Graph-Analytical Method for Determining the Untreated and Treated with the Herbicide Area around the Stem with Overlapping When the Working Body is Made in the Form of a Probe

V V Tsybulevskiy¹, B F Tarasenko¹*, S V Oskin¹
¹Kuban State Agrarian University named after I. T. Trubilin, Russian Federation

E-mail: valera-1913@mail.ru, b.tarasenko@inbox.ru, kgauem@yandex.ru

Abstract. In order to solve the problem of uniform surface treatment of bored areas of perennial plantations (treatment with herbicides) the graph-analytical method of examination of treatment quality (determination of untreated and treated area around the overlapped die) is proposed. To do this, you need to specify the diameter of the stamp of perennial planting, the overall size of the deflector in the form of a stylus, its position in the space relative to the diameter of the stamp of perennial planting, the size of the overlap zone when treating with herbicides in the gardens, the distance between the dies and the operating speed of the unit to determine the geometric and operating parameters of the sprayer. The whole stage of the working device (probe), when it is working in the nozzle zone is divided into 4 stages. Analysis of the graphical image of the stylus trajectory during movement around the stamp gives an idea of the surface treatment process with herbicides during spraying. In the first stage, part of the borehole zone is treated with overlap, while in the third stage, the untreated area around the die is left untreated. The dependencies of determining these areas depending on the geometric dimensions of the dies, their location in the gardens, the length and angle of the stylus and the operating speed of the unit are derived. According to the different trajectories of movement, in the process of influence of a stylus on a stamp there is a change of direction of an air-droplet stream, as a result of which the flow of a working liquid and accordingly the processed area changes. It is possible to determine the deviation of the actual rate of fluid flow from the specified rate at different points in the borehole area by calculating the areas treated with overlap and untreated. All obtained dependencies will serve for optimization of geometrical and mode parameters of the working device (feeler gauge) during its operation in the borehole zone.

1. Introduction
Science and practice have proved that the potential yield loss of fruit and berry crops from weeds is 7.2% [1]. Moreover, for the productive functioning of the garden ecosystem, it is necessary to develop and use methods to suppress the growth of weed plants (agricultural, chemical). This is necessary to reduce their competition with fruit plants. From the use of herbicides, the reduction of weediness is 90–98% [2, 3]. Also, protective measures are aimed at the destruction of diseases, agricultural pests. In this connection, there is a problem of plant protection, and it is very relevant both in the Russian Federation and abroad. Spraying efficiency is determined by a rational combination of chemicals, their consumption rates and working fluids, machine operating conditions, which determine the number of
drops of the optimal size, density and uniformity of the coating of the object with minimal loss of drugs. At the same time, existing machines for applying herbicides do not provide droplets of the same size, the environmental requirement for the loss of working fluid, lower dose rates, and high process reliability. At the same time, pneumatic jet working bodies are promising, which can be used for any type of sprayer, and the most promising is a slotted spray with a flat feeding nozzle and a rotary device. The purpose of the research is to increase the uniformity of surface treatment of near-trunk zones of perennial plantations and to improve the technological scheme of sprayers. The objectives of the goal are as follows: study of the spraying process with a slot nozzle with a flat feeding nozzle and a rotary device; determination of theoretically geometric and operational parameters of the working body in the form of a probe; drawing up a mathematical model to determine the surface area of the processing with overlapping near the stem and the remaining untreated and the size of the probe. This article is devoted to the implementation of tasks.

2. Materials and methods
When solving the problem, the calculations were carried out using Matcad 2000 programs and PC programs [1,4]. The research algorithm is as follows.

1. A graphical analytical method is proposed for studying the quality of processing (determining the untreated and treated area around the strain with overlapping) when the working body is made in the form of a probe. To determine the areas of double processing and the untreated surface with herbicides in the near-trunk zone in order to find the design parameters of the rotary device made in the form of a loop, hereinafter referred to as the probe “Figure 1”, we construct a graph of the trajectory of its movement “Figure 2”.

![Figure 1](image1.png)  ![Figure 2](image2.png)

**Figure 1.** Scheme of the rotary probe: 1-probe; 2-bar; 3-atomizer; 4-lever; 5-spring; 6-hinge.

**Figure 2.** Zones formed during processing of the device in the form of a probe.

In accordance with various trajectories of movement, in the process of the probe’s influence on the shaft, the direction of the air-droplet jet changes, as a result of which the flow rate of the working fluid and, accordingly, the treated area change.

2. It is possible to determine the deviation of the actual norm of the flow rate of the working fluid from the set at different sites in the near-barrel zone by measuring areas treated with overlap and untreated. Since the probe (AB) “Figure 2” performs translational and rotational motion around the tree trunk, its trajectory is composed of three trajectories corresponding to the three corners of the probe installation, defining three processing steps: 1 step - touch the stem with the probe (the initial angle of installation of the probe to the direction of movement α), before setting it to the angle α₁ (the angle at which the end of the probe begins to slide along the stem); 2nd step - sliding the end of the probe
(point A), along the stem until the moment the impact on the shaft is stopped (point A₂) and turning it by an angle of α₂; Step 3 - setting the probe to its original state at the initial angle α.

Analysis of the graphic image of the probe trajectory during movement around the stem “Figure 2” gives an idea of the process of surface treatment with herbicides during spraying. In the first step, part of the near-trunk zone is processed with overlap, and in the third, the untreated area near the stem remains. Determination of the geometric dimensions of the probe and the installation angle at which it begins to slide along the stem “Figure 3”.

3. The size of the probe, taking into account the angle α of its installation to the stem is determined by

\[ AB = \frac{(OC + OF)}{\sin \alpha}, \]  \hspace{1cm} (1)

where the distance OF - half the overlap zone; distance OS - the surface to be treated in the near-barrel zone.

To find the trajectory of motion at stage 1, the coordinates of point A (AG; AF) were determined relative to the line of the OS passing through the center of the trunk perpendicular to the direction of movement.

\[ AF = \frac{OC + OF}{\sin \alpha} \cdot \cos \alpha \quad \text{and} \quad \frac{OC \cdot \cos \alpha - OD}{\sin \alpha}, \]  \hspace{1cm} (2)

\[ AG = OC + OF. \]  \hspace{1cm} (3)

Replacing the geometric expressions and accepting: \( OC = H \) is the distance from the center of the stem to the hinge of the working body; \( OD = R \) is the radius of the stem; \( OF = \frac{ZP}{2} \) - half of the overlap zone; \( AB = L \) is the length of the probe, received

\[ \text{point } A(L \cdot \cos \alpha - H \cdot \cos \alpha - R \cdot \sin \alpha, H + \frac{ZP}{2}). \]  \hspace{1cm} (4)

Consider the position of the probe at which it begins to slide along the stem, its angle of inclination is α₁ “Figure 4”
4. Determination of angle $\alpha_1$: from figure 4 it follows that $OC = OK_1 + K_1C; \quad OK_1 = OA_1 / \cos \alpha_1; \quad K_1C = K_1B_1 \cdot \sin \alpha$.

Substituting the values $OK_1$ and $K_1C$ received

$$ OC = \frac{A_1O}{\ctg \alpha_1} + (A_1B_1 - \frac{A_1O}{\ctg \alpha_1}) \cdot \sin \alpha_1. \quad (5) $$

After the transformation (5) received

$$ CO \cdot \cos \alpha_1 = OA_1 - A_1B_1 \cdot \sin \alpha_1 \cdot \cos \alpha_1 - OA_1 \cdot \sin^2 \alpha_1. \quad (6) $$

Replacing geometric expressions and accepting $OA_1 = R$ is the radius of the stem; $A_1B_1 = L \cdot$ probe length; received

$$ H \cdot \cos \alpha_1 = R - L \cdot \sin \alpha_1 \cdot \cos \alpha_1 - R \cdot \sin^2 \alpha_1. \quad (7) $$

To find the angle $\alpha_1$, we transformed equation (7) by taking, the equation took the form

$$ (-H-R) x^4 + 2Lx^3 + 2Rx^2 - 2Lx + (H-R) = 0. \quad (8) $$

Solving equation (8), we obtained

$$ x_4 = \frac{-L + \sqrt{L^2 - H^2 + R^2}}{-H - R} \quad (9) $$

knowing the value of $x_i$ determined the value of the angle $\alpha_1$

$$ \alpha_1 = 2 \cdot \arctg \left( \frac{-L + \sqrt{L^2 - H^2 + R^2}}{-H - R} \right). \quad (10) $$

Knowing the coordinates of the $A_1$ point $(G_1A_1, G_1C)$ - the end of the probe at which it begins to slide along the long-standing tree stem “Figure 4” and the inclination angle $\alpha_1$, we obtained the value of the $A_1$ point $(L \cdot \sin \alpha_1, R \cdot \sin \alpha_1)$ given parametrically.

5. Determination of the trajectory of the movement of point A in the range from the angle $\alpha$ to the angle $\alpha_1$. To determine the area of double treatment with herbicides near the standard space, we construct the trajectory of the probe from point A to point $A_1$, i.e. in the range from the moment the stem touches to the moment when the end of the probe begins to slide along the long-term stand, the initial angle $\alpha$ changes to $\alpha_1$. To do this, we built an intermediate position of the probe “Figure 5” at an angle $\alpha_3$, the value of which is within $\alpha_1 \leq \alpha_3 \leq \alpha$ and determined the coordinates of point $A_3$ $(A_3G_3, G_3C)$ to determine the trajectory function with the further use of these coordinates given by parametric.

**Figure 4.** The location of the probe relative to the stem at the start bypass (slip) on the tree trunk.

**Figure 5.** The position of the probe at the time of bypassing the stem.
The projection of the $A_3B_3$ probe on the $y$ axis and the projection of the end of the $G_3C$ probe on the $x$ axis were determined graphically “Figure 5”

$$A_3G_3 = A_3B_3 \cdot \sin \alpha_3.$$  (11)

From figure 5 it follows that

$$G_3C = A_3B_3 \cdot \cos \alpha_3 - \frac{H \cdot \cos \alpha_3 - R}{\sin \alpha_3}.$$  (12)

Having replaced in expression (12) with the corresponding previously accepted notation, we got the coordinates of point $A_3$

$$A_3(L \cdot \sin \alpha_3, L \cdot \cos \alpha_3 - \frac{H \cdot \cos \alpha_3 - R}{\sin \alpha_3}).$$  (13)

To find the function of movement of the end of the probe during the reverse stroke, we divided the angle change range from $\alpha$ to $\alpha_1$ into eleven parts in order to obtain twelve coordinates of the points $A_i$, which were calculated by substituting different values of the current angle $\alpha$ into formula 13 for approximation.

The coordinates of the end of the probe were entered into the vectors VX and VY, then by the linfit (VX, VY, F) function, which returns the vector of linear regression coefficients of the general form given by the second-order function, where the vector F is written in symbolic form $(1, x, x^2)$.

After approximation, we obtained an equation of the form $y = a \cdot x^2 + b \cdot x + c$, in which the root-mean-square error of the approximation of the “cloud” of initial points, whose coefficients are stored in the vectors VX and VY, is minimal, “Figure 6”.

![Figure 6](image)

**Figure 6.** The positions of the probe end (points $A_i$) when traversing the stem from angle $\alpha$ to angle $\alpha_1$.

After finding the coefficients of the probe return equation ($a = K_2$, $b = K_1$ and $c = K_0$), we substituted the values of the points $A_i$ in the obtained equation, found the sum of the squared deviations for calculating the variance, and checked the obtained function for adequacy.

6. Determination of the area of double treatment with herbicides near the standard zone. The area of double processing lies between the arc $AP$ passing through the points $A_i$ and the initial position of the probe $AB$, set at an angle $\alpha$. To determine the area of double treatment with herbicides near the standard zone, one of the integration limits was determined; for this, the coordinates of the point P of the intersection of the tangent to the AB branch were calculated at the initial installation angle $\alpha$ and the approximated function of the probe backward motion equation passing along the $A_P$ arc through the $A_i$ points, the second the limit of integration is the ordinate of the end of the probe (point A).

The general view of the pattern of surface coating during double treatment had the form.

$$S = \int_{x_k_1}^{x_1} (K_2 \cdot x^2 + K_1 \cdot x + K_0)dx - \int_{x_k_1}^{x_1} \left(\frac{x}{\tan \alpha} + b_1\right)dx.$$  (14)

where $S$ is the area of double processing near the standard zone; $x_1$ - the value of the ordinate of the end of the probe (point A); $x_k_1$ - value of the ordinate of point P; $K_2$, $K_1$, $K_0$ - coefficients of the approximated function of the equation stylus reverse motion; $b_1 = (H \cdot \cos \alpha - R) / \sin \alpha$.  

$$5$$
7. Determination of untreated area with herbicides near the standard zone. The untreated area near the standard zone is formed when the probe approaches the stem, and also when the probe leaves the zone of its contact with the stem “Figure 7”. The return time to the starting position of the working body was determined when moving from angle $\alpha_2$ to angle $\alpha$, “Figure 8”.

![Figure 7](image7.png)  
**Figure 7.** Untreated area near the standard zone.  

![Figure 8](image8.png)  
**Figure 8.** Probe trajectory during return to starting position.

8. To determine the untreated area with herbicides near the standard zone, we determined the function of the movement of the end of the probe when it leaves the contact zone with the stem and the integration limits. From figure 7 it follows that the untreated area represents the figure $A_2LD_0A_0RWA_2$, the area of which was determined by the following formula

$$S_{no} = \int_{CE}^{CL} f(\cup A_2WR) - \int_{CE}^{CN} f(\cup A_2LD_0) + \int_{CN}^{CL} f(A_0B_0) - \int_{CN}^{CL} f(\cup A_2LD_0),$$  \hspace{1cm} (15)

where $W$ is the intersection of the arcs $A_2WR$ and $A_0B_0$.

