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EVALUATION OF COMPACTIONING IMPACT OF TRACTOR TRAIN RUNNING SYSTEMS ON SOIL ON THE BASIS OF WHEELED TRACTOR OF 14 KN TRACTION CLASS

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ABSTRACT

A comparative assessment of the compliance of the compacting effect of the MTZ-80-2PTS-4M (tractor transport aggregate) movers with the established standards on the soil under operating conditions was made. The average density of soil composition on the stubble and the field for sowing in the horizon of 0-50 cm along the track of the trailer with a minimum and maximum load on the mover exceeded the control data by 28.9-31.2% and 38.2-42.3, respectively. The increase in bulk density and hardness of the treated soil was higher on average by 9.5-11% and 5.5-9.5%, respectively in comparison with the stubble background. The excess of the established norms for the mechanical impact of movers on the soil for the maximum specific pressure was 35.3-45.9% over the entire range of loads on the mover and for the maximum normal stress in the soil was 21.9% at maximum load. Under test conditions, the running system of the 2PTS-4M trailer did not ensure compliance with the established standards for the impact on the soil within the entire range of changes in operational loads on the movers.

Keywords: tractor, trailer, compaction, wheel, deformation

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INTRODUCTION

A significant volume of technological transportation (up to 40%) in agriculture is carried out by tractor transport units, as well as transport and technological means that combine the functions of transport and technological machines (tractor trailed fertilizer spreaders, feeders, etc.) [1-4]. As a rule, wheeled tractors are used in transportation since they are more versatile than tracked ones, have lower cost and operating costs, and have higher transport speeds.

The movement of transport aggregates, especially based on energy-saturated wheeled tractors, along agricultural agro-backgrounds during technological transportation leads to intensive rutting, slipping and soil compaction by tractor and trailer movers [5-9]. At the recommended levels of permissible pressure on the soil, during field work, within 0.04-0.15 MPa, the pressure of wheeled tractors is 0.09-0.17 MPa, and trailers - up to 0.3-0.4 MPa [10, 11].

Increasing the degree of mechanical impact of the running systems of tractors, agricultural machinery and transport and technological means on the soil is the reason for the deterioration of its physical properties, over-compaction, including the subsurface layer, and the development of erosion processes [12-16]. This process is one of the main factors in the deterioration of the agrophysical state of the soil and the decrease in its effective fertility, which determines the relevance of bringing the level of technogenic impact of agricultural machinery movers to the indicators recommended by agricultural technology [17-20].

The purpose of the scientific work is to compare the compliance of the soil compaction value with the running systems of a wheeled tractor train with the established standards, under various driving conditions.

The goal was achieved by solving the following tasks:

a) Determine the indicators of the physical and mechanical properties of the base along the track of the running systems of the tractor and trailer and on an undeformed background (control).

b) Adjust the normative values of the tractor and trailer movers' impact on the soil, taking into account the specifics of the testing of the transport aggregate.

c) Determine for the tractor and trailer movers the maximum values of the specific pressure on the soil, the normal stress in the soil, as well as the compacting effect.

d) Assess the compliance of the actual level of compaction effect of the transport aggregate movers on the soil with the standard values.

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MATERIALS AND METHODS

Field tests of the aggregate (Figure-1) were carried out in the fields of the farm “Nepochatoy N.N” located in the Mariinsk district of the Kemerovo region in 2021. The measurement technique complied with the requirements of the current regulatory documents (GOST 20915-2011, GOST 26953-86, GOST 26954-86, GOST 26955-86), as well as using private methods and recommendations [21]. The method used included the determination of the normalized indicators of the level of mechanical impact of a pneumatic tire on the soil base and the parameters of its physical and mechanical state according to the method "trace-out of the trace" method for various values of the trailer operating weight and driving conditions of the aggregate [21-24].

