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RESEARCH OF PROPERTIES OF CONSTANT TECHNOLOGICAL TRACK OF A BRIDGE-TYPE FIELD MACHINE

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Abstract: One of the most important conditions for the sufficient adhesion of the wheels of the bridge-type agricultural machine to the supporting surface and the minimum resistance to their rolling are the physical and mechanical properties of traces of a constant tramline. The study of these properties is the real basis for ensuring a high efficiency of the operation of bridge-type agricultural equipment. However, the physico-mechanical properties of soil traces of a constant tramline are practically not studied. The aim of the research is to study the correlation between the indicators of the physicomechanical properties of the soil footprint of the constant tramline and their influence on the adhesion and traction of bridge agricultural equipment. Experimental studies were carried out both according to generally accepted and developed methods, and provided for the use of modern control and measuring equipment.
Processing of experimental data was carried out on a PC using regression analysis. The object of experimental research was a bridge-type agricultural machine having a design we have developed. As a result of the study, it was found that the density and hardness of the soil in the 0…5 cm layer of traces of a constant tramline substantially depend on soil moisture content.
A high nonlinear correlation was established between the hardness and density of the soil track of the track, which is approximated by a quadratic equation. Its practical use allows us to predict the density of traces of the constant tramline and vice versa from the results of hardness measurements. From the position of ensuring maximum coupling properties and traction of the bridge-type agricultural machine when it moves along the soil track of a constant tramline, it has been established that an increase in the hardness of the latter requires an increase in air pressure in the tire of its wheels and vice versa.
The studies confirm the fact that the maximum efficiency of the movement of the bridge-type agricultural equipment along the soil traces of a constant tramline can be achieved only if the air pressure in the tires of its wheels is correctly set. The magnitude of the latter, in turn, depends on the physico-mechanical properties of the soil trace of a constant tramline.

Keywords: constant tramline, bridge-type agricultural machine, monitoring of the properties, physical and mechanical properties of the soil, experimental studies.

INTRODUCTION

The main problem to be solved in the theory of rolling the drive wheel of a mobile power-unit is to improve the quality of its adhesion to the supporting surface to ensure high traction (Kutkov, 2014, Bulgakov et al., 2016).

The coupling of the drive wheel of the bridge-type agricultural machines with the supporting surface of the traces of a constant tramline is due to the action of the following forces: friction between the soil and the supporting surfaces of the tire; gears arising from the emphasis of the tires on the soil; force acting in the plane of cut of a bar of soil located between the soil couplings.

Each of these forces is a component of the active tangential force, numerically equal to the soil reaction to the listed components. It is also known that the greater the mechanical strength of the soil and the adhesion force of the wheel to the supporting surface of its rolling, the greater the leading moment and the greater traction force can be realized by the wheel (Panchenko, Kyurchev, 2008., Nadykto et al. 2015, Nadykto, Velychko, 2015, Nadykto et al., 2015). With a significant density of the soil supporting surface on the formation of adhesion, and, consequently, on traction, the friction force between the soil and the supporting surfaces of the tire significantly affects. As the density of the soil decreases, the depth of penetration of the couplings into it increases, as a result of this, traction forces are more affected by the engagement forces of the couplings of the tire on the soil and friction in the plane of the cut of the bar of soil located between the couplings. It is also known (Kutkov, 2014) that the rolling resistance of the wheels of a mobile power tool depends on the properties of the soil, characterized by a volume compression coefficient. This indicator is closely correlated with soil hardness.

Based on the foregoing, it follows that one of the most important conditions for the sufficient adhesion of the wheels of the bridge-type agricultural machines to the supporting surface and the minimum resistance to their rolling are the physico-mechanical properties of traces of a constant tramline. The study of its properties is the real basis for ensuring a high efficiency of the operation of bridge-type agricultural equipment. However, the physico-mechanical properties of soil traces of a constant tramline are practically not studied.

