infiltration rates, increased available water capacity, etc. (Tullberg et al., 2018). It represents an efficient way for managing the soil compaction by confining all load-bearing wheels to the least possible area of permanent traffic lanes (Galambošová et al., 2017).

The tractor theory informs that rolling of a wheel with an elastic rim along a deformable surface is characterised by energy consumption for overcoming the rolling resistance forces (Simikič et al., 2014; Kutkov, 2014).In this case, the main research tasks of tractor wheel rolling are: identification of a correlation of parameters and conditions of its rolling; search for criteria for evaluating the wheel rolling process; and determination of the ways how to reduce the rolling resistance (Kutkov, 2014). It should be noted that the dependence of rolling resistance coefficient of tractor wheels on the physical and mechanical properties of soil surface (especially the moisture, density and hardness) along which the wheels move has not been sufficiently considered and studied. The process of rolling of bridge agricultural equipment wheels along the compacted soil of permanent lanes practically remains unstudied although its energy costs are lower.

The very appearance of controlled traffic farming (Antille at al., 2015; Bulgakov et al., 2017; Gasso et al., 2013; Bulgakov et al., 2018) makes it possible to solve a fundamental contradiction in the "driver–soil" system. Essentially, if the energy tool is to achieve the high traction and hitching properties, its drivers must encounter dry, levelled, and solid supporting surface. However, plant cultivation requires fluffy-structured environment with optimal density and moisture. In practice, such requirements can be satisfied only when the movement zones of energy tools (the technological zone of field) and the zones of plant growth (the agrotechnical zone of field) are clearly differentiated (Chamen, 2015; Kingwelland Fuchsbichler, 2011; Onal, 2012.). In this system, the agricultural bridge represents permanent traffic lanes; permissible boundaries for performing technological operations can vary significantly. Furthermore, optimal working conditions for the bridge agricultural equipment can differ significantly from the ideal conditions for the growth and development of cultivated plants. Issue of studying the impact dependences of physico-mechanical properties of the soil of permanent traffic lanes on the rolling resistance of bridge agricultural equipment wheels when moving along them becomes relevant.

In tractor theory, the coefficient of rolling resistance f_k is a dimensionless criterion for the wheel rolling evaluation, which takes into account the tangential force and resistance (Kutkov, 2014). It is calculated as the ratio of rolling resistance

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P_f to normal vertical load acting upon the wheel f_k (Kutkov, 2014):

$$f_k = \frac{Đ_f}{G_N} \tag{1}$$

There are many scientifically substantiated expressions for the calculation of rolling resistance coefficient f_k of a tractor wheel. The most frequently used is the Granvuane-Goryachkin dependence:

$$f_k = 0.86 \left[\frac{G_N}{k_r \cdot b_0 \cdot D_0^2} \right]^{\frac{1}{3}} \tag{2}$$

where:

k_r – volumetric crushing coefficient of soil ($N \cdot m^{-3}$)

D_0, b_0 – static diameter and the tire width of wheel, respectively (m)

Fig. 1 Experimental agricultural bridge equipment during a laboratory research of its rolling resistance along the permanent traffic lanes

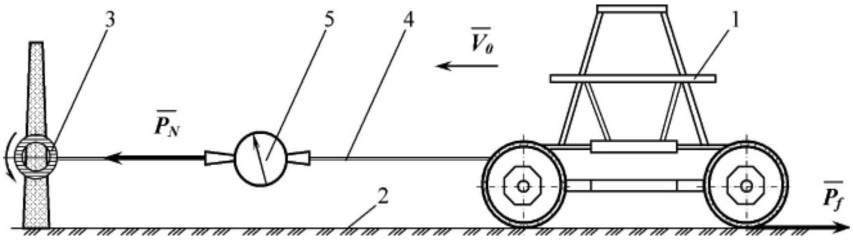

Fig. 2 Laboratory complex for the rolling resistance force determination of agricultural bridge equipment along the tracks of permanent traffic lanes

Fig. 3 Devices for determination of physical and mechanical properties of the soil in tracks of permanent traffic lanes
1 – Revyakin hardness tester; 2 – MG-44 hygrometer; 3 – densitometer

The impacts of tire design, air pressure, movement speed, vertical load, etc. on the resistance coefficient of its rolling has been studied in sufficient detail (Panchenko and Kyurchev, 2008; Nadykto at al., 2015; Nadykto and Velichko, 2015; Nadykto et al., 2019). In practice, the rolling resistance coefficient value of tractor wheel is not calculated, but it is selected from the reference tables depending on the soil structure or road type. Moreover, the rolling resistance coefficients of propulsors of different machines differ significantly when driving under the same conditions. However, the wheel performance of agricultural bridge while moving along the permanent traffic lanes has not been sufficiently studied. The rolling process of bridge agricultural equipment wheels along compacted soil of permanent traffic lanes remains practically unstudied.

This investigation strives to establish relationships between the impacts of physico-mechanical properties of soil tracks of permanent traffic lanes and the rolling resistance of agricultural bridge equipment wheels.

Material and methods

The physical object of experimental research was a bridge agricultural equipment (Fig. 1) that was developed by Bulgakov et al. (2019). Equipment undercarriage is a trolley and the wheels with pneumatic tires of a standard size 9.5R32 are attached to its frame by four axles.

When considering the rolling process of bridge agricultural equipment wheels along the soil tracks of permanent traffic lanes, the general factors accompanying the operation of wheels were excluded: uneven movement, ascent or descent, the bearing resistance in the wheel hub, and air resistance. This research is based on the assumption that the bridge agricultural equipment wheels with constant air pressure in their tires roll along the tracks of horizontal section of permanent traffic lanes at a uniform speed.

The rolling resistance force of bridge agricultural equipment wheels along the tracks of permanent traffic lanes was determined by the principle of its "free" movement along the supporting surface. The indicated "free movement" of agricultural bridge equipment along the tracks of permanent traffic lanes was carried out by its forced movement (Fig. 2).

The laboratory complex (Fig. 2) consisted of agricultural bridge equipment [1], wheels rolling freely along the formed tracks [2] of permanent traffic lanes. The free movement of agricultural bridge equipment [1] along the tracks [2] was effectuated by means of a traction mechanism [3], which was attached to it by the cable [4]. The effort necessary for free movement of the equipment [1] along the tracks [2] was recorded using dynamometer [5].

The basis for laboratory determination of the rolling resistance force of agricultural bridge equipment along the tracks of permanent traffic lanes is the equality of its rolling resistance force P_f and the force P_N at which it was rolling according to the dynamometric device (Fig. 2).

Physico-mechanical properties of the soil tracks of permanent traffic lanes were measured in a depth of 0–5 cm. For the purposes of soil hardness determination, Revyakin hardness tester was used (Fig. 3).

The soil density in the tracks was measured by a densitometer of own design (Fig. 3). The soil moisture was measured by MG-44 moisture meter (Fig. 3).

The standard Revyakin hardness tester (Fig. 3) consisted of a guide rod with a relatively small support surface, and a telescopic rod with a tip (a flat plunger with a working surface of 1 cm^2), which was used for soil penetration to a depth of 5 cm. Tester telescopic rod was connected to the handle by a spring. When pressure is applied to the handle, the spring is compressed. Its deformations are recorded by a recording device through a special transmission mechanism. The tip was plunged through the compacted soil layers of the tracks in a slow manner and with a uniform force. On a millimetre paper, the hardness tester recorded a hardness diagram with continuous distribution of hardness value by depth. Ultimately, the hardness H (Pa) was determined as follows:

$$H = \frac{h_a \cdot q}{s} \tag{3}$$

where:

h_a – average ordinate value of the hardness diagram (cm)
q – instrument calibre (hardness of the hardener spring) (N·cm^{-1})
s – cross-sectional area of the hardness tester piston (cm^2)

The MG-44 on-board electronic digital moisture meter (Fig. 3) is designed to measure the relative soil moisture using a sensitive radio frequency sensor with the range of 1–100%.The unit measurement time is max. 3 s. It is powered by an internal DC power supply unit. The measured relative humidity is counted from the liquid crystal indicator located on the front panel of indicator device. When measuring the soil track moisture, the electrode of MG-44 device was plunged into the soil to the depth of 0–5 cm. The sensor emits directed electromagnetic wave of high frequency, the part of which is absorbed by water molecules, and part is reflected in the sensor direction. By measuring the reflection coefficient of wave from a substance, which is directly proportional to the moisture content, the relative moisture value is shown on the device display.