(a) (b) (c)

Figure-1. Tractor transport aggregate MTZ-80 + 2PTS-4M: a - general view of the aggregate; b - tractor agricultural trailer 2PTS-4M; c - trailer running gear with tires Voltyre Ya-324A (9.00-16).

During the study of the tractor transport aggregate the following values were recorded and measured:

- absolute humidity, hardness, and ground density;
- linear dimensions of the contact patch (width and length), as well as the static radius of the tractor and trailer propulsion tire, correlated with the parameters of the base;
- weight of the trailer;
- overlapping traces of tractor and trailer movers.

The test conditions for the aggregates are given in Table-1.

Table-1. Test conditions for the aggregates.

Indicator	Indicator value	
Technological operation	**cargo transportation (ground)**	
Agro background	stubble grain	field for sowing
Previous processing	Not available	cultivation (10 cm)
Soil type and mechanical composition	medium dark gray forest loam	
Absolute humidity in the layer 0-30 cm, % (HB)	34.76 (0.81HB)	32.81 (0.84HB)

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By regulatory documents (GOST 26953-86, GOST 26954-86, GOST 26955-86), the impact assessment data of the movers of the tractor transport aggregate on the soil were determined. The parameters of the pneumatic tires of the movers of the tractor transport aggregate with a change in the operating weight of the trailer and taking into account the driving conditions, obtained from the measurement results, are given in Table-2. Determination of the parameters of the tire contact patch with the soil is shown in Figure-2.