Analysis of latest researches and publications. There is a lot of experience in prospecting research works aimed at establishing a correlation between the density and hardness of the soil (Vasiliev, 2007, Kushnarev et al., 2010, Nadykto, Uleksin, 2008). It should be noted that the hardness of the soil is affected not only by its density, but also by moisture, which is unevenly distributed both over the surface of the field and in the depth of the soil (Kushnarev et al., 2010).

There are two known methods for measuring soil hardness – positional and continuous (dynamic) (Vasiliev, 2007, Kushnarev et al., 2010). The positional method for measuring soil hardness involves the use of instruments such as a hardness tester (density meter) of the Revyakin system. In a positional diagram, the tip of the penerometer moves perpendicularly to the surface of the soil. Continuous (dynamic) measurement of soil hardness is a tool to intensify the process of taking information about soil state by hardness.

Using positional measurements of soil density and hardness, the researchers established correlation relationships between these indicators under field conditions (Vasiliev, 2007, Kushnarev et al., 2010, Nadykto, Uleksin, 2008). An analysis of scientific publications found that there is a fairly strong correlation between the density and hardness of the soil. From which it follows that the results of hardness measurements can predict the value of soil density. But for this, each time before and after measurements of the hardness and density of the soil in the field, it is necessary to calibrate or compare the hardness and its density. In case of precipitation during the collection of information, it is necessary to repeat the operations of comparing the hardness and density of the soil.

However, the physical and mechanical properties of the soil under the conditions of an agricultural agricultural background differ significantly from the properties of a compacted, leveled track of a permanent tramline.

The latter does not allow the use of analytical dependencies linking these indicators among themselves. There is practically no information on assessing the properties of a constant tramline. Studies in the direction of monitoring the properties of a constant tramline and their influence on the adhesion and traction of bridge agricultural equipment have not been carried out sufficiently.

Purpose of the research. The aim of this study is to study the correlation between the indicators of the physico-mechanical properties of the soil footprint of a constant tramline and their influence on the adhesion and traction of bridge agricultural machines.

MATERIAL and METHODOLOGY

The physical object of experimental studies was a bridge-type agricultural equipment of the design we developed (Bulgakov et al., 2019) (Fig. 1). This agricultural equipment l has a wheel chassis with pneumatic tires of a standard size 9.5R32.

Physico-mechanical properties of the soil in traces of a constant tramline were measured in a layer thickness of 0…5 cm. The hardness tester of the Revyakin system was used to determine soil hardness (Fig. 2). The soil density in the tramlines was measured with a densitometer of our design, and soil moisture content with a MG-44 moisture meter (Fig. 2).

To exclude the random component of the error in determining the physical and mechanical parameters of the soil in the traces of a constant tramline, the experiments were carried out in multiple repetitions. The obtained values of the indicators were averaged. The error of direct experimental measurement of the parameters by the devices shown in Fig. 2, did not exceed 2%.

Figure 1 Bridge-type agricultural equipment with pneumatic wheels moving along the soil tracks of a permanent tramline

Figure 2 Measuring instruments for determining the physical and mechanical properties of the soil in traces of a permanent tramline: 1 – hardness tester of the Revyakin system; 2 – hygrometer MG-44; 3 – densitometer

RESULTS and DISCUSSION

The study of the properties of soil traces of a constant tramline showed that the values of such indicators as soil density and hardness in a layer of 0…5 cm depend significantly on soil moisture content. With increasing humidity of the soil track of the rut from 10 to 45%, the soil density in it decreases from 1.60 to 1.30 g·cm^{-3} (Fig. 3).