A specially developed densitometer (Fig. 3) based on the "cutting cylinder" principle was used to measure the soil track density in permanent traffic lanes. It is a metal base with a handle, which has three cutting cylinders attached to it (to determine the average sample value). To take soil samples from the top layer (0–5 cm) of tracks, a densitometer with cutting cylinders is put into soil by hitting the device´s back part with a hammer. After filling the cutting cylinders with soil, the density value ρ (g·cm^{-3}) can be calculated as follows:

$$\rho = \frac{m_t - m_0}{3 \cdot v_c} \tag{4}$$

where:

m_t, m_0 – weight of suspended densitometer with and without soil (g)
v_c – single cutter cylinder volume (cm^3)

Measurement of each parameter was repeated 10 times with their uniform placement along the entire length of pilot section of permanent traffic lanes. The measurement results were averaged. Statistical characteristics of measurements were calculated using the Microsoft Office Excel software. The error of direct experimental measurements of parameters using the devices shown in Fig. 3 did not exceed 2%.

In addition to mathematical calculations, statistical analysis of data was performed using the Microsoft Office Excel software. To establish the functional dependence between measured parameters, the standard procedure of statistical analysis using the "Trend Line" function was used in Microsoft Office Excel software. The functional dependence accuracy was estimated by determining the coefficient of (R^2) reliability (correlation) of model, the best value of which is 1. For these purposes, the additional settings were adjusted in the Microsoft Office Excel software. The closer the obtained value to 1, the higher the model reliability.

Based on the measurement results, the following statistical characteristics were determined:

1. Average value Y:

$$Y = \frac{\sum y_i}{n} \tag{5}$$

where:

y_i – parameter value in i measurement
n – measurement quantity

2. Average quadratic deviation (standard) σ:

$$\sigma = \sqrt{\frac{\sum (y_i - Y)}{n}} \tag{6}$$

3. Coefficient of variation K (%):

$$K = \frac{100 \cdot \sigma}{Y} \tag{7}$$

Variability of the index measurement process was considered insignificant if the coefficient of variation K did not exceed 10%. If its value is higher than 10%, but less than 20% – the variability was considered average. If K >20%, then the variability was considered significant. In this case, the reasons for obtaining such measurement results were studied, and the method of their determination was corrected and repeated.

Results and discussion

The results showed that there is a sufficiently strong correlation between impacts of physical and mechanical properties of soil of permanent traffic lanes on the rolling resistance coefficient of agricultural bridge equipment wheels. The impact of soil moisture in tracks of permanent traffic lanes on the rolling resistance coefficient of equipment wheels is shown in Fig. 4. Here, the columns show the average quadratic deviation of this indicator. Analysis shows that an increase in soil moisture in tracks leads to an increase in the rolling resistance coefficient as well. Based on Fig. 4, the coefficient of variation of rolling resistance did not exceed 10%, which indicates a slight variability (variability) in the definition of this indicator.

When the soil track moisture content increases from 10% to 45%, the rolling resistance coefficient of wheels increases from 0.06 to 0.1, which is 66% in percentage terms. However, in order to overcome the rolling resistance of agricultural bridge equipment wheels, the engine power consumption is proportional to value of f_k during the movement, resulting in increasing of energy consumption by the same percentage. The nature of relationship between the indicators shown in Fig. 4 can be explained by the fact that, with an increase in the moisture content of soil tracks, the losses due to soil compaction increase when the agricultural bridge equipment moves along the lanes. The indicated losses grow larger through the increase in the contact area of wheel tire with the supporting surface, and the increase in track depth produced by the wheels pressing on the soil. As a result, the rolling resistance coefficient of wheels increases while moving along the tracks. Ultimately, in this case, the energy consumption for soil deformation significantly exceeds the energy consumption for tire deformation of agricultural bridge equipment wheels (Bulgakov et al., 2019).

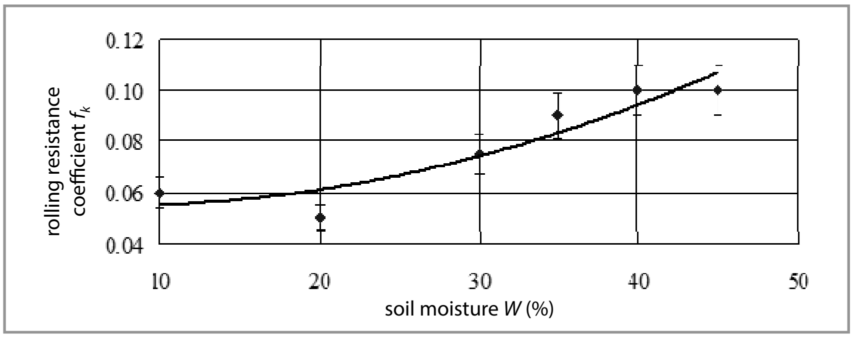

Fig. 4 Dependence of the rolling resistance coefficient f_k of bridge agricultural equipment wheels on the moisture content W in soil tracks of permanent traffic lanes

The dependence between the rolling resistance coefficient f_k and the soil moisture is sufficiently exactly approximated as follows:

$$f_k = 4 \cdot 10^{-5}\, W^2 - 5 \cdot 10^{-4}\, W + 0.0562 \quad (8)$$

where:

W – soil moisture in tracks of permanent traffic lanes (%)

The accuracy of obtained analytical expression (Eq. 8) can be estimated by the value of correlation coefficient, the square value of which is R^2 = 0.8767 in relation to experimental data. The high value of the latter indicates potential practical use of the analytical dependence obtained (Eq. 8) in assessing the energy losses due to the movement of agricultural bridge equipment wheels along the permanent traffic lanes, taking into account the soil moisture content.

Since the soil moisture in tracks of permanent traffic lanes naturally affects hardness and density indicators, their changes are also reflected in the rolling resistance coefficient of agricultural bridge equipment wheels (Figs 5 and 6). Figs 5 and 6 show the average quadratic deviation of these indicators.

Analysis of experimentally obtained dependences (Figs 5 and 6) showed that increasing the hardness H and density ρ of the soil tracks lead to decreasing of the rolling resistance coefficient f_k of agricultural bridge equipment wheels moving along them. This decrease is of quadratic nature. The coefficient of variation of rolling resistance did not exceed 8.5%, indicating a slight variability in the definition of this indicator. Therefore, it is sufficiently accurately described as follows:

$$f_k = 0.0247H^2 - 0.2093H + 0.499 \quad (9)$$

where:

H – soil hardness in tracks of permanent traffic lanes (determined by the Revyakin system) (MPa)

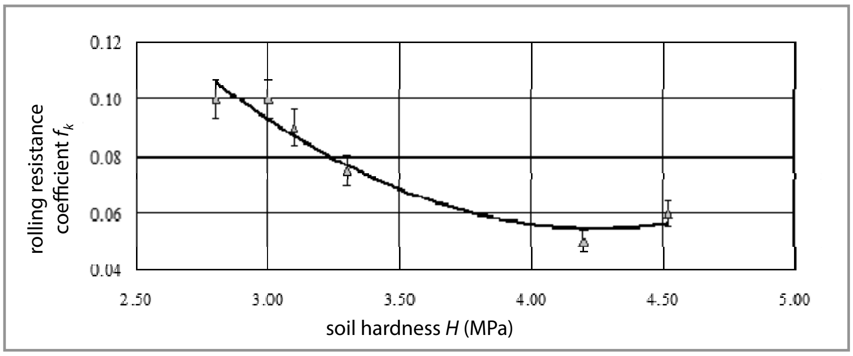

Fig. 5 Dependence of the rolling resistance coefficient f_k of agricultural bridge equipment wheels on the hardness H of soil tracks of permanent traffic lanes

$$f_k = 0.335\rho^2 - 1.1256\rho + 0.9991 \qquad (10)$$

where:

