INFLUENCE OF TYPES OF TRACTOR RUNNING GEARS ON THE VALUE OF HOP GARDEN ROW SPACING COMPACTION
/
ВЛИЯНИЕ ТИПОВ ДВИЖИТЕЛЕЙ ТРАКТОРОВ НА ВЕЛИЧИНУ УПЛОТНЕНИЯ ПОЧВЫ В МЕЖДУРЯДЬЯХ ХМЕЛЬНИКОВ

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ABSTRACT

Based on experimental research, a method of comparing areas of compaction by tractor running gears in field conditions and in hop garden row spacing was suggested. Zones of inefficient and intensive use of hop garden row spacing area were determined. Also, a solution to the row spacing zone optimization problem was given. The results of experimental research on soil density in case of compaction by track and wheel tractors were presented.

АННОТАЦИЯ

По экспериментальным исследованиям предложена методика сравнения площадей уплотнения движителями трактора в полевых условиях и в междурядье хмельника. Определены зоны неэффективного и интенсивного использования площади междурядья хмельника. Также приведено решение задачи оптимизации зон междурядья. Приведены результаты экспериментальных исследований плотности сложения почвы при уплотнении гусеничного и колесного тракторов.

INTRODUCTION

A negative factor of the solution to modern problems of energy saving through a sharp increase in the power-to-weight ratio of tractors and maximum operating width of the machine-tractor aggregate (MTA), which is provided by the required weight of the tractor itself, is high soil compaction under its running gear (Alatyrev et al., 2018; Vasiliev, 2013). Unfortunately, such a trend can be observed in fields of crop farming with multiple interrow tillage too. A high power-to-weight ratio enables performing unique operations of deep soil loosening; however, this operation is not always possible in perennial hop gardens.

In the present paper a method of calculating areas of compaction by tractor running gear in field conditions and in hop garden row spacing was suggested, zones of inefficient and intensive use of hop garden row spacing area were determined based on experimental measurements in the territory of hop gardens of the Chuvash Republic and Mari-El Republic, calculations of intensive use zone of hop garden row spacing were made.

To compare the area of compaction by running gears of the machine-tractor aggregate (MTA) based on known constants of the running gear width, it is feasible to introduce the parameter of relative area of compaction by running gears. We assume that main soil compaction takes place under tractor wheels (tracks) and we take the rear, wider wheel width as the track width. At the same time, in modern hop growing technologies in use up to 12...14 passes on row spacing are provided for *(Vasiliev A.O. et al, 2017; Zakharov et al., 2016; Zakharov et al., 2017).*

The most acceptable theoretical and empirical explanations of shear deformations as a result of compaction by tractor wheels are given in the works of (*Medvedev et al., 2017*) and also in *(Niziolomski et al., 2016; Obour et al., 2017; Peng et al., 2012; Silva et al., 2018; Szatanik-Kloc et al., 2018)*. Here is the description of the research.

In research of shear deformations impact on destruction of weeds roots similar confirming indicators were obtained *(Schnaitter et al., 2016*). The relationship of the deformation from the elongation was drawn based on the obtained data (*Medvedev et al., 2017*).

Similar negative impact of soil compaction, for example, for potatoes was analyzed in (*Rees et al., 2015*). Even presence of small compaction sites with 6 cm thickness influenced growth and yield of the crop.

MATERIALS AND METHODS

The relative compaction area is determined in the following way:
for a track tractor in hop garden row spacing

$$v_к = \frac{2b_g}{b_n} 100 \ [\%], \tag{1}$$

where: b_g is track width [m] ;
$b_1, b_2 \dots b_n$ is hop garden row spacing width [m].

For a track tractor in field conditions

$$v_к = \frac{2b_g}{b_m} 100 \ [\%], \tag{2}$$

where: b_m is MTA operating width in field conditions [m].

For a wheel tractor in the hop garden row spacing

$$v_к = \frac{2b_к}{b_n} 100 \ [\%], \tag{3}$$

where: b_k is rear wheel width [m].

For a wheel tractor in field conditions

$$v_к = \frac{2b_к}{b_m} 100 \ [\%]. \tag{4}$$

The accepted initial data: b_K = 0.4 m (MTZ-921 tractor), b_g = 0.3 m (T-54V tractor), hop garden row spacing b_1=2.25 m, b_2 =2.5 m, b_3 - 3.3 m and the operating width of the field MTA b_m=6.0 m (harrowing aggregate), b_m=3.6 m (KRG-3,6 cultivator).

The above mentioned explains absence of any hop roots under running gear tracks and in gauge area of row spacing at the plow layer depth established by visual inspection during sampling and soil crossovers in hop gardens of the Chuvash Republic.

Consequently, the problem requires more thorough study and optimization.

On the whole, light-grey forest soils are also present in hop gardens of the Chuvash Republic; according to mechanical composition, there are middle and heavy loamy soils (northern regions of the Chuvash Republic). Based on agrochemical analysis data, there is 2.1...2.5 % humus content in the fertile layer. The mean fertile layer depth is 23.5…28 cm. The soil reaction is medium acid. There is no or little, within 1.5...5% range, hop garden slope.

On both sides of the tractor track or wheel pit, two trenches *I* and *II* (Figure 1) are dug and flexible steel strips *1* with cross-section of 0.2x10 mm^2 are laid from the first trench towards the other one. The number of flexible elements is selected depending on the soil deformation analysis depth, for example, in 0.1 m along the vertical line. Circular cross-section guide bushings with 4...6 mm diameter are used to lay them. It was experimentally proven that in this case natural soil texture at the given moment of the research and its monolithic nature do not change as the rod diameter is small comparing to the steel strip width.

The steel strip end is attached to the rod end in deepening *II* and is laid through the soil fragment under analysis to trench *I*. Strip ends in trench *I* are rigidly fixed in special clamp *2*, the opposite ends in trench *II* are in free state.

After the passage of the machine-tractor aggregate a transverse soil crossover is undertaken along the vertical line of steel strip laying and deformation value *Δh* on each strip is determined. Also, length reduction *Δl* of the free strip end in trench II is measured and the soil deformation value under the drive unit track is determined based on this reduction.

Thus, it was established that under the impact of vertical loads upper soil layers undergo much bigger deformations. It was noted that deformations get less with deepening. However, the steel strip bending nature remains the same for all layers under analysis (Figure 1).

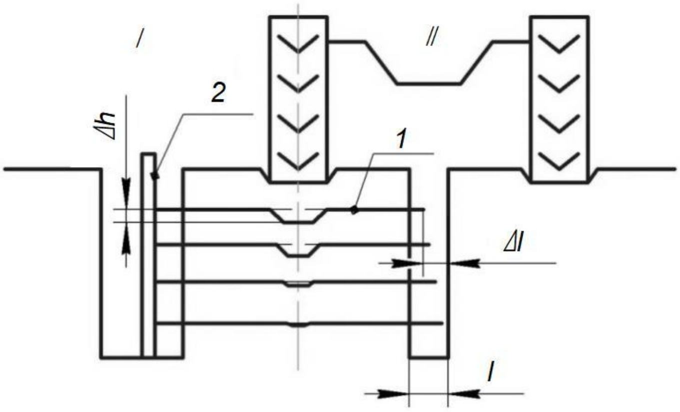

Fig. 1 - Soil deformation determination scheme
1-strip; 2 – clamp; I and II – trenches.

Taking into account a high number of MTA passes in case of the traditional hop growing technology (up to 14 passes), with inter-row cultivation unable to ensure sufficient treatment depth, compacted strips under tractor tracks in hop garden row spacing are permanent. Correspondingly, quantitative reduction of the blocked hop garden row spacing area is required for improvement of hop growing conditions. To solve the problem, the function $b_z = f\left(b_m, b_k\right)$ was analyzed (Figure 2).

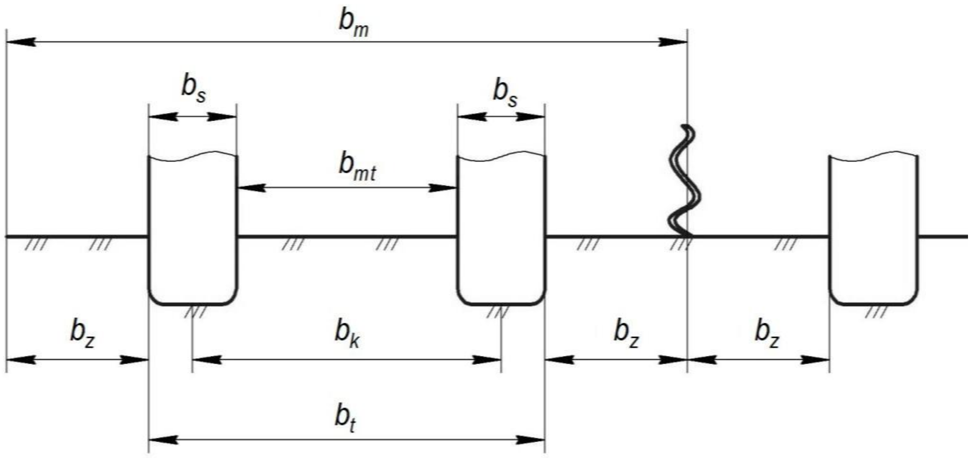

Fig. 2 - Scheme of initial data for calculation of efficient row spacing use
(notation in the text)

The following data were selected as initial data:

1) tractor width by rear wheels (track) $b_t = b_k + b_s$ [m];
2) row spacing width $b_m = b_t + 2b_z$ [m];
3) rear wheel tire (track) width b_s=0.4 m for MTZ tractors; b_s= 0.3 m for LTZ tractors; b_s=0.23 m for T-30A, "Agromash-30TK" tractors;
4) minimum tractor track – b_k :b_k =1.4 m for MTZ; b_k =1.2 m for LTZ tractor [5]; b_k =1.1 m and 1.2 m for T-30A and "Agromash-30TK"; b_k =0.98 m for T-54V tractor;
5) plant protective area width b_k [m];
6) width of the inter-wheel area under the tractor b_{mt} [m].

Relative indicators are calculated using the following expressions:

1) compacted area under tractor wheels:

$$\delta_g = \frac{2b_s}{b_m} 100 \quad [\%] \tag{9}$$

2) inter-wheel area under the tractor:

$$\delta_{mt} = \frac{b_{mt}}{b_m} 100 \quad [\%] \tag{10}$$

3) zone of inefficient row spacing use:

$$\delta_m = \frac{2b_s + b_{mt}}{b_m} 100 \ \ [\%] \tag{11}$$

4) zone of intensive row spacing use:

$$\delta_i = \frac{2b_z}{b_m} 100 \ \ [\%] \tag{12}$$

RESULTS

The obtained calculation data are given in Tables 1-3.

Table 1

Relative area of compaction by running gears of MTZ-921 and T-54V tractors in hop garden row spacing of different width

Hop garden row spacing width, [m]	Relative area of compaction of hop garden row spacing, [%]	
	by MTZ-921 tractor wheels	by T-54V tractor tracks
2.25	35.56	26.67
2.50	32.00	24.00
3.30	24.40	18.02

Experimental research was conducted in hop gardens of "Agrokhmel" LLC of Vurnary region of the Chuvash Republic, where primarily T-54V track tractors are used, and "Leninskaya Iskra" Pilot Research Collective Farm of Yadrin region of the Chuvash Republic.

There MTZ-921 wheel tractors are used. Soils of hop gardens of "Agrokhmel" LLC are primarily dark-grey forest soils with the mean humus content of 4.1%, at the depth up to 0.2 m (with 2.4...3.1% humus content), those of "Leninskaya Iskra" Pilot Research Collective Farm are grey forest soils with humus content of 2.9% at the depth of 0.2 m.

Table 2

Relative area of compaction by running gears of MTZ-921 and T-54V tractors in field conditions

Field MTA operating width [m]	Relative area of compaction of hop garden row spacing [%]	
	by MTZ-921 tractor wheels [%]	by T-54V tractor tracks [%]
6.0 m (harrowing aggregate)	13.3	10.0
3.6 m (KRG-3,6 cultivator)	22.2	16.67

Table 3

Comparison of field MTAs for different hop garden row spacings by compaction area

Hop garden row spacing width [m]	The ratio of area of compaction by tractor running gears in hop garden row spacing to field MTA compaction area			
	harrowing		cultivator	
	MTZ-921	T-54V	MTZ-921	T-54V
2.25	2.6676	2.67	1.6003	1.5998
2.5	2.4006	2.4	1.4401	1.4397
3.3	1.8184	1.82	1.0909	1.0905

As it can be seen from tables 1-3, due to the limitedness of hop garden row spacing, as is the case with row spacings of similar crops (vineyards and horticultural crops), soil compaction by tractor running gears comparing to field MTA for tractors under consideration (harrowing and cultivation) is 1.1-2.67 times as high.

The soil density was obtained on the basis of the ratio of dried mass of cylinder-shape soil sample obtained by pressing a hollow thin cylinder in soil at the depth of 0...30 cm to its volume.

The results obtained during the experiments show that the soil in hop gardens where track tractors are used has a higher density than in areas where wheel tractors are used (Figures 3, 4). The obtained results conform to the research data of tractor running gears impact on grey forest soil in maize cultivation.

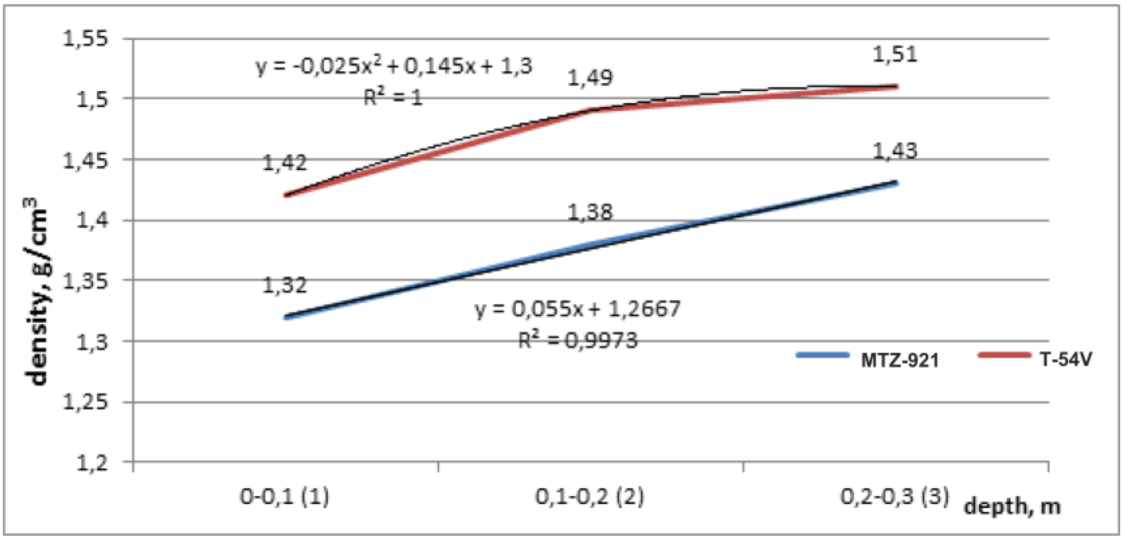

Fig. 3 - Diagram of soil density under tractor support running gears *(based on 27 measurements)*

