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ABSTRACT

Vibrations of the sprayer field boom in the transverse-vertical plane result in a decrease in the quality of the technological operation. This is especially true in relation to the operation of small-sized single-support wheelbarrow-type sprayers. One of the possible solutions to compensate for the effect of transverse vibrations of the boom on the quality of spraying is the use of adaptive sprayers with a variable root angle of the spray torch, responding to the position occupied by the sprayer in relation to the surface being treated. The purpose of the work is to optimize the current values of the frontal spray angles of the nozzles of the adaptive distribution system of a small boom sprayer. The novelty of the study lies in the fact that, unlike industrial agricultural machinery, insufficient attention is paid to the implementation of technologies using small-scale mechanization tools. A prototype of a single-support boom motor sprayer was used as the object of study. The field experiment was carried out at the experimental sites of the Oryol State Agrarian University. Registration of data on the deviation of the sprayer from the vertical axis was carried out using a specially developed mathematical processing of the decrypted experimental data was carried out by a spreadsheet processor in the Microsoft Excel environment. The study of the obtained analytical dependencies was carried out in the environment of the mathematical calculation system Mathcad 14.0. The work used the method of nomogramming functions of several variables. It has been experimentally established that during operation the maximum deviations of the sprayer from the vertical can be up to 30°. At the same time, the average amplitude of the transverse operating vibrations of the boom of a single-support barrow-type boom sprayer ranges from +11° to -18°. The amplitude of lateral vibrations of a single-support sprayer depends on the operator's preparedness and the speed of movement of the unit. Balancing the sprayer is important, taking into account the moment of forces caused by the weight of the one-sided field boom. A formula has been derived for calculating the spray width of one sprayer, taking into account the geometric parameters of a single-support sprayer, as well as its angle of inclination in the transverse-vertical plane. An analytical relationship has been obtained that makes it possible to calculate the required limits of the root angle of the spray pattern of an adaptive sprayer, taking into account the installation distance of the sprayer, relative to the vertical plane passing through the support point of the sprayer. The values of the root spray angles were found for the deflectors of adaptive sprayers, with the amplitude of oscillations of the sprayer from -18° to +11° in the transverse-vertical plane. A nomogram has been developed to determine the optimal values of the frontal angles of the spray pattern of sprayer nozzles. An analytical technique for optimizing the current values of frontal spray angles has been proposed, taking into account the position of the distribution system and performed for the first time. The practical value of the study lies in the possibility of using a formula to determine the limits of change in root spray angles when designing and developing adaptive sprayers. The technique can be used to develop software for the control complex of a sprayer equipped with an adaptive system for distributing working fluid in changing conditions.

Keywords: small-sized sprayer, sprayer, spray angle, field boom, transverse vibrations, spray uniformity, nomogram.

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I. INTRODUCTION

In the processes of selection and primary seed production of plants, improvement of gardening and park farming, as well as on citizens' personal plots, single-support small-sized wheelbarrow-type boom sprayers are used. Among the most famous models offered by manufacturers are equipment from Wintersteiger (Austria), Euro Pulve (France), Walkover International (England), and a sprayer produced by JSC GSKB (Zernoochistka) Voronezh (Russia). Single-support sprayers have a number of advantages compared to a single-axle two-wheeled design: they are less metal-intensive, more maneuverable, do not require re-adjusting the track, and when switching to a different row spacing, they can be moved along narrow paths. At the same time, they are less stable in the transverse-vertical plane, which entails the need for constant monitoring of the horizontal position of the rod and excessive stress on the operator.

It is known that even slight vibrations of the boom lead to a deterioration in the quality of spraying: with increasing spray height, evaporation and drift of particles of the working fluid increase; The low height of the nozzles determines the absence of overlap zones and exceeding the rate of application of the active substance. As a result, conditions are created for insufficient inhibition of the development of weeds [1], acceleration of resistance (addiction) of pests [2, 3] to the drug and a decrease in its toxicological effect on pathogens [4] in the "under-application" zone. An increase in the concentration of the active substance causes burns of plant leaves [5]. For the environment, one of the main risk factors is the drift of small drops and the flow of large drops from the treated surface. It has been established that during spraying, the proportion of small droplets with a low rate of gravitational settling (less than 80 microns) ranges from 1...2% [6] to 5...6% [7] and more. In general, losses of herbicides during demolition can be 20...90%, and damage to crops that are not subject to this treatment is in some cases found at a distance of up to 20 km from the spraying sites [8].

