DOI: https://doi.org/10.17816/0321-4443-611160

Original Study Article

Justification of range limits of root spray angle of an adaptive spraying device

Sergey A. Rodimtsev[1], Ilya A. Dembovsky[2]

[1] Oryol State University named after I.S. Turgenev, Oryol, Russian Federation;
[2] Oryol State Agrarian University named after N.V. Parakhin, Oryol, Russian Federation

ABSTRACT

BACKGROUND: Oscillations of the sprayer field boom in the transverse-vertical plane causes a decrease in the quality of the technological operation. This is especially true in relation to the operation of small-sized single-support barrow-type sprayers. One of the possible solutions to compensate the effect of transverse oscillations of the boom on the quality of spraying is the use of adaptive sprayers with a variable root angle of the spray jet, responding to the position taken by the sprayer in relation to the surface being treated.

AIM: Justification of the necessary limits for changing the spray angles of an adaptive sprayer for a single-support spraying device. The novelty of the research lies in the fact that insufficient attention is paid to the implementation of technologies using means of small-scale mechanization, unlike industrial agricultural machinery.

METHODS: A prototype of a single-support boom motor sprayer was used as the study object. The field experiment was carried out at the experimental area of the Oryol State Agrarian University. Data acquisition on the deviation of the sprayer from the vertical axis was carried out using a specially developed angle gauge. A spreadsheet processor in the Microsoft Excel environment was used to perform mathematical processing of the decrypted experimental data. The study of the obtained analytical dependencies was carried out in the environment of the Mathcad 14.0 mathematical calculation system.

RESULTS: It has been experimentally found that the maximum deviations of the sprayer from the vertical can be up to 30° during operation. At the same time, the average amplitude of the transverse operating oscillations of the boom of a single-support barrow-type boom sprayer ranges from +11° to -18°. The amplitude of the transverse oscillations of a single-support sprayer depends on the operator's skills and the unit motion velocity. Balancing the sprayer is important due to the moment of force caused by the weight of the one-sided field boom. A formula for calculation of the spray width of one sprayer, taking into account the geometric parameters of a single-support sprayer, as well as its inclination angle in the transverse-vertical plane, has been derived. An analytical relationship that makes it possible to calculate the required limits of the root angle of the spray jet 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, has been obtained. The values of the root spray angles for the deflectors of adaptive sprayers, with the sprayer oscillations amplitude from -18° to +11° in the transverse-vertical plane, were found.

CONCLUSIONS: The practical value of the study lies in the potential of using the formula to determine the range limits of root spray angles when designing and developing adaptive sprayers.

Keywords: small-sized sprayer; sprayer; spray angle; field boom; transverse oscillations; spraying quality.

To cite this article:
Rodimtsev SA, Dembovsky IA. Justification of range limits of root spray angle of an adaptive spraying device. *Tractors and Agricultural Machinery.* 2024;91(1):81–90. DOI: https://doi.org/10.17816/0321-4443-611160

Received: 21.10.2023 **Accepted:** 25.01.2024 **Published online:** 15.03.2024

DOI: https://doi.org/10.17816/0321-4443-611160

Оригинальное исследование

Обоснование пределов изменения корневых углов распыла адаптивного распылителя опрыскивателя

С.А. Родимцев[1], И.А. Дембовский[2]

[1] Орловский государственный университет им. И.С. Тургенева, Орел, Российская Федерация;
[2] Орловский государственный аграрный университет им. Н.В. Парахина, Орел, Российская Федерация

АННОТАЦИЯ

Обоснование. Колебания полевой штанги опрыскивателя в поперечно-вертикальной плоскости влекут снижение качества технологической операции. Указанное обстоятельство особенно актуально в отношение работы малогабаритных одноопорных опрыскивателей тачечного типа. Одно из возможных решений компенсации влияния поперечных колебаний штанги на качество опрыскивания — применение адаптивных распылителей с изменяемым корневым углом факела распыла, реагирующих на положение, занимаемое распылителем по отношению к обрабатываемой поверхности.

Цель работы — обоснование необходимых пределов изменения углов распыла адаптивного распылителя для одноопорного опрыскивателя. Новизна исследования заключается в том, что в отличие от производственной сельскохозяйственной техники, вопросам реализации технологий с применением средств малой механизации уделяется недостаточно внимания.

Материалы и методы. В качестве объекта исследования использовался макетный образец одноопорного штангового мотоопрыскивателя. Полевой эксперимент проводился на опытных участках Орловского ГАУ. Регистрация данных по отклонению опрыскивателя от вертикальной оси выполнялась с помощью специально разработанного угломера. Математическая обработка дешифрованных опытных данных выполнялась табличным процессором в среде Microsoft Excel. Исследование полученных аналитических зависимостей проводилось в среде системы математических расчетов Mathcad 14,0.

Результаты. Экспериментально установлено, что в процессе работы максимальное отклонение опрыскивателя от вертикали может составлять до 30°. При этом, средняя амплитуда поперечных рабочих колебаний штанги одноопорного штангового опрыскивателя тачечного типа составляет от +11° до -18°. Амплитуда поперечных колебаний одноопорного опрыскивателя зависит от подготовленности оператора и скорости передвижения агрегата. Важное значение имеет балансировка опрыскивателя, с учетом момента сил, вызванного весом односторонней полевой штанги. Выведена формула для вычисления ширины распыления одним распылителем, учитывающая геометрические параметры одноопорного опрыскивателя, а также угол его наклона в поперечно-вертикальной плоскости. Получена аналитическая зависимость, позволяющая рассчитать требуемые пределы корневого угла факела распыла адаптивного распылителя, с учетом расстояния монтажа распылителя, относительно вертикальной плоскости, проходящей через точку опоры опрыскивателя. Найдены значения корневых углов распыла для дефлекторов адаптивных распылителей, при амплитуде колебаний опрыскивателя от -18°до +11° в поперечно-вертикальной плоскости.

Заключение. Практическая ценность исследования заключается в возможности использования формулы для определения пределов изменения корневых углов распыла при проектировании и разработке адаптивных распылителей опрыскивателей.

Ключевые слова: малогабаритный опрыскиватель; распылитель; угол распыла; полевая штанга; поперечные колебания; качество внесения.

Как цитировать:
Родимцев С.А., Дембовский И.А. Обоснование пределов изменения корневых углов распыла адаптивного распылителя опрыскивателя // Тракторы и сельхозмашины. 2024. Т.91, № 1. С. 81–90. DOI: https://doi.org/10.17816/0321-4443-611160

Рукопись получена: 21.10.2023 **Рукопись одобрена:** 25.01.2024 **Опубликована онлайн:** 15.03.2024

BACKGROUND

Single-support small-sized barrow-type boom sprayers are commonly utilized in several processes, including plant selection, primary seed production, gardening, park farming, and other practices on individual plots. Equipment from Wintersteiger (Austria), Euro Pulve (France), and Walkover International (England) and a sprayer produced by GSKB (Zernoochistka) Voronezh (Russia) are among the most renowned models offered by manufacturers. Single-support sprayers offer several advantages over single-axle two-wheeled designs: they consume less metal, are more maneuverable, do not require track reconfiguration, and can be easily moved along narrow paths when switching row spacing. However, they are less stable in the transverse–vertical plane, requiring constant monitoring of the horizontal position of the boom and placing excessive stress on the operator.

Even slight vibrations of the boom can lead to deterioration in the spraying quality. With an increase in the spray height, evaporation and drift of the working fluid particles also increase. The low height of the nozzles ensures the absence of overlap zones and prevents exceeding the application rate of the active substance. Consequently, conditions are created for insufficient inhibition of weed development [1], acceleration of resistance (addiction) of pests [2, 3] to pesticide products, and a decrease in its toxicological effect on pathogens [4] in the "under-application" zone. An increase in the concentration of the active substance can cause burns on 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. During spraying, the proportion of small droplets with a low rate of gravitational settling (<80 microns) has been found as 1%–2% [6] and 5%–6% [7]. Generally, losses of herbicides during drift can range from 20% to 90%, and damage to crops that are not subject to this processing has been detected at distances of up to 20 km from the spraying sites [8].

The uniform application of protective measures should be ensured, regardless of elastic vibrations of the boom, resonance phenomena, or current changes in the microrelief. The issue of compensating for boom deflection in trailed, mounted, and self-propelled sprayers has been systematically addressed for many years. Various technical and technological solutions are available, including applying spring–lever suspensions for replicating field topography [9], applying vibration dampers to minimize vibrations of the field boom [10], combining different cross-sections of the distributing rod to suppress vibrations [11], employing a fan nozzle with a variable spray angle in conjunction with pulse-width modulation technology [12], and adjusting the merging of flows from adjacent nozzles based on the magnitude of the boom oscillations [13]. In recent years, small-scale mechanization methods have been used in conjunction with modern technologies. Therefore, issues concerning the theoretical justification for the functioning conditions, design parameters, and technological operating modes of these mechanization methods should be incorporated into new engineering projects.

The results of studies conducted earlier by the authors of this article [14, 15] suggest that the use of sprayers spray nozzle that respond adaptively to their position in relation to the treated surface is a universal solution to the problem of compensating for deviations of the boom of a small-sized sprayer in the transverse–vertical plane. In this case, there is no need to equip the sprayer with complex and bulky lever-copying devices, and the overlap pattern of the processed strips is maintained by changing the geometry of the spray patterns of individual nozzles [16–19].

According to the existing prerequisites, **the aims and objectives of this study** can be formulated as follows.

The study aimed to determine the limits of change in the root spray angles of the adaptive sprayer of a barrow-type single-support boom sprayer.

Research objectives:

1. Assess the amplitude of operational vibrations of the boom in the transverse–vertical plane for a single-support sprayer.
2. Analyze the influence of the transverse deflection of the sprayer on the width of the processed strip from the spray nozzle.
3. Determine the dependence of the required spray pattern angle of the adaptive sprayer on the inclination angle of the single-support sprayer in the transverse–vertical plane.

MATERIALS AND METHODS

To address problem 1, a prototype of a single-support boom motor sprayer (Fig. 1a), previously developed by us [20], was utilized as the subject of study. The field experiment was conducted at the experimental sites of the Oryol State Agrarian University. The experiments were replicated three times, with a measurement error not exceeding 5%. Data on the sprayer deviation from the vertical axis were recorded using a specially designed inclinometer (Fig. 1b), which comprised a measuring scale firmly mounted on the sprayer frame and a hinged indicator arrow equipped with a balance weight [21]. The current readings of the inclinometer were recorded using a self-powered car recorder. Subsequent mathematical processing of the decrypted experimental data was conducted using a spreadsheet processor in Microsoft Excel.

DOI: https://doi.org/10.17816/0321-4443-611160

Theoretical substantiation of the influence of sprayer boom vibrations on the distribution parameters of the working fluid was conducted using widely accepted engineering calculation methods. The analytical dependencies derived were analyzed using the mathematical calculation software Mathcad 14.0 (Russian version).

RESULTS AND DISCUSSION

According to the results of an experiment evaluating the operational vibrations of a single-support sprayer with a right-handed boom in the transverse–vertical plane, the following is established. 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)°. Peak deviation values are relatively uncommon and are mainly influenced by the operator's competence and the speed of the sprayer movement. The average values of the maximum inclination angles range from +11° to −18°. These values are crucial when selecting the operating modes of adaptive sprayers, which can be employed to regulate the spray pattern geometry.

In addition, analysis of the transverse vibration diagram (Fig. 2) indicates the presence of right-sided asymmetry. This asymmetry is likely caused by a slight shift in the center of gravity of the prototype sprayer, resulting from the imbalance of the moment of force from the weight of the one-sided field boom. One possible solution to rectify this design flaw is equipping the sprayer with a tracking balancing mechanism [22]. Such a device can adjust the balance of the sprayer by positioning the tank spatially, depending on the amount of working fluid in it.

To determine the theoretical width of the spray pattern with one sprayer, we describe the geometric parameters of the sprayer with the diagram presented in Fig. 3.

Considering the possibility of the sprayer deflection only in the plane of the drawing, the frame OA, with height h, undergoes transverse movements by an angle α relative to the hinge O. A horizontal boom AB of length l is installed perpendicular to the frame OA and is rigidly connected to it.

The spray pattern is an isosceles triangle CBD with a constant angle β at vertex B. The bisector BM, drawn to the base of the triangle CBD, is strictly perpendicular to the horizontal boom AB and represents the height p of the triangle CBD. Here, the base CD, equal to b_0, is the line of contact of the spray pattern with the surface being treated.

As illustrated in Fig. 3, a change in the sprayer position angle α results in a corresponding deviation of the CBD spray pattern from its original position. Moreover, the length of the spray pattern contact line with the surface being treated also changes ($C_iD_i = b_i$).

We examine the influence of the lateral deviations of a single-support motorized sprayer on the working width of a field sprayer positioned at a distance l from the symmetry axis of the sprayer passing through its support point O.

Fig. 1. A prototype of a single-support boom motor sprayer (*a*) and a device for measuring values of horizontal inclinations of a field boom (*b*).

Рис. 1. Опытный образец одноопорного штангового мотоопрыскивателя (*a*) и устройство для измерения величины горизонтальных отклонений полевой штанги (*b*).

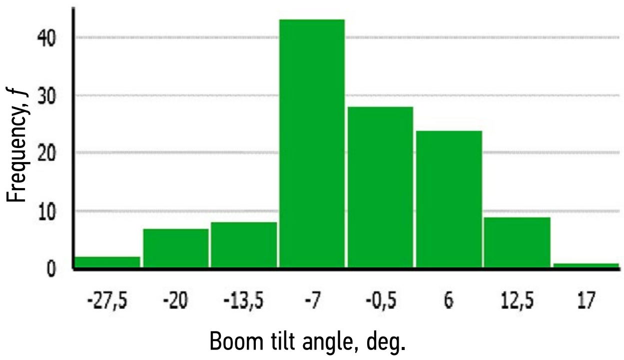

Fig. 2. A distribution histogram of oscillation values of the boom of the single-support sprayer in transverse-vertical plane.
Рис. 2. Гистограмма распределения значений величины колебаний штанги одноопорного опрыскивателя в поперечно-вертикальной плоскости.

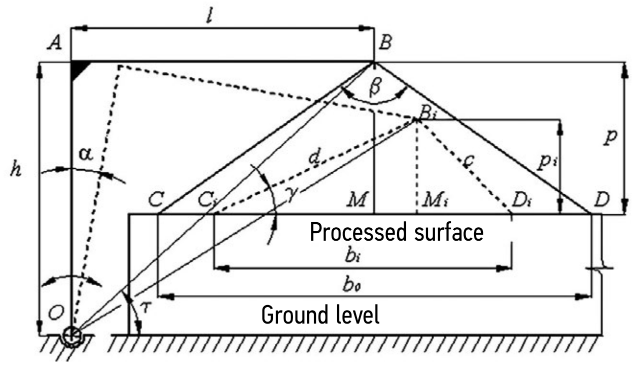

Fig. 3. An analytical model of variation of spray jet operation width of sprayer injectors at boom oscillations in transverse-lateral plane.
Рис. 3. Схема к расчету изменения ширины захвата факела распыла форсунок опрыскивателя, при колебаниях штанги в поперечно-вертикальной плоскости.

According to the cosine theorem, the square of any side of a triangle equals the sum of the squares of the other two sides, minus twice the product of these sides and the cosine of the angle between them. Hence,

$$b_i = \sqrt{d^2 + c^2 - 2dc \cdot \cos\beta}\,, \tag{1}$$

where b_i, d and c represent the sides of the scalene triangle $C_iB_iD_i$, formed by the spray pattern and the surface being processed when the sprayer frame is deflected at a certain angle α.

To determine sides d and c of the triangle $C_iB_iD_i$, we divide the triangle into two right triangles, $C_iB_iM_i$ and $M_iD_iD_i$ with leg $p_i = B_iM_i$.

According to the equations for the relationship between the sides and angles of the right triangle $C_iB_iM_i$, we present the following:

$$d = \frac{p_i}{\sin\gamma}, \tag{2}$$

where γ is the angle at the triangle base.

The triangle $C_iD_iD_i$ is formed by the displacement of the CBD triangle due to the frame rotation by an angle α. Then, angle γ can be defined as the difference between angle α and one of the angles of the equilateral triangle CBD, at its base. Hence, we obtain the following:

$$\gamma = 90^\circ - \frac{\beta}{2} - \alpha\,. \tag{3}$$

By connecting points B and B_i with the support point O, we define p_i as the difference in the heights of the triangles CBD and $C_iB_iD_i$ relative to the support surface.

The angle τ between straight line OB_i and the supporting surface is determined by the function:

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

therefore, if

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

than

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

hence, taking into account (4)

$$d = \frac{p - \left[\left(h - \sqrt{h^2 + l^2}\right) \cdot \sin\left(\operatorname{arctg}\frac{h}{l} - \alpha\right)\right]}{\sin\left(90^\circ - \frac{\beta}{2} - \alpha\right)}. \tag{7}$$

To calculate the side c of the triangle $C_iB_iD_i$ we use the already known vertex angle B_i and height p_i:

$$c = \frac{p_i}{\cos\left(\frac{\beta}{2} - \alpha\right)} = \frac{p - \left[\left(h - \sqrt{h^2 + l^2}\right) \cdot \sin\left(\operatorname{arctg}\frac{h}{l} - \alpha\right)\right]}{\sin\left(90^\circ - \frac{\beta}{2} - \alpha\right)}. \tag{8}$$

After simple transformations, Eq. (1), for calculating the spray width according to the geometric parameters of a single-support sprayer and the angle of transverse inclination of the frame, can finally be presented in the following form:

$$b_i = \sqrt{\begin{aligned}&\left[p-\left(h-\sqrt{h^2+l^2}\right)\cdot\sin\left(\operatorname{arctg}\frac{h}{l}-\alpha\right)\right]\times\\&\times\left(\left[\frac{1}{\sin\left(90^\circ-\frac{\beta}{2}-\alpha\right)}\right]^2+\left[\frac{1}{\cos\left(\frac{\beta}{2}-\alpha\right)}\right]^2-2\left[\frac{1}{\sin\left(90^\circ-\frac{\beta}{2}-\alpha\right)}\right]\left[\frac{1}{\cos\left(\frac{\beta}{2}-\alpha\right)}\right]\cdot\cos\beta\right)\end{aligned}}. \quad (9)$$

A graphical representation of Eq. (9) is illustrated in Fig. 4 with the values $p = 0{,}5$ m; $h = 0{,}9$ m; $l = 1$ m; $\beta = 110°$. As indicated, when the sprayer boom is in a horizontal position, the width b of the spray pattern is ~1.43 m. However, when the sprayer is tilted by an angle α ranging from −15° to +20° in the transverse–vertical plane, the width b varies from 2.60 m to 0.46 m, which is an increase of more than 1.8 to 3.1 times.

When determining the necessary limits for changing the root spray angle β of the sprayer, we proceed from the premise of maintaining a constant operating width b_i. The transverse deviations of the horizontal projection of the sprayer when the boom is tilted in the transverse–vertical plane are insignificant and are thus not considered in the calculations. Additionally, the vertical position of the sprayer axis is assumed to be stable (owing to the effect of a vertical stabilization device).

According to the theorem of sines, we obtain the following (Fig. 3):

$$\frac{BD}{\sin 90^\circ} = \frac{b_0}{\sin\beta}, \quad (10)$$

hence,

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

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 $b_0/2$:

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

By substituting Eq. (12) into Eq. (11), we obtain

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

According to the diagram in Fig. 3, the current value of p will change in accordance with Eq. (6). Thus,

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

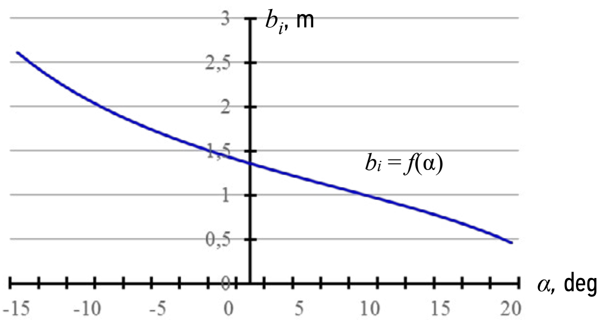

Fig. 4. Dependence of width of operation lane for one sprayer on sprayer inclination in transverse-vertical plane.
Рис. 4. Зависимость ширины полосы обработки одним распылителем от отклонения опрыскивателя в поперечно-вертикальной плоскости.

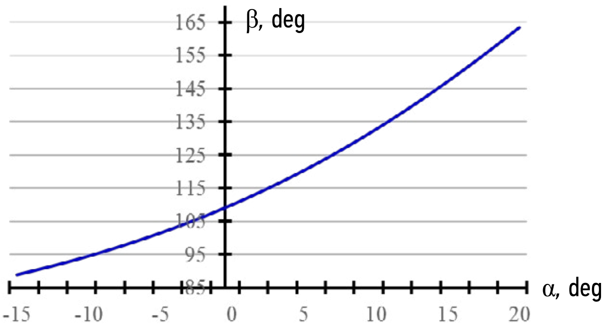

Fig. 5. Dependence of demanded values of spray angle of an adaptive sprayer on inclination angle of the single-support sprayer in transverse-vertical plane.
Рис. 5. Зависимость значений требуемого угла распыла адаптивного распылителя от угла наклона одноопорного опрыскивателя в поперечно-вертикальной плоскости.

DOI: https://doi.org/10.17816/0321-4443-611160

The final expression for the influence of the angle α of the position of a single-support sprayer on the required spray angle β, considering the distance l of the sprayer projection relative to the vertical axis passing through the sprayer support point, is as follows:

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

For the numerical values provided in Eq. (15) and the given value of b_0 as 1,43 m, a graphical representation of the dependence $\beta = f(\alpha)$ is presented in Fig. 5. With a strictly vertical position of the sprayer ($\alpha = 0°$; the horizontal position of the field boom), the root spray angle $\beta = 110°$ allows for a processing strip with a design width of 1.43 m. When the sprayer is tilted to the left, to the value $\alpha = -15°$, the distance from the spray nozzle to the surface being treated increases and, consequently, the width of the processing strip increases (Fig. 3). As illustrated in the graph in Fig. 5, to maintain the same working width b_0, the required spray angle β_i should be equal to 89°. Therefore, the sprayer inclination angle α of 20° determines the opening of the spray pattern angle to $\beta = 164°$.

Equation (15) can be employed to compute the necessary limits for altering the spray angle of one sprayer, considering established average values of boom vibrations in the transverse–vertical plane. Thus, according to previously obtained experimental values of the boom oscillation angles and the reduction of the maximum operating values to average values, we obtain $\alpha = +11°$ to -18°. For the given limits of boom oscillations in the transverse–vertical plane, changes in the spray angle with the adaptive sprayer should be $\beta = 86°–135°$ at a distance l of 1 m.

In a deflector sprayer, the spray pattern angle is shaped into a flat cone by the cone angle of the restrictive collars located at the deflector periphery [17]. Consequently, the angles of the taper, formed by the outer sides of each reflective deflector, are determined by the calculated spray angles of a given adaptive sprayer deflector. Considering the distance of each sprayer from the symmetry plane of the sprayer passing through the support point, the numerical values of these angles are determined using Eq. (15) and are summarized in Table 1.

Table 1. Values of root spray angles β for deflectors of adaptive sprayers at values of α = -18°...+11°

Таблица 1. Значения корневых углов β распыла для дефлекторов адаптивных распылителей, при значениях α = -18°–+11°

Distance of the adaptive sprayer installation point from the axis of the sprayer support, m	Limits for changing the angles of the spray pattern, deg.		
	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

CONCLUSIONS

This study establishes that the maximum limits of lateral vibrations of a barrow-type single-support boom 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 ranges from +11° to −18°. An equation is derived for calculating the spray width of one spray nozzle according to the geometric parameters of a single-support sprayer and its angle of inclination in the transverse–vertical plane. One possible solution to the issue of compensating for the quality of the working fluid distribution during transverse vibrations of the sprayer boom is the utilization of spray nozzles with a spray geometry that adapts to the position occupied by the sprayