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Interaction Model Between a Curvilinear Working Surface And Soil.

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ABSTRACT

One of the tasks of the tillage is to ensure energy supply to soil reservoir in this form, the number and sequence that provide required its State spending less energy as possible. One way to solve this problem is to break the surface of the wedge for a few consecutive wedges with small increments and thereby obtain a curved surface. On this basis, the estimated scheme and mathematical dependences describing changes speed of soil formation and profile on the curved surface of the splitting wedge from its parameters and properties of soil. The analysis of the obtained relationships.
Keywords: soil layer, wedge, working body, settlement scheme, curvilinear surface, curvature radius, angle of statement, friction coefficient.

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INTRODUCTION

It is known that all the existing working organs of soil-cultivating tools are geometrically shaped in the form of flat or curved wedges. The flat wedges include such working parts as ploughshare, knives, paws of plane cutters, harrow teeth, etc., and to curvilinear ones - spherical disks of borons, dumps of plows, hillocks, etc., as well as some racks of working bodies, for example, paws.

The process of destruction of the soil layer is based on the continuous transfer of pressure from the working part and the creation of a stress-strain state on its surface [1, 2, 3, 4]. According to the theory of strength used in soil cultivation, the main stresses are tangential and normal. The predominance of one species over other stresses determines the nature of the deformation of the soil layer, for example, by shear or separation. In the theory of soil cultivation, a two-sided (flat) and three-sided wedges are taken to study the stress-strain state of the soil environment on the surface of the working organ.

RESULTS AND DISCUSSIONS

In the general case, the design model of the process of interaction of a flat wedge with a soil environment is shown in Figure 1.