Under these conditions, special attention should be paid to ensuring uniform application of protective equipment, regardless of elastic vibrations of the rod, resonance phenomena or current changes in the microrelief. Thus, for trailed, mounted and self-propelled sprayers, the problem of compensating for boom deflection has been systematically solved for many years. There are known technical and technological solutions based on copying the field topography using spring-lever suspensions [9], vibration dampers of the field rod [10], suppression of vibration of the distribution rod by combining its different cross sections [11], using a fan nozzle with a variable spray angle together with pulse-width modulation technology [12], changes in the merging of flows of adjacent nozzles, depending on the magnitude of the boom oscillations [13], etc. Means of small-scale mechanization have recently taken a stable place in the implementation of modern technologies. Therefore, issues of theoretical justification for the conditions of their functioning, design parameters and technological operating modes remain relevant and require reflection in new engineering projects.

The results of our earlier studies [14, 15] allow us to assert that a universal solution to the problem of compensating for deviations of the boom of a small-sized sprayer in the transverse-vertical plane can be the use of sprayers that adaptively respond to the position they occupy in relation to the surface being treated. In this case, there is no need to equip the sprayer with complex and massive lever copying devices, and maintaining the overlap pattern of the processed strips is achieved by changing the geometry of the spray torches of individual nozzles [16-19].

а б

Figure 1: A prototype of a single-support boom motor sprayer (a) and a device for measuring the magnitude of horizontal deviations of the field boom (b)

Based on the existing premises, the purpose and objectives of the study are formulated.

Purpose of the study: optimization of the spray pattern angles of the adaptive sprayer of a wheelbarrow-type field boom sprayer.

Research objectives:

1. Assessment of the amplitude of operating vibrations of the boom of a single-support sprayer in the transverse-vertical plane;
2. Analysis of the influence of the lateral deflection of the sprayer on the working width of the field sprayer;
3. Determination of the dependence of the values of the required spray pattern angle of the adaptive sprayer on the angle of inclination of the single-support sprayer in the transverse-vertical plane;
4. Determination of the limits for changing the root spray angles of the adaptive sprayer of a single-support boom sprayer of a wheelbarrow type;
5. Optimization of the current frontal spray angles of the distribution system nozzles, based on their functional relationships with influencing factors and the development of a nomogram for determining the optimal values of the frontal angles of the spray pattern of sprayer nozzles in production conditions.

II. MATERIALS AND METHODS

When solving the first problem, a prototype of a single-support boom motor sprayer (Fig. 1, a), which we had previously developed [20], was used as the object of study. The field experiment was carried out at the experimental sites of the Oryol State Agrarian University. Repetition of experiments - 3 times; measurement error - no more than 5%. Data recording on the deviation of the sprayer from the vertical axis was carried out using a specially designed inclinometer (Fig. 1, b). The latter consists of a measuring scale rigidly mounted on the sprayer frame and a hinged indicator arrow equipped with a plumb line [21]. The current readings of the protractor were recorded using a self-powered car recorder. Subsequent mathematical processing of the decrypted experimental data was performed by a spreadsheet processor in Microsoft Excel.

The theoretical substantiation of the influence of vibrations of the sprayer boom on the distribution parameters of the working fluid was carried out on the basis of generally accepted engineering calculation methods. The study of the obtained analytical dependencies was carried out in the environment of the mathematical calculation system Mathcad 14.0 (Russian version). The work used the method of nomogramming functions of several variables.

III. RESULTS AND DISCUSSION

The results of an experiment to evaluate the operating vibrations of a single-support sprayer with a right-handed boom in the transverse-vertical plane established the following. The maximum deviation angles of the sprayer from the vertical can range from +17° (left-side slope, in the direction of travel) to -30° (right-side slope, in the direction of travel). In this case, the arithmetic mean value of the transverse vibration angle is -3(±0.4)°. It is important to note that peak deviation values are quite rare and depend mainly on the operator's training and the speed of movement of the sprayer. The average values of the maximum inclination angles lie in the range from +11° to -18°. It is these values that will be decisive when choosing the operating modes of adaptive sprayers, which allow you to control the geometry of the spray plume.

