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Substantiation of the disk soil-cultivating tool parameters for all forms of farming

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Abstract. Increasing soil fertility is provided by the introduction of perfect disk tillage implements. This study is aimed at optimizing the parameters of disk tillage implements, taking into account the peculiarities of interaction between the working elements and the soil-soil on the condition of tillage on the stubble. In this case, it is taken into account that the disc working tool must be well adapted to heavy soils. Despite the diversity of solved problems in determining the geometric shape of disk implements designed to work on heavy soils, still not enough justified parameters of the disk working body. Therefore, this paper establishes the dependence of disc parameters on the depth of working the soil, taking into account the friction forces to ensure the condition of clamping of the material. Theoretical studies allow us to establish the relationship of disc parameters with soil treatment modes to ensure sustainable operation. Particularly, the influence of the shape of disk working organ on providing conditions of sliding cutting is revealed. Formulas for determining the parameters of the disk tillage tool and the method of its calculation can find practical use in the development of the working body in the factory conditions.

1 Introduction

The improvement of any machine associated with the cultivation of the soil is unthinkable without taking into account the physical and mechanical properties of the treated medium. The degree of looseness, the creation of lumps of a given size by the tillage tool, forms a different ratio of the soil phases – solid, liquid and gaseous. The structure of the soil is characterized by the volume weight and the value of the ratio between capillary and non-capillary boreholes.

The analysis of the results of studies of the physical and mechanical properties of the Kuban soil indicates that the working body of the tillage tool should be well adapted to heavy, sticky, over-watered and having powerful sod soils.

Only a rotary machine can handle this task.

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2 Materials and methods

The rotary disk tillage unit under study is designed for cultivating the soil on stubble. A stable technological process when cultivating the soil on stubble is achieved in the absence of vegetation accumulation in front of the disk, which is achieved by pinching the plants between the blade of the disk and the soil surface. The angle of pinching depends, in turn, on the radius r of the disk and the depth h of tillage [1, 2]. When the radius of the disk decreases, a stable pinching of the material is achieved. To justify the size of the disk, we determine the set of $I_з$ values of the radius of the disk, at which the pinching condition is me

$$R \geq R_з , \tag{1}$$

where $R_з$ – the minimum value of the disk radius for the specified processing depth H when the pinching condition is met.

We find the set I_c with acceptable values of the radius of the disk from the condition for ensuring sliding cutting:

$$R \leq R_c , \tag{2}$$

where R_c – the maximum value of the disk radius for a given processing depth H when the sliding cutting condition is met.

The set of I possible values of R lies between the limit values of $R_з$ and R_c, i.e. it is the intersection of the sets $I_з$ and I_c:

$$I = I_з \cap I_c . \tag{3}$$

We determine the conditions for pinching the particle between the blade of the disk and the surface of the soil.

The particle located between the disc blade and the soil surface at the point O is affected by the following forces: N – the normal reaction of the blade, F_m – the friction force of the blade, N_g – the normal reaction of the soil, F_g – the friction force of the soil (Figure 1). In Figure 1, AB – the tangent to the blade of the disk at the point O, which is the intersection point of the circle of the blade of the disk with the surface of the field.

The frictional forces are related to the corresponding normal reactions by the relations:

$$F_m = N \cdot tg\varphi_m ; \tag{4}$$

$$F_g = N_g \cdot tg\varphi_1 , \tag{5}$$

where φm – the angle of friction of the particle on the blade of the disc;
φ1 – the angle of friction of the particle on the surface of the field.

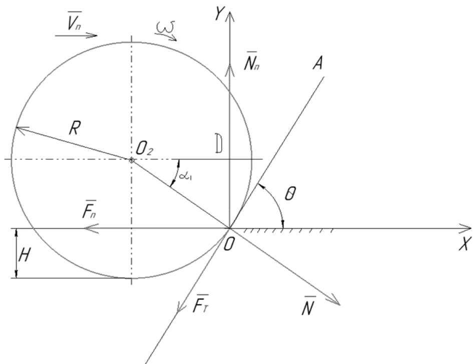

Fig. 1. Determination of pinching conditions.

When the DRPA is working, the field surface is always covered with particles of various materials. The forces acting on the particle form a flat system that is arranged at one point.

