LOOSENING AND LEVELING DEVICE FOR PREPARING SOIL FOR MELON CROPS
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РЫХЛИТЕЛЬНО-ВЫРАВНИВАЮЩЕЕ УСТРОЙСТВО ДЛЯ ПОДГОТОВКИ ПОЧВЫ ПОД БАХЧЕВЫЕ КУЛЬТУРЫ

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ABSTRACT
The analysis of soil cultivation technologies for sowing melon crops was carried out. The design of a combined soil tillage tool capable of plowing, pre-sowing treatment and formation of irrigation furrows in one pass was substantiated. The main tillage is recommended to be done by front plow tools for smooth plowing. Plow bodies of two bottom plows should be mounted along the symmetry axis of the implement according to the lister scheme, which allows not to carry out a full rotation of soil layers and provides automatic formation of irrigation furrow. A loosening and leveling device for strip pre-sowing soil tillage in the sowing zone has been developed. The use of a combined soil tillage tool can reduce labor costs up to 25%, energy consumption for soil preparation up to 50%, reduce the duration of work, reduce soil compaction and retain moisture in the soil layer.

РЕЗЮМЕ
Проведен анализ технологий обработки почвы под посев бахчевых культур. Обоснована конструкция комбинированного почвообрабатывающего орудия, способного за один проход выполнять вспашку, предпосевную обработку и формирование поливных борозд. Основную обработку почвы рекомендовано проводить плужными рабочими органами фронтального плуга для гладкой вспашки. Плужные корпуса двухкорпусного плуга необходимо устанавливать по оси симметрии орудия по листерной схеме, что позволяет осуществлять не полный оборот пластов почвы и обеспечивает автоматическое формирование поливной борозды. Разработано рыхлительно-выравнивающее устройство для полосовой предпосевной обработки почвы в зоне посева. Использование комбинированного почвообрабатывающего агрегата позволяет снизить затраты труда до 25 %, энергопотребление на подготовку почвы до 50 %, сократить продолжительность проведения работ, уменьшить уплотнение почвы и сохранить влагу в почвенном слое.

INTRODUCTION
The most important link in the system of measures to ensure high quality agricultural crops and high yields of melon crops is soil cultivation. Success in cultivating melon crops largely depends on time and quality of soil cultivation, on how it is carried out and the perfection of machine design. In recent years, the capacity and potential of agricultural tractors have increased significantly, but the methods of tillage mostly remained the same, which in many cases is not justified agronomically *(Mamatov F.M. et al, 2018; Litvinov S.S. and Bykovskiy Yu.A., 2013; Mitev G., 2016; Moskvitchev A.Yu. et al, 2011; Reicosky D.C., 2015).*

Multiple passes of agricultural machinery through the cultivated field lead to soil compaction, which results in decrease in the yield of melon crops.

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Operations of the main and pre-sowing tillage are energy consuming *(Celik A. and Raper R.L., 2012; Mitkov V.B. et al, 2016; Sarauskis E. et al, 2012; Mirzaev B. et al, 2019)*. In this connection, there is a need to create new combined tools that allow the use of energy-saving methods of soil cultivation while reducing the number of passes of units across the field and reducing the duration of work *(Lal R. and Shukla M.K., 2004; Kudzaev A.B. et al, 2017; Elizarov V.P. et al, 2011; Mosyakov M.A. and Zvolinskiy V.N., 2015)*.

The main purpose of the research is to substantiate the layout scheme and design parameters of the loosening and leveling work tool of the combined tool for soil preparation for melon crops.

MATERIALS AND METHODS

When preparing the soil for sowing melon crops in a certain sequence, a number of technological operations are carried out: plowing, irrigation furrows formation, pre-sowing treatment. For their simultaneous performance, the authors offer a combined aggregate for strip tillage. It consists of two bodies of frontal plow, located on a lister scheme.

Such working bodies allow strip plowing of the area with the simultaneous formation of irrigation furrows, due to the incomplete turnover of layers. On both sides of the formed irrigation furrow, there are ridges of plowed soil layers, and in this area it is necessary to carry out pre-sowing tillage *(Romaneckas K. et al, 2016; Starovoytov V. et al, 2017; Izmailov A.Yu. et al, 2013)*.

