Theoretical Substantiation of the Angle of Mounting a Flat Ridge-Forming Disc of a Row Crop Cultivator

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Abstract. The authors have developed a row-crop cultivator equipped with a ridge former, which allows performing high-quality operations of row crop cultivation in one pass. The inter row cultivation is carried out with a row-crop cultivator, on each section of which two ridge formers are mounted so that their flat discs are directed towards the row of plants at an acute angle, and the extreme edges of the wings of the V-shaped sweeps are located at the lower base of the soil ridge. When the row-crop cultivator moves, the V-shaped sweeps loosen the soil to the required depth and cut the weeds, and the flat discs move the soil layer coming off the wings of the V-shaped sweeps towards the rows of plants, hilling them and burying the weeds. In the presented article, the authors theoretically substantiate the angle of attack of a flat disc for burying weeds with a layer of soil of the required thickness. It was found that the angle of attack depends on the radius of the flat disc and the depth of its movement in the soil, the initial dimensions of the ridge and the physical and mechanical properties of the soil.

1 Introduction

Cultivating row crops according to the traditional cultivation technology provides for two or three times of inter row cultivation with row-crop cultivators that have special working bodies or spraying with chemical solutions - herbicides. The width of the protective zone is

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increased with each subsequent tillage, as a result, the uncultivated area along the cultivated plants increases. The use of herbicides, in addition to the positive advantage - the elimination of weeds by 70 ... 80 %, has a negative side - a decrease in the yield of cultivated plants up to 15 % [1, 2, 3, 4, 5, 6].

2 Objects and methods of research

To eliminate the aforementioned disadvantages, the authors have devised a cultivation method [7] and technical means for row crop tending [8, 9, 10]. The proposed technical means provide loosening of the soil, destruction of weeds between rows and in protective zones along the rows of cultivated plants without the use of herbicides that cause great environmental contamination. With this method of crop tending, it is enough to perform one or two mechanized tillage operations of row spacings.

Row spacings are tilled with a special row-crop cultivator (Fig. 1), on each section of which two ridge-formers are mounted in such a way that their flat discs are directed towards the rows of cultivated plants at an acute angle (Fig. 2).

Fig. 1. Row-crop cultivator
When the row-crop cultivator moves, the V-shaped sweeps 1 loosen the soil to the required depth and cut the weeds, and the flat discs 2 move the soil layer coming off the wings of the sweeps towards the rows of cultivated plants, thereby hilling cultivated plants and covering weeds.

### 3 Research results

Hilling of cultivated plants is carried out by pushing the soil volume $V_i$, m$^3$, with each flat disc (Fig. 3a) from the row spacing to the soil ridge. After the soil is moved to the top of the ridge, it partially falls down at an angle of natural slope of the soil ridge $\gamma$, deg., which, depending on the physical and mechanical properties of the soil, ranges from 26° to 40° (angle $B_1A_1D_1$ of the figure $A_1B_1E_1D_1$). The thickness of the layer $h_1$, m, on the soil ridge depends on the angle of attack $\alpha$, deg., flat discs, as well as the depth $h$, m, their travel in the soil (Fig. 3b).
Summarizing the above calculations, we can conclude that for burying weeds and hilling cultivated plants, it is required that the volume of soil $V_1$, m$^3$, which should be moved to the original ridge of the soil, be equal to the volume of soil in the formed secondary ridge $V_2$, m$^3$,

$$V_1 = V_2. \quad (1)$$

To determine the volume of soil $V_1$, m$^3$, transferred to the top of the initial ridge formed by a flat disc, we use Fig. four.
Fig. 4. Determination of the shifted volume of the soil depending on the angle of attack $\alpha$ of a flat disc.

The volume of the soil, $m^3$, shifted by one flat disc at the angle of attack $\alpha$,

$$V_1 = 0.5 \frac{S_{IQG}}{Q} \frac{G}{I} = 0.5 S_{IQG} \ell, $$  \hspace{1cm} (2)$$

where $S_{IQG}$ – cross-sectional area of the furrow formed after the passage of the working body of a ridge planter with a flat disc, $m^2$; $\ell = GI$ - path travelled by a flat disc per unit of time, m.

From Fig. 3a it follows that the distance:

$$\ell = UZ \cdot \cos \alpha, $$  \hspace{1cm} (3)$$

where $UZ$ – chord of a flat disc, m.