For small values $OA_2$ - (size of the stem), the integration limits take other values, since in this case the point $W$ is the intersection of the straight line $A_0B_0$, and equation 15 takes the form

$$S_{no} = \int_{CE}^{TW} f(\cup A_2WR) - \int_{CE}^{TW} f(\cup A_2LD_0) + \int_{CN}^{TW} f(A_0B_0) - \int_{CN}^{TW} f(\cup A_2LD_0).$$  \hspace{1cm} (16)

The direction of movement of the probe is indicated in Figure 7 by arrows. To find the untreated area near the standard zone, the function of movement of the working body along the $A_2WR$ arc was determined by equations (15) and (16). During the bypass of the stem, the probe is installed at an angle $\alpha_2$, after which the opening mechanism is activated, which sets the probe to the initial angle $\alpha$.

The angle of return $\beta$ to the starting position was determined by the difference between the initial angle $\alpha$ and $\alpha_2$. When the working body moves from point $A_2$ to point $A_4$, the intermediate values of point $A_j$ are described by the trajectory of movement along an arc with a radius of $A_2B_2$, simultaneously moving with the speed of the unit in the standard zone for time $t_r$, “Figure 8”, forming a trajectory (arc $A_2WR$). The return time to the initial position of the working body was determined when moving from the angle $\alpha_2$ to the angle $\alpha$, setting the values of the aggregate speed $V_p$ and the distance $CC_4$, which the aggregate will pass from the center of the stem to the place when the working organ is installed in its original position at an angle $\alpha$, “Figure 8”.

For the case under consideration, the time to return the probe to its original position is.

$$t_r = \frac{CC_4 - (L + R) \cdot \cos \alpha_2 + L \cdot \cos \alpha}{V_p}$$  \hspace{1cm} (17)

9. To determine the function of movement of the working body along the arc $A_2WR$, we specified the coordinates of the points $A_j$ parametrically $A(x_j, y_j)$

$$x_j = A_2B_2 \cdot \sin(\alpha_2 + \Delta \beta),$$  \hspace{1cm} (18)
\[ y_j = \left( OA_2 + A_2B_2 \right) \cdot \cos \alpha_2 - A_2B_2 \cdot \cos(\alpha_2 + \Delta \beta) + \frac{\Delta \beta \cdot V_p \cdot \text{tr}}{\beta}, \]  

(19)

where \( \Delta \beta \) is the increment of the angle of return to the initial position, degrees \((0 \leq \Delta \beta \leq \beta)\).

Moving the end of the probe when returning to its original position, we find the spline approximation. With it, the original function is replaced by segments of polynomials passing through three adjacent nodal points. The coefficients of the polynomials were calculated so that the first and second derivatives were continuous.

Using a cubic spline \((X, Y)\) determined the function of movement of the working body along the arc \(A_2WR\). Then, according to equations (15) or (16), the untreated area near the standard zone was determined.

Given the diameter of the stem \(- D\), the initial angle of installation of the probe \(- \alpha\), the overlap of the treatment area \(- z\), the distance from the center of the stem to the hinge of the probe \(- H\), the distance between the posts \(S\), the operating speed of the unit \(V_p\) and the distance the probe is installed at the initial angle after going around the stem was determined: probe size; the area treated twice; non-cultivated area near the standard zone.

3. Results and discussion

Given the distance \((CC_4 \text{ figure 8})\) of setting the probe to the initial angle, after it was circled around the stem, we determined the time to return to the initial position of the probe, and we selected the spring of the necessary stiffness by returning it by determining the moment of inertia of the working body. The calculation results according to the algorithm are shown in table 1.

Table 1. The area of two multiple and uncultivated surfaces during the operation of the fixture in the garden (cm\(^2\)) and its size to the hinge (m) depending on the diameter of the tree trunk (m) and its installation angle (degrees).

| Diameter, D | Installation angle, \( \alpha \) | Probe length, L | Area treated twice | Area cultivated |
|-------------|---------------------------------|----------------|-------------------|-----------------|
| 0.2         | 60°                             | 0.318          | 2632.38           | 34.06           |
| 0.2         | 90°                             | 0.275          | 3015.41           | 4.88            |
| 0.2         | 30°                             | 0.550          | 2564.23           | 130.04          |
| 0.1         | 60°                             | 0.318          | 3971.98           | 10.41           |
| 0.1         | 90°                             | 0.275          | 3331.12           | 1.91            |
| 0.1         | 30°                             | 0.550          | 2889.88           | 34.96           |

These tables can be used when developing a working body for work in gardens. For other values, you can use the above algorithm

4. Conclusions

As a result of research, the following are theoretically determined:

- the composition of the mathematical model, which allows to determine the surface area and the degree of damage from deformation;
- geometric and operational parameters of the working body in the form of a probe, where it is assumed that the distance between the trees \(S = 3m\), the distance from the center of the tree to the hinge of the device \(N = 0.2m\), the floor of the overlap zone for agricultural needs \(z = 0.15m\), the operating speed of the unit \(V = 5 \text{ km / h}\).

5. References

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