In addition, analysis of the transverse vibration diagram (Fig. 2) indicates the clear presence of right-sided asymmetry. Obviously, the latter is caused by a slight shift in the center of gravity of the prototype sprayer, due to the imbalance of the moment of force from the weight of the one-sided field rod. One of the options for eliminating this design flaw could be to equip the sprayer with a tracking balancing mechanism [22]. Such a device is capable of adjusting the balancing of the sprayer by the spatial position of the tank, depending on the amount of working fluid in it.

In order to determine the theoretical width of the spray torch with one sprayer, we describe the geometric parameters of the sprayer with the diagram shown in Fig. 3.

Allowing for the possibility of deflection of the sprayer only in the plane of the drawing, the frame OA, height h, has transverse movements at an angle α relative to the hinge O. A horizontal rod AB of length l is installed perpendicular to the frame OA and is rigidly connected to it.

The spray torch is an isosceles triangle CBD with a constant angle β, at vertex B. The bisector VM drawn to the base of the triangle SVD is strictly perpendicular to the horizontal rod AB and, at the same time, is the height p of the triangle SVD. Here, the base CD=b0 is the line of contact of the spray torch with the surface being treated.

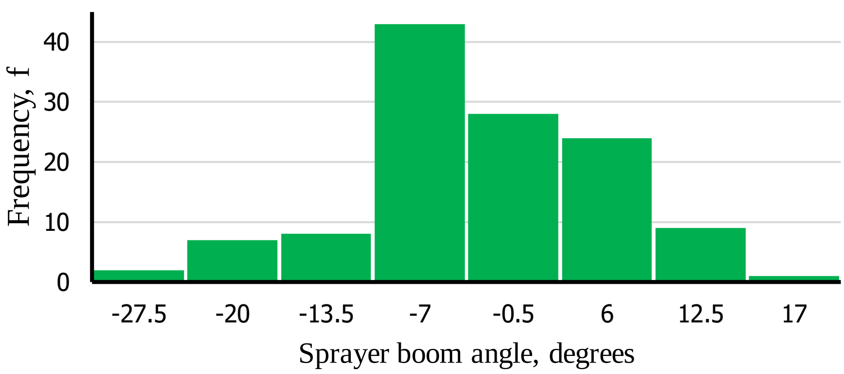

Figure 2: Histogram of the distribution of vibration values of the boom of a single-support sprayer in the transverse-vertical plane

As can be seen from Fig. 3, when the angle α of the position of the sprayer changes, a corresponding deviation of the SVD spray torch occurs from its original position. At the same time, the length of the contact line of the spray torch with the surface being treated will also change (CiDi=bi).

Let us analyze the influence of the lateral deviations of a single-support motorized sprayer on the working width of a field sprayer located at a distance l from the symmetry axis of the sprayer passing through its support point O.

From the cosine theorem it is known that the square of any side of a triangle is equal to the sum of the squares of its two other sides minus twice the product of these sides and the cosine of the angle between them. From here:

$$b_i = \sqrt{d^2 + c^2 - 2dc \times cos\beta} \quad (1)$$

where bi, d, c are the sides of the scalene triangle CiBiDi, formed by the spray torch and the surface being treated, when the sprayer frame is deflected at a certain angle α.

To determine the sides d and c of the triangle CiBiDi, we divide it into two rectangular ones CiBiMi and MiDiDi, with leg pi = BiMi.

Using the formulas for the relationship between the sides and angles of the right triangle CiBiMi, we write:

$$d = \frac{p_i}{sin\gamma}, \quad (2)$$

where γ is the angle at the base of the triangle.

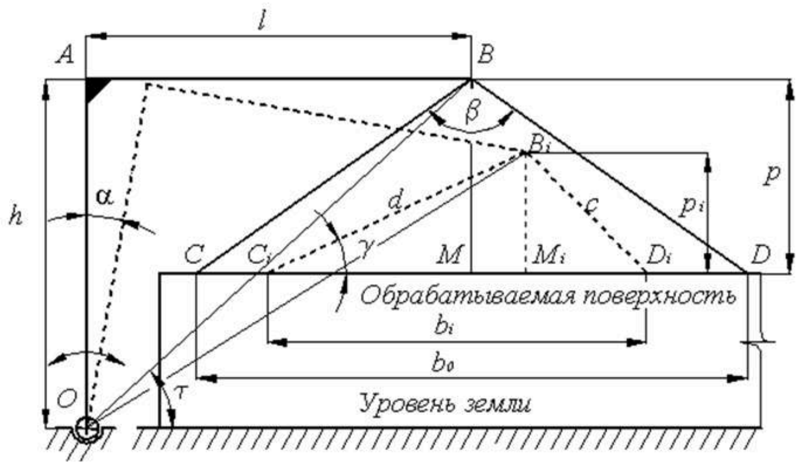

Figure 3: Scheme for calculating the change in the width of the spray torch of the sprayer nozzles when the boom oscillates in the transverse-vertical plane

The CiDiDi triangle is formed by the displacement of the CBD triangle due to the rotation of the frame by an angle α. Then, angle γ can be defined as the difference between angles α and one of the angles of the equilateral triangle CBD, at its base. From here:

$$\gamma = 90° - \frac{\beta}{2} - \alpha \quad (3)$$

By connecting points B and Bi with the support point O, we define pi as the difference in the heights of the triangles SVD and CiBiDi relative to the support surface.

It is obvious that the angle τ between the straight line OBi and the supporting surface is determined by the function.

$$tg\tau = \frac{h}{l}, \tag{4}$$

therefore, if

$$OB = OB_i = \sqrt{h^2 + l^2}, \tag{5}$$

That

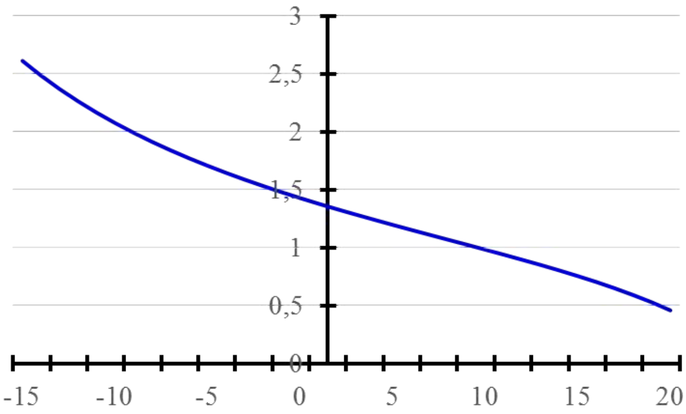

Figure 4: Dependence of the width of the processing strip with one sprayer on the deflection of the sprayer in the transverse-vertical plane

$$p_i = p - \left(h - \sqrt{h^2 + l^2} \times sin(\tau - \alpha)\right), \tag{6}$$

from where, taking into account (4)

$$d = \frac{p - \left(\left(h - \sqrt{h^2 + l^2}\right) \times sin\left(arctg\frac{h}{l} - \alpha\right)\right)}{sin\left(90° - \frac{\beta}{2} - \alpha\right)} \tag{7}$$

To calculate the side c of the triangle CiBiDi, we will use the already known angle at the vertex Bi and height pi:

$$c = \frac{p_i}{cos\left(\frac{\beta}{2} - \alpha\right)} = \frac{p - \left(\left(h - \sqrt{h^2 + l^2}\right) \times sin\left(arctg\frac{h}{l} - \alpha\right)\right)}{cos\left(\frac{\beta}{2} - \alpha\right)} \tag{8}$$

After some transformations, equality (1) for calculating the spray width, taking into account the geometric parameters of a single-support sprayer, as well as the angle of transverse inclination of the frame, will finally be written in the form:

$$b_i = \sqrt{\left(p-\left(h-\sqrt{h^2+l^2}\right)\times sin\left(arctg\frac{h}{l}-\alpha\right)\right)\left(\left[\frac{1}{sin\left(90°-\frac{\beta}{2}-\alpha\right)}\right]^2+\left[\frac{1}{cos\left(\frac{\beta}{2}-\alpha\right)}\right]^2 - -2\left(\frac{1}{sin\left(90°-\frac{\beta}{2}-\alpha\right)}\right)\left(\frac{1}{cos\left(\frac{\beta}{2}-\alpha\right)}\right)\times cos\beta\right)} \quad (9)$$

The graphical representation of formula (9) is illustrated in Fig. 4 for values p=0.5m; h=0.9m; l=1m; β=110°. As can be seen, with a horizontal position of the sprayer boom, the width b of the distribution strip of the working fluid with one sprayer is about 1.43 m. However, even when the sprayer is deviated by an angle α from -15° to +20° in the transverse-vertical plane, the width b varies from 2.60m to 0.46m, i.e. more than 1.8...3.1 times.