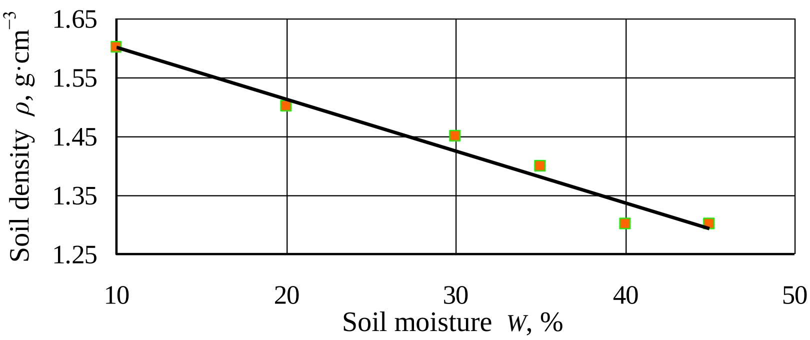

Figure 3 Effect of the soil moisture content *W* on a soil density *ρ* of the soil footprint permanent tramline

A similar picture can be observed when changing the hardness of the soil traces of the permanent tramline from its moisture (Fig. 4).

From the analysis of the graph presented in Fig. 4, it follows that with an increase in the soil moisture content of the track marks from 10 to 45%, the soil hardness in the track decreases from 4.5 to 2.8 MPa.

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The nature of the dependences of the indicators on a Fig. 3 and Fig. 4 has a linear character. The square of the correlation coefficients of their bonds is quite high and amounts to $R^2 = 0.96$.

The relationship between the density of soil traces of a constant tramline and its hardness is shown on Fig. 5.

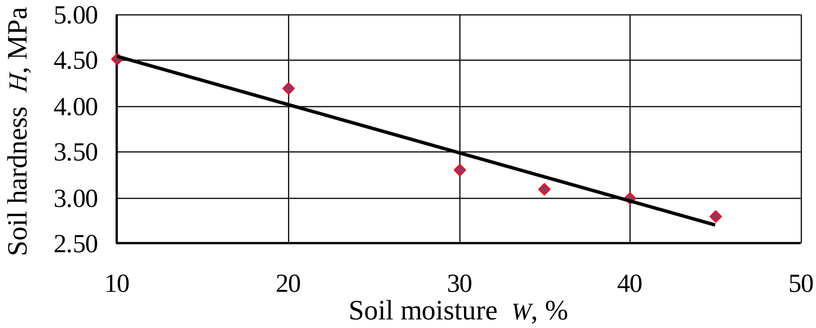

Figure 4 Effect of the soil moisture content *W* on a hardness *H* of the soil traces of the permanent tramline

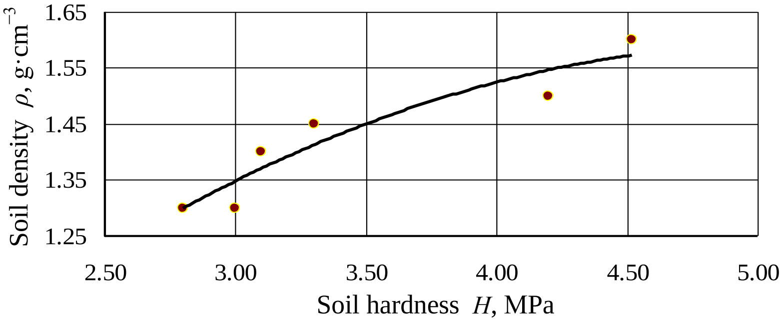

Figure 5 Effect of the soil hardness *H* on soil density *ρ* of the soil footprint of a permanent tramline

Analysis of the graph presented on Fig. 5 shows that there is a high nonlinear correlation between the density and hardness of the soil footprint of a constant tramline. The square of the correlation coefficient of the relationship between these indicators is $R^2 = 0.89$, which is significantly lower than the values of the coefficients of correlation relations. This proves that according to the results of soil hardness measurements, it is possible to predict the density of traces of a permanent tramline and vice versa.