The chord of a flat disc:

$$UZ = 2 r_{na} \sin \frac{\theta}{2}, $$  \hspace{1cm} (4)$$

where $r_{na}$ – radius of a flat disc, m.

Having substituted expression (4) in (3) we get:

$$\ell = 2 r_{na} \sin \frac{\theta}{2} \cdot \cos \alpha. $$  \hspace{1cm} (5)$$

The area

$$S_{IQG} = S_{UWZ} \cdot \sin \alpha, $$  \hspace{1cm} (6)$$

where $S_{UWZ}$ – contact area of a flat disc with the soil, $m^2$.

The contact area of a flat disc with the soil, $m^2$,

$$S_{UWZ} = S_{OUWZ} - S_{OUZ}, $$  \hspace{1cm} (7)$$

where $S_{OUWZ}$ – area of the flat disc sector, $m^2$; $S_{OUZ}$ – area of the triangle $\triangle OUZ$, $m^2$. 
The area, m$^2$, of the flat disc sector

$$S_{OUWZ} = 0.5 r_{\text{na}}^2 \frac{\theta}{360}. \quad (8)$$

From Fig. 3a it follows that the triangle $\Delta OUZ$ – is isosceles, consequently:

$$S_{OUZ} = 2 S_{OUT} = 2 \cdot 0.5 \, UT \cdot TO = UT \cdot TO. \quad (9)$$

$$UT = 0.5 \, UZ = 0.5 \cdot 2 \, r_{\text{na}} \sin \frac{\theta}{2} = r_{\text{na}} \sin \frac{\theta}{2}. \quad (10)$$

$$TO = OW - TW = r_{\text{na}} - h. \quad (11)$$

Having substituted (10) and (11) into (9), we get

$$S_{OUZ} = r_{\text{na}} \sin \frac{\theta}{2} (r_{\text{na}} - h). \quad (12)$$

Having substituted (8) and (12) into (7), we determine the area of contact of a flat disc with the soil:

$$S_{UWZ} = 0.5 r_{\text{na}}^2 \frac{\theta}{360} - r_{\text{na}} \sin \frac{\theta}{2} (r_{\text{na}} - h). \quad (13)$$

Substituting (13) into (6), we determine the cross-section area of the furrow (Fig. 4):

$$S_{IQG} = [0.5 r_{\text{na}}^2 \frac{\theta}{360} - r_{\text{na}} \sin \frac{\theta}{2} (r_{\text{na}} - h)] \sin \alpha. \quad (14)$$

By substituting expressions (5) and (14) into (2), and making the appropriate transformations, we obtain:

$$V_1 = \left[ 0.5 r_{\text{na}}^2 \frac{\theta}{360} - r_{\text{na}} \sin \frac{\theta}{2} (r_{\text{na}} - h) \right] \cdot 2 r_{\text{na}} \sin \frac{\theta}{2} \sin \alpha \cdot \cos \alpha. \quad (15)$$

The formed volume of the soil, m$^3$,

$$V_2 = V_{A1B1C1CBA} = S_{A1B1C1CBA} \cdot C_1 P_1, \quad (16)$$

where $S_{A1B1C1CBA}$ – cross-section area of the soil layer made by one flat disc, m$^2$.

From Fig. 4 it follows that $II = \ell$. In view of expression (5)

$$C_1 P_1 = II = \ell = 2 r_{\text{na}} \sin \frac{\theta}{2} \cdot \cos \alpha. \quad (17)$$

The area $S_{A1B1C1CBA}$ to be sought we will determine in the following way:

$$S_{A1B1C1CBA} = S_{A1B1C1C'} A1 - S_{A1B1C'B'}, \quad (18)$$

where $S_{A1B1C1C'} A1$ – area of a half of the cross-section of the secondary soil ridge, m$^2$; $S_{A1B1C'B'}$ – area of a half of the cross-section of the initial soil ridge, m$^2$.

We will represent the area $S_{A1B1C1C'/A1}$ in the form of two areas – a triangle and a rectangle:

$$S_{A1B1C1C'/A1} = S_{A1B1B'/C} + S_{B1'B1C'C'}. \quad (19)$$

The area of a triangle, m$^2$, ...
where \(B_1B_1' = H + h_1, \text{ m}; H – \text{height of the initial soil ridge, m.}\)

\[A_1B_1' = B_1B_1' \tan \gamma = (H + h_1) \tan \gamma.\]  

By substituting (21) into (20), and, having made the corresponding transformations, we obtain:

\[S_{A_1B_1B_1'} = \frac{(H + h_1)^2 \tan \gamma}{2}.\]

The area of a rectangle, m\(^2\),

\[S_{B_1' B_1 C_1' C_1'} = B_1B_1' \cdot B_1C_1.\]

From Fig. 4 it follows that

\[B_1C_1 = B_1Y + YC_1 = \frac{h_1}{\tan \gamma} + \frac{F}{2},\]

where \(F – \text{width of the top of the soil ridge, m.}\)

Substituting the obtained value in (23) and performing the appropriate transformations, we get:

\[S_{B_1' B_1 C_1' C_1'} = \frac{h_1(H + h_1)}{\tan \gamma} + \frac{F}{2}.\]

Substituting (22) and (25) into (19), and by performing the appropriate transformations, we obtain:

\[S_{A_1B_1C_1'C_1'/A_1} = \frac{(H + h_1)^2 \tan \gamma}{2} + \left(H + h_1 \left( \frac{h_1}{\tan \gamma} + \frac{F}{2} \right) \right).\]

We will represent the area \(S_{A_1B_1C_1'C_1'}\) in the form of two areas – a triangle and a rectangle:

\[S_{A_1B_1C_1'C_1'} = S_{A_1B_1B_1'} + S_{B_1'B_1C_1'C_1'}.\]

The area of the triangle, m\(^2\),

\[S_{A_1B_1B_1'} = \frac{BB' \cdot AB'}{2},\]

where \(BB' = H, \text{ m.}\)

\[AB' = BB' \tan \gamma = H \tan \gamma.\]
After substituting (29) into (28), and corresponding transformations, we will obtain:

$$S_{A1B1C1CBA} = \frac{(H + h_1)^2 \tan \gamma + 2 \left( H + h_1 \left( \frac{h}{\tan \gamma} + \frac{F}{2} \right) \right) - H(H \tan \gamma + F)}{2}.$$  

(30)

Substituting (30) and (17) in (16), and performing the appropriate transformations, we determine the volume of soil, m$^3$, obtained after moving it to the ridge with one disc:

$$V_2 = \left( (H + h_1)^2 \tan \gamma + 2 \left( H + h_1 \left( \frac{h}{\tan \gamma} + \frac{F}{2} \right) \right) - H(H \tan \gamma + F) \right) \cdot r_{\text{na}} \sin \frac{\theta}{2} \cdot \cos \alpha.$$  

(31)

To determine the required angle of attack $\alpha$, deg., of a flat disc, we equate expression (15) to (31):

$$\left[ 0,5 \ r_{\text{na}}^2 \frac{\theta}{360^\circ} - r_{\text{na}} \sin \frac{\theta}{2} (r_{\text{na}} - h) \right] \cdot 2 \ r_{\text{na}} \sin \frac{\theta}{2} \sin \alpha \cdot \cos \alpha =$$

$$= \left( (H + h_1)^2 \tan \gamma + 2 \left( H + h_1 \left( \frac{h}{\tan \gamma} + \frac{F}{2} \right) \right) - H(H \tan \gamma + F) \right) \cdot r_{\text{na}} \sin \frac{\theta}{2} \cdot \cos \alpha.$$  

(32)

Making transformations of equation (32), we will determine the angle of attack of a flat disc:

$$\alpha = \arcsin \frac{\left( (H + h_1)^2 \tan \gamma + 2 \left( H + h_1 \left( \frac{h}{\tan \gamma} + \frac{F}{2} \right) \right) - H(H \tan \gamma + F) \right)}{2 \left[ 0,5 \ r_{\text{na}}^2 \frac{\theta}{360^\circ} - r_{\text{na}} \sin \frac{\theta}{2} (r_{\text{na}} - h) \right]}.$$  

(33)

4 Conclusion

Thus, to create a secondary ridge with the required thickness of the soil layer $h_1$, it is necessary to mount a flat disc at an angle of attack $\alpha$, which, given the dimensions of the initial soil ridge $F$ and $H$ and the angle of natural slope of the soil $\gamma$, depends on the radius of the flat disc $r_{\text{na}}$ and the depth of its travel in the soil $h$.

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