When setting the task of determining the necessary limits for changing the root spray angle β of the sprayer, we proceed from the premise of maintaining a constant working width bi. Due to the insignificance of the transverse deviations of the horizontal projection of the sprayer when the rod is tilted in the transverse-vertical plane, we do not take these deviations into account in the calculations. In addition, we accept the assumption that the vertical position of the sprayer axis is stable (provided by a vertical stabilization device).

In accordance with the theorem of sines we have (see Fig. 3):

$$\frac{BD}{sin90°} = \frac{b_0}{sin\beta}, \quad (10)$$

Where

$$\beta = arcsin\frac{b_0}{2BD} \quad (11)$$

From the Pythagorean theorem, the square of half the length of the hypotenuse BD is equal to the sum of the squares of the legs p and b0/2, or:

$$BD = \sqrt{p^2 + \left(\frac{b_0}{2}\right)^2} \quad (12)$$

Substituting (12) into (11) we get:

$$\beta = arcsin\frac{b_0}{2\left(\sqrt{p^2+\left(\frac{b_0}{2}\right)^2}\right)} \quad (13)$$

From the diagram in Fig. 3 it is obvious that the current value of p will change in accordance with dependence (6). Taking into account that

$$\tau = arctg\frac{h}{l}, \quad (14)$$

the final record of the influence of the angle α of the position of a single-support sprayer on the required spray angle β, taking into account the distance l of the sprayer's projection, relative to the vertical axis passing through the sprayer's support point, can be represented in the form:

$$\beta = 2arcsin\frac{b_0}{2\left(\sqrt{\left[p-\left(\left(h-\sqrt{h^2+l^2}\right)\times sin\left(arctg\frac{h}{l}-\alpha\right)\right)\right]^2+\left(\frac{b_0}{2}\right)^2}\right)} \quad (15)$$

For the previously given numerical values included in formula (15) and the given value b0=1.43m, a graphical interpretation of the dependence β=f(α) is shown in Fig. 5. It is clearly seen that with a strictly vertical position of the sprayer (α=0°; horizontal position of the field boom), the root spray angle β=110° allows for a treatment strip with an estimated width of 1.43 m. When the sprayer is tilted to the left, to the value α=- 15°, the distance from the spray nozzle to the surface being treated increases and, consequently, the width of the processing strip (see Fig. 3). As follows from the graph in Fig. 5, in

order to maintain the same working width b0, the required spray angle βi should be equal to 89°. Accordingly, the angle of inclination of the sprayer α=20° determines the opening of the spray angle to β=164°.

Using formula (15) makes it possible to calculate the required limits for changing the spray angle of one nozzle, with established average values of rod vibrations in the transverse-vertical plane. Thus, based on previously obtained experimental values of the rod oscillation angles and reducing their maximum operating values to average values, we obtain: α = +11°...-18°. For the given limits of vibration of the rod in the transverse-vertical plane, changes in the spray angle by the adaptive sprayer should be β=86°...135°, at a distance l=1 m.

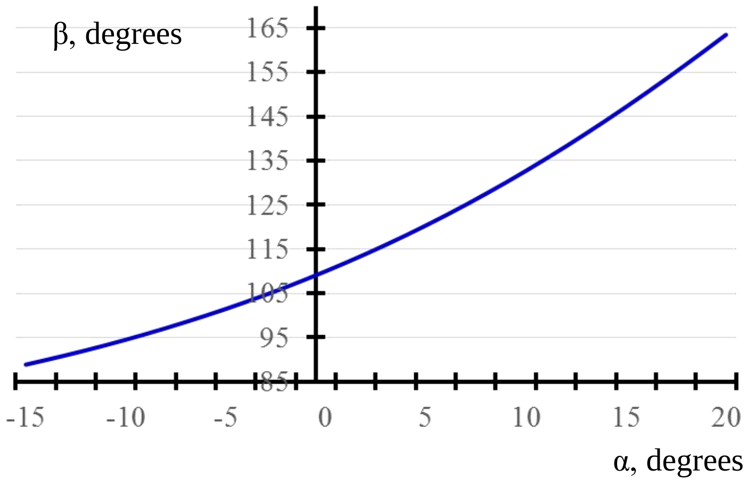

Figure 5: Dependence of the values of the required spray angle of the adaptive sprayer on the angle of inclination of the single-support sprayer in the transverse-vertical plane

For a deflector sprayer, the spray pattern angle in the form of a flat cone is formed by the cone angle of the restrictive collars at the periphery of the deflector [17]. Consequently, the angles of their taper formed by the outer sides of each reflective deflector will be determined by the calculated spray angles of a given adaptive atomizer deflector. Taking into account the distance of each sprayer from the symmetry plane of the sprayer passing through the support point, the numerical values of these angles are found using formula (15) and are summarized in table.