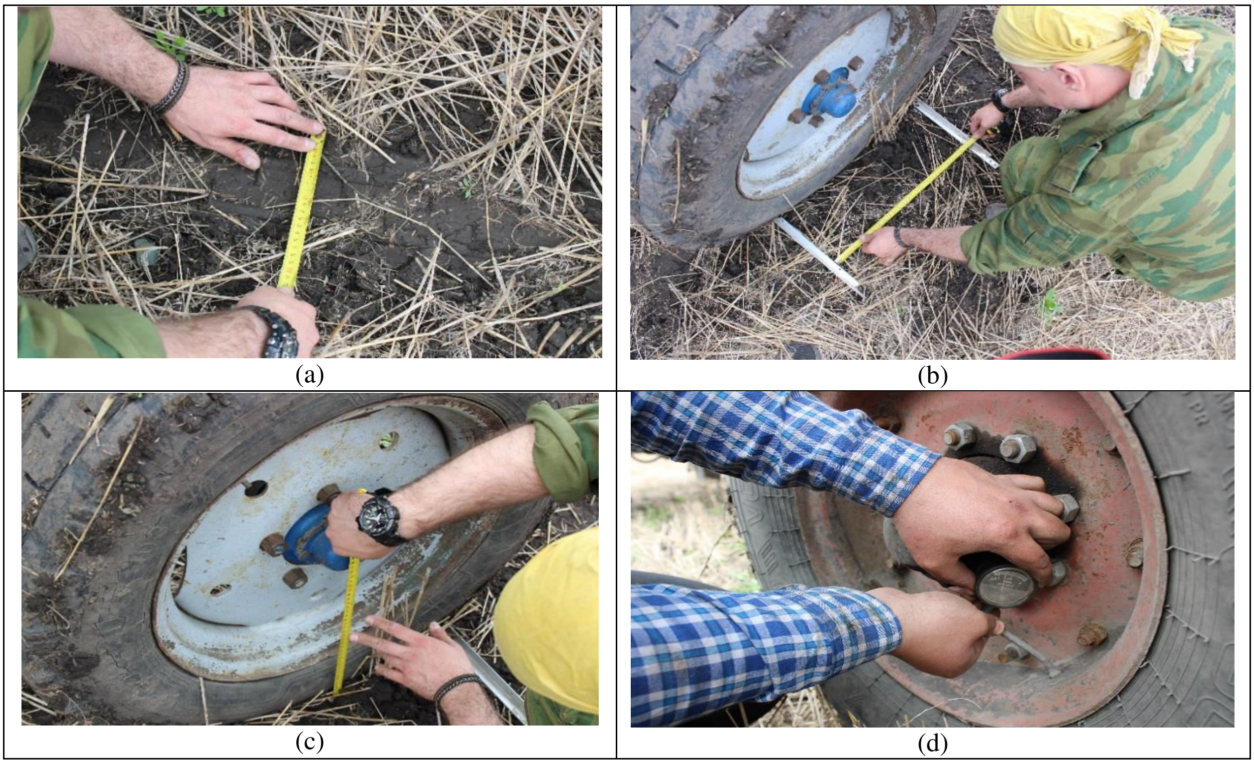

Figure-2. Determination of the parameters of the contact patch of the aggregate movers with the soil: a - the width of the contact patch of the mover with the soil (width of the mover track); b - the length of the contact patch of the mover with the soil; c - static radius of the tire; d - internal pressure in the tire.

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Table-2. Characteristics of pneumatic tires for the wheels of the MTZ-80+2PTS-4M tractor train during field tests.

Name of indicator	Tractor MTZ -80		Trailer 2PTS-4M		
	front axle	rear axle	trailer loading, %		
			0	50	100
Tire size	7.5-20	15.5R38	9.00-16		
The load on the base created by the mover (normally, statically) m_k, kN	6.35	10.5	4.30	8.73	13.18
Internal tire pressure, MPa	0.8	2.0	2.2		
Contact patch area (on a rigid base) F_k, m^2	0.0442	0.1558	0.0489	0.0754	0.0816
Agro background: unpaved road					
The size of the contact patch with the soil, m:					
- length a_k	0.470	0.775	0.410	0.500	0.520
- width b_k	0.150	0.320	0.190	0.240	0.250
Static radius r_0, m	0.420	0.710	0.440	0.410	0.370
Agro background: cereal stubble					
The size of the contact patch with the soil, m:					
- length a_k	0.490	0.790	0.410	0.500	0.510
- width b_k	0.180	0.265	0.200	0.250	0.235
Static radius r_0, m	0.360	0.695	0.430	0.400	0.360
Agro background: field for sowing					
The size of the contact patch with the soil, m:					
- length a_k	0.590	0.930	0.520	0.550	0.630
- width b_k	0.250	0.380	0.265	0.255	0.270
Static radius r_0, m	0.330	0.670	0.410	0.385	0.330

RESULTS AND DISCUSSIONS

Under the test conditions, depending on the level of loading with technological material (0-100%), the operating weight of the trailer varied from 1720 to 5270 kg. Thus, taken into account, the vertical load on a single mover varied in the range of 4.30-13.18 kN.

In the process of determining the physical and mechanical parameters of the soil, measurements were taken in the soil layer to a depth of 50 cm in increments of 10 cm. Numerous studies indicate that it is this soil horizon that is subjected to the greatest compaction from the running systems of tractors and agricultural machinery [21, 25-28].

Absolute moisture in the studied soil layers is presented in Table-3.

Table-3. Absolute moisture content (%) of the soil in the control in a layer of 0-50 cm when testing the MTZ-80 + 2PTS-4M aggregate on agricultural backgrounds.

Agro background	Soil horizon, cm					Average value for 0-30 cm
	0-10	10-20	20-30	30-40	40-50	
Cereal stubble	31.83	39.45	41.17	47.75	42.39	37.48
Field for sowing	30.18	38.81	38.6	34.64	32.88	35.86

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The density and hardness of the soil according to the traces of the MTZ-80 + 2PTS-4M aggregate movers and in the control are shown in Figures-3 and 4.

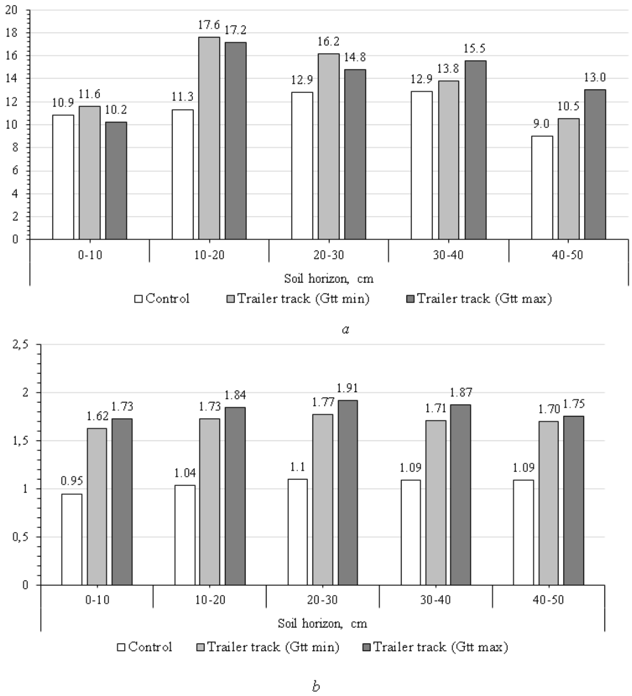

Figure-3. Density of soil composition (g/cm^3) in a layer of 0-50 cm in the footprints of the trailer 2PTS-4M and in the control: a - cereal stubble, b - field for sowing.

The average density of soil composition on the stubble and the field for sowing in a layer of 0-50 cm along the trail, with a minimum load on the trailer mover, was 1.49 and 1.70 g/cm3, respectively, which is higher than the same indicator in the control (1.06 g /cm^3) by 28.9 and 38.2%, respectively. The track density at the maximum load on the mover was 1.54 and 1.82 g/cm^3, exceeding the control value by 31.2 and 42.3%, respectively. The greatest increase in density is observed at maximum load: on the stubble - in the 10-20 cm horizon - 1.65 g / cm^3 and on the soil for sowing - in the 20-30 cm horizon - 1.91 g / cm^3, demonstrating a corresponding excess of the control indicator by 35.8 and 45%.

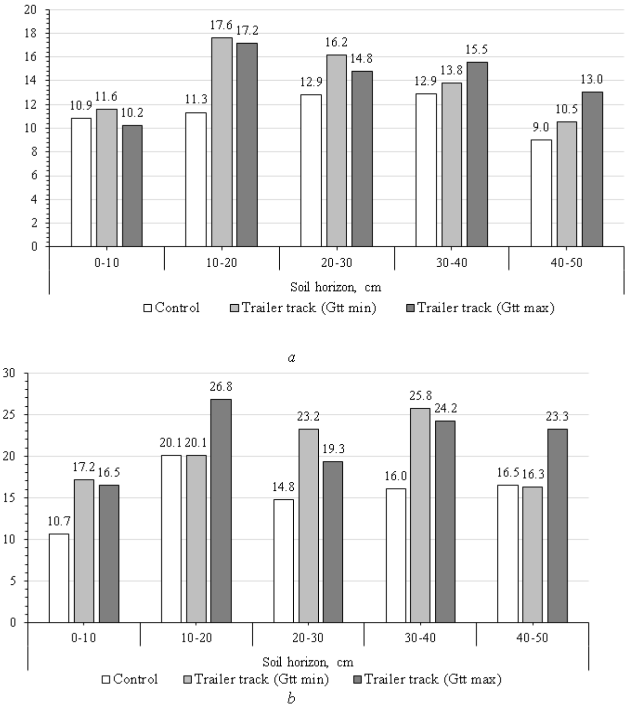

Figure-4. Soil hardness (kg/cm^2) in a layer of 0-50 cm in the footprints of the trailer 2PTS-4M and in the control: a - cereal stubble, b - field for sowing.