The equilibrium conditions in the projections on the coordinate axes of the *XOY* coordinate system have the form:

$$\sum X_i = N \cdot sin\left(\theta - F_g - F_m\right) \cdot sin\,\theta = 0\,; \tag{6}$$

$$\sum Y_i = N_{\varPi} - F_m \cdot sin\left(\theta - N_g\right) \cdot cos\,\theta = 0\,. \tag{7}$$

In order for the particle not to be pushed out, it is necessary that the sum of the projections on the coordinate axis *OX* of all the forces acting on the particle be non-positive, so the condition must be met:

$$F_g + F_m \cdot cos\,\theta \geq N \cdot sin\,\theta\,. \tag{8}$$

We express the friction forces in terms of the normal forces and the corresponding friction angles:

$$N_g \cdot tg\varphi_1 + N \cdot tg\varphi_m \cdot cos\,\theta \geq N \cdot sin\,\theta\,. \tag{9}$$

From equation (7), we express N_g:

$$N_g = F_m \cdot sin\,\theta + N_{\varPi} \cdot cos\,\theta\,, \tag{10}$$

and substitute the resulting expression in the formula (9):

$$\left(F_m \cdot sin\,\theta + N \cdot cos\,\theta\right) \cdot tg\varphi_1 + N \cdot tg\varphi_m \cdot cos\,\theta \geq N \cdot sin\,\theta\,. \tag{11}$$

We take into account expression (4) and divide the right and left parts of the last space by $cos\,\theta$:

$$tg\varphi_m \cdot tg\varphi_1 \cdot tg\theta + tg\varphi_1 + tg\varphi_m \geq tg\theta\,; \tag{12}$$

$$\frac{tg\varphi_m + tg\varphi_1}{1 - tg\varphi_m \cdot tg\varphi_1} \geq tg\theta\,. \tag{13}$$

Finally, we obtain the condition of pinching the particle between the blade of the disk and the surface of the field:

$$\theta \leq \left(\varphi_m + \varphi_1\right). \tag{14}$$

From ΔDOO_2:

$$cos\,\theta = \frac{OB}{OO_2} = \frac{R - H}{R} = 1 - \frac{H}{R}\,. \tag{15}$$

Then

$$R = \frac{H}{1 - cos\,\theta}\,. \tag{16}$$

Given expression (14), we obtain a set of I_3 values of the radius of the disk, for which

$$R \geq \frac{H}{1 - cos\left(\varphi_m + \varphi_1\right)}\,. \tag{17}$$

Figure 2 shows the area of the coordinate plane *R-H* corresponding to the set I_3.

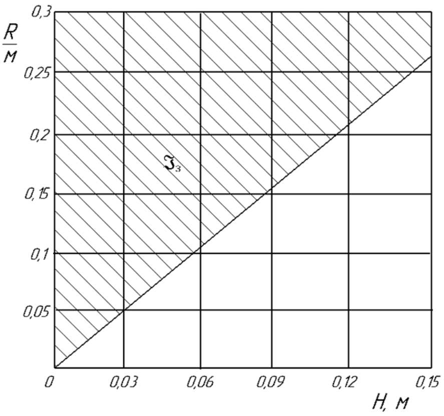

Fig. 2. The range of values of the radius of the disk, providing pinching of plant residues between the blade and the surface of the field.

We determine the conditions for cutting with sliding plant residues, pinched between the blade of the disc and the surface of the field. This condition is satisfied when the vector of the resulting cutting force goes beyond the friction cone.

Consider the limit position, when the resulting reaction of the soil coincides with the formation of the friction cone of the disc blade at the surface of the field, see Figure 3.

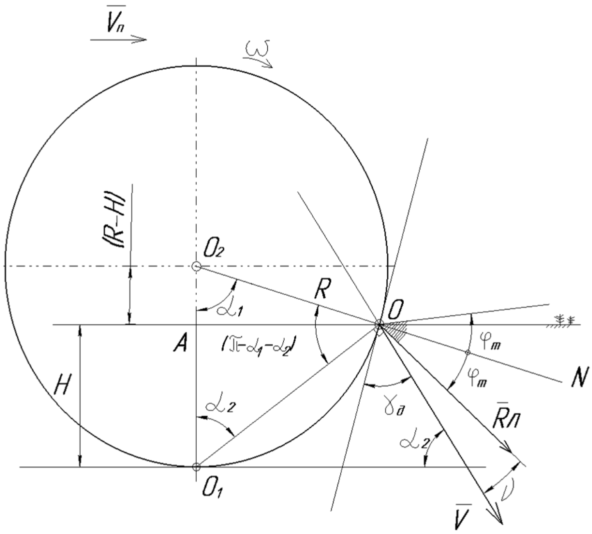

Fig. 3. Coincidence of the resulting soil reaction with the shape of the friction cone of the disc blade at the field surface

From *ΔAOO₂*:

$$AO = \sqrt{OO_2^{\,2} - AO_2^{\,2}} = \sqrt{H \cdot (2 \cdot R - H)}\ ; \tag{18}$$

$$tga_2 = \frac{AO}{AO_1} = \frac{2 \cdot R}{H} - 1\,. \tag{19}$$

Then:

$$\pi = \pi - a_1 - a_2 + \frac{\pi}{2} + v + \varphi_{m'} . \tag{20}$$

Then:

$$\frac{\pi}{2} + v + \varphi_m - a_1 - a_2 = 0 . \tag{21}$$

Taking into account the reduction formulas and the oddness of the *tg* function, expression (6) takes the form:

$$v = arctg\left(\frac{1 + f \cdot tg\left(a_1 + a_2\right)}{f - tg\left(a_1 + a_2\right)}\right). \tag{22}$$

3 Results and discussion

The last expression allows us to trace the dependence of the angle v of the deviation of the soil reaction vector on the direction of the vector of the absolute velocity of the disk blade at the field surface (Figure 4).