For this purpose, a loosening and leveling device is designed, the parameters of which should be substantivized.

As a result of the combined tool usage, the following agrotechnical requirements for pre-sowing soil tillage must be fulfilled: the number of clods of up to 25 mm in the layer 0-10 cm must be no less than 80%.

In this case, the soil density in the horizon of 0-10 cm should be from 1.1 to 1.2 g/cm^3 *(Mamatov F.M. and Mirzaev B.S., 2018)*.

RESULTS

To realize the set goal various design variants of loosening and leveling devices for the combined soil tillage tool for melon crops were considered (fig.1-5).

<u>*Variant 1*</u> (fig.1). The leveling device is a ski-shape leveler *1* and a slatted roller *2*. Levelers are installed symmetrically in the longitudinal axis of the unit over the ridges of arable beds at a certain attack angle. A slatted roller, which additionally destroys the soil clods and compacts the soil in the crops sowing area is located behind each of them. Studies have shown that this type of loosening and leveling device does not fully cope with its functions, not ensuring full compliance with agricultural requirements.

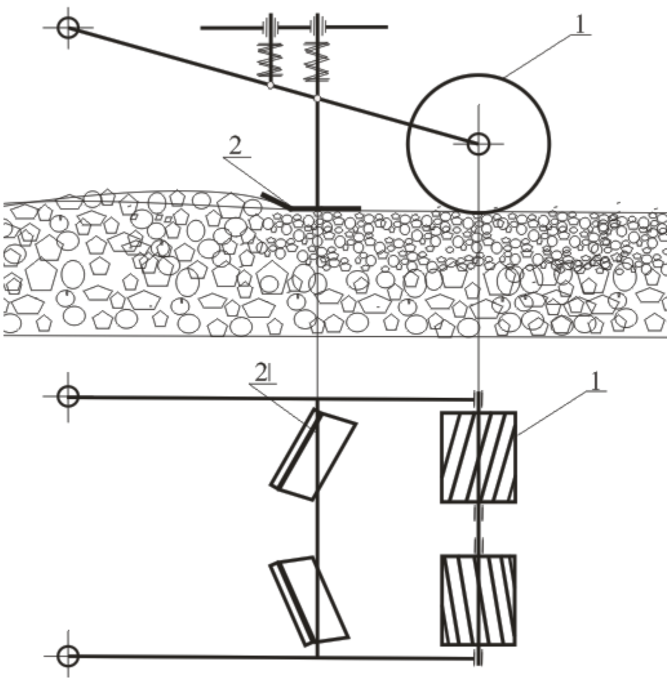

Fig. 1 - Loosening and leveling device (Variant 1)
1 - slatted roller; 2 – leveler

Variant 2 (fig.2). The device consists of ski-shape levelers *1* and flat discs with blade elements *2*. The levelers are mounted symmetrically on the longitudinal axis of the aggregate above the arable beds ridges. Blocks of the flat discs with the blade elements are mounted behind each of them. The leveled surface of the field is exposed to the discs, which additionally crush the soil clods.

In this case the leveling of the surface is partially violated. Such a working element does not fully meet agricultural requirements. Obviously, the presence of a special leveler in its design is not quite justified, as in the first variant.

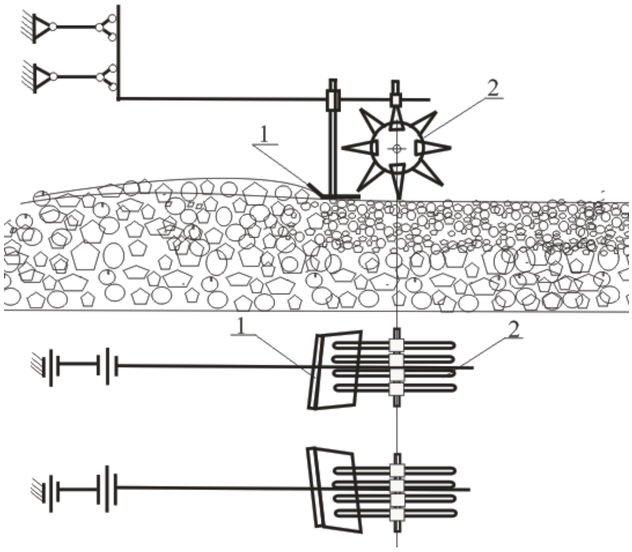

Fig. 2 - Loosening and leveling device (Variant 2)
1 - leveler; 2 - flat disc with blade elements

Variant 3 (fig.3). The device design is provided with rotary hoes *1* and slatted rollers *2*. Hoes blocks crush large soil clods on the ridges of the soil arable beds. The slatted rollers mounted behind them additionally crush them, compacting and leveling the soil selectively. The disadvantage of this design is incomplete performance of the rotary hoes.

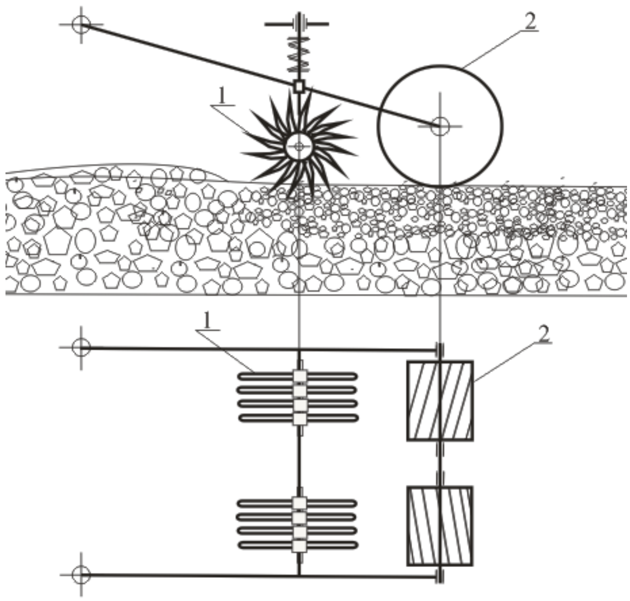

Fig. 3 - Loosening and leveling device (Variant 3)
1 - hoe wheel (rotary hoe); 2 - slatted roller

Variant 4 (fig.4). It includes flat discs with the blade elements *1* and slatted rollers *2*. Two blocks of flat discs with blade elements crush large soil clods on the ridges of the soil arable beds. The slatted rollers mounted behind them additionally crush, compacting and leveling the soil selectively. Such working bodies work better than the previous variants. Nevertheless, the discs blocks are subjected to clogging with soil and vegetation residues, and increasing distance between discs in the blocks leads to uneven tillage.

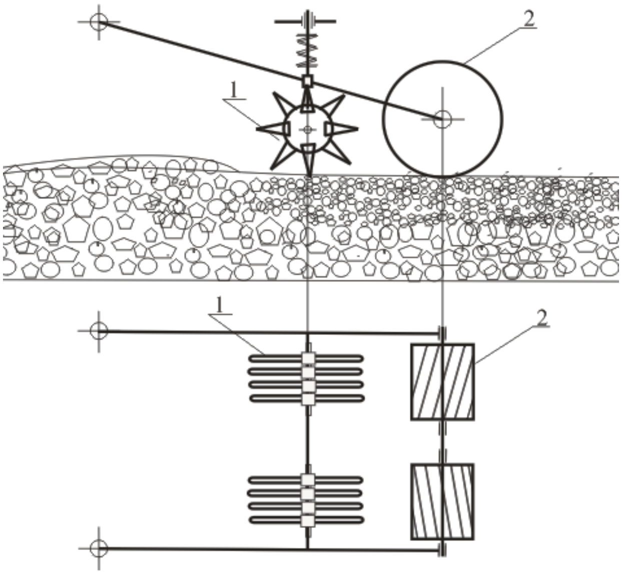

Fig. 4 - Loosening and leveling device (Variant 4)
1 - flat disc with blade elements; 2 - slatted roller

Variant 5 (fig.5). It consists of discs with multi-directional spherical blade elements *1* and slatted rollers *2*. The discs are combined into blocks located above the ridges of the arable beds. Having differently directed spherical blade elements, they crush soil clods. Behind them there are slatted rollers, which additionally crush compacted soil and level the soil in the sowing area selectively. This working body allows ensuring full implementation of agricultural requirements when using it *(Aldoshin N. et al, 2020)*. This option is the most effective in work, so it was chosen for further research.

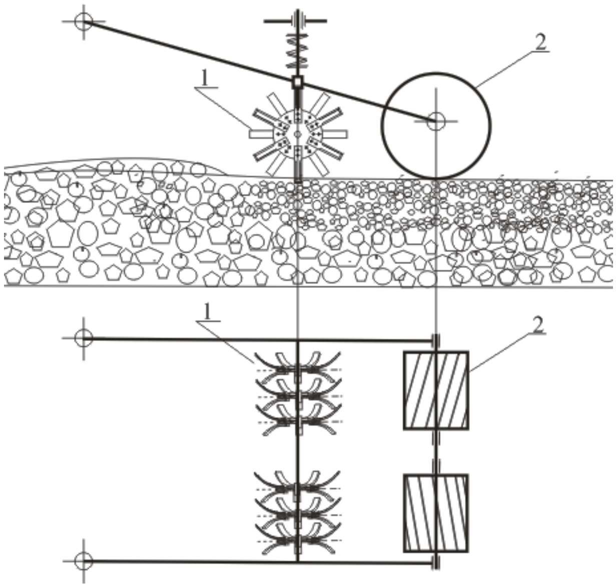

Fig. 5 - Loosening and leveling device (Variant 5)
1 - disc with multi-directional spherical blade elements; 2 - slatted roller

The efficiency of the loosening and leveling device (variant 5) is largely determined by the correct choice of its design parameters. Justification of soil-tilling discs with multi-directional spherical blade elements was done by us earlier. On this basis, the following parameters were accepted: diameter of the blade working body – 400 mm; radius of curvature of the blade element – 455 mm; thickness of the blade element – 4 mm, width – 40 mm *(Mamatov F.M. and Mirzaev B.S., 2018)*. The general view of the developed working body is shown in fig. 6.

Fig. 6 - General view of rotary soil-tilling working body with multi-directional spherical blade elements

Let's perform the calculation of the slatted roller. Its main parameters are: radius r_{KT}, slat height h_{SL}, the attack angle of slat γ_{SL}, the number of slats n_{SL}, the width of section B_S. Values of the most parameters of the roller are closely interrelated and they depend on its main parameter – the radius.

The radius value should be such that when meeting with a large clod, the roller is easily rolled over it.

If condition (1) is met, the soil clod between the field surface and the outer edge of the roller is pinched, soil compaction is excluded (fig. 7).

$$\delta \le \varphi_1 + \varphi_2, \tag{1}$$

where:

δ – angle of pinching, [deg];

φ_1 – clod friction angle against the roller, [deg];

φ_2 – soil to soil friction angle, [deg].

When the roller slat is exposed to the side surface, the soil clod penetrates into the soil at a certain depth h_2.

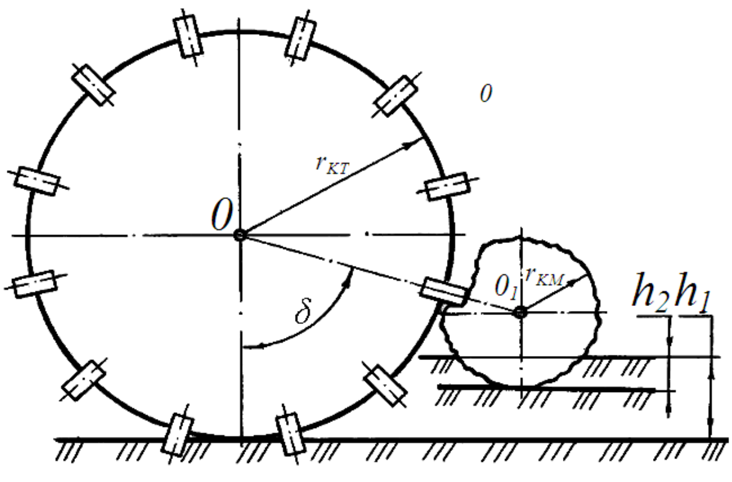

Fig. 7 - Scheme for determining the roller diameter

From figure 7, you can see that

$$r_{KT}\cdot(1-\cos\delta)-h_1=r_{KM}\cdot(1+\cos\delta)-h_2, \quad (2)$$

where: r_{KM} – the soil clod radius, [m];

h_1 – the roller depth penetration, [m];

h_2 – the clod depth penetration, [m].

Thus, the radius of the roller r_{KT} will be determined:

$$r_{KT}=r_{KM}\cdot\frac{1+\cos\delta}{1-\cos\delta}+\frac{h_1}{1-\cos\delta}-\frac{h_2}{1-\cos\delta}, \quad (3)$$

Knowing that:

$$\frac{ctg^2\delta}{2}=\frac{1+\cos\delta}{1-\cos\delta}, \quad (4)$$

We obtain:

$$r_{KT}=r_{KM}\frac{ctg^2\delta}{2}+\frac{h_1-h_2}{1-\cos\delta}, \quad (5)$$

The number of the roller slats is determined from the nature of its interaction with the soil. Rolling of the roller is accompanied by sliding. Sliding value varies along the path length. This leads to the fact that some parts of the soil are deformed in different ways. In addition, the slatted roller, in contrast to smooth rollers, affects the soil cyclically with its slats, which also leads to uneven soil deformation. The areas affected by the slats are more deformed, the areas between the slats - less. At a certain depth the deformed areas are connected by adjacent slats. Theoretically, the soil deformation should be equal at this depth, but because of roller sliding the difference in the deformation value exists.

The slat makes a rotational motion about the rotation axis of the roller at a rate ωr_{KT} (where: ω – angular rate, rad/s; r_{KT} – roller radius, m) and makes a translational motion together with the aggregate with rate v (fig. 8).

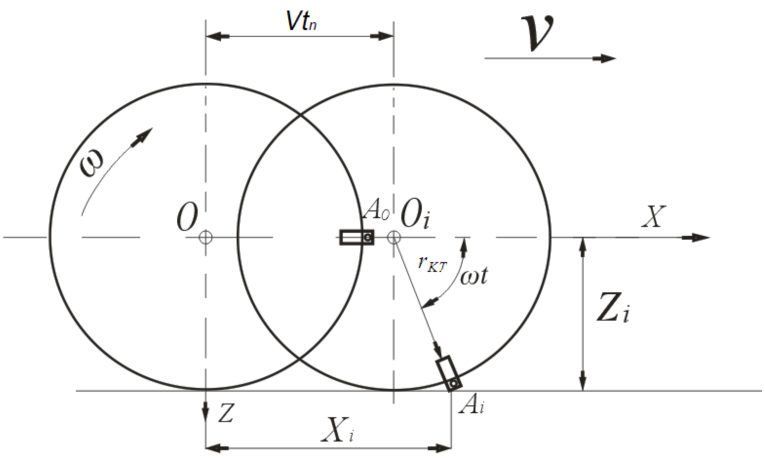

Fig. 8 - Scheme for determining the equation of the roller slat motion

Let's consider the movements of the extreme point A of the roller slat, which is at the initial moment in position A_0. After a certain period of time t the roller axis will move to the position O_i, passing the path $S_n=Vt_n$, and the roller disc will rotate by an angle ωt. As a result, point A will move from position A_0 to position A_i and its coordinates will be determined by the equations:

$$X_i=Vt_n+r_{KT}\cdot\cos\omega t, \quad (6)$$

$$Z_i=r_{KT}\cdot\sin\omega t, \quad (7)$$

The equations characterize the path of absolute motion of point A in parametric form. This path is a cycloid ("trochoid"). Any point of the roller slat describes the path of an extended cycloid in the process of work. Since several slats (8-12 pcs.) are fixed on one disc of the roller, the corresponding points of these slats describe the same cycloids, but shifted forward along the machine. So, if the previous roller slat with its furthest point from the rotation axis describes path 1 (fig. 9), the path 2 of the subsequent slat will be shifted horizontally by some distance S_n, called the feed on the slat. The feed on the slat $S_n=Vt_n$, where t_n – time, for which the subsequent slat in relative motion will take the position of the previous one, i.e. it will rotate by an angle equal to the central angle between them. The more slats on the roller disc, the less this time.

Therefore,

$$t_n = \frac{t_{do}}{n_{SL}}, \tag{8}$$

where: t_{do} – time, for which the roller disc turns by one revolution;

n_{SL} – slat number on the roller disc.

