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Theoretical Studies on the Justification of the Angle of Installation in Relation to the Direction of Movement of the Improved Harrow Leveller

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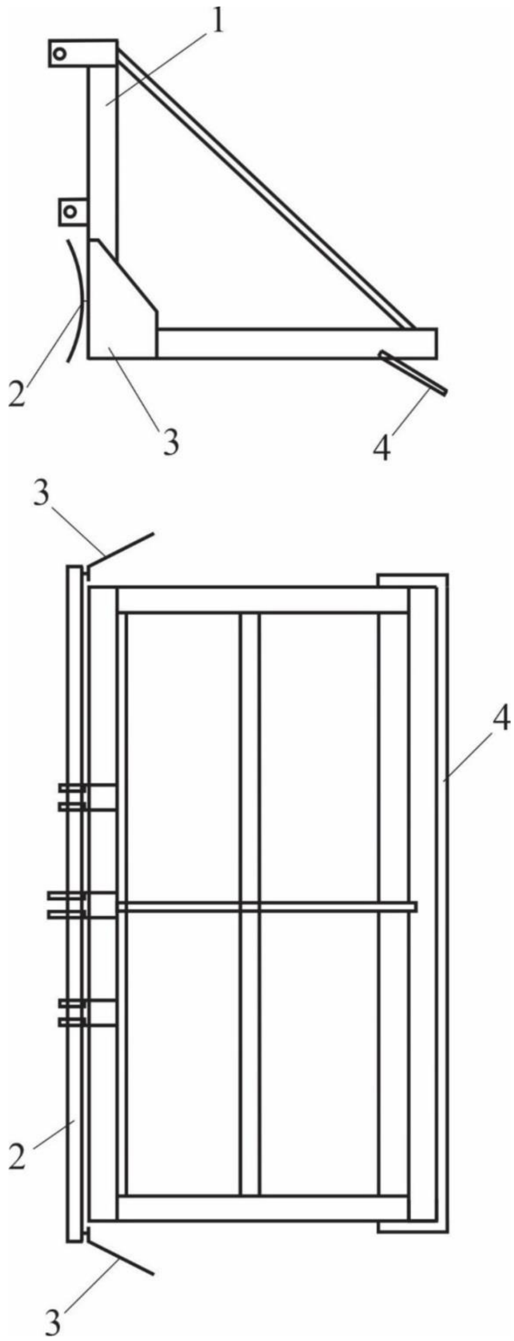
Abstract: The article presents the results of the theoretical studies on the justification of the angle of installation in relation to the direction of movement of the improved harrow leveller. According to it, in order to ensure free sliding of soil pieces along the working surface of the soil leveler, its installation angle of installation in relation to the direction of movement should be less than 55°.

Keywords: leveler, installation angle of the leveler in relation to the direction of movement, leveler with full curved surface, the resistance of the field surface to the movement of the soil.

INTRODUCTION. At the present time, the VP-8.0 pre-sowing leveler, MV-6.0, MV-6.5 and artificial harrow levellers are widely used in our country for the preparation of land for planting [1-5]. In this case, levelers level the surface of the fields, compact them as required and grind large lumps. But because they are trailers, they have low productivity, are inconvenient to use, and do not meet the requirements of minimum and economical tillage. Based on the above, a comprehensive suspension leveler was developed at SRIAM, which improved the work process [6-10]. The conducted tests showed that during the working process, the piled soil in front of the leveler of this harrow leveller is spilled to the side, and piles of soil are formed on both sides of it. To level these piles of soil, we have developed an improved harrow leveller (Fig. 1).

This article presents the results of theoretical studies on the justification of the angle of installation in relation to the direction of movement of the improved harrow leveller.



