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Rationale of driven element geometric parameters for herbicides applying in foam composition

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Summary. The article is devoted to the construction of the driven element for subsoil band applying of liquids in crop growing since one of the most important tasks of agricultural production is maximum crop yields obtaining. This problem solution is possible only under condition of the active use of crops protection from diseases and pests. Nowadays the chemical method of plants protection is the most effective and allocated, that is plants treatment in which liquid means of protection are its main part. They can be applied in two ways: the surface (with subsequent laying or without it) and the subsoil ones.

Disadvantages of surface applying are the following: some portion of the working liquid is lost unproductively exposed to evaporation, weathering, photochemical decomposition and so on, in most cases the preparation applied on the surface, acts only against vegetative plants, that is during a short-term period. That is why such treatments are called chemical weeding. Finally all above listed things result in decreasing of total treatment effectiveness and environment contamination. To some extent above mentioned problems can be solved under condition of subsoil pesticide application. The driven element geometric parameters of which were proved in the article was developed to raise the cultivated area quality.

Key words: driven element, subsoil application, chemical means application, plant protection, foam layer.

INTRODUCTION

Rationale of the driven element necessary geometric parameters for plant protection means application to the foam composition is given. They are to provide soil crushing after the driven element which provides the foam distribution on the width of the band cultivated.

ANALYSIS OF RECENT RESEARCH AND PUBLICATIONS

There are some data in the literature studying the driven element for liquid fertilizers application. Yu.V. Muravyev, S.Kh. Dubovskoi, V.B. Ilyinsky, Sh.B. Bayrambekov, A.V. Klochkov, O.V. Gordeyenko studied the driven element and the band application of liquid chemical means.

OBJECTIVE

The set of driven elements (DE) constructions for the subsoil band application of liquids in crop growing are examined in study [2], [8-19]. All of them proved for use of A-hoe blades as a basis of DE. In the process of their movement a hollow in which a liquid is injected is formed under the soil layer. To evaluate dimensions of this space and its form a model of a dihedral wedge α is used (fig. 1) [1,2]. Its own height h, the deep of running H, and rate of movement V_0. The angel of soil and metal friction as well as a soil state are considered to be fixed.

In the process of wedge movement under the soil layer [20], as a result of their interaction a free space (FS) is formed after the wedge which does not contain falling soil singularities. FS is limited by a dynamic marginal surface (DMS), followed by a transitional range (TR). The entire soil flow (ESF) the low limit of which is also its own DMS is placed after TR. The concentration of separately falling soil particles in TR changes from zero value to 100% as it removes from FS and approaches to ESF.

In the plane of dihedral wedge vertical cut set contained vector V_0 the stated zones are limited by curves LMNP (fig. 1) and LBC (fig. 1 A) or LC (fig. 1B and 1C). Here LMNP is a dynamic limit, that is a line of cut set of DMS ESF, and LBC or LC are the lines of cut set of DMS between DE and FS. The surface of spalling (in the same vertical cut set – line AK) or outrunning crack is oriented in a certain way [3]. Line AK limits a range of soil destroying by the wedge.

In studies [1,2] special attention is given to identifying a limit between FS and DE. The fact is that for the qualitative liquid dispensation under the soil layer by means of spraying it is necessary that the jet of spraying will completely be in FS and does not touch TR. With this in view [1, 2] various separately falling particles movement schemes are studied. Such three variants when a wedge front surface particle does not touch (A), when a particle touches a wedge front surface and changes its rate on the module and direction (B) and when a particle passes the wedge front surface with touch without changes of free falling rate (C) illustrates (Fig. 1).

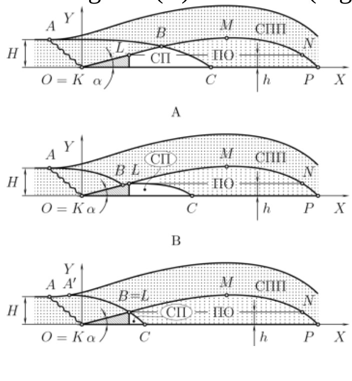

Fig. 1. Schemes of separately falling particles movement trajectories variants after interaction with dihedral wedge.

In this very case subsoil applying of plant protection chemical means in the foam layer is meant [7,21]. During the process two areas in kinematic shade of dihedral wedge FS and TR can be taken into operation (their volume can be indicated $V_{КТ}$), and also volume of the area under the ploughshare $V_{ПЛ}$. Their total volume can be indicated $V_{П}$:

$$V_{П} = V_{ПЛ} + V_{КТ} . \tag{1}$$

For the qualitative realization of the application technological process without gaps and faults it is necessary:

first, that the capacity of the foam generator would be enough for the whole filling by the foam of volume $V_{П}$;

second, that soil crushing after the driven element contributes to the foam distribution on the width of the cultivated band.

To ensure the first condition achievement during the calculation of the total volume FS and TR ($V_{КТ}$) or the same of the volume placed below curve LMNP, assumptions should be taken as ones which can lead to overstating the estimates value $V_{КТ}$, but not on the contrary. Furthermore volume achieved in such a way should be used in the process of the foam generator capacity rationale.

To ensure the second condition realization it is necessary to take into account that the foam supply is realized on the canal which is situated in a leg kinematic shade in the plane of symmetry of the driven element. In this case to distribute the foam evenly on the width of the bind it is necessary that the crushing soil fills the axial portion of the plane first, and only then the peripheral one. In this way the foam transference in sides from the place of its outlet will be achieved. The more the lag on soil crushing in peripheral plane parts, the higher transporting effect. You should not be afraid of such effect redundancy. The superfluous foam will be redistribute once again by the way of pressing out but already in the direction of the driven element running in volume $V_{П}$, in the place where free space left.

Ideally it is necessary for capacity of the foam generator to be redundant. Foam compression leads to the increase of the effects described. In this way the problem can be made only by the area of the open furrow, where volume $V_{П}$ interacts to the atmosphere. But this is a separate problem which can be solved by various means, introducing a freedom formative peak to the driven element construction in particular. There are another ways of this subproblem solving. We are not going to stop on them now.