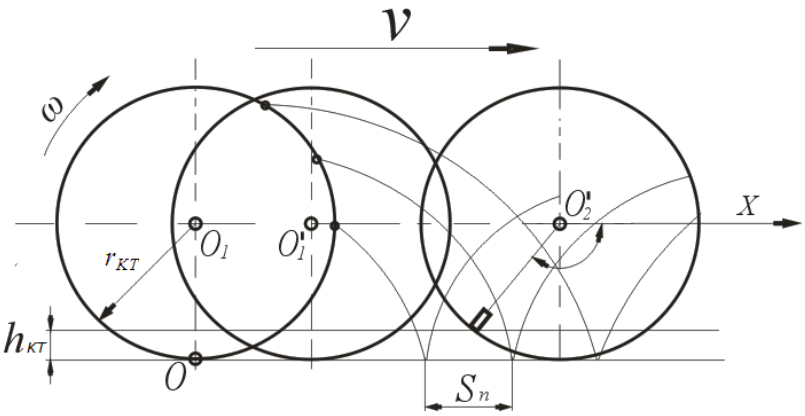

Fig. 9 - Kinematics of the roller motion

Revolution time is determined from the condition $\omega t_{do} = 2\pi$, where $t_{do} = \frac{2\pi}{\omega}$, and $t_n = \frac{2\pi}{\omega n_{SL}}$.

By substituting for t_n its value in the initial equation, we obtain:

$$S_n = \frac{\vartheta 2\pi}{\omega n_{SL}}, \tag{9}$$

where: ϑ – translation rate of aggregate.

The uniformity of compaction of the lower layers and loosening of the upper soil layer depends on the value S_n. The soil deformation area is determined by one slat.

The roller slat penetrates the soil at the rotation angle α_1, which corresponds to the time t_1, and comes out of the soil at the rotation angle α_2, which corresponds to the time t_2, (fig. 10). From the figure, we define the angles of input α_1 and output α_2.

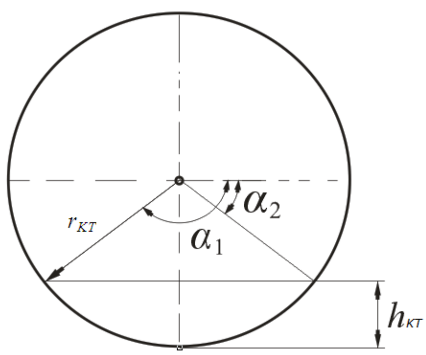

Fig. 10 - Scheme for determining angles α_1 and α_2

From the equation:

$$\frac{r_{KT}-h_{KT}}{r_{KT}}=\sin\alpha_1, \tag{10}$$

$$\alpha_1=\arcsin\frac{r_{KT}-h_{KT}}{r_{KT}}, \tag{11}$$

$$\alpha_1=\pi-\alpha_1, \tag{12}$$

Then the time value:

$$t_1=\frac{\alpha_1}{\omega}=\frac{\left(\arcsin\frac{r_{KT}-h_{KT}}{r_{KT}}\right)}{\omega}, \tag{13}$$

$$t_2=\frac{\alpha_2}{\omega}=\frac{\left(\pi-\arcsin\frac{r_{KT}-h_{KT}}{r_{KT}}\right)}{\omega} \tag{14}$$

The length of the deformed soil on the field surface can be determined as difference:

$$\Delta X=X_2-X_1=v\cdot(t_2-t_1)+r_{KT}(\cos\omega t_2-\cos\omega t_1) \tag{15}$$

Substituting values t_2 and t_1 from equation (13) in (14) we obtain:

$$\Delta X=\vartheta\left(\frac{\pi-\arcsin\frac{r_{KT}-h_{KT}}{r_{KT}}}{\omega}\right)-2(r_{KT}-h_{KT}) \tag{16}$$

Then the number of slats will be:

$$n_{SL}=\frac{2\pi r_{KT}}{\vartheta\left(\frac{\pi-\arcsin\frac{r_{KT}-h_{KT}}{r_{KT}}}{\omega}\right)-2(r_{KT}-h_{KT})} \tag{17}$$

The value of the attack angle of slat γ_{SL} should meet the following requirements: to contribute to the roller load balancing with the rotation angle; to contribute to the partial smoothing of the arable land by shifting the soil. Optimal attack angle γ_{SL} will be such, at which the greatest uniformity of drum rotation in providing the soil particles sliding on the slat surface is achieved. To provide the uniformity of the slats input and output from the soil, it is necessary that at full output of one end of the slat, the other end of the slat should be completely in the soil (fig. 11).