Table. Values of root angles β of spray for deflectors of adaptive sprayers, with values of α=-18°...+11°

Distance of the adaptive sprayer installation point from the sprayer support axis, m	Limits of change in spray pattern angles, degrees.		
	min	nom	max
0,5	99	110	123
1,0	86	110	135
1,5	76	110	149
2,0	67	110	164
2,5	60	110	179

Graphic interpretation of expressions (9; 15) was used to construct an optimization nomogram (Figure 6). The nomogram makes it possible to obtain the values of the current frontal spray angles that satisfy the permissible width of the processing strip, at any position of the sprayer boom.

Agrotechnical requirements for the spraying process allow uneven distribution (variation coefficient) of the working fluid - no more than 25% for low-volume and conventional spraying, and no more than 40% for ultra-low-volume spraying [23]. Then, taking into account the permissible unevenness of the application of the liquid preparation of 25%, the deviation limits of the width of the processing strip with one nozzle will be from 1.07 to 1.78 m, with a frontal spray angle of 110°. As can be seen from the upper sector of the nomogram, the liquid distribution parameters obtained by spraying nozzles located at a distance of l=2.5 m from the rolling center (at rod position angles ±2°) fit into the indicated interval; l=2.0 m (±3°); l=1.5 m (±4°); l=1.0 m (-6°...+7°). The spray pattern of the nozzle closest to the center of the rod's swing provides acceptable parameters for liquid distribution at rod slopes from -11° to +13°. The upper sector of the nomogram demonstrates the dependence of the width of the spray zone on the angle of inclination to the horizon of the distribution system (rod), with a corresponding distance of the nozzle from the rolling center. The lower sector shows a graphical formalization of the function of the influence of the angle of inclination of the rod on the required frontal spray angle, which ensures the optimal processing width with the corresponding nozzle.

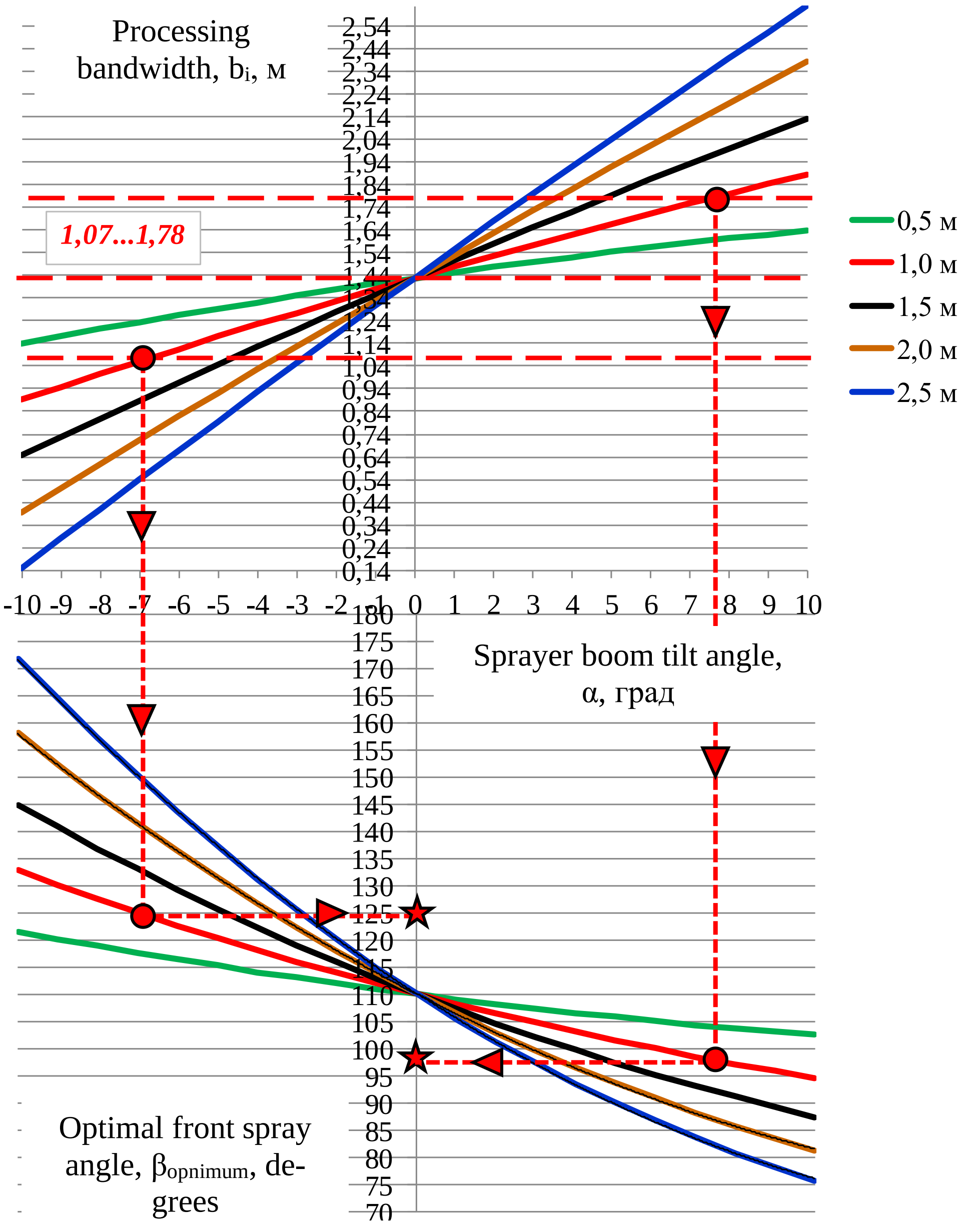

Fig. 6. Nomogram for determining the optimal current values of the front angles of the spray pattern of sprayer nozzles during vertical vibrations of the distribution system (for a spray angle of 110°)

IV. CONCLUSION

These studies have established that the maximum limits of lateral vibrations of a barrow-type boom single-support sprayer range from +17° (left-hand slope, in the direction of travel) to -30° (right-side slope, in the direction of travel). However, the average amplitude of operating vibrations is in the region =+11°...-18°. A formula has been obtained for calculating the spray width of one sprayer, taking into account the geometric parameters of a single-support sprayer, as well as its angle of inclination in the transverse-vertical plane. It has been established that one of the possible solutions to the problem of compensating for the quality of distribution of the working fluid during transverse vibrations of the sprayer boom can be the use of sprayers with a spray geometry that adaptively responds to the position occupied by the sprayer in relation to the surface being treated. An analytical relationship has been obtained that makes it possible to calculate the required limits of the root spray angle of the adaptive sprayer, taking into account the distance l of the sprayer's outreach, relative to the vertical axis passing through the sprayer's support point. The values of the root spray angles were found for the deflectors of adaptive sprayers, for the limits of sprayer oscillations from -18° to +11° in the transverse-vertical plane. The proposed nomogram makes it possible to graphically obtain the optimal values of the frontal spray angles of spray nozzles located at different distances at any position of the sprayer distribution rod. The technique is applicable in the development of software for the control complex of a sprayer, equipped with an adaptive system for distributing working fluid in changing conditions. In addition, with proper refinement, the described methodological approaches can be used to quickly create the most preferred schemes for placing various sprayers on the boom and installing the latter in production conditions.

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Tree Richness and Carbon Storage in Developing a Tropical Evergreen Forest after Slash-and-Burn in the Lacandon Region, Mexico

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ABSTRACT

The objectives were to quantify tree richness and estimate carbon stored during the recovery and development of tropical evergreen forest (BTP) affected by the traditional slash and burn (RTQ) system practiced by the Lacandon-Mayan ethnic group. This research was carried out in the Lacandona region of Mexico. The aim was to determine whether the RTQ system maintains tree species richness and whether stored C is recovered.

Methods. Dismantled areas were located with the RTQ system from 5, 10, and 20 years ago (BTR5, BTR10, and BTR20, respectively). To obtain tree richness, botanical collections of all tree species present in 0.1 ha plots of BTR5, BTR10, and BTR25, as well as two BTP plots (BTP1 and BTP2, respectively) were carried out. In each plot, height, diameter at breast height, and number of individuals of each tree species were recorded. To estimate the stored C, the equation proposed by Chave et al., (2005) was used, which relates the DAP and the density of the wood of each species.

Keywords: regeneration rainforest, environmental services, species richness, biodiversity, and tropical rainforest.

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