THE MAIN RESULTS OF THE RESEARCH

The condition of estimated value redundancy of volume $V_{П}$ in general and $V_{КТ}$ in particular is achieved if we suppose that particle after meeting with front plane KL of a dihedral wedge and after passing on it, does not loose horizontal constituent of its normalized velocity which is equal to $v_X = v_0$. Vertical constituent of the particle velocity can be identified by applying condition of its not disturbed sliding on the front surface:

$$v_y = v_0 \, tg\, \alpha . \tag{2}$$

In this very point one should understand that in the general case any surface PO (line KL) is not a straight line therefor angle α monotonously changes while moving KL in limits:

$$\alpha \in [\alpha_k, \alpha_l], \qquad \alpha_k \ge \alpha_l , \tag{3}$$

where: α_k – angle between a horizontal line and a tangent to line KL of the front surface PO in point K, α_l – the same angle in point L of the particle isolation from the front surface.

Taking into account given assumptions and expressions (2), (3) in the moment of the soil particle isolation from the front surface PO in point L with coordinates (x_l, y_l) its horizontal v_{xl} and vertical v_{y_l} constituents of velocity will be equal:

$$\mathrm{v_{xl}} = v_0 , \quad \mathrm{v_{yl}} = v_0 \cdot \mathrm{tg}\, \alpha_l . \tag{4}$$

In this case parametrical equations of the particle fly trajectory which is line LMNP in fig. 1, can be written as:

$$\mathrm{x} = x_l + v_0\, t , \quad y = y_l + v_0 \mathrm{tg}\, \alpha_l\, t - \frac{g\, t^2}{2} , \tag{5}$$

where: variable t, which means current time, plays the role of parameter and g – acceleration of free falling.

Excepted t from both equations (5) which identifying a body position in moment t we will get equation of the fly trajectory (line LMNP):

$$y = y_l + (x - x_l)\, \mathrm{tg}\, \alpha_l - \frac{g(x - x_l)^2}{2\, v_0^2} . \tag{6}$$

Maximum fly distance (abscissa x_P of point P) we can find used expressions (5) under condition that $y = 0$. Finally we have:

$$x_P = x_l + \frac{v_0^2}{g} \mathrm{tg}\alpha_l + \frac{v_0}{g} \sqrt{v_0^2\, \mathrm{tg}\alpha_l^2 + 2\mathrm{g} y_l} . \tag{7}$$

Vertical constituent of velocity is known to be defined by expression:

$$v_y = v_0\, \mathrm{tg}\, \alpha_l - g\, t , \tag{8}$$

then based on requirement $v_y = v_{ym} = 0$ and expression (8) we define the point of time t_m when a particle will get to point M of the maximum rise on its fly trajectory $LMNP$:

$$t = t_m = \frac{v_0 \ \mathrm{tg}\alpha_l}{g} . \qquad (9)$$

Ordinate y_m of point M or maximum height of a particle rise can be defined from the second equation (5) by substitution in it t (9):

$$y_m = y_l + \frac{v_0^2 \ \mathrm{tg}\,\alpha_l^2}{2g} . \qquad (10)$$

Derivation of equation of ploughshares front surface A-hoe driven element. The scheme of the driven element left ploughshare in condition of movement under the soil layer is given with the use of right axonometric rectangular axes $OXYZ$ in fig. 2. Coordinate system $OXYZ$ is placed and oriented in such a way that planes OXZ and OXY coincide accordingly with planes of cutting and symmetry PO, and abscissa axis is parallel to vector $\vec{v}_0$ of normalized velocity PO and coincides with it in direction. A share point (point K_1) lies on axis OZ and is distant from the beginning of coordinates (the leghth of segment OK_1) on the value of the leg half thickness which is not shown in the figure.

The form and dimensions of a ploughshare given in fig. 2 are adequate to the construction developed beforehand and given in study [2]. It is obtained experimentally.

After numeralization of the front ploughshare surface it is defined that it is a fragment of a parabolic cylinder generatrix of which K_2L_1 is quadratic parabola and lineal guide is oriented along normal to generatrix and coincides with a ploughshare cutting edge K_1K_4 .

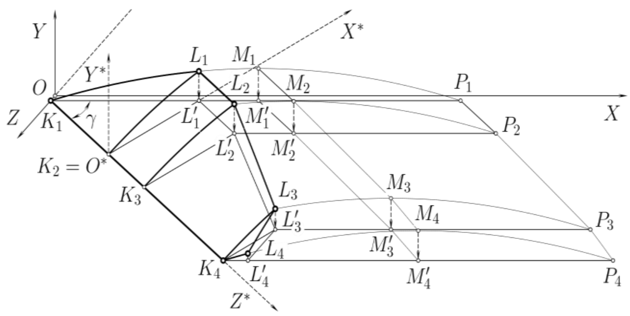

Fig. 2. The scheme of the driven element left ploughshare in the movement state under the soil layer

A new right rectangular axes $O^*X^*Y^*Z^*$ can be analyzed from the point of reference O^* which coincides with point K_2 which in common can be situated at any place on the ploughshare cutting edge K_1K_4. The plane of coordinates $O^*X^*Z^*$ of a new coordinates system is oriented horizontally and coincides with a coordinate plane OXZ of the system $OXYZ$ which was analyzed beforehand. Its applicate axis O^*Z^* is crossed with abscissa axis OX of the previous coordinate system under angle γ, which is equal to an angle half of the ploughshare extent of opening PO.

Thus the left ploughshare cylinder front surface is defined by the equation of generatrix O^*L_1 in a new coordinate system:

$$y^* = a_2 x^{*2} + a_1 x^* + a_0 \ , \qquad (11)$$

where: $a_0 =$ 0,0; $a_1 =$ 0,498009; $a_2 = -$ 0,003299. And also by the equation of guiding line K_1K_4 in the previous coordinate system:

$$z = \mathrm{tg}\gamma\, x + b \, , \qquad (12)$$

where: b - a shift of the ploughshare according to the plane of symmetry PO which is equal to a half of the leg thickness measured on the level of ploughshare mount.

Fig. 3 which is derivative from Fig. 2 and is a vertical projection of a ploughshare and forming lines of plane which is formed in kinematic ploughshare shade in the process of its movement.