The relationship between the indicators in Fig. 5 is fairly accurately approximated by an equation of the form:

$$\rho = -0.0547 \cdot H^2 + 0.5592 \cdot H + 0.1629 , \qquad (1)$$

where:

ρ – soil density of the soil footprint of a permanent tramline, $g \cdot cm^{-3}$;

H – soil hardness in a permanent tramlines determined by the Revyakin system, MPa.

Next, we evaluate the effect of the physico-mechanical properties of the soil footprint of the permanent tramline on the quality of adhesion and traction of the bridge-type agricultural equipment. For this, the maximum tangential traction force that the wheel of the bridge-type agricultural vehicle develops, is represented by this dependence (Guskov, 1996):

$$P_{k\max} = \delta_{\max} \cdot S_k \cdot k_0 \cdot L , \qquad (2)$$

where δ_{max} – slip coefficient (maximum) of the propulsion of the bridge agricultural machine; S_k – the sum of the vertical projections of the thrust surfaces of the wheels of the bridge-type agricultural machine immersed in soil, m^2; k_0 – volume crushing coefficient of the wheel bearing surface

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(permanent tramline track), N·m^{-3}; L – the length of the arc of the coupling of the couplings of the wheel of the bridge-type agricultural machine with the supporting surface (following a permanent tramline), m.

Also, the traction of the wheel of the bridge-type agricultural machines with a constant tramline track should be sufficient so that it can develop maximum tangential traction (Kutkov, 2014):

$$P_{k\max} = \varphi \cdot N_{ek} \,, \tag{3}$$

where φ – coefficient of adhesion, implemented by the propulsion of the bridge-type agricultural machines according to the conditions of its interaction with the supporting surface; N_{ek} – vertical operational load acting on the bridge wheel, N.

Equating equations (5) and (11) we obtain:

$$\delta_{\max} \cdot S_k \cdot k_0 \cdot L = \varphi \cdot N_{ek} \ . \tag{4}$$

Expressions for determining the value L and S_k are as follows (Guskov, 1996):

$$L = \left(r_0 + h_z\right)\left(\operatorname{arctag}\frac{f_k\left(1-f_k^2\right)^{\frac{1}{2}}}{0.5-f_k^2} + 2 f_k^2\right), \tag{5}$$

$$S_k = \pi \cdot h_z \left[\left(2r_0 - h_z\right)\cdot\left(b_0 - h_z\right)\right]^{\frac{1}{2}}, \tag{6}$$

where r_0, b_0 – static radius and width of the wheel of the bridge-type agricultural machine, m; f_k – coefficient of rolling resistance of the wheel of the bridge-type agricultural machine; h_z – normal tire deflection (Guskov, 1996), m:

$$h_z = \frac{N_{ek}}{\pi \cdot \rho_w \cdot \sqrt{2r_0 \cdot b_0}} \,, \tag{7}$$

where: ρ_w – pressure of the air in the tire, Pa.

Earlier studies of the work of the wheel of a bridge-type agricultural machine along the soil track of a permanent tramline made it possible to analytically establish a sufficiently accurate dependence of the coefficient of its volumetric crushing on the value of hardness, *H*:

$$k_0 = \frac{0.636 \cdot N_{ek}}{b_0 \cdot 4r_0^2 \cdot \left(0.0247\cdot H^2 - 0.2093\cdot H + 0.499\right)^3} \ . \tag{8}$$

We have also found that the coefficient of rolling resistance f_k of a wheel of a bridge-type agricultural tool depends on the physicomechanical properties of the soil track of a constant tramline. In particular, depending on its hardness *H*, the coefficient of rolling resistance f_k is rather accurately described by a quadratic equation of the form:

$$f_k = 0.0247\cdot H^2 - 0.2093\cdot H + 0.499 \ . \tag{9}$$

After substituting expressions (5) – (9) in (4), we have obtained a computational model that allows us to study the processes of traction of the wheel of the bridge agricultural tool depending on its design parameters on the one hand, and the physico-mechanical properties of traces of a permanent tramline on the other.

The result of the analysis of the study of dependence (4), taking into account (5) – (9), it follows that the higher the hardness of the traces of a permanent tramline, the higher the air pressure is advisable in the tire. The nature of this dependence is shown in Fig. 6.

The analysis of the obtained dependence in Figure 6 shows that with an increase in the hardness of the tracks of the permanent tramline from 1.0 to 3.5 MPa, the air pressure in the tire of the wheels of the bridge-type agricultural machine must be increased from 60 to 650 kPa, i.e. 10 times. Naturally, the value of the maximum possible air pressure in the tire is determined by its technical characteristic. For the indicated tire brand used in this bridge-type agricultural vehicle, this value is 160 kPa. Therefore, the operation of the bridge-type agricultural machine with maximum tire pressure is possible only with a hardness of the traces of a permanent tramline of 2.25 MPa and higher. However, with less hardness of the soil footprint, the air pressure in the tire of its wheels must be reduced. This allows you to provide high traction and coupling properties of the bridge agricultural tool when it moves along the soil track of a constant tramline. For example, with a hardness value H = 1 MPa, the pressure ρ_w in the tire of the wheel should be 80 kPa.

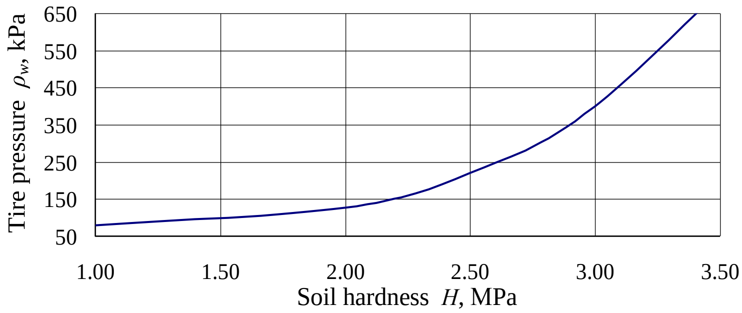

Figure 6 The effect of the hardness H of the soil trace of a permanent tramline on the required air pressure ρ_w in the tires of the wheels of the bridge-type agricultural machine

The obtained dependence of the required pressure in the tire of the wheels of the bridge-type agricultural machine on the hardness of the soil track of the constant tramline (Fig. 6) generalizes the condition under which its maximum coupling properties are achieved.

The studies we have provided confirm the fact that the maximum efficiency of the movement of the bridge-type agricultural machine along the soil traces of a permanent tramline can be achieved only if the air pressure in the tires of its wheels is correctly set. The magnitude of the air pressure in the tires, in turn, depends on the physicomechanical properties of the soil trace of a constant tramline.

CONCLUSIONS

1. The study of the properties of soil traces of a constant tramline showed that the values of density and hardness in a layer of 0…5 cm depend significantly on humidity. With an increase in the moisture content of the soil track of the rut from 10 to 45%, the density in it decreases from 1.60 to 1.30 g.cm^{-3}, and the hardness decreases from 4.5 to 2.8 MPa.

2. A high nonlinear correlation between the hardness and density of the soil footprint of the permanent tramline, which is approximated by the quadratic equation, was experimentally established. Its practical use allows us to predict the density of traces of a permanent tramline and vice versa from the results of hardness measurements.

3. From the position of ensuring maximum coupling properties and traction of the bridge-type agricultural machine when it moves along the soil track of a permanent tramline, it has been established that an increase in the hardness of the tramline surface requires an increase in air pressure in the tire of its wheels and vice versa.

4. The studies confirm the fact that the maximum efficiency of the movement of bridge-type agricultural equipment on the soil traces of a permanent tramline can be achieved only if the air pressure in the tires of its wheels is correctly set. The magnitude of the air pressure, in turn, depends on the physico-mechanical properties of the soil trace of a permanent tramline.

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