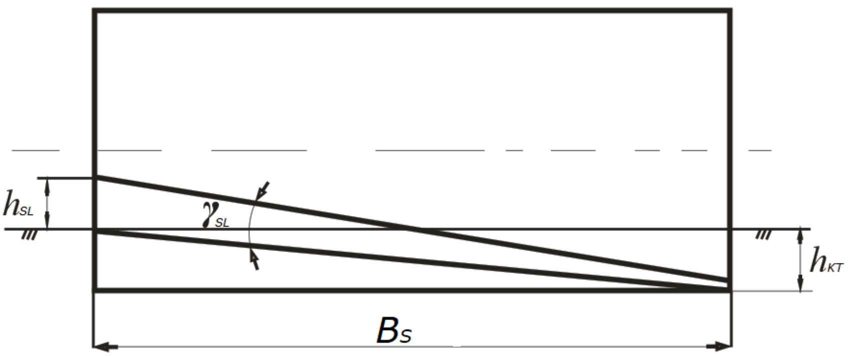

Fig. 11 - Scheme for determining the attack angle of the slat γ_{SL}

To fulfill this condition, it is necessary:

$$tg\gamma_{SL} = \frac{h_{KT} + h_{SL}}{B_S} \quad (18)$$

Where: h_{KT} – depth of the roller penetration into the soil;

h_{SL} – slat height;

B_S – width of the roller single section.

To obtain an angle γ_{SL}, the slats on the adjacent discs should be fixed with some offset by angle β_{OF}, which should be determined from equation:

$$\beta_{OF} = \arccos\frac{r_{KT} - h_{KT}}{r_{KT}} \quad (19)$$

On the other hand, to fulfil the condition of the soil displacement, the angle γ_{SL} must meet the condition:

$$\gamma_{SL} \langle \frac{\pi}{2} - \varphi_{fr} \quad (20)$$

Where: φ_{fr} – soil friction angle.

In our case γ_{SL} ≈12^0. This fully satisfies the condition of the equation (20).

Thus, on the basis of carried out researches the experimental sample of the loosening and leveling device included in the combined tool was designed and manufactured. It consists of a series of blocks of rotary tillage working bodies with multi-directional spherical blade elements and slatted rollers (fig. 12).

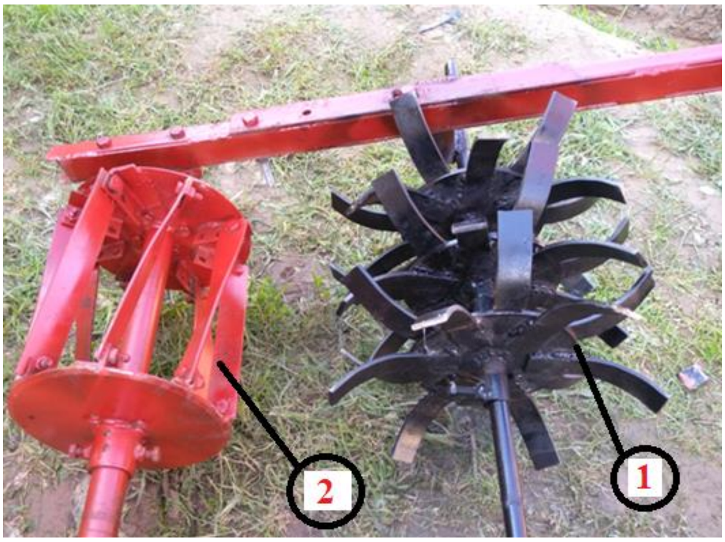

Fig. 12 - General view of the experimental loosening and leveling device for combined tillage tool
1 - rotary loosening working body with multi-directional spherical blade elements; 2 - slatted roller

CONCLUSIONS

The use of a combined tool for strip tillage for melon crops can reduce labor and energy costs by 25% and 50% respectively. This reduces the work duration, retains moisture in the soil, protects the field surface from compaction by reducing the number of passes of the aggregate and ensures high quality of technological operations.

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