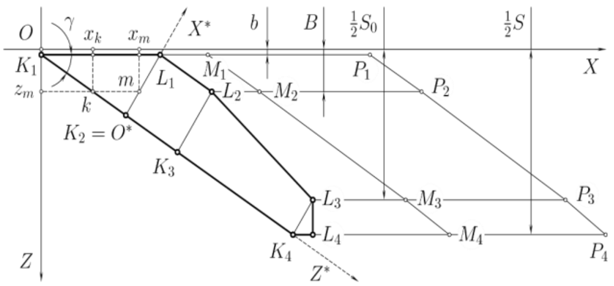

Fig. 3. Vertical projection of a ploughshare and forming lines of plane which is formed in kinematic ploughshare shade in the process of its movement

One should get rid of new coordinates x^*, y^* in expression (11) in order to get equation of the ploughshare front surface in previous coordinates x, y and z. To do it we should consider an optional point m which is situated on required surface and for which $z^* = 0$. Its ordinate is $y_m = y_m^*$ and therefore one can write that:

$$y = a_2 x^{*2} + a_1 x^* + a_0 \ . \qquad (13)$$

Besides abscissa x_m of point m can be defined as:

$$x_m = \frac{x_m^*}{\sin\gamma} + \frac{z_m - b}{\mathrm{tg}\gamma} . \qquad (14)$$

Solved (14) with reference to x^* we get:

$$x_m^* = x_m \sin\gamma + (b - z_m)\cos\gamma \ . \qquad (15)$$

Neglected indices m in expression (15) and done substitution into (13) we get required equation of a ploughshare surface expressed through three previous coordinates:

$$y = a_2\left[x\sin\gamma + (b-z)\cos\gamma\right]^2 + \\ + a_1\left[x\sin\gamma + (b-z)\cos\gamma\right] + a_0 \, . \qquad (16)$$

Equations of planes limiting a ploughshare forming front surface. We agree to understand that a ploughshare front surface $K_1K_2K_3K_4L_4L_3L_2L_1$ is nothing but a fragment of the surface (16) cut by six vertical planes containing lines $K_1K_4, K_4L_4, L_4L_3, L_3L_2$ and L_2L_1.

Equation of the vertical plane getting through cutting edge K_1K_4 is equation of this cutting edge $z = \mathrm{tg}\gamma x + b$ (12). At the same time it is a crossing line of the mentioned vertical plane and a ploughshare front surface. By the way of substitution $z = \mathrm{tg}\gamma x + b$ (12) in equation (16) come to $y = a_0 = 0$ and assure that our argumentations are correct and derivation of obtained equation of a ploughshare front surface (16). Coordinates (x_{k1}, z_{k1}) of starting point K_1 are known:

$$x_{k1} = 0 , \qquad z_{k1} = b \, . \qquad (17)$$

Coordinates (x_{k4}, z_{k4}) of dead point K_4 define from equation tg (12) decided that a half of the driven element bind width is $\frac{1}{2}S$. Finally we get

$$z_{k4} = \frac{1}{2}S \, , \qquad x_{k4} = \frac{S-2b}{2\ \mathrm{tg}\ \gamma} \, . \qquad (18)$$

Equation of a vertical plane coming across horizontal line L_1L_2 situated on height h we find from (16) based on requirement $y = h$:

$$a_2\left[x\sin\gamma + (b-z)\cos\gamma\right]^2 + \\ + a_1\left[x\sin\gamma + (b-z)\cos\gamma\right] + a_0 - h = 0 \, . \qquad (19)$$

Finally we get:

$$z = x\mathrm{tg}\gamma + b + \frac{a_1 \mp \sqrt{a_1^2 - 4a_2(a_0 - h)}}{2a_2\cos\gamma} \, . \qquad (20)$$

If we take into account that a_0 = 0,0; a_1 = 0,498009; a_2 = − 0,003299, then we can state that one should use an upper sign in (20).

Coordinates (x_{l1}, z_{l1}) and (x_{l2}, z_{l2}) of points L_1 and L_2 of line L_1L_2 we define from (20):

$$x_{l1} = \frac{\sqrt{a_1^2 - 4a_2(a_0 - h)} - a_1}{2a_2\sin\gamma} \, , \qquad z_{l1} = b \, , \qquad (21)$$

$$x_{l2} = \frac{B-b}{\mathrm{tg}\ \gamma} + \frac{\sqrt{a_1^2 - 4a_2(a_0 - h)} - a_1}{2a_2\sin\gamma} \, , \qquad z_{l2} = B \, , \qquad (22)$$

where: B = 28,0 mm – is a half of the width of an arc forming part of a A-hoe driven element defined from constructive considerations.

Equation of vertical plane containing line L_2L_3 we can define through equation of the line coming across two points L_2 and L_3 with coordinates (x_{l2}, z_{l2}) and (x_{l3}, z_{l3}) accordingly. Coordinates L_2 (21) are known and coordinates of point L_3 can be defined from requirement that, first, $z_{l3} = \frac{1}{2}S_0$, and ,second, line L_3K_4 is perpendicular K_1K_4. As equation of line L_3K_4 is the following:

$$z = \mathrm{tg}\left(\frac{1}{2}\pi + \gamma\right)(x - x_{k4}) + z_{k4} \, , \qquad (23)$$

then the account of values x_{k4} , z_{k4} :

$$x_{l3} = \frac{1}{2}(S - S_0)\ \mathrm{tg}\gamma + \frac{S-2b}{2\mathrm{tg}\gamma} \, , \qquad z_{l3} = \frac{1}{2}S_0 \, . \qquad (24)$$

Now having used known coordinates (x_{l2}, z_{l2}) and (x_{l2}, z_{l3}) of points L_2 and L_3 (22) we can write equation of vertical plane crossing line L_2L_3 :

$$\frac{x - x_{l2}}{x_{l3} - x_{l2}} = \frac{z - z_{l2}}{z_{l3} - z_{l2}} \, . \qquad (25)$$

Equation of vertical planes containing lines K_1L_1 and K_4L_4 are defined by applicates $z_{k1} = b$ and $z_{k4} = \frac{1}{2}S$:

$$z = b \ \text{и} \ z = \frac{1}{2}S \, . \qquad (26)$$

Equation of vertical plane containing line L_3L_4 can be defined by using known abscissa x_{l3} of point L_3 (24):

$$x = x_{l3} \, . \qquad (27)$$

Integral of a hollow volume contained under the ploughshare front surface and limited by vertical planes crossing the outline lines of the ploughshare vertical projection. To calculate total volume $V_{ЛП}$ contained between the plane of cutting ($y = 0$), ploughshare front surface (16) and five vertical planes containing lines K_1K_4, K_4L_4, L_4L_3, L_3L_2, L_2L_1 we use double integration, $V_{ЛП}$ being divided by vertical planes into three parts:

$$V_{ЛП} = V_{ЛП1} + V_{ЛП2} + V_{ЛП3} \, , \qquad (28)$$

where: $V_{ЛП1}, V_{ЛП2}, V_{ЛП3}$ - parts of given volume, contained between pairs of planes: $z = b$ and $z = z_{l2}$; $z = z_{l2}$ and $z = z_{l3}$; $z = z_{l3}$ and $z = z_{k4}$.

Further we calculate $V_{ЛП1}$, for this we write integral expression:

$$V_{ЛП1} = \int_{b}^{z_{l2}} \int_{x_1(z)}^{x_2(z)} (a_2u^2 + a_1u + a_0)\ dx\,dz\,, \qquad (29)$$

where:

$$u = u(x, z) = x\sin\gamma + (b - z)\cos\gamma\,, \qquad (30)$$

and alinements $x_1(z)$ and $x_2(z)$ are defined from equation (12) and (20):

$$x_1(z) = (z - b)\ \mathrm{ctg}\,\gamma\,,\quad x_2(z) = (z - b)\ \mathrm{ctg}\,\gamma + c\,, \qquad (31)$$

$$c = \frac{\sqrt{a_1^2 - 4a_2\left(a_0 - h\right)} - a_1}{2a_2\ \sin\gamma}\,. \qquad (32)$$

For integration (29) we rewrite it as:

$$V_{ЛП1} = \int_{b}^{z_{l2}} \left\{ \int_{x_1(z)}^{x_2(z)} (a_2u^2 + a_1u + a_0)\ dx \right\} dz = \int_{b}^{z_{l2}} I(z)\,dz\,, \qquad (33)$$

where:

$$I(z) = \int_{x_1(z)}^{x_2(z)} (a_2u^2 + a_1u + a_0)\ dx\,. \qquad (34)$$

As in (34) " x " is variable then:

$$du = \sin\gamma\ dx\,, \qquad (35)$$

and it means:

$$I(z) = \frac{1}{\sin\gamma} \int_{u_1}^{u_2} (a_2u^2 + a_1u + a_0)\ du\,, \qquad (36)$$

where limits of integration:

$$u_1 = 0\,, \qquad u_2 = c\sin\gamma\,, \qquad (37)$$

We get by substitution $x = x_1(z)$ and $x = x_2(z)$ (31) in definition u (30).

After integration we get:

$$I(z) = \frac{1}{\sin\gamma}\left(\frac{a_2}{3}u^3 + \frac{a_1}{2}u^2 + a_0u \right)\Bigg|_{u_1}^{u_2} = \\ = \frac{a_2c^3\sin^2\gamma}{3} + \frac{a_1c^2\sin\gamma}{2} + a_0c\,. \qquad (38)$$

Substitution of the result in (33) after integration gives:

$$V_{ЛП1} = \left[\left(\frac{a^2c\sin\gamma}{3} + \frac{a_1}{2} \right) c\sin\gamma + a_0 \right]\ \left(B - b\right)c\,, \qquad (39)$$

required meaning of initial double integral (29).

For calculation $V_{ЛП2}$ we write integral expression as well:

$$V_{ЛП2} = \int_{z_{l2}}^{z_{l3}} \int_{x_1(z)}^{x_2(z)} (a_2u^2 + a_1u + a_0)\ dx\,dz\,, \qquad (40)$$

which differs from (29) by integration limits. In particular now expressions $x_1(z)$ and $x_2(z)$ are defined from equations (12) and (25):

$$x_1(z) = (z - b)\mathrm{ctg}\gamma\,, \\ x_2\left(z\right) = \frac{z - z_{l2}}{z_{l3} - z_{l2}}(x_{l3} - x_{l2}) + x_{l2}\,. \qquad (41)$$

Values x_{l2} and z_{l2} (22) and also x_{l3} and z_{l3} (24) are already known. Their substitution in (40) and (41) gives:

$$V_{ЛП2} = \int_{B}^{\frac{1}{2}S_0} \int_{x_1(z)}^{x_2(z)} (a_2u^2 + a_1u + a_0)\ dx\,dz\,, \qquad (42)$$

where: $x_1(z)$ as beforehand, is defined by expression (41), and $x_2(z)$ is defined as:

$$x_2(z) = \frac{z - B}{\frac{1}{2}S_0 - B}\left[\frac{1}{2}\left(S - S_0\right)\mathrm{tg}\gamma + \frac{S - 2b}{2\mathrm{tg}\gamma} - \right. \\ \left. - \frac{B - b}{\mathrm{tg}\gamma} - c\right] + \frac{B - d}{\mathrm{tg}\gamma} + c\,, \qquad (43)$$

where: c – is defined by expression (32) as beforehand. After simplification (43) gives:

$$x_2(z) = \frac{(z - B)\left(S - S_0\right)\mathrm{tg}\gamma - 2c}{S_0 - 2B} + \frac{z - b}{\mathrm{tg}\gamma} + c\,, \qquad (44)$$

Integration (42) is similar to the previous case ((33)-(39)). That is why we rewrite expression (42) like iterated integral:

$$V_{ЛП2} = \int_{B}^{\frac{1}{2}S_0} \left\{ \int_{x_1(z)}^{x_2(z)} (a_2u^2 + a_1u + a_0)dx \right\} dz = \int_{B}^{\frac{1}{2}S_0} I(z)\,dz, \qquad (45)$$

where:

$$I(z) = \int_{x_1(z)}^{x_2(z)} (a_2u^2 + a_1u + a_0)\ dx = \\ = \frac{1}{\sin\gamma} \int_{u_1}^{u_2} (a_2u^2 + a_1u + a_0)\ du, \qquad (46)$$

and, in its turn:

$$u = u(z, x) = x\sin\gamma + (b - z)\cos\gamma\,, \quad du = \sin\gamma dx\,, \qquad (47)$$

and also:

$$u_1 = 0\,, \quad u_2 = \left[\frac{(z - B)\,(S - S_0)\ \mathrm{tg}\gamma - 2c}{S_0 - 2B} + c\right]\sin\gamma \qquad (48)$$

and c – corresponds to its definition (32).

Taking into account values of integration limits u_1 and u_2 (48), after having been integrated (46) we get:

$$I(z) = \frac{1}{\sin\gamma}\left(\frac{a_2}{3}u^3 + \frac{a_1}{2}u^2 + a_0 u\right)\Bigg|_{u_1}^{u_2} = \\ = \frac{1}{\sin\gamma}\left(\frac{a_2}{3}u_2^3 + \frac{a_1}{2}u_2^2 + a_0 u_2\right), \tag{49}$$

and then having in mind (45), (48) we write:

$$V_{ЛП2} = \frac{1}{\sin\gamma}\int_B^{\frac{1}{2}S_0}\left(\frac{a_2}{3}u_2^3 + \frac{a_1}{2}u_2^2 + a_0 u_2\right)dz = \\ = I_2 + I_1 + I_0, \tag{50}$$

where:

$$I_0 = \frac{a_0}{\sin\gamma}\int_B^{\frac{1}{2}S_0} u_2 dz, \quad I_1 = \frac{a_1}{2\sin\gamma}\int_B^{\frac{1}{2}S_0} u_2^2 dz, \\ I_2 = \frac{a_2}{3\sin\gamma}\int_B^{\frac{1}{2}S_0} u_2^2 dz. \tag{51}$$

For integration (51) we will understand that $u_2 = u_2(z)$ (48) and therefore:

$$du_2 = \frac{(S - S_0)\sin^2\gamma}{(S_0 - 2B)\cos\gamma}dz, \tag{52}$$

$$u_2\big|_{z=B} = \left(c - \frac{2c}{S_0 - 2B}\right)\sin\gamma, \\ u_2\big|_{z=\frac{1}{2}S_0} = \left[\frac{(S - S_0)\,\mathrm{tg}\gamma}{2} - \frac{2c}{S_0 - 2B} + c\right]\sin\gamma. \tag{53}$$

With the account of expressions (52), (53) integrals (51) will become:

$$I_0 = \frac{a_0(S_0 - 2B)\cos\gamma}{(S - S_0)\sin^3\gamma}\int_{u_2|_{z=B}}^{u_2|_{z=\frac{1}{2}S_0}} u_2 du_2, \tag{54}$$

$$I_1 = \frac{a_1(S_0 - 2B)\cos\gamma}{2(S - S_0)\sin^3\gamma}\int_{u_2|_{z=B}}^{u_2|_{z=\frac{1}{2}S_0}} u_2^2 du_2, \tag{55}$$

$$I_2 = \frac{a_2(S_0 - 2B)\cos\gamma}{3(S - S_0)\sin^3\gamma}\int_{u_2|_{z=B}}^{u_2|_{z=\frac{1}{2}S_0}} u_2^3 du_2. \tag{56}$$

After integration (54), (55) and (56) we get:

$$I_0 = \frac{a_0(S_0 - 2B)\cos\gamma}{2(S - S_0)\sin^3\gamma}u_2^2\Bigg|_{u_2|_{z=B}}^{u_2|_{z=\frac{1}{2}S_0}} = \\ = \frac{a_0(S_0 - 2B)}{8}(S - S_0)\,\mathrm{tg}\gamma, \tag{57}$$

$$I_1 = \frac{a_1(S_0 - 2B)\cos\gamma}{6(S - S_0)\sin^3\gamma}u_2^3\Bigg|_{u_2|_{z=B}}^{u_2|_{z=\frac{1}{2}S_0}} = \\ = \frac{a_1(S_0 - 2B)\sin\gamma}{48}(S - S_0)^2\,\mathrm{tg}^2\gamma, \tag{58}$$

$$I_1 = \frac{a_2(S_0 - 2B)\cos\gamma}{12(S - S_0)\sin^3\gamma}u_2^4\Bigg|_{u_2|_{z=B}}^{u_2|_{z=\frac{1}{2}S_0}} = \\ = \frac{a_2(S_0 - 2B)\sin^2\gamma}{192}(S - S_0)^3\,\mathrm{tg}^3\gamma. \tag{59}$$

Finally having summarized (57), (58) and (59) we get value of volume $V_{ЛП2}$ (50):

$$V_{ЛП2} = \frac{1}{8}(S_0 - 2B)(S - S_0)\,\mathrm{tg}\gamma \times \\ \times\left\{a_0 + \frac{\sin^2\gamma}{6\cos\gamma}(S - S_0)\left[a_1 + \frac{a_2\sin^2\gamma}{4\cos\gamma}(S - S_0)\right]\right\}. \tag{60}$$

For calculation of $V_{ЛП3}$ we write down integral expression:

$$V_{ЛП3} = \int_{z_{l3}}^{z_{k4}}\int_{x_1(z)}^{z_{l3}}(a_2u^2 + a_1u + a_0)dx\,dz, \tag{61}$$

which differs from (40) by integration limits. Exception is low limit $x_1(z) = (z - b)\,\mathrm{ctg}\,\gamma$, which corresponds to expression (41) as before. Values z_{l3} and x_{l3} (24) as well as z_{k4} (18) are already known. Substitution z_{l3} (24) and z_{k4} into (61) gives iterated integral:

$$V_{ЛП3} = \int_{\frac{1}{2}S_0}^{\frac{1}{2}S}\left\{\int_{x_1(z)}^{x_{l3}}(a_2u^2 + a_1u + a_0)\,dx\right\} = \int_{\frac{1}{2}S_0}^{\frac{1}{2}S} I(z)dz, \tag{62}$$

where:

$$I(z) = \int_{x_1(z)}^{x_{l3}}(a_2u^2 + a_1u + a_0)\,dx = \\ = \frac{1}{\sin\gamma}\int_{u_1}^{u_2}(a_2u^2 + a_1u + a_0)\,du, \tag{63}$$

and in its turn:

$$u_1 = 0, \quad u_2 = \frac{S - S_0\sin^2\gamma - 2z\cos^2\gamma}{2\cos\gamma}. \tag{64}$$

Integration (63) after substitution of u_1 and u_2 (63) brings to expression (49) obtained beforehand, which taking into account iterated integral (62) and integration limits (64) gives:

$$V_{ЛП3} = \frac{1}{\sin\gamma}\int_{\frac{1}{2}S_0}^{\frac{1}{2}S}\left(\frac{a_2}{3}u_2^3 + \frac{a_1}{2}u_2^2 + a_0u_2\right)dz = \\ = I_2 + I_1 + I_0, \tag{65}$$

$$I_0 = \frac{a_0}{\sin\gamma} \int_{\frac{1}{2}S_0}^{\frac{1}{2}S} u_2 dz\ , \quad I_1 = \frac{a_1}{2\sin\gamma} \int_{\frac{1}{2}S_0}^{\frac{1}{2}S} u_2^2 dz\ ,$$
$$I_2 = \frac{a_2}{3\sin\gamma} \int_{\frac{1}{2}S_0}^{\frac{1}{2}S} u_2^3 dz\ . \quad (66)$$

For integration (66) we will understand that $u_2 = u_2(z)$ (64) and, therefore:

$$du_2 = -\cos\gamma\ dz\ , \quad (67)$$

$$u_2\big|_{z=\frac{1}{2}S_0} = \frac{S - S_0}{2\cos\gamma}\ , \quad u_2\big|_{z=\frac{1}{2}S} = \frac{(S - S_0)\sin^2\gamma}{2\cos\gamma}\ , \quad (68)$$