ρ – soil density in tracks of permanent traffic lanes (g·cm^{-3})

It should be noted that the correlation between the hardness of soil tracks with the rolling resistance coefficient f_k (Eq. 9) is stronger than the relationship between the density of soil tracks and the rolling resistance coefficient f_k (Eq. 10). The square of correlation of f_k is $R^2 = 0.9395$ for the hardness of soil tracks, and $R^2 = 0.8419$ for the density of soil tracks.

The nature of experimentally obtained dependencies shown in Figs 6 and 7 can be explained by the circumstance that the increase in hardness and density of soil tracks lanes promotes reduction of the energy applied to agricultural bridge equipment wheels to perform such operations as vertical crushing of the soil and the formation of compacted tracks and friction of the tire tread upon the supporting surface in the contact area. Therefore, in order to reduce the coefficient f_k during the movement of agricultural bridge equipment along the tracks of permanent traffic lanes, it needs to be a practically undeformable surface. When moving along such a solid and dense supporting surface, the wheel rolling resistance is minimal.

Based on the aforementioned, the rolling resistance coefficient of agricultural bridge equipment wheels moving along soil tracks of permanent traffic lanes can be sufficiently accurately estimated by the track hardness value. This allows establishing a relationship between the equipment wheel parameters and physico-mechanical properties of soil tracks with the indicators of track formation. For this, we equate dependencies (2) and (9). As a result, there is:

$$0.86\left[\frac{G_N}{k_r \cdot b_0 \cdot D_0^2}\right]^{\frac{1}{3}} = \qquad (11)$$
$$0.0247H^2 - 0.2093H + 0.499$$

From the obtained equality (Eq. 11), it is possible to express the coefficient of volumetric crushing of soil:

$$k_r = \frac{0.636 \cdot G_N}{b_0 \cdot D_0^2\left(0.0247H^2 - 0.2093H + 0.499\right)^3} \qquad (12)$$

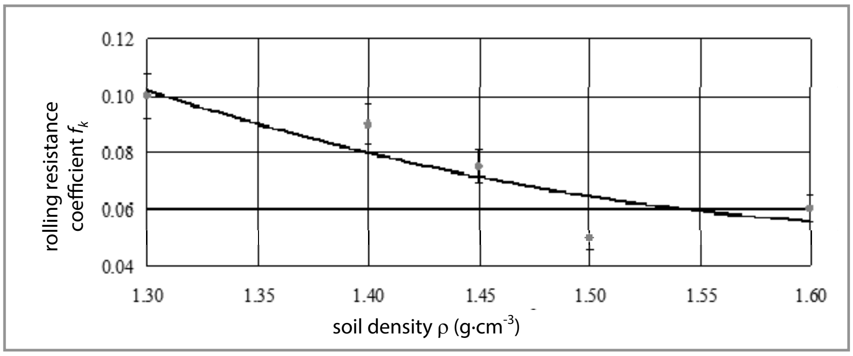

Fig. 6 Dependence of the rolling resistance coefficient f_k of agricultural bridge equipment wheels on the density ρ of soil tracks of permanent traffic lanes

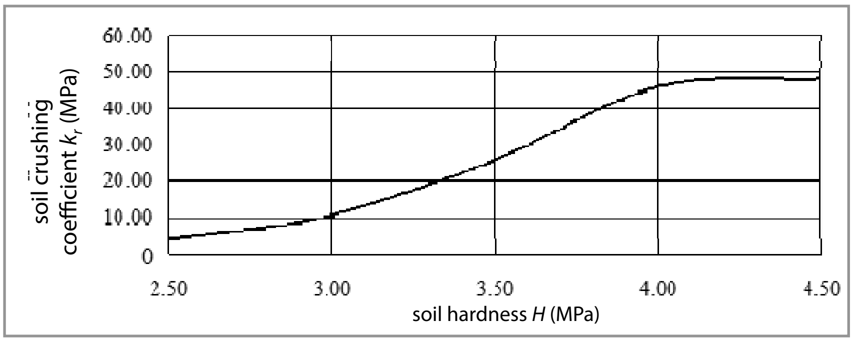

Fig. 7 Dependence of the coefficient of volumetric crushing k_r of soil tracks on soil hardness H

By substituting the 9.5R32 tire parameters D_0 and b_0 of agricultural bridge equipment (of own design), and the value of normal vertical load G_N acting upon the equipment wheels, an analytical dependence (Eq. 12) was obtained, which establishes a relationship between the coefficient of volumetric crushing k_r of soil in tracks of permanent traffic lanes and soil hardness H (Fig. 7).

Analysing the dependence presented in Fig. 7, with an increase of 2.5–4.0 MPa in hardness of soil tracks of permanent traffic lanes, the coefficient of volumetric crushing of soil also increases from 4 MPa to 45 MPa. Further increasing of soil hardness did not result in any significant increase in the coefficient of volumetric crushing of soil. The experimentally obtained graphical dependence (Fig. 7) is suitable for indirect estimation of the k_r value by the soil hardness indicator H, since the very methodology of determining the coefficient of volumetric crushing of soil is somewhat more complicated than determining its hardness.

The results indicate that indirect estimation of the rolling resistance coefficients of agricultural bridge equipment wheels moving along the tracks of permanent traffic lanes, and the coefficient of volumetric crushing of soil in terms of its hardness is sufficiently exact. This allows, if necessary, to determine the indicated parameters analytically from the experimentally measured values of hardness of soil tracks of permanent traffic lanes according to Eqs 9 and 12.

Conclusions

1. When the moisture content of soil tracks of permanent traffic lanes increases from 10% to 45%, the rolling resistance coefficient of agricultural bridge equipment wheels (of own design) increases from 0.06 to 0.1, which is 66%.
2. When the hardness of soil tracks of permanent traffic lanes increases from 2.8 MPa to 4.5 MPa and its density from 1.3 g·cm^{-3} to 1.6 g·cm^{-3}, the rolling resistance coefficient of agricultural bridge equipment wheels moving along the lanes decreases from 0.1 to 0.06, and it is of a quadratic nature.
3. Increasing the hardness of the soil tracks from 2.5 MPa to 4.0 MPa results

in intense increasing of the coefficient of volumetric crushing of soil from 4 MPa to 45 MPa. However, further increasing of hardness of soil tracks did not lead to any practical development of the coefficient of volumetric crushing of soil.

4. To reduce the rolling resistance coefficient of agricultural bridge equipment wheels moving along the soil tracks of permanent traffic lanes, the contact surface needs to be undeformable.

References

ANTILLE, D. L. – CHAMEN, W. C. T. – TULLBERG, J. N. – LAL, R. 2015. The potential of controlled traffic farming to mitigate greenhouse gas emissions and enhance carbon sequestration in arable land: a critical review. In Transactions of the ASABE, vol. 58, no. 3, pp. 707–731.

BARWICKI, J. – GACH, S. – IVANOVS, S. 2012. Proper utilization of the soil structure for the crops today and conservation for future generations. In Engineering for Rural Development, vol. 11, pp. 10–15.

BULGAKOV, V. – ADAMCHUK, V. – KUVACHOV, V. – IVANOVS, S. 2017. Research of possibilities for efficient use of wide span tractor (vehicle) for controlled traffic farming. In Engineering for Rural Development: 16 International Scientific Conference, Proceedings, vol.16, Jelgava, Latvia, pp. 281–287.

BULGAKOV, V. – ADAMČUK, V. – NOZDROVICKÝ, L. – KUVAČOV V. 2018. Study of effectiveness of controlled traffic farming system and wide span self-propelled gantry-type machine. In Research in Agricultural Engineering, vol. 64, no. 1, pp. 1–7.

BULGAKOV, V. – KUVACHOV, V. – OLT, J. 2019. Theoretical study on power performance of agricultural gantry systems. In Proceedings of the 30th International DAAAM Symposium "Intelligent Manufacturing and Automation", 23–26th October 2019, vol. 30, no.1, pp. 0167–0175.

CHAMEN, W.C.T. 2015. Controlled traffic farming – from worldwide research to adoption in Europe and its future prospects. In Acta Technologica Agriculturae, vol. 18, no. 3, pp. 64–73.

CHEN, H. – WU, W. – LIU, X. – LI, H. 2010. Effect of wheel traffic on working resistance of agricultural machinery in field operation. In Transactions of the Chinese Society of Agricultural Machinery, vol. 41, no. 2, pp. 52–57.

GALAMBOŠOVÁ, J. – MACÁK, M. – RATAJ, V. – ANTILLE, D. L. – GODWIN, R. J. – CHAMEN, W. C. T. – ŽITŇÁK, M. – VITÁZKOVÁ, B. – ĎUĎÁK, J. – CHLPÍK, J. 2017. Field evaluation of controlled traffic farming in Central Europe using commercially available machinery. In Transactions of the ASABE, vol. 60, no. 3, pp. 657–669.

GALAMBOŠOVÁ, J. – MACÁK, M. – RATAJ, V. – BARÁT, M. – MISIEWICZ, P. 2020. Determining trafficked areas using soil electrical conductivity – a pilot study. In Acta Technologica Agriculturae, vol. 23, no. 1, pp. 1–6.

GASSO, V. – SØRENSEN, C.A.G. – OUDSHOORN, F.W. 2013. Controlled traffic farming: A review of the environmental impacts. In European Journal of Agronomy, vol. 48. pp. 66–73.

ISBISTER, B. – BLACKWELL, P. – RIETHMULLER, G. – DAVIES, S. – WHITLOCK, A. – NEALE, T. 2013. Controlled Traffic Farming Technical Manual. Department of Agriculture and Food, Western Australia. 78 pp.

KUTKOV, G. 2014. Tractors and Automobiles: the Theory and the Technological Properties, Moscow, 506 pp. (In Russian: Tractory i avtomobili: teorija i tehnologicheskie svoistva).

KINGWELL, R. – FUCHSBICHLER, A. 2011. The whole-farm benefits of controlled traffic farming: An Australian appraisal. In Agricultural Systems, vol. 104, no. 7, pp. 513–521.

NADYKTO, V. – ARAK, M. – OLT, J. 2015. Theoretical research into the frictional slipping of wheel type undercarriage taking into account the limitation of their impact on the soil. In Agronomy Research, vol. 13, no. 1, pp. 148–157.

NADYKTO, V. T. – VELYCHKO, O. V. 2015. Forecasting the development of energy ratio of agricultural tractors. In Mechanization and Electrification of Agriculture, vol. 1 (100), pp. 147–151.

NADYKTO, V. – BULGAKOV, V. – KYURCHEV, S. – NESVIDOMIN, V. – IVANOVS, S. – OLT, J. 2019. Theoretical background for increasing grip properties of wheeled tractors based on their rational ballasting. In Agraarteadus, vol. 30, no. 2, pp. 78–84.

ONAL, I. 2012. Controlled traffic farming and wide span tractors. In Agricultural Machinery Science, vol. 8, no. 4, pp. 353–364.

PANCHENKO, A. –KYURCHEV, V. 2008. A study of the draft and coupling qualities of wheeled tractors. In Proceedings of the Tavria State Agrotechnological University, vol. 8, no. 9, Melitopol. pp. 31–36. (In Ukrainian: Doslidzhennya tyahlovykh ta zchipnykh yakostey kolisnykh traktoriv).

SIMIKIČ, M. – DEDOVIČ, N. – SAVIN, L. 2014. Power delivery efficiency of a wheeled tractor at oblique drawbar force. In Soil and Tillage Research, vol. 141, pp. 32–43.

TULLBERG, J. – DIOGENES, L. A. – BLUETT, C. – EBERHARD, J. – SCHEER, C. 2018. Controlled traffic farming effects on soil emissions of nitrous oxide and methane. In Soil and Tillage Research, vol. 176, pp. 18–25.