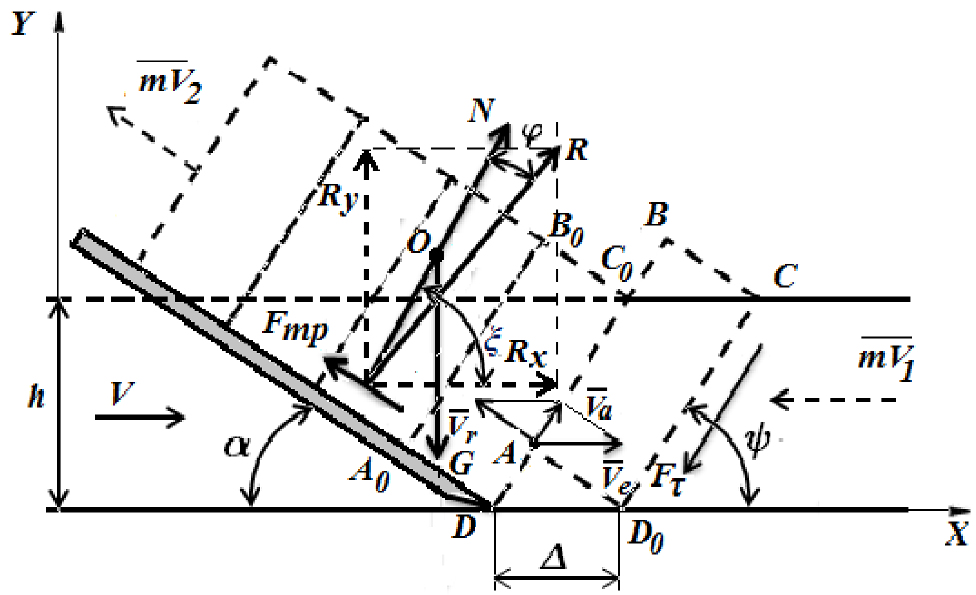

Figure 1: Calculation model of interaction flat wedge with soil

It is believed that when the wedge moves from point D to point D_0 by a distance Δ, the soil array moves from the $ABCD$ position to the position $A_0B_0C_0D_0$. First, the massif with the momentum mV_1 is pressed into the undeformed mass, and then the array with the momentum $mV_2$is condensed. The collision stress F_τ at point $D_0$is greater than at point D. As soon as the stress of the crushing exceeds the soil resistance of the shear, a shear plane AB (a crack develops) appears at the front of the wedge blade, directed at an angle ψ to the bottom of the furrow, and a prismatic soil array $A_0B_0C_0D_0$. Further, after its separation, the soil array slides over the surface of a flat wedge with a coefficient of friction f, without undergoing new deformations. The dimensions of the separated array depend on the physicomechanical properties of the soil, the thickness of the formation (depth of treatment) h and the angle α of setting the working face of the wedge to the horizontal (to the bottom of the furrow). In this case, the total elementary forces of the soil particles (arrays) acting on the part of the wedge are reduced to the resultant R, which depends on the normal reaction on the surface of the wedge N and is defined as $R = N/\cos\varphi$, where $\varphi$is the angle of external friction.

Note that to slip the soil array along the working surface of the wedge, it is necessary to satisfy the condition $\xi > \varphi$, where $\xi = \pi/2-\alpha$; φ is the angle of friction; α is the angle of installation (setting) of the working face of the wedge to the horizontal (to the bottom of the furrow). In the case when $\xi < \varphi$, the particle moves along with the wedge in the wedge motion direction.

In contrast to the generalized calculation model, it has been established by experimental studies that when the flat wedge interacts with the soil, the rate of formation of the soil form tends to infinity at some instant of time, and the inertial component of the reservoir resistance and the component associated with the change in the strain rate increase sharply. As a consequence, energy consumption for soil cultivation is increasing. At the same time, it is possible to reduce the rate of deformation of the soil layer by reducing the angle α of the wedge to the bottom of the furrow. However, with a decrease in the angle α ($\alpha_1 > \alpha_2 > \alpha_3$) at a constant treatment depth (*h-const*), the length *l* of a flat wedge, in accordance with the dependence $l = h / \sin(\alpha)$, increases ($l_1 < l_2 < l_3$) (Fig. 2). This, in turn, leads to an increase in the cost of overcoming the friction of the soil layer on the working surface of the wedge. Moreover, within the recommended angles $\alpha = 15^0 \ldots 35^0$, the length *l* of a flat wedge can decrease approximately by 2 times.