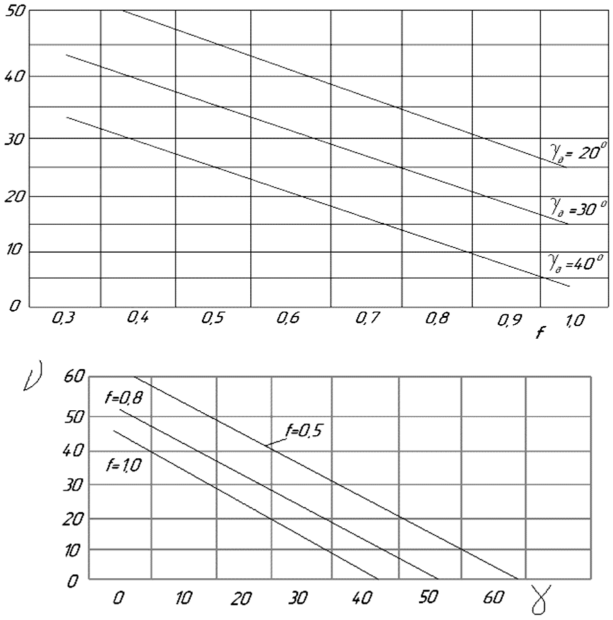

Fig. 4. The dependence of the angle V between the vectors of the soil reaction to the blade of the disc on: a) the coefficient of friction f; b) the cutting angle.

From the above graphs, it can be seen that as the depth of the disk immersion in the soil increases to the level of the disk axis, the deviation of the soil reaction vector from the direction of the absolute velocity vector decreases (Figure 4). This is due to the fact that at the points of the blade that interact with the soil at the site A_1O_1, the velocity vector approaches the normal, i.e., the cutting angle γ_d increases in the direction from the field surface at point A_1 to the bottom of the furrow at O_1. Its values have a decisive influence on the angle v, provided that the coefficient of friction is constant.

After simple transformations:

$$A=\frac{\dfrac{\sqrt{2RH-H^2\cdot(2R-H)}}{(R-H)\cdot H}+f\left(\dfrac{\sqrt{2RH-H^2}}{R-H}+\dfrac{2R}{H}-1\right)-1}{\dfrac{\sqrt{2RH-H^2}}{R-H}+\dfrac{2R}{H}-1+f\left(1-\left(\dfrac{2R}{H}-1\right)\cdot\dfrac{\sqrt{2RH-H^2}}{R-H}\right)}; \qquad (23)$$

$$f=A; \qquad (24)$$

$$f-\frac{\dfrac{\sqrt{2RH-H^2\cdot(2R-H)}}{(R-H)\cdot H}+f\left(\dfrac{\sqrt{2RH-H^2}}{R-H}+\dfrac{2R}{H}-1\right)-1}{\dfrac{\sqrt{2RH-H^2}}{R-H}+\dfrac{2R}{H}-1+f\left(1-\left(\dfrac{2R}{H}-1\right)\cdot\dfrac{\sqrt{2RH-H^2}}{R-H}\right)}=0. \qquad (25)$$

In Figure 5, the hatching shows the area corresponding to the set of disk I_c values of the disk radius, at which the sliding cutting condition is met.

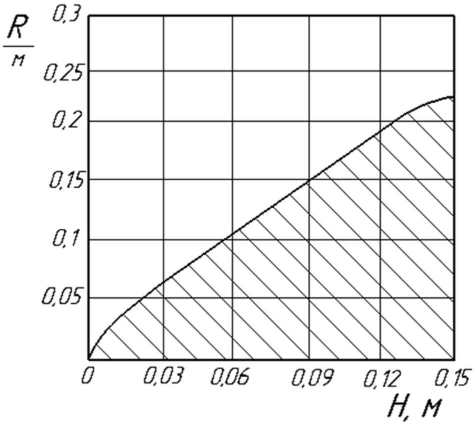

Fig. 5. The set of R values at which the sliding cutting condition is met (H = 0,13 m, f = 0,9).

The latter equation allows us to achieve two goals:

- to ensure a stable flow of the technological process of cutting vegetation particles located on the surface of the field;
- determine the maximum possible depth of treatment for disks of a given radius under given soil conditions.

4 Conclusion

The analysis of the dependencies in Figures 5 and 2 shows that the set I does not satisfy condition 3. Consequently, a smooth disk does not provide a stable technological process of tillage. Therefore, we recommend using a cut-out disc, which provides sliding cutting under the condition of pinching plant residues, cleanses them when leaving the soil and increases its fertility [3, 4, 5, 6].

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