1-a frame equipped with a suspension device; 2-full curved surface leveler; 3-soil leveler; 4-compactor

Figure 1. Construction scheme of a grinder-leveler equipped with a leveler with a full curved surface and a soil leveler

Materials and methods. The pile of soil formed by the spilling of the soil piled in front of the leveler to its side is leveled by the soil leveler by leveling it to the side. Based on this, we determine the installation angle of the soil leveler in relation to the direction of movement on the condition that it scatters the soil pieces to the side to the maximum distance. For this purpose, we study the movement of soil particles under the influence of a soil leveler and after separation from it [11] (Fig. 2). During the movement of the soil leveler, the piece of soil that meets it at point M_1 begins to move together with it at a speed φ_1 in the direction deviating from the normal to its working surface by the angle of friction $V_a = \dfrac{V \sin \gamma_{TYo}}{\cos \varphi_1}$, and after some time it separates from it at point M_2 and V_a continues its motion along the surface of the field with the initial velocity and stops at point M_3. A piece of soil travels a distance L after it is separated from the soil leveler until it stops moving. To determine this distance, the differential equation of the movement of a piece of soil on the field surface along the V_a direction, that is, along the X axis, is created. It will look like this:

$$m\frac{d^2X}{dt^2} = -F, \qquad (1)$$

where m – the mass of a piece of soil, kg; t – time, s; F – the resistance of the field surface to the movement of the soil, N.

The movement of a piece of soil is caused by the force of its friction on the field surface $F = f_T mg$ (where f_T – the soil-to-soil friction coefficient; g – the acceleration of free fall, m/s^2). Taking this into account, expression (1) becomes:

$$m\frac{d^2X}{dt^2} = -f_T mg. \qquad (2)$$

Reducing both sides of this equation to m and integrating, we get:

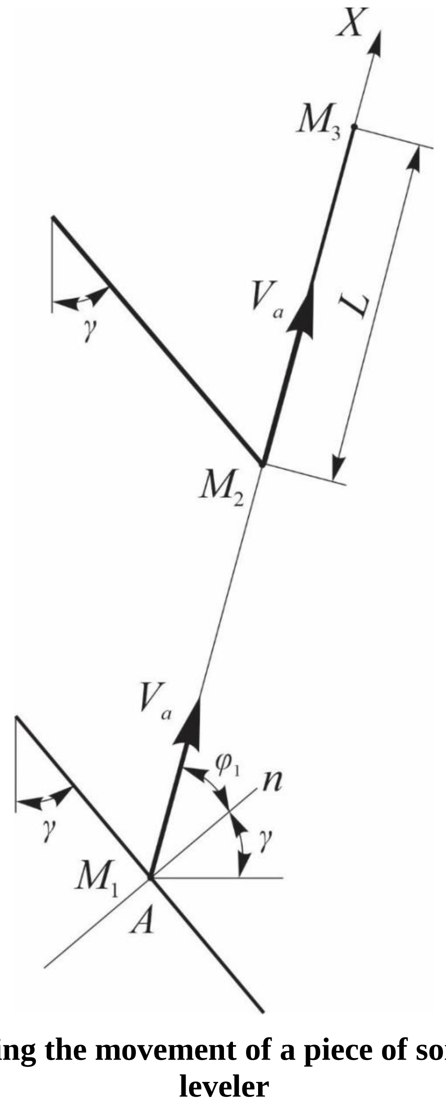


Figure 2. A scheme for studying the movement of a piece of soil under the influence of a soil leveler

$$V_X = -f_T gt + C_1 \quad (3)$$

and

$$X = -f_T g \frac{t^2}{2} + C_1 t + C_2, \quad (4)$$

where C_1, C_2 – are integration constants.

We determine the integration constants C_1 and C_2 using the following initial conditions: $V_X = V_a = \frac{V \sin \gamma_{TYo}}{\cos \varphi_1}$ and $X = 0$ in $t = 0$. Substituting these into equations (3) and (4) we find that they are $C_1 = \frac{V \sin \gamma_{TYo}}{\cos \varphi_1}$ and $C_2 = 0$. Given these determined values of C_1 and C_2, expressions (3) and (4) become:

$$V_X = V \frac{\sin \gamma_{TYo}}{\cos \varphi_1} - f_T gt \quad (5)$$

and

$$X = Vt \frac{\sin \gamma_{TYo}}{\cos \varphi_1} - f_T g \frac{t^2}{2}. \quad (6)$$