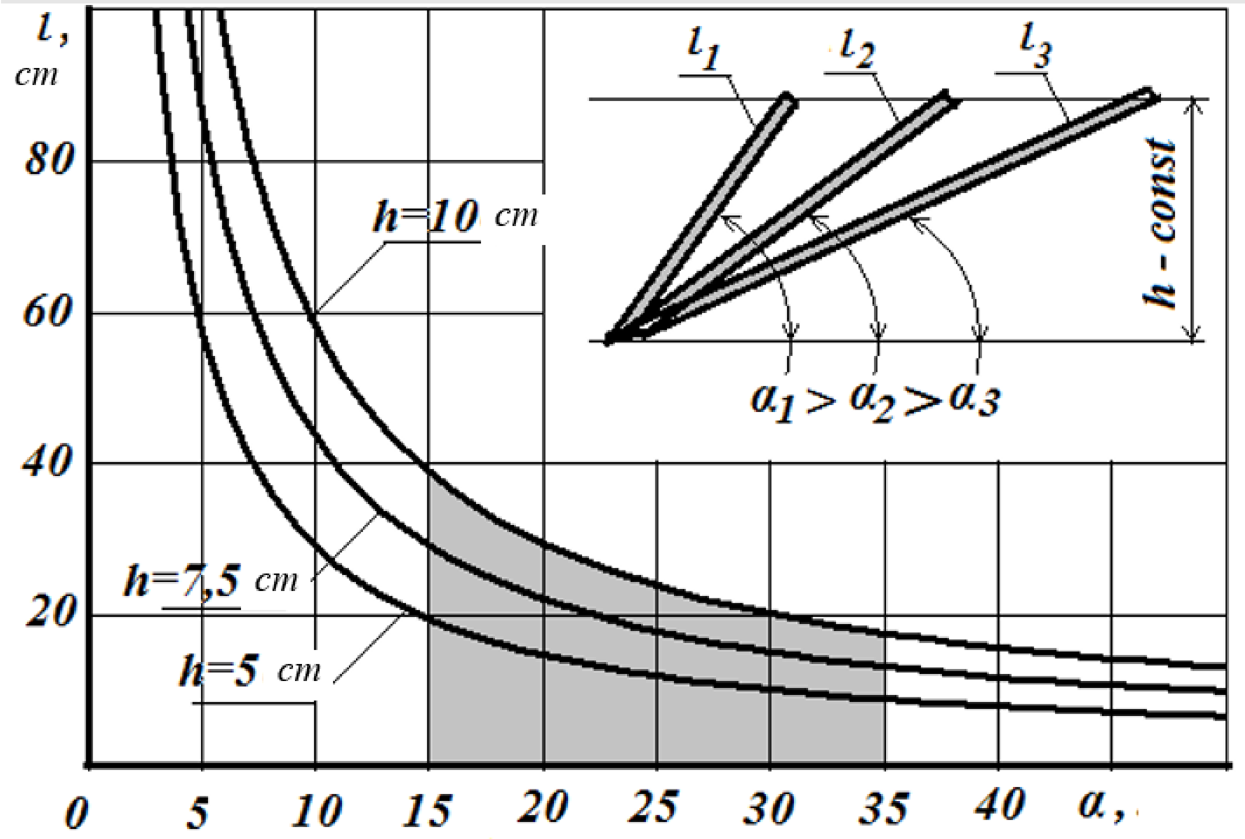

Figure 2: Dependence of the wedge length l on the angle of its setting α

Thus, it is possible to resolve the existing contradiction if the wedge surface is divided into several successive wedges with a small increment of the angle corresponding to a small increment of the deformation $\Delta\varepsilon$. Thus, according to Fig. 3, during the action of a flat wedge with an angle α_1 on a soil medium of volume *abcd*, the formation deforms upon transition to a working surface with a volume of cdc_1d_1. Further, the soil layer, moving along the flat surface of the wedge, does not experience any significant effect from the wedge. Further, the effect of a wedge with a new angle α_2 on the formation results in an intensification of the displacement of the wedge with a c_2d_2 face. Multiple sequential build-up of the initial wedge will result in the formation of a polyhedral surface $abb_1b_2 \ldots b_n$ with different angles α_n. Finally, with a sufficiently small increment ($\Delta\alpha \to 0$), the surface of the wedge from polyhedral $abb_1b_2 \ldots b_n$ becomes curvilinear, which corresponds to the continuity of the process of soil deformation.

To determine the parameters of the shape of the working element (for example, the paw joint), we consider the mathematical description of its curvilinear surface profile (Figure 4). The direction of the tangent changes as the point moves from *M* to M_1 along the curve. To measure the rate of this change, we take

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tangents at the ends of some arc and find the angle ϑ between them and divide this angle by the length ΔS of the arc MM_1. Letting point M to point M_1, we find the limit of the ratio:

$$\lim_{\Delta S \to 0} \frac{\theta}{\Delta S} = \rho \quad (1)$$

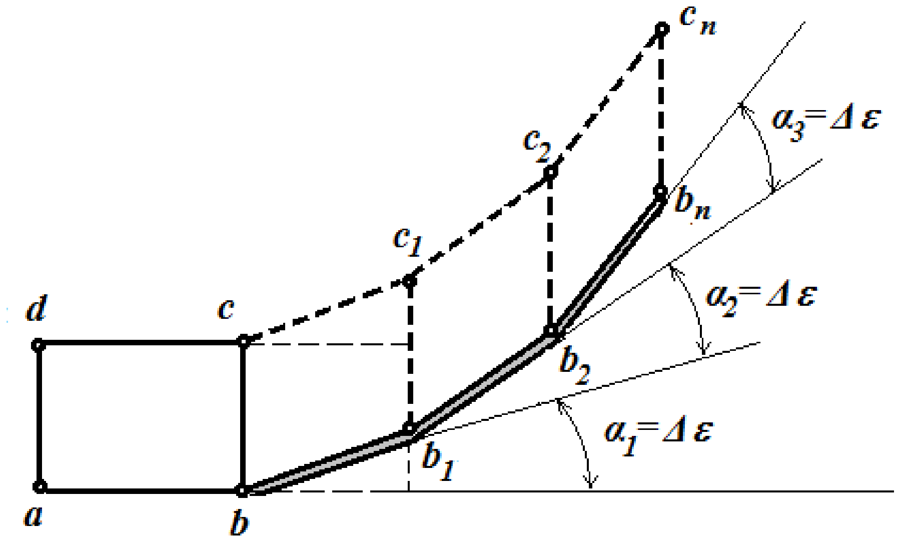

Figure 3: Scheme of deformation soil layer by a concave wedge with varying angle α_n

The quantity ρ is called the *curvature* of the curve at a given point, and it is defined as the limit of the ratio of the angle of rotation of the tangent on an arc contracting to a given point, that is, to the length of this arc. The curvature ρ coincides with the coefficient k in the Frenet-Serre formulas [5]:

$$k = \rho = \left| \frac{d\vec{\tau}}{dS} \right| = \lim_{\Delta S \to 0} \frac{|\Delta \tau|}{\Delta S} = \lim_{\Delta S \to 0} \frac{\theta}{\Delta S}, \quad (2)$$

Thus, when measuring the rate of change in the direction of the tangent, it becomes possible to estimate the curvature ρ, which shows how much the curve deviates in shape from the shape of the straight line. The greater the curvature, the stronger this deviation. The inflection point is characterized by the vanishing of the value of the second derivative $\frac{d^2Y}{dX^2}$, and at the same time the curvature, that is, the rectification point of the plane curve. The reciprocal of the *curvature* is the *radius of curvature* of the curve r:

$$\frac{1}{\rho} = r \quad (3)$$

The sign of *curvature* coincides with the sign of the derivative $\frac{d^2Y}{dX^2}$ and determines the direction of the concavity of the curve in the direction of increasing ordinates.

The unit radius of the vector $\bar{r}(t)$ of the point m with respect to some fixed point is a complex function of time $\bar{r}(t) = S(t)$. From the differential geometry, formulas are known that establish the relationships between the unit vectors of the natural axes and the vector-function of the curve:

$$\frac{d\bar{r}}{ds} = \bar{\tau}, \frac{d\bar{r}}{ds} = \frac{1}{r}\bar{n} = \rho\bar{n} \quad (4)$$

Using the definition of velocity and the Serre-Frenet formula [5], we obtain:

$$\bar{V} = \frac{d\bar{r}}{dt} = \bar{\tau} \cdot \frac{dS}{dt}; \quad \frac{d\bar{\tau}}{dS} = \frac{d\bar{\tau}}{d\theta} \cdot \frac{d\theta}{dS} \quad (5)$$

If the definition (4) is scalarly multiplied by unit vectors and the angle between them is $\pi / 2 - \theta$, then the *radius of curvature* is characterized by the parameters *V* and θ:

$$\frac{1}{r} = \frac{\dot{\theta}}{V} \quad (6)$$

When interacting with the working surface of the wedge, the soil particle acquires the velocity *V* and moves along the trajectory MM_1 (Fig. 4), which is caused by a change in the interaction angle between the velocity vector of the working surface of the wedge and the velocity vector of the soil particle. The curved wedge acts more intensively on the soil environment. Moreover, the angle α is not constant but varies within certain limits.

When the curvilinear wedge is applied to the soil with an angle α, the soil layer is deformed when going over to the working face (Figure 5). Further, moving along the face, the layer receives additional impact from the curvature of the wedge, which is given by the change in the angle *α*. Multiple successive increases in the wedge angle lead to the formation of elementary blocks that are located along the trajectory *L*. on the surface of the wedge. The deforming properties of the curved surface depend on the nature of the changes in the indicated angles *α* and θ. Moreover, the thickness of the formation before the wedge *h* is greater than on the wedge h_k. With decreasing curvature of the wedge surface, the value of h_k decreases.

