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Research Paper

Practical applications analysis and economic efficiency of the method on assessment of the sealing action from the tracked mover on the soil layer

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Abstract

The article describes and evaluates the economic efficiency of applying a modern approach to solving the problem of soil compaction by tracked movers using a new method based on the theory of hereditary creep of elastoviscoplastic materials, taking into account new factors (the time of the impact of movers on the base, rheological properties of the soil, etc.), as well as using a new devices and techniques for determining the physico–mechanical characteristics of the soil layer and modern specialized software products.

Keywords: *Sealing Action; Economic; Soil Compaction.*

1. Introduction

Repeated impact of running systems of agricultural machines on the soil negatively affects the yield of cultivated crops due to excessive compaction of the fertile layer. The reduction of this negative influence can be achieved through the use of innovative approaches [1] to improve operational proper-ties of existing machines involved in tillage and cultivation of crops, as well as to the creation of new units of equipment.

The analysis of scientific works shows that the existing theoretical dependences do not fully reflect the influence of design parameters and perfor-mance characteristics of the tracked mover on the traction properties of the ma-chine and its sealing action on the soil layer. The coefficients applied in mathematical models of interaction between the mover and the ground in many cases are noninvasive parameters of the "mover – support base" system, the presence of rheological properties of the deformable soil layer is also not taken into account.

Developed with the use of the theory of hereditary creep of elastic-viscoplastic materials the method for assessing the sealing action of the tracked mover on the soil layer [2] takes into account the change in time of its physical and mechanical characteristics and allows to determine the optimal from the point of view of the seal indicators of the external force action on the part of the running system of the machine in the given conditions of motion [3], [4].

Recommendations on the use of the developed method, a detailed analy-sis of the modes of operation of the machine and the parameters of the state of the soil layer (density, humidity, thickness, etc.) on the treated area can reduce the compacting harmful effects on the part of the movers and thus increase the yield of cultivated crops.

2. Research method

The theory of hereditary creep of elastoviscoplastic materials allows to the most complete describe processes of deformation of the soil layer, flowing in time. The peculiarity of the mathematical model, based on this theory and reflecting the dependence of the deformation in the soil layer from the stresses under the tracks of the caterpillar, is the variable τ, which allows you to "re-member" the history of loading:

$$\varepsilon(t)=\frac{1}{E_{poch}}\left[\sigma_n(t)+\int_0^t K(t-\tau)\sigma_n(\tau)d\tau\right] \quad (1)$$

Where ε(t) – deformation; σn(t), σn(τ) – pressure; Epoch – the instantaneous modulus of deformation of soil; K(t-τ) – function of speed creep; t – time of observation; τ – is the time preceding the moment of observation t.

When deforming the soil "brick" is in a difficult state of stress. In this case, the components of the deformation tensor deviator are determined individually, in accordance with the peculiarities of the deformation development in each direction:

$$J_1=\varepsilon_x+\varepsilon_y+\varepsilon_z,$$

$$J_2=\varepsilon_x\varepsilon_y+\varepsilon_x\varepsilon_z+\varepsilon_y\varepsilon_z-\frac{1}{4}\gamma_{xy}^2-\frac{1}{4}\gamma_{zx}^2-\frac{1}{4}\gamma_{yz}^2,$$

$$J_3=\begin{vmatrix}\varepsilon_x & \frac{1}{2}\gamma_{yx} & \frac{1}{2}\gamma_{zx}\\ \frac{1}{2}\gamma_{xy} & \varepsilon_y & \frac{1}{2}\gamma_{zy}\\ \frac{1}{2}\gamma_{xz} & \frac{1}{2}\gamma_{yz} & \varepsilon_z\end{vmatrix}, \quad (2)$$

Where the coefficients J1, J2, J3 are the invariants of the deformed state; εx, εy, εz and γ2yz, γ2zx, γ2xy are respectively linear and angular deformations of the given soil volume.

The principal deformations ε1, ε2, ε3 are defined as the roots of the equation:

$$\varepsilon^3 - J_1 \cdot \varepsilon^2 + J_2 \cdot \varepsilon - J_3 = 0 \tag{3}$$

The sum of the principal deformations along three mutually perpendicular axes is a relative change in volume:

$$e = \varepsilon_1 + \varepsilon_2 + \varepsilon_3 \tag{4}$$

Through the relative change in volume, it is possible to reach the most important estimate indicator of the interaction of the tracked mover with the soil layer, which affects the yield of crops – the final density of the soil after the passage of the tractor:

$$\rho_{kon} = \frac{\rho_{nach}}{1-e} \tag{5}$$

where ρnach – the initial density of the soil; ρkon – the final density of the soil (after the passage of the tractor).
The variable K(t-τ) in expression (1) is a creep rate function:

$$K(t-\tau) = \frac{e^{-\beta \cdot t}}{t} \sum_{n=1}^{\infty} \frac{[A \cdot G(\alpha)]^n \cdot t^{\alpha \cdot n}}{G(\alpha \cdot n)} \tag{6}$$

Where α, β, A – creep speed function parameters, varying depending on the nature of the load and the parameters of the soil layer; G (α) – Eulerian gamma function.
Instantaneous soil deformation modulus Epoch is determinate in experi-ments with stamp [6-8].
Stress σn(t) are determined by the equations of curves of relaxation:

$$\sigma_n(t) = E_{poch} \cdot \dot{\varepsilon}_n \cdot t - E_{poch} \cdot \dot{\varepsilon}_n \int_0^t T(t-\tau)\tau d\tau \tag{7}$$

$$\sigma_n(t) = E_{poch} \cdot \dot{\varepsilon}_n \cdot (t_2 - t) - E_{poch} \cdot \dot{\varepsilon}_n \int_0^{t_1} T(t-\tau)\tau d\tau - E_{poch} \cdot \dot{\varepsilon}_n \int_{t_1}^{t} T(t-\tau)(t_2-\tau) d\tau$$

Where $\dot{\varepsilon}_n$ is the speed of deformation on the section; t, t1, t2 – time of de-formation; T (t-τ) – function of the speed of stress relaxation.
Expressions (9) and (10) are given for the triangular law of development of deformations with equal linear speed of change of a function ε (t) at both sites. Similarly, with the application of the theory of hereditary creep of the elastic–viscous–plastic materials hatch equations to determine the stresses un-der the caterpillar for unequal linear of change of a function ε(t) and for the trapezoidal law of development of deformations in the soil layer. The mathematical model is described in more detail in works [2], [9].