Taking into account that the final speed of the piece of soil is zero, from (6) we find the time of its movement after separation from the soil leveler:

$$t = \frac{V \sin \gamma_{TYo}}{f_T g \cos \varphi_1}. \quad (7)$$

Putting this value of t in (6), we determine the distance traveled by the piece of soil after separation from the soil leveler:

$$L = \frac{V^2 \sin^2 \gamma_{TYo}}{2 f_T g \cos^2 \varphi_1}. \quad (8)$$

This expression is the lateral spread distance of the soil

$$L_{Yo} = \frac{V^2 \sin^2 \gamma_{TYo}}{2 f_T g \cos^2 \varphi_1} \cos\left(\gamma_{TYo} + \varphi_1\right). \quad (9)$$

As can be seen from this expression, the distance of the soil fragments to the side depends on the speed of movement, the installation angle of the soil leveler in relation to the direction of movement, and the friction coefficient of the soil on the soil and the angle of friction of the soil on the working surface of the soil leveler.

According to expression (9), increasing the speed of movement and decreasing the coefficient of soil-to-soil friction leads to an increase in the distance of soil leveling to the side.

But according to this expression, the angles of installation and friction of the soil to its working surface in relation to the direction of movement of the soil leveler, that is, the effect of γ_{TYo} and φ_1 on the lateral scattering distance of the soil cannot be directly estimated.

In order to evaluate the effect of angles γ_{TYo} and φ_1 on the lateral scattering distance of the soil, we plot the graphs of the change of L_{Yo} depending on γ_{TYo} and φ_1 according to the expression (9) (Fig. 3).

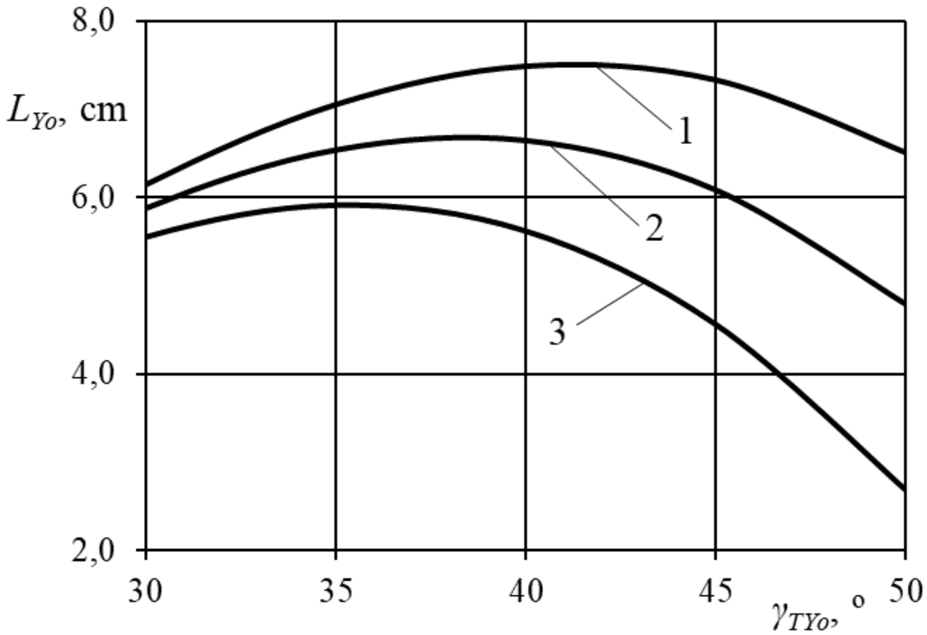
The analysis of the graphical connections presented in Figure 3 shows that at all values of the friction angle, the distance of leveling the soil to the side changed according to the convex parabola law depending on the installation angle of the soil leveler in relation to the direction of movement, that is, it first increased and then decreased. As the angle of soil friction increases, the distance of soil leveling to the side decreases.