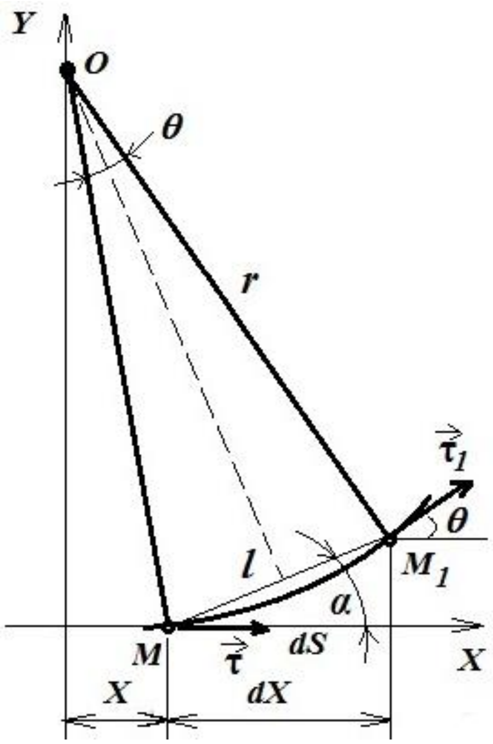

Figure 4: Scheme for analyzing the shape of the longitudinal profile of the wedge working surface

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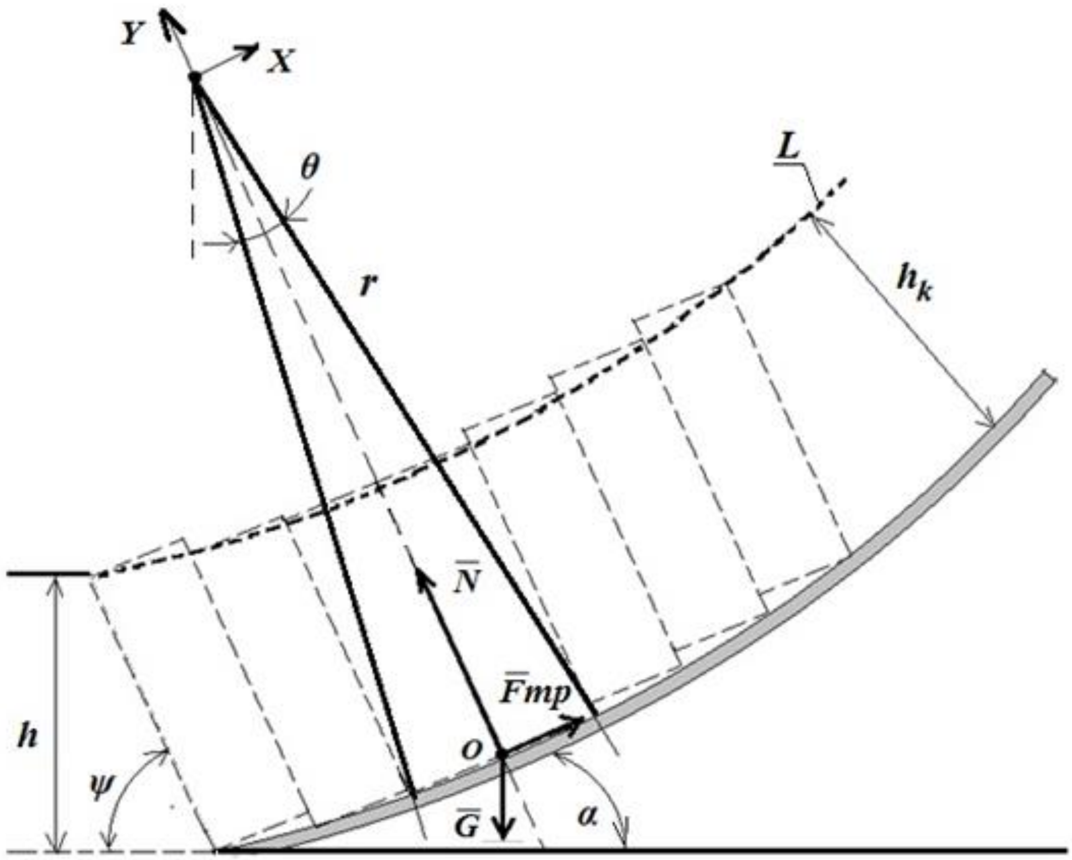