The average hardness of the soil on the stubble and the field for sowing along the track of the trailer at the minimum load on the mover was 13.94 and 20.52 kg/cm^2, respectively, which is higher than the same indicator in the control (11.38 kg/cm^2), respectively, by 18.4 and 23.9%. The track hardness at the maximum load on the mover was 14.14 and 22.02 kg/cm^2 and exceeded the control hardness by 19.5 and 29.1%, respectively.

When establishing the standard values for the level of mechanical impact of the aggregate movers on the soil, according to the GOST 26953-86 method, soil moisture values in the 0-30 cm layer were taken into account (see Table-3).

The adjustment of the norms was carried out using the amendments regulated by the standards (GOST 26953-86, GOST 26954-86, GOST 26955-86) for two main indicators of the compacting effect: maximum pressure on the soil - 100 kPa (q_{max}), normal stress in the soil (at a depth of 0 .5 m) - 25 kPa (σ_h). The value of the corrective modifications was determined by the parameters of the tractor and trailer and their pneumatic tires, the mode of operation of the studied movers, the scheme of mutual overlap of the tracks of the aggregate, and the conditions of its movement (Figure-5 and Table-4).

VOL. 18, NO. 15, AUGUST 2023 ISSN 1819-6608
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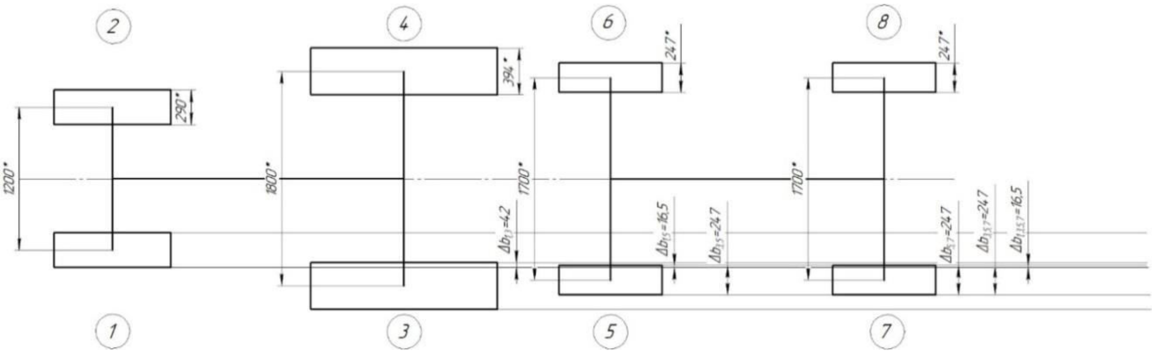

Figure-5. Determination of the mutual overlapping of traces of the MTZ-80 + 2PTS-4M aggregate.

Table-4. Determination of the number of movers moving along one track, graphically.

Overlap Δb, mm	**Mover number**				**The number of movers moving along one track *N***
	1(2)	**3(4)**	**5(6)**	**7(8)**	
42					-
16,5					-
247					2
247					2
247					3
16,5					-
Number of traces	1	2	3	4	

The maximum specific pressure of a single mover on the soil is calculated by the formula, kPa [29]

$$q_{max} = 1{,}49 \cdot 10^{-5} \frac{E_{\mathrm{t}}^{5/4}}{\sqrt{1+\frac{E_{\mathrm{t}}}{E_o}}} \left(\frac{104}{p_w} + 134\right) \frac{G_{\mathrm{k}}^{2/3}}{\sqrt{BDk}} \quad (1)$$

where E_o, E_{t} - the modulus of elasticity of the soil and the tires of the mover, respectively, kPa; k - coefficient $k = 1 - 0{,}00165x^5$ ($x = \frac{D}{B}$ for $\frac{D}{B} \leq 3{,}4$ and $x = 6{,}6 - \frac{D}{B}$ for $\frac{D}{B} > 3{,}4$); p_w - internal tire pressure, kPa; G_{k} - load on a single mover, kN; B - tire profile width, m; D - outer diameter of the tire, m.