With the account of proposed substitution $dz = -du_2 / \cos\gamma$ (67) and new meanings of integration limits (67) integrals (66) become:

$$I_0 = \frac{a_0}{\text{tg}\,\gamma} \int_{u_2|_{z=\frac{1}{2}S}}^{u_2|_{z=\frac{1}{2}S_0}} u_2 du_2\ , \quad I_1 = \frac{a_1}{2\ \text{tg}\,\gamma} \int_{u_2|_{z=\frac{1}{2}S}}^{u_2|_{z=\frac{1}{2}S_0}} u_2^2 du_2\ ,$$
$$I_2 = \frac{a_2}{3\ \text{tg}\,\gamma} \int_{u_2|_{z=\frac{1}{2}S}}^{u_2|_{z=\frac{1}{2}S_0}} u_2^3 du_2\ . \quad (69)$$

After integration they give:

$$I_0 = \frac{a_0 u_2^2}{2\ \text{tg}\,\gamma}\Bigg|_{u_2|_{z=\frac{1}{2}S}}^{u_2|_{z=\frac{1}{2}S_0}} = \frac{a_0 (S - S_0)^2 (1 - \sin^4\gamma)}{8\ \text{tg}\gamma\ \cos^2\gamma}\ , \quad (70)$$

$$I_1 = \frac{a_1 u_2^3}{6\ \text{tg}\,\gamma}\Bigg|_{u_2|_{z=\frac{1}{2}S}}^{u_2|_{z=\frac{1}{2}S_0}} = \frac{a_1 (S - S_0)^3 (1 - \sin^6\gamma)}{48\ \text{tg}\,\gamma\ \cos^3\gamma}\ , \quad (71)$$

$$I_2 = \frac{a_2 u_2^4}{12\ \text{tg}\,\gamma}\Bigg|_{u_2|_{z=\frac{1}{2}S}}^{u_2|_{z=\frac{1}{2}S_0}} = \frac{a_2 (S - S_0)^4 (1 - \sin^8\gamma)}{192\ \text{tg}\,\gamma\ \cos^4\gamma}\ . \quad (72)$$

Finally having summarized (70), (71) and (72) we get expression for calculation of volume $V_{ЛП3}$ (61) which, after formal conversions, is expressed in:

$$V_{ЛП3} = \frac{(S - S_0)^2}{8\ \text{tg}\,\gamma} \times$$
$$\times \left\{ a_0 (1 + \sin^2\gamma) + \frac{S - S_0}{6\cos^3 y} \times \right. \quad (73)$$
$$\left. \times \left[a_1 (1 - \sin^6\gamma) + \frac{a_2 (S - S_0)(1 - \sin^8\gamma)}{4\cos\gamma} \right] \right\}\ .$$

Now taking into account obtained expressions for $V_{ЛП0}$ (39), $V_{ЛП1}$ (60) and $V_{ЛП2}$ (73), volume $V_{ЛП}$ (28) is considered to be defined.

Area of ploughshare front surface. For calculation of area $S_Л$ of a ploughshare front surface we will remind that in system of coordinates $O^*X^*Y^*Z^*$ it looks like a parabolic cylinder with generatrix $y^* = a_2 x^{*2} + a_1 x^* + a_0$ (11) and guiding line which is parallel to applicate axis O^*Z^*. In this case required surface $S_Л$ can be calculated by applying curvelinear integral of the first kind:

$$S_Л = \int_{O^*}^{L_1} \left[z^*(x^*(l))\big|_{(K_4 L_4 L_3 L_2)} - z^*(x^*(l)\big|_{(K_1 L_1)} \right] dl\ , \quad (74)$$

where: l – an arc length measured along generatrix curve $y^* = a_2 x^{*2} + a_1 x^* + a_0$ (11), beginning from point O^* (where $x^* = 0$) and ending by point with current value $x^* = 0$, $z^*(x^*(l))\big|_{(K_4 L_4 L_3 L_2)}$ and $z^*(x^*(l))\big|_{(K_1 L_1)}$ – applicates of crossing points of guideline l with marginal sectionally joint lines and $K_1 L_1$.

Differential dl of arc length l of curve $y^* = a_2 x^{*2} + a_1 x^* + a_0$ (11) is defined on known formula [5]:

$$dl = \sqrt{1 + \left(\frac{dy^*}{dx^*} \right)^2} dx^*\ , \quad (75)$$

where:

$$\left(\frac{dy^*}{dx^*} \right)^2 = (2a_2 x^* + a_1)^2 = 4a_2^2 x^{*2} + 4a_1 a_2 x^* + a_1^2\ . \quad (76)$$

Introduce denotation:

$$\Phi(x^*) = 4a_2^2 x^{*2} + 4a_1 a_2 x^* + a_1^2 + 1\ , \quad (77)$$

and substitute variable of integration in (74) from l to x^*. As a result we have:

$$S_Л = \int_0^{x_{l1}^*} \left[z^*(x^*)\big|_{(K_4 L_4 L_3 L_2)} - z^*(x^*)\big|_{(K_1 L_1)} \right] \sqrt{\Phi(x^*)}\ dx^*\ , \quad (78)$$

where: x_{l1}^* – abscissa of point L_1; $z^*(x^*)\big|_{(K_4 L_4 L_3 L_2)}$ and $z^*(x^*)\big|_{(K_1 L_1)}$ – applicates of crossing points of guideline, the location of which is defined by abscissa x^*, with marginal sectionally joint lines $K_4 L_4 L_3 L_2$ and $K_1 L_1$.