3. Results and analysis

With the help of the specialized program [5] developed on the basis of mathematical model, the simulation of the process of interaction of the tracked mover with the soil layer was carried out. It is revealed that to a large extent the compaction of the soil ρn after the tractor passage is influenced by the dis-placement of the pressure center ν and the speed of the machine Vtr. The calcu-lated data are given in tables 1, 2. Increasing the travel speed reduces the contact time of running system with the support surface. The soil does not have time to settle, so that its verti-cal deformation λv and the density after passage of the tractor ρn decrease, as can be seen from the curves of the graph (figure 1).

Table 1: Results of Calculation of Indicators of Soil Layer Deformation Process By

Indicator	V_{tr}, m/s			
	0,89	1,1	1,25	1,7
ρ_{n1}, g/cm^3	0,983	0,96	0,952	0,931
ρ_{n2}, g/cm^3	1,031	0,995	0,987	0,955
ρ_{n3}, g/cm^3	1,036	0,998	0,99	0,958
ρ_{n4}, g/cm^3	1,04	1,001	0,992	0,96
λ_v, cm	4,07	3,05	2,8	1,87
δ,%	0,0857	0,097	0,0982	0,1394

Table 2: Results of the Calculation of the Output Parameters of the Interaction of the Tracked Movers with the Soil Layer At Different Coefficients N.

Indicator	ν						
	0,08	0,024	0,031	0,084	0,136	0,185	0,235
ρ_{n1}, g/cm^3	0,98	0,93	0,93	0,92	0,91	0,90	0,90
ρ_{n2}, g/cm^3	1,03	0,96	0,95	0,94	0,91	0,91	0,90
ρ_{n3}, g/cm^3	1,03	0,97	0,97	0,97	0,98	1,02	1,08
ρ_{n4}, g/cm^3	1,04	0,98	0,98	0,99	1,02	1,06	1,10
λ_v, cm	4,07	2,54	2,57	3	3,69	4,64	5,68
δ,%	0,08	0,73	1,51	2,23	3,31	4,74	6,8

The displacement of the center of pressure under operating conditions is influenced by the traction resistance formed during the performance of a given agricultural operation. The smaller the displacement of the center of pressure, the more evenly distributed the load on the supporting branch of the caterpillar and the less seal soil the passage of the tractor (figure 2).
The obtained results were tested in practice in the cultivation of barley varieties "pioneer". By preliminary assessment of the conditions of movement of the machine in the performance of basic agricultural operations was developed a list of measures to reduce the harmful sealing effect of the tracked movers on the soil: 1) during continuous cultivation, it was recommended to place an additional load of 150 kg on the front of the frame to equalize the stress plot under the caterpillar; 2) the speed of the machine when sowing barley and rolling crops was increased from 8 km/h to 11 km/h.

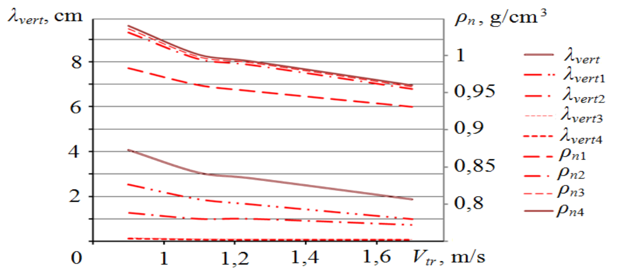

Fig. 1: Dependencies of the Vertical Deformation of the Layer (Λverti) and Density of the Soil (Pni) Under the Supporting Rollers of the Tractor Speed

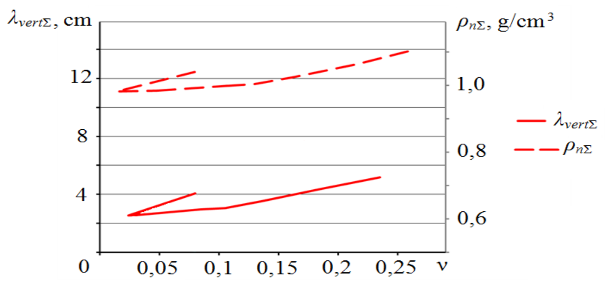

Fig. 2: Dependence of the Total Vertical (Λvertσ) Deformation and Density of the Soil (Pnσ) after Passage of the Tractor from the Ratio of the Displacement of the Center of Pressure N.

Due to the proposed measures were able to reduce the density of the soil under the "traces" of the tracks of the tractor, on average 9–11%. The yearly increase in barley yield due to the application of these measures to reduce the compaction was three, 5 center/ha.

4. Conclusion

The practical application of the developed method allowed reducing the density of the soil after the passage of the tracked tractor, which had a positive impact on crop productivity. The development and improvement of such methods, systematization and analysis of the calculation data will make it pos-sible to assess the impact of movers of any agricultural machines on the soil layer and develop specialized recommendations for choosing the optimal pa-rameters and modes of their operation, ensuring the lowest soil compaction.

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