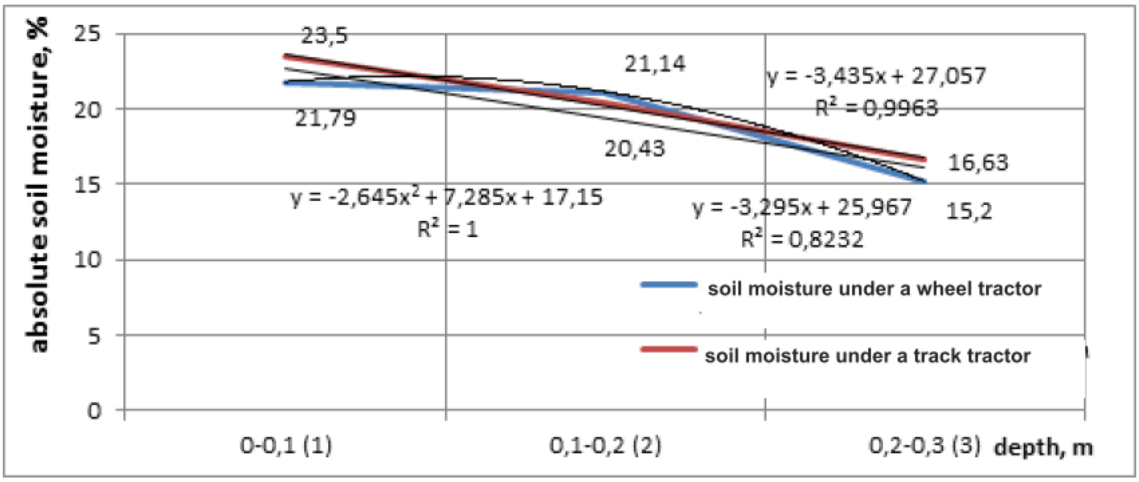

Fig. 4 - Absolute soil moisture under tractor support running gears at the plow layer depth
(based on 27 measurements)

As a result of experimental data processing, the relations between soil density and soil moisture and the depth of the layer under consideration in parametric form were obtained:

- For compaction by T-54V tractor tracks:

$$\begin{cases} \omega_a = -3.435x + 27.05 \\ \gamma = -0.025x^2 + 0.145x + 1.3 \end{cases}, \tag{5}$$

where: ω_a is the soil moisture [%];
γ is the soil density [kg/m^2];
x is depth of the layer [m].

- For compaction by MTZ-921 tractor wheels:

$$\begin{cases} \omega_a = -3.292x + 25.96 \\ \gamma = 0.055x + 1.266 \end{cases}, \tag{6}$$

By solving parametric equations 5 and 6, the explicit equations were obtained:

- For T-54V tractor:

$$\gamma = 0.0021\omega_a^2 - 0.182\omega_a + 4.06 \tag{7}$$

- For MTZ-921 tractor:

$$\gamma = -0.0171\omega_a + 1.702. \tag{8}$$

The graphical expression of equations 7 and 8 is given in Figure 5.

The conclusion based on ratios 7 and 8 and diagrams (Figure 5) is the following. Soil density and soil moisture are in a linear relationship, and soil density under MTZ-921 tractor tracks is less subjected to changes with moisture growth (or reduction). If we imagine an opposite picture of moisture content dependence on compacted condition of soil, we get a rather low moisture-holding capacity of the compacted area. In case of the experiment a minimum quantity of hop roots was observed under the tractor running gear tracks.

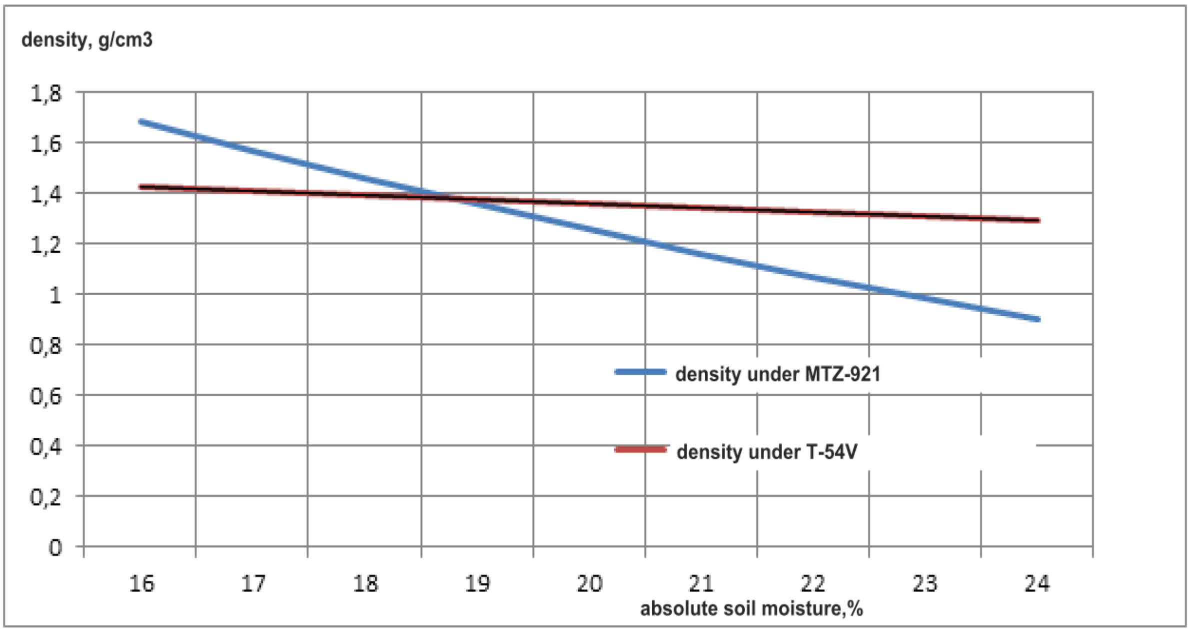

Fig. 5 - The ratio soil density and soil moisture in the compacted area under tractor running gear tracks in hop garden row spacing

Based on the above described experiment, we drew the following diagrams that characterize vertical shear processes on both sides of the running gear track (Figure 6).

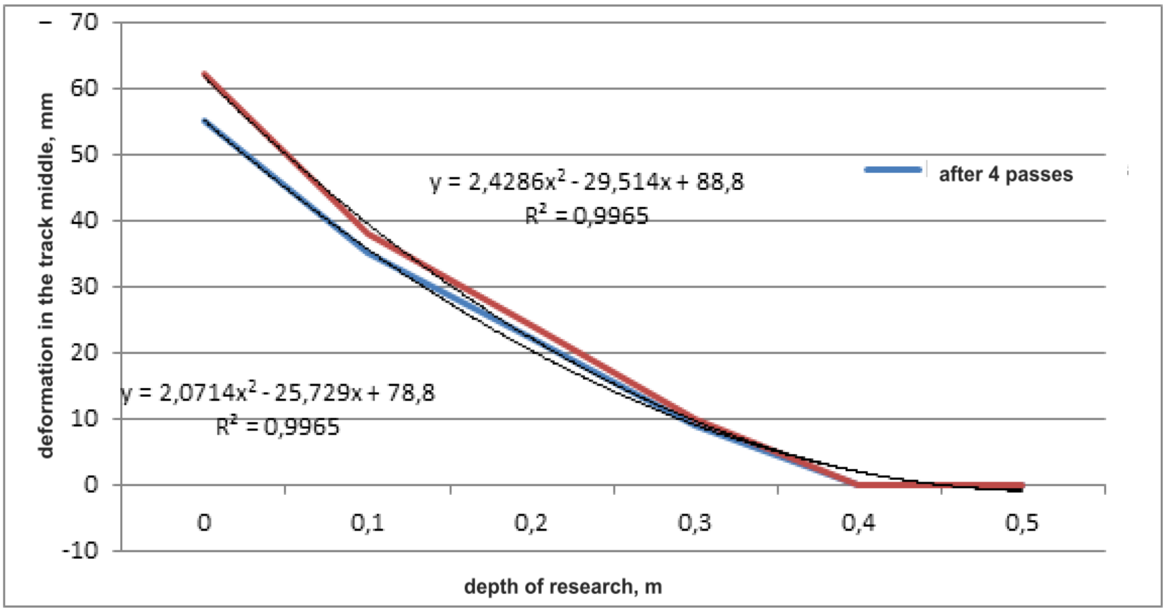

Fig. 6 - Shear vertical deformation along the wheel track (mm) by depth, m

In hop gardens the negative impact of power means running gears spreads on the whole gauge area. During soil crossovers for soil sampling (54 measurements) it was established that at the plow layer depth of 0...0.3 m there are no ("Leninskaya Iskra" Pilot Research Collective Farm) or few ("Agrokhmel" LLC) hop roots between tractor tracks.

The analysis of shear vertical deformation along the wheel track and its spread by depth (Figure 7) shows that after a triple passage over the same track there is almost no soil layer displacement.

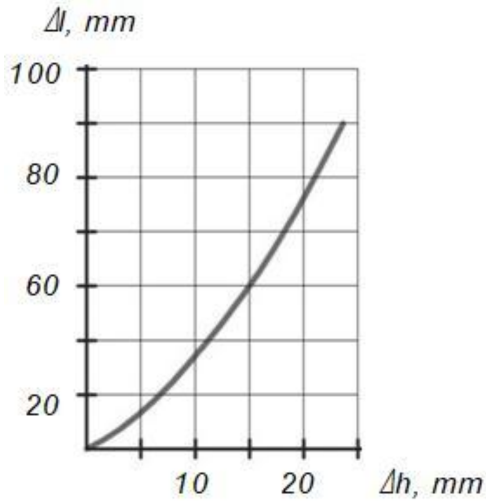

Fig. 7 - Relation of the deformation and the elongation

However, for our case the reverse diagram is of interest (Figure 7). In case of deformation 10 mm elongation reaches up to 30 mm, in case of Δh=20 mm elongation is up to 90 mm, that is such absolute elongation destroys any root system.

A detailed examination of the process of increased soil compaction with tracked tractor thrusters revealed the following. It occurs incrementally, under the front of the track, the value of the distributed load is less than under the rear. Also under the track roller, there is also an instantaneous vertical force more than in between the rollers. Thus, the caterpillar loads the bearing surface cyclically according to the principle "track roller - intermediate zone" with increasing vertical force from the first track roller to the last. It is the repeated cyclic compaction that is the basis of soil compaction.

Also, tracked tractors have increased vibration transmission to the ground. The wheeled tractor transmits minimal vibrations to the porous surface due to the elasticity of the pneumatic tires and the presence of air in the chambers. Despite the presence of a torsion bar suspension on a crawler tractor T-54B, transverse and longitudinal vibrations are fully transferred to the soil, which greatly enhances its compaction.

The results of the analysis of function $b_z = f\left(b_m, b_k\right)$ are presented in tables 4 and 5.

Table 4

Structure of inefficient and intensive hop row spacing use zones with different parameters b_k and b_m for b_m = 2.25 and 2.5 m

No.	Tractor	δ_g ,%	δ_{mt} ,%	δ_m , %	δ_i , %	δ_g ,%	δ_{mt} ,%	δ_m , %	δ_i , %
		$b_m = 2.25$ [m]				$b_m = 2.5$ [m]			
1	MTZ-80/82 (b_k=1.4 m)	35.6	44.4	80	20	32	40	72	28
2	LTZ (b_k=1.2 m)	26.7	40	66.7	33.3	24	36	60	40
3	T-25A (b_k=1.1 m)	20.4	38.7	59.1	40.9	18.4	34.8	53.2	46.8
4	30TK (b_k=1.2 m)	20.4	30.2	56.9	36.5	18.4	38.8	57.2	42.8
5	T-54V (b_k=0.98 m)	26.7	30.2	56.9	43.1	24	27.2	51.2	48.8

Table 5

Structure of inefficient and intensive hop row spacing use zones with different parameters b_k and b_m for b_m = 3.0 and 3.33 m

No.	Tractor	δ_g,%	δ_{mt},%	δ_m, %	δ_i, %	δ_g,%	δ_{mt},%	δ_m, %	δ_i, %
		$b_m = 3.0$ [m]				$b_m = 3.33$ [m]			
1	MTZ-80/82 (b_k=1.4 m)	26.7	3.33	60	40	24	30	54	46
2	LTZ (b_k=1.2 m)	20	30	50	50	18	28	45	35
3	T-25A (b_k=1.1 m)	15.3	29	44.3	55.7	13.8	26.1	39.9	60.1
4	30TK (b_k=1.2 m)	15.3	32.3	47.6	52.4	13.8	29.1	42.9	57.1
5	T-54V (b_k=0.98 m)	20	22.7	42.7	57.3	18	20.4	38.4	61.6

Here the following equation is valid:

$$\delta_m = \delta_g + \delta_m \text{ [\%]}. \quad (13)$$

The calculation data (Tables 4, 5) were used for drawing diagrams of intensive use of hop garden row spacing with different planting width (Figures 8, 9).

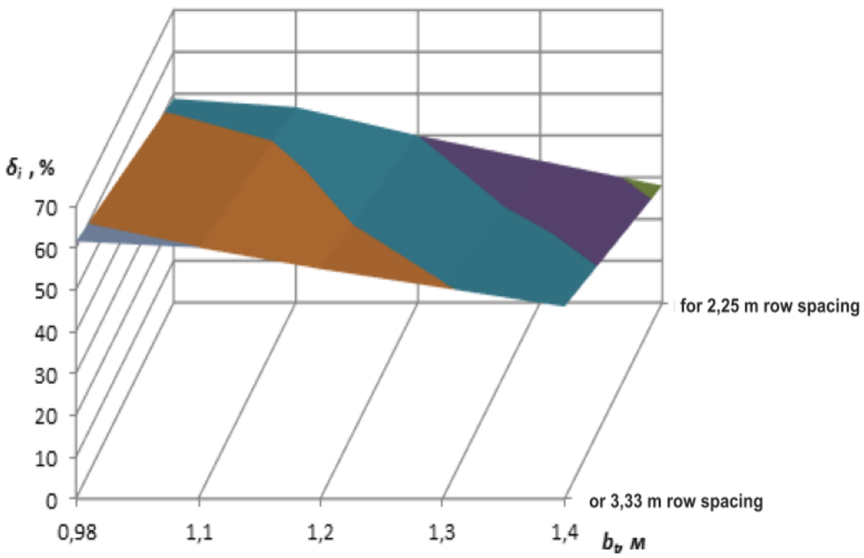

Fig. 8 - The relation between the zone of intensive use of hop garden row spacing δ_i and tractor track width b_k and hop garden row spacing b_m.

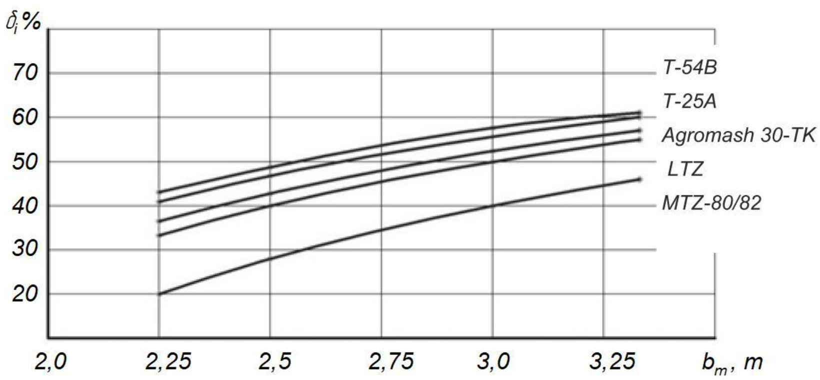

Fig. 9 - Diagrams of the zone of intensive use of hop garden row spacing with different planting width b_m

CONCLUSIONS

1. A method of calculating areas of compaction by tractor running gears in field conditions and in hop garden row spacing was suggested. The given method can also be used in vineyards and on berry bush grounds in gardens. An increase in the area of compaction in hop gardens comparing to field conditions, primarily, due to limited nature of row spacing was revealed.

2. The results of experimental research of soil density in hop gardens of the Chuvash Republic were presented. The relation between soil density and its moisture was given. Despite the opinion of small soil compaction by track tractors, soil density under T-54V tracks is greater comparing to MTZ-921 wheel tractor (Figure 1).

3. The value of the zone of intensive hop garden row spacing use increases with introduction of prospective high-yield hop varieties. The given analytical solutions show that the zone of intensive hop garden row spacing use of over 60% is achieved with the use of T-54V and T-25A tractors with the minimum track during planting of a hop garden with row spacing of 3.33 m.

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