Figure 5: The calculation scheme of interaction curved wedge with soil

Consider the material balance $(m\dot{V} = 0)$, considering that a system of forces acting on an elementary layer of soil is applied to a wedge with a curved surface:

$$\vec{N} + \vec{G} + \vec{F}mp = 0, \qquad (7)$$

$\vec{N}$ - normal reaction of soil formation on the wedge surface;

$\vec{G}$ - gravitational force (*G=mg*);

$\vec{F}mp$ - friction force (*Fmp=fN*).

The projection of the acting forces on the OX and OY axes allows one to obtain:

$$mg \cdot sin(\alpha) \cdot cos(\theta) - Fmp = 0 \quad (8)$$

$$N - mg \cdot cos(\alpha) = 0 \quad (9)$$

Then the material balance is:

$$m\dot{V} = mg \cdot sin(\alpha) \cdot cos(\theta) - f \cdot mg \cdot cos(\alpha) \quad (10)$$

After a reduction by *m*, we have equations [5]:

$$\dot{V} = g(sin\,\alpha \cdot cos\,\theta - f\,cos\,\alpha), \quad (11)$$

$$\frac{V^2}{\rho} = \dot{\theta} \cdot V = g \cdot sin(\alpha) \cdot cos(\theta) \quad (12)$$

Dividing (11) by (12) we obtain:

$$\frac{dV}{V}=-f\frac{cos(\alpha)}{cos(\theta)\cdot sin(\alpha)}d\theta \quad ,$$

or $$\frac{dV}{V}=-f\frac{ctg(\alpha)}{cos(\theta)}d\theta \quad (13)$$

Integrating (13), we have

$$lnV=\int d\theta - f\cdot ctg(\alpha)\cdot\int\frac{d\theta}{cos(\theta)}+lnC, \quad (14)$$

After the transformation (14), taking into account that

$$cos(\alpha)=\frac{1-\left(tg\frac{\theta}{2}\right)^2}{1+\left(tg\frac{\theta}{2}\right)^2} \quad (15)$$

define:

$$ln(V)=\theta-f\cdot ctg(\alpha)\cdot ln\left|\frac{1+\left(tg\frac{\theta}{2}\right)^2}{1-\left(tg\frac{\theta}{2}\right)^2}\right|, \quad (16)$$

or $$ln(V)=\theta+f\cdot ctg(\alpha)\cdot ln\left|\frac{1-\left(tg\frac{\theta}{2}\right)^2}{1+\left(tg\frac{\theta}{2}\right)^2}\right|+ln(C), \quad (17)$$

C – integration constant.
As a result, we get:

$$V=e^{\theta}\cdot\left|\frac{1-\left(tg\frac{\theta}{2}\right)^2}{1+\left(tg\frac{\theta}{2}\right)^2}\right|^{f\cdot ctg(\alpha)} \quad (18)$$

Considering, that $\theta=0$ and $V=V_0$ obtain $C = V_0$ and formula (18) will

$$V=V_o\cdot e^{\theta}\cdot\left|\frac{1-\left(tg\frac{\theta}{2}\right)^2}{1+\left(tg\frac{\theta}{2}\right)^2}\right|^{f\cdot ctg(\alpha)} \quad (19)$$

Having expressed the angle of contiguity θ through the radius of curvature r and the contracting chord l, which corresponds to the length of the opener (Figure 4), we establish

$$tg\frac{\theta}{2}=\frac{l}{2h}, \quad h=\sqrt{r^2-\left(\frac{l}{2}\right)^2}=\frac{1}{2}\sqrt{4r^2-l^2}$$