By the assumption made earlier about the equal distribution of the load over the contact patch of the tire with the base, the pressure value is assumed to be averaged, Mpa

$$q_{\mathrm{av}} = \frac{G_{\mathrm{k}}}{BL}, \quad (2)$$

where L - length of the bearing surface of the wheel, m.

The length of the contact area of the wheel with the supporting surface, m

$$L = r_{rr}\alpha_o + \sqrt{2r_{rr}h}; \quad (3)$$

$$\alpha_o = arctg\sqrt{\frac{2r_{rr}h - h^2}{r_{rr} - h}}, \quad (4)$$

where r_{rr} - reduced radius of the elastic wheel, m; h - track depth, m.

Maximum normal stress in the soil at a depth of h=0.5 m for each single mover, kPa

$$\sigma_h = 0{,}637 q_{av} \left[arctg \frac{ab}{h\sqrt{a^2+b^2+h^2}} + \frac{hab(a^2+b^2+2h^2)}{(a^2+h^2)(b^2+h^2)\sqrt{a^2+b^2+h^2}}\right], \quad (5)$$

where

a - 1/2 length of the contact area, m;
b - 1/2 width of the contact area, m;
q_{av} - average pressure of a single mover, kPa.

Based on the data obtained (Figure-4), using the methodology (GOST 26953-86, GOST 26954-86, GOST 26955-86) and dependencies (1) - (5), indicators for assessing the level of compacting effect of the MTZ-80 tractor and trailer 2PTS-4M movers on the soil were calculated and compared with the established norm within the investigated range of operational loads (Figure-6).

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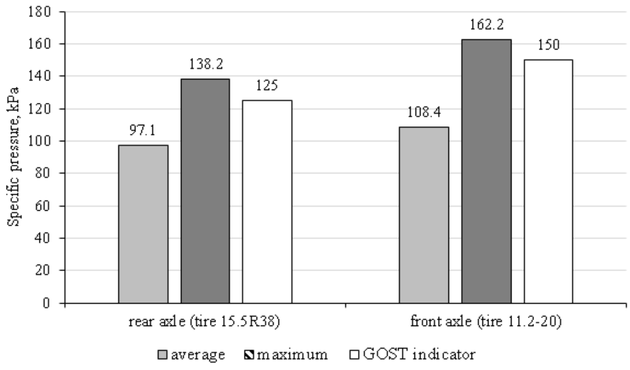
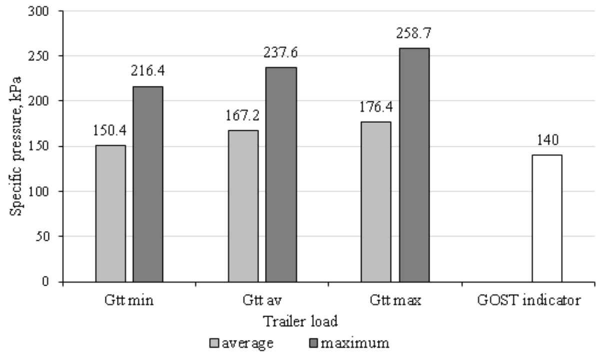


a



b

Figure-6. Maximum (q_{max}) and average (q_{cp}) specific pressures of tractor train movers on the soil: a - MTZ-80 tractor; b - trailer 2PTS-4M.

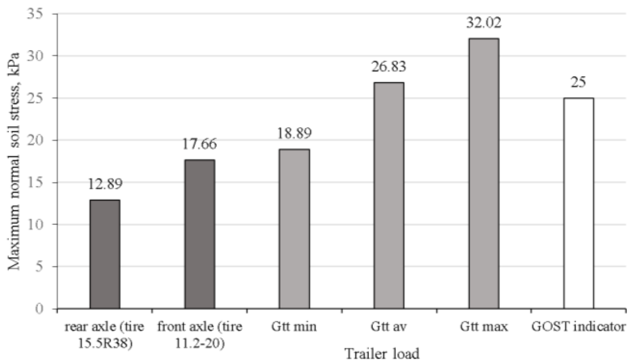


Figure-7. Maximum normal stress in the soil at a depth of 0.5 m (σ_h) from the impact of the movers of the MTZ-80 + 2PTS-4M tractor train.