Further area $S_Л$ can be expressed in the sum of three fragments:

$$S_Л = S_{Л1} + S_{Л2} + S_{Л3}\ , \quad (79)$$

where: $S_{Л1}$, $S_{Л2}$ and $S_{Л3}$ – areas of ploughshare front surface fragments contained between pairs of guidelines, crossing the ends of cuts $K_4 L_4 L_3 L_2$ and $L_3 L_2$. Based on (78) $S_{Л1}$, $S_{Л2}$ and $S_{Л3}$ can be defined as:

$$S_{Л1} = \int_0^{x_{l4}^*} \left[z^*(x^*)\big|_{(K_4 L_4)} - z^*(x^*)\big|_{(K_1 L_1)} \right] \sqrt{\Phi(x^*)}\ dx^*\ , \quad (80)$$

$$S_{Л2} = \int_{x^*_{l4}}^{x^*_{l3}} \left[z^*(x^*)\Big|_{(L_4L_3)} - z^*(x^*)\Big|_{(K_1L_1)} \right] \sqrt{\Phi(x^*)}\, dx^* , \quad (81)$$

$$S_{Л3} = \int_{x^*_{l3}}^{x^*_{l2}} \left[z^*(x^*)\Big|_{(L_3L_2)} - z^*(x^*)\Big|_{(K_1L_1)} \right] \sqrt{\Phi(x^*)}\, dx^* , \quad (82)$$

where: x^*_{l2}, x^*_{l3} and x^*_{l4} – abscissas of points L_2, L_3 and L_4; $z^*(x^*)\big|_{(K_4L_4)}$, $z^*(x^*)\big|_{(L_4L_3)}$, $z^*(x^*)\big|_{(L_3L_2)}$ and $z^*(x^*)\big|_{(K_1L_1)}$ – applicates of crossing points of guideline, location of which is defined by abscissa x^*, with marginal cuts of straight lines K_4L_4, L_4L_3, L_3L_2 and K_1L_1. At the same time $z^*(x^*)\big|_{(K_4L_4)}$, $z^*(x^*)\big|_{(L_4L_3)}$, $z^*(x^*)\big|_{(L_3L_2)}$ and $z^*(x^*)\big|_{(K_1L_1)}$ can be taken as equations of straight lines, fragments of which are cuts K_4L_4, L_4L_3, L_3L_2 and K_1L_1.

Most of named above points and straight lines are defined by us beforehand in system of coordinates OXZ. To define the same values in system of coordinates $O^*X^*Z^*$ we use conversion [6]:

$$\begin{cases} z = z^* \sin\gamma - x^* \cos\gamma + z_{k2} \\ x = z^* \cos\gamma + x^* \sin\gamma + x_{k2} \end{cases} , \quad (83)$$

where:

$$z_{k2} = \text{tg}\gamma\, x_{k2} + b , \quad (84)$$

— defined from equation (12), and:

$$x_{k2} = x_{l1} - x^*_{l1} \sin\gamma \quad (85)$$

— from Fig. 3. In its turn x_{l1} have already defined by expression (21), and x^*_{l1} with the account of (31) and (32) is equal to the following:

$$x^*_{l1} = c \sin\gamma = \frac{\sqrt{a_1^2 - 4a_2(a_0 - h)} - a_1}{2a_2} . \quad (86)$$

We write down in the result:

$$x_{k2} = c \cos^2\gamma , \quad (87)$$

$$z_{k2} = c \sin\gamma \cos\gamma + b . \quad (88)$$

Now substitution of x_{k2} (87) and z_{k2} (88) in (83) gives:

$$\begin{cases} z = z^* \sin\gamma - x^* \cos\gamma + c \sin\gamma \cos\gamma + b, \\ x = z^* \cos\gamma + x^* \sin\gamma + c \cos^2\gamma. \end{cases} \quad (89)$$

Further having used substitution (89) we will get equations of straight lines, the fragments of which are cuts K_4L_4, L_4L_3, L_3L_2 and K_1L_1. Thus straight line $z = b$ run through cut K_1L_1 and it means:

$$z^*(x^*)\Big|_{(K_1L_1)} = x^* \text{ctg}\,\gamma - c \cos\gamma . \quad (90)$$

Equation of straight line $z^*(x^*)\big|_{(L_3L_2)}$ running through cut L_3L_2 we obtain from equation (44) by way of substitution in it expressions for *x*, *z* (89) and the following formal conversions:

$$\begin{aligned} z^*(x^*)\Big|_{(L_3L_2)} &= x^* \text{ctg}\gamma \left[\frac{S_0 - 2B}{S - S_0}(1 - \text{ctg}^2\gamma) - 1 \right] + \\ &+ 1\frac{B - b}{\sin\gamma} - c\frac{\cos\gamma}{\sin^2\gamma} \left[\frac{S_0 - 2B}{S - S_0} - \cos^2\gamma - 1 \right] . \end{aligned} \quad (91)$$

Equation of straight line $z^*(x^*)\big|_{(L_4L_3)}$ running through cut L_4L_3 we get by substitution of value $x = x_{l3}$ (24) in low equation $x = x(x^*, z^*)$ (89) and the following solving according to z^*:

$$\begin{aligned} z^*(x^*)\Big|_{(L_4L_3)} &= -x^* \text{tg}\gamma + \\ &+ \frac{1}{2}\left[(S - S_0)\frac{\sin\gamma}{\cos^2\gamma} + \frac{S - 2b}{\sin\gamma} \right] - c \cos\gamma . \end{aligned} \quad (92)$$

Equation of straight line $z^*(x^*)\big|_{(K_4L_4)}$ we get by means of cut K_4L_4 by substitution of value $z = z_{l3}$ (24) in low equation $z = z(x^*, z^*)$ (89) and the following solving according to z^*:

$$\frac{1}{2} S_0 = z^* \sin\gamma - x^* \cos\gamma + c \sin\gamma \cos\gamma + b ,$$

$$z^*(x^*)\Big|_{(K_4L_4)} = x^* \text{ctg}\gamma + \frac{S_0}{2\sin\gamma} - c \cos\gamma - \frac{b}{\sin\gamma} . \quad (93)$$

To identify integration limits x^*_{l2}, x^*_{l3} and x^*_{l4} it is necessary to solve system of converting coordinates (89) according coordinate x^* and substitute consequently in obtained coordinates applicable points L_2, L_3 and L_4.

Solving (89) according to x^*, z^* is the following:

$$\begin{cases} z^* = z \sin\gamma + x^* \cos\gamma - c \cos\gamma - b \sin\gamma, \\ x^* = -z \cos\gamma + x \sin\gamma + b \cos\gamma. \end{cases} \quad (94)$$

Taking into account that abscissa is $x^*_{l2} = x^*_{l1}$, then to simplify final expression x^*_{l2} we find from the second equation (94) by substituting in it $x = x_{l1}$ and $z = z_{l1}$. At the same time we use substitution (32). As a result we get:

$$x^*_{l2} = c \sin\gamma . \quad (95)$$

Abscissa x^*_{l3} can be find by using values $x = x_{l3}$ and $z = z_{l3}$ (24):

$$x_{l3}^{*} = \frac{S - S_0}{2\cos\gamma} . \qquad (96)$$

Abscissa x_{l4}^{*} can be find taking into account the fact that point L_4 is located on the crossing of cuts of straight lines L_4L_3 and K_4L_4, which are parallel to axes of coordinate system $OXYZ$ and that is why $x = x_{l4} = x_{l3}$ (24) and $z = z_{l4} = z_{k4}$ (18). After substitutions and formal conversions we have:

$$x_{l4}^{*} = \frac{(S - S_0)\sin^2\gamma}{2\cos\gamma} . \qquad (97)$$

Now all elements of integrals (80), (81) and (82) are defined. Rewrite the first of them by substitution $z^*(x^*)\big|_{(K_1L_1)}$ (90) and $z^*(x^*)\big|_{(K_4L_4)}$ (93):

$$S_{Л1} = \frac{S_0 - 2b}{2\sin\gamma}\int_0^{x_{l4}^{*}} \sqrt{\Phi(x^*)}\; dx^* . \qquad (98)$$

Further we substitute $z^*(x^*)\big|_{(K_1L_1)}$ (90) and $z^*(x^*)\big|_{(L_4L_3)}$ in expression (81)

$$S_{Л2} = \int_{x_{l4}^{*}}^{x_{l3}^{*}} \left\{ \frac{1}{2}\left[(S - S_0)\frac{\sin\gamma}{\cos^2\gamma} + \frac{S - 2b}{\sin\gamma} \right] - 2x^*\mathrm{ctg}\gamma \right\} \times \times\sqrt{\Phi(x^*)}\; dx . \qquad (99)$$

In the same way having done substitution $z^*(x^*)\big|_{(K_1L_1)}$ (90) and $z^*(x^*)\big|_{(L_3L_2)}$ (91) in expression (82) we get

$$S_{Л3} = \int_{x_{l3}^{*}}^{x_{l2}^{*}} \left\{ x^*\mathrm{ctg}\gamma\left[\frac{S_0 - 2B}{S - S_0}(1 - \mathrm{ctg}^2\gamma) - 2 \right] + \frac{B - b}{\sin\gamma} - c\frac{\cos\gamma}{\sin^2\gamma}\left[\frac{S_0 - 2B}{S - S_0} - \cos^2\gamma - 1 \right] + c\cos\gamma \right\} \times \times\sqrt{\Phi(x^*)}\; dx^* . \qquad (100)$$

We introduce two indefinite integrals

$$I_{\Phi1}(x^*) = \int \sqrt{\Phi(x^*)}\; dx^* ,\; I_{\Phi2}(x^*) = \int x^*\sqrt{\Phi(x^*)}\; dx^* . \qquad (101)$$

Having used tables [4] we integrate first $I_{\Phi1}(x^*)$ and then $I_{\Phi2}(x^*)$ (100). As a result we get:

$$I_{\Phi1}(x^*) = \frac{1}{4a_2}\left\{ (2a_2x^* + a_1)\Phi(x^*)^{1/2} + + \ln\left| 2a_2x^* + a_1 + \Phi(x^*)^{1/2} \right| \right\} , \qquad (102)$$

$$I_{\Phi2}(x^*) = \frac{1}{12a_2^2}\Phi(x^*)^{3/2} - \frac{a_1}{2a_2}I_{\Phi1}(x^*) . \qquad (103)$$

Now having used indefinite integrals (102) and expressions (98), (99) and (100) we get

$$S_{Л1} = \frac{S_0 - 2b}{2\sin\gamma} I_{\Phi1}(x^*)\Big|_0^{x_{l4}^{*}} , \qquad (104)$$

$$S_{Л2} = \frac{1}{2}\left[(S - S_0)\frac{\sin\gamma}{\cos^2\gamma} + \frac{S - 2b}{\sin\gamma} \right] I_{\Phi1}(x^*)\Big|_{x_{l4}^{*}}^{x_{l3}^{*}} - -\mathrm{ctg}\gamma\left[\frac{1}{6a_2^2}\Phi(x^*)^{3/2} - \frac{a_1}{a_2}I_{\Phi1}(x^*) \right]\Big|_{x_{l4}^{*}}^{x_{l3}^{*}} , \qquad (105)$$

$$S_{Л3} = \left\{ \mathrm{ctg}\gamma\left[\frac{S_0 - 2B}{S - S_0}(1 - \mathrm{ctg}^2\gamma) - 2 \right] \times \times\left[\frac{1}{12a_2^2}\Phi(x^*)^{3/2} - \frac{a_1}{2a_2}I_{\Phi1}(x^*) \right] \right\}\Big|_{x_{l3}^{*}}^{x_{l2}^{*}} + + \left\{ \left[\frac{B - b}{\sin\gamma} - c\frac{\cos\gamma}{\sin^2\gamma}\left(\frac{S_0 - 2B}{S - S_0} - \cos^2\gamma - 1 \right) + + c\cos\gamma \right] I_{\Phi1}(x^*) \right\}\Big|_{x_{l3}^{*}}^{x_{l2}^{*}} . \qquad (106)$$

Obtained expressions (104), (105) and (106) complete procedure of area defining (79) of driven element front ploughshare surface and presuppose a set of substitutions: (102), (103), (77) and (32), and limits of summarizing (95), (96) and (97) as well.

CONCLUSIONS

Obtained analytic expressions connect constructive parameters A-hoe DE with its depth and driven operation velocity. Such calculations are necessary in the case of projecting combined DE in which functional use of space under DE and hollow in the soil is supposed and this hollow is formed after DE in the process of its driven operation. In particular obtained expressions are necessary for projecting A-hoe DE provided for subsoil injection of herbicides in a foam layer.

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ОБОСНОВАНИЕ ГЕОМЕТРИЧЕСКИХ ПАРАМЕТРОВ РАБОЧЕГО ОРГАНА ДЛЯ ВНЕСЕНИЯ ГЕРБИЦИДОВ В СОСТАВЕ ПЕНЫ

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Аннотация. Недостатки поверхностного внесения это то что некоторая часть рабочей жидкости непродуктивно теряется, подвергаясь выпаровыванию, выветриванию, фотохимическому распаду и т.п.. в большинстве случаев препарат, внесенный поверхностно, действует только против вегетирующих растений, то есть не продолжительный часовой период. Именно по этому такие обработки называются химической прополкой. В конце концов все перечисленное приводит к снижению общей эффективности обработок и загрязнения окружающей среды. При внутрипочвенном внесении пестицидов упомянутые выше проблемы в некоторой степени удается решить.

Ключевые слова: рабочих органов, внутрипочвенное внесения, внесение химических средств, защита растений, слой пены.