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$$tg\frac{\theta}{2} = \frac{l}{\sqrt{4r^2 - l^2}}$$

Hence we find the adjacent angle:

$$\theta = 2 \cdot arctg\left(\frac{l}{\sqrt{4r^2 - l^2}}\right) \quad (20)$$

Then finally get a relationship for determining the speed of movement of the soil layer over the opener with a curved surface:

$$V = V_0 \cdot e^{2 \cdot arctg\left(\frac{l}{\sqrt{4r^2 - l^2}}\right)} \cdot \left|1 - \frac{l^2}{2 \cdot r^2}\right|^{f \cdot ctg(\alpha)} \quad (21)$$

Formula (21) shows the dependence of the velocity *V* of the movement of the soil formation along the curvilinear surface of the wedge on the friction coefficient *f*, the setting angle *α*, the length *l*, and the radius of curvature *r* of the wedge.

To determine the profile of the surface of the working member of the paw coulter, we integrate the function (21) in time in the interval from 0 to *t*:

$$S = V_0 \cdot t \cdot e^{2 \cdot arctg\left(\frac{l}{\sqrt{4r^2 - l^2}}\right)} \cdot \left|1 - \frac{l^2}{2 \cdot r^2}\right|^{f \cdot ctg(\alpha)} \quad (22)$$

The final formula (22) determines the influence of the friction coefficient *f*, the setting angle *α*, the wedge length *l*, and the radius of curvature r on the changes in the profile *S* of the paw seed surface when the soil element moves along a curved surface.

Graphical interpretations of the obtained dependences (21) and (22), taking into account the slip condition of the soil formation along the working surface of the wedge, are shown in Figures 6 and 7. Thus, in Figure 6, the dependence of the change in the velocity *V* of the soil movement along the curved surface of the wedge from the setting angle wedge *α* for different values of the coefficient of friction *f* taking into account the slip condition of the soil formation along the curved wedge.