Depending on the load on the running system of the 2PTS-4M trailer (see Figures-6, 7), q_{max} varies within 216.4-258.7 kPa and σ_h - 18.89-32.02 kPa. The excess of the established norms is 35.3-45.9% for q_{max} within the entire range of loads on the mover, 21.9% for σ_h at maximum load.

In the works of I.P. Ksenevich [21], a universal criterion U is proposed as a complex indicator for assessing the level of machine impact on the soil from agricultural aggregates. Its maximum value is determined by the absence of the influence of the compacting effect of the running system of the aggregate on the formation of the yield of the cultivated crop and is set to [U]≤75 kN/m.

The compacting effect exerted by a single wheel, kN/m

$$U_1 = 1.25 B_{c1} q_{max1}, \quad (5)$$

where B_{c1} - track width of a single wheel, m;
q_{max1} is the maximum pressure of a single mover on the soil, kPa.

The gap value Δ between the wheels installed in a row on the same tractor axle, in case of their doubling, is found based on the scheme for graphical determination of the amount of overlap of the tracks of the aggregate.

The sealing effect in the mover trace increases if another mover passes next to it with a gap Δ ($0 \leq \Delta \leq 2B_c$), by the following value, kN/m

$$U_{i,\Delta} = U_i + \left(0{,}4 - 0{,}2\frac{\Delta}{B_{c(i+1)}}\right) U_{i+1}, \quad (6)$$

where U_i, U_{i+1} - the compacting effect on the soil, respectively, in the i and (i+1) tracks, before the passage of the neighboring mover, kN/m;
$B_{c(i+1)}$ - track width of (i+1) mover, m.

If the gap is greater $\Delta \leq 2B_{c(i+1)}$, then the (i+1) mover does not affect the compacting effect in the track of the i mover.

The compacting effect on the soil in the track after the mover passes along the track of the previous one with the distance between the longitudinal axes of the movers l ($0 \leq l < \frac{B_{cj}+B_{c(j+1)}}{2}$) increases by a value, kN/m

$$U_{j,l} = U_{j,l=0} + 2\frac{l}{B_{cj}+B_{c(j+1)}}\left(U_{j,\Delta=0} - U_{j,l=0}\right), \quad (7)$$

where $U_{j,\Delta=0}$ and $U_{j,l=0}$ - indicators of impact in the traces of movers, respectively, at $\Delta = 0$ and $l = 0$. The value of $U_{j,\Delta=0}$ is calculated by formula (6), and the value of $U_{j,l=0}$ – by formula (8).

The distance between the longitudinal axes of the movers l is found based on the scheme for graphical determination of the amount of overlap of the traces of the unit (Figure-5).

Compaction from the wheel following the first, when the wheels move according to the "trail-to-trail" scheme, kN/m.

$$\mathrm{U_i} = 1{,}25\mathrm{k_i}\chi[\lg \mathrm{i} - \lg(\mathrm{i}-1)]\mathrm{B_{c1}q_{max\,i}} + 1{,}25\Delta \mathrm{B q_{max\,i}}, \quad (8)$$

where χ - the indicator of the dynamics of accumulation of plastic deformation of the soil under its repeated loading;
k_i - coefficient taking into account the increase in soil compaction with increasing pressures of subsequent impacts,
$k_i = \frac{1}{\chi[\lg i - \lg(i-1)]} - \left(\frac{1}{\chi[\lg i - \lg(i-1)]} - 1\right)\frac{q_{i-1}}{q_i}$, when $q_i > q_{i-1}$;
$k_i = 1$, when $q_i \geq q_{i-1}$;

$\Delta B = B_{c\ i-1} - B_{c\ i}$ when $B_{c\ i-1} > B_{c\ i}$ and $\Delta B = 0$ when $B_{c\ i-1} < B_{c\ i}$
i = 2, 3, … - index of mover (in order) following the front wheel track.