We determine the values of the installation angle of the soil leveler in relation to the direction of movement, which ensure the maximum distance of the soil leveling to the side. For this, expression (9) is derived by γ_{TYo} and the obtained result is set to zero [12]:

$$\frac{V^2}{2 f_T g \cos\varphi_1}\left[\sin^2\gamma_{TYo}\left(-\sin\left(\gamma_{TYo}+\varphi_1\right)\right)+\right.$$

$$\left.+2\sin\gamma_{TYo}\cos\gamma_{TYo}\cos\left(\gamma_{TYo}+\varphi_1\right)\right]=0. \qquad (10)$$

In this expression, only the expression in the middle parenthesis can be zero, that is:



1 – φ_1 = 25°; 2 – φ_1 = 30°; 3 – φ_1 = 35°

Figure 3. Graphs of change of L_{Yo} depending on γ_{TYo} at different values of φ_1

$$\sin^2\gamma_{TYo}\left(-\sin\left(\gamma_{TYo}+\varphi_1\right)\right)+2\sin\gamma_{TYo}\cos\gamma_{TYo}\cos\left(\gamma_{TYo}+\varphi_1\right)=0. \qquad (11)$$

Let both sides of this equation be $\sin\gamma_{TYo}$, and write it in the following form:

$$2\cos\gamma_{TYo}\cos\left(\gamma_{TYo}+\varphi_1\right)-\sin\gamma_{TYo}\sin\left(\gamma_{TYo}+\varphi_1\right)=0. \qquad (12)$$

Using the rules known from trigonometry [13], we make $\cos\gamma_{TYo}\cos(\gamma_{TYo}+\varphi_1)$ and $\sin\gamma_{TYo}\sin(\gamma_{TYo}+\varphi_1)$ in expression (12) look like this:

$$\cos\gamma_{TYo}\cos(\gamma_{TYo}+\varphi_1)=\frac{1}{2}\left[\cos(\gamma_{TYo}+\varphi_1-\gamma_{TYo})+\cos(\gamma_{TYo}+\varphi_1+\gamma_{TYo})\right]=$$

$$=\frac{1}{2}\left[\cos\varphi_1+\cos(2\gamma_{TYo}+\varphi_1)\right] \qquad (13)$$

$$\sin\gamma_{TYo}\sin(\gamma_{TYo}+\varphi_1)=\frac{1}{2}\left[\cos(\gamma_{TYo}+\varphi_1-\gamma_{TYo})-\cos(\gamma_{TYo}+\varphi_1+\gamma_{TYo})\right]=$$

$$=\frac{1}{2}\left[\cos\varphi_1-\cos(2\gamma_{TYo}+\varphi_1)\right] \qquad (14)$$

Taking into account these obtained results, the expression (12) will have the following form:

$$\cos\varphi_1+\cos(2\gamma_{TYo}+\varphi_1)-\frac{1}{2}\left[\cos\varphi_1-\cos(2\gamma_{TYo}+\varphi_1)\right]=0; \qquad (15)$$

or

$$3\cos(2\gamma_{TYo}+\varphi_1)+\cos\varphi_1=0. \qquad (16)$$

From this

$$\gamma_{TYo}=\frac{1}{2}\left[\arccos\left(-\frac{1}{3}\cos\varphi_1\right)-\varphi_1\right]. \qquad (17)$$

it follows that.

Results and discussion. By putting φ_1 in the expression (17) the values known from the literature (25-35°) [14, 15], we determine that the installation angle of the soil leveler should be in the range of 35-41° in relation to the direction of movement in order to maximize the leveling of the soil to the side. Comparing these data with the data presented in Figure 3, we see that they are in perfect agreement with each other.

So, according to the conducted studies, the installation angle of the soil leveler should be in the range of 35-41° in relation to the direction of movement.

During the working process of the soil leveler, it is necessary to ensure free sliding of soil pieces along its working surface so that the soil does not stick to its working surface and the soil does not accumulate in front of it. This is ensured when the following condition is met:

$$\gamma_{TYo}=90-\varphi_1. \qquad (18)$$

Conclusion. Putting the above values of φ_1 in this expression, we determine that the angle of its installation in relation to the direction of movement should be less than 55° in order to ensure free sliding of soil pieces along the working surface of the leveler. Therefore, the soil leveler fully satisfies the condition that the soil leveler can freely slide along the working surface, provided that the distance of leveling the soil to the side is maximum.

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