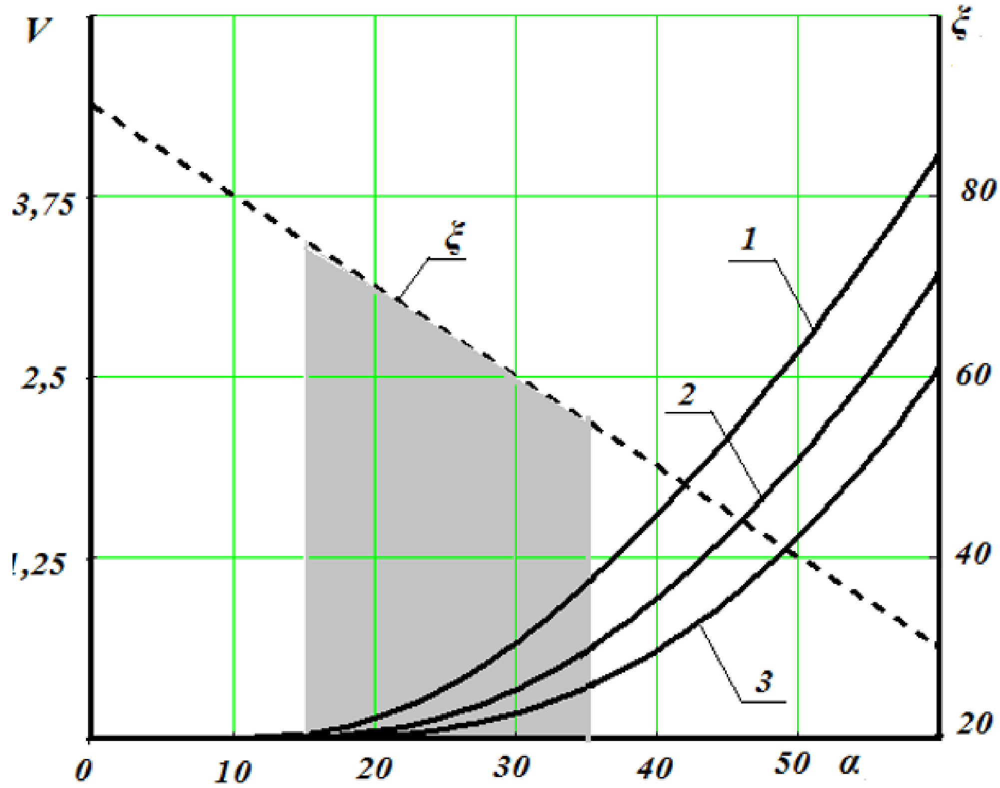

Figure 6: Dependences of the change in the speed *V* of the motion of the soil element along the curved surface of the wedge from the angle of the wedge *α*, for different values of the coefficient of friction:*1- f=0,4; 2 –f=0,5; 3- f=0,6*.

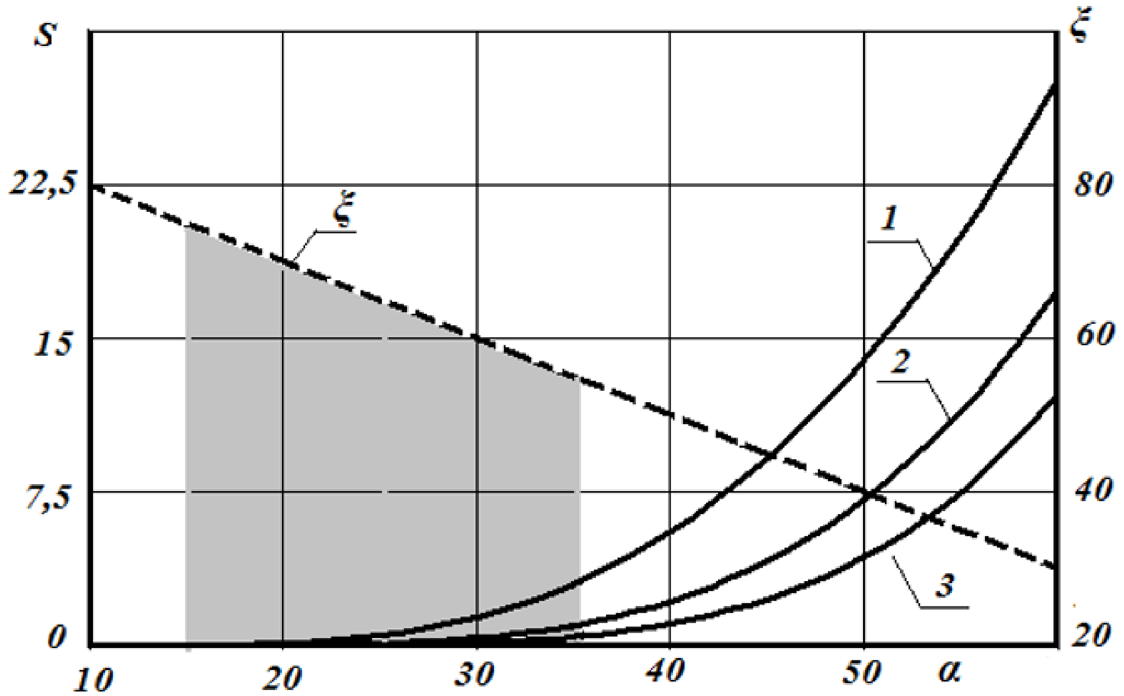

Figure 7: Dependences of the change in the profile *S* of the surface of the paw opener when the soil element moves along the curved surface of the wedge from the angle of the wedge *α* for different curvature radii*r*: 1 *– r=10cm*; 2 *– r=25cm*; 3 *– 4 r= 40 cm*

Figure 7 shows the dependence of the change in the profile *S* of the surface of the paw opening when the soil element moves along the curved surface from the angle of the wedge a for different curvature radius *r*.

CONCLUSION

From the data obtained it follows that, provided that the soil mass slides along the working surface of the wedge ($\xi>\varphi$) and the different values of the friction coefficient *f* and the radius of curvature *r*, the angle of the wedge α varies from 15^0 to 35^0.

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