Considering the data on the parameters of the tires of the aggregate from the table. 2, we accept for calculation that $q_i \geq q_{i-1}$ and $B_{c\ i-1} > B_{c\ i}$, as well as χ=1,0 [21].

The total indicator U in each trace of the mover after the passage of the aggregate is determined by the addition of various kinds of impacts, kN/m.

$$U_j = U_1 + \sum_{i=2}^{n_1} U_{i,\Delta} + \sum_{j=2}^{n_2} U_{j,l}, \quad (9)$$

Where
n_1 - the number of movers moving with gaps relative to the first one;
n_2 - is the number of movers moving along the trail of the first one.

The obtained value of the total compaction effect was compared with the established allowable norm [U]. According to the criterion $\sum_{j=1}^{n} U_j \leq [U]$ we concluded the general level of technogenic load on the soil provided by the wheels of the tractor transport aggregate, based on a graphical analysis of their arrangement scheme (Figure-5). The results of the calculation are shown in Figure-8.

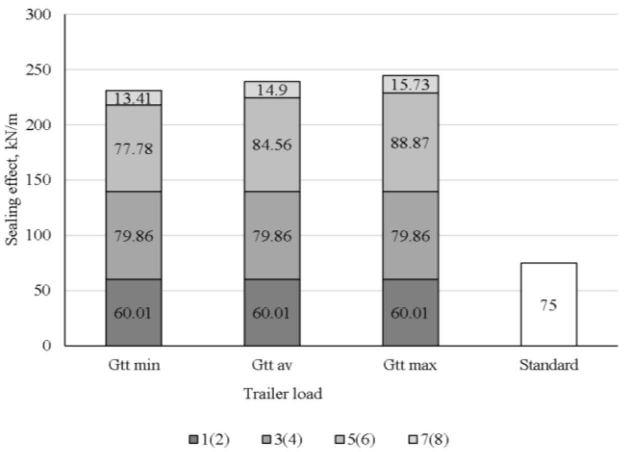


Figure-8. Calculation results of the criterion U (kN/m) for the aggregate movers.

When calculating the criteria for the compacting effect of the aggregate movers on the soil according to a private method, depending on the load on the chassis of the trailer, the maximum compaction effect of its movers on the soil varies within 231.1-244.5 kN/m, exceeding the established norm by 67.5 -69.3% within the entire range of mover loads.

CONCLUSIONS

The movement of a tractor train along agro backgrounds leads to a significant over-compaction of the soil by its running systems. The cultivated soil is subject to the greatest negative impact, the increase in the density and hardness of which, on average, is higher by 9.5-11% and 5.5-9.5%, respectively in comparison with the stubble background. Comfortable conditions for grain crops are provided with soil density within 1.1 ... 1.3 g / cm^3 for the prevailing soil type such as soddy-podzolic medium loamy [30] in the territory of the Kemerovo region. For this reason, the level of impact of the running systems of the MTZ-80+2PTS-4M tractor transport aggregate on the soil when driving on agricultural backgrounds should be considered unacceptable.

The excess of the established norms is 35.3-45.9% for q_{max} when the load changes from minimum to maximum, 21.9% for $\sigma_h$at maximum load. According to criterion U, the excess of the established norm when the trailer is loaded to the maximum changes slightly and amounts to 67.5-69.3%.

Thus, under the test conditions, the running system of the 2PTS-4M trailer does not meet the requirements of the standards for the impact on the soil, both established by GOST and by a private calculation method, within the entire range of changes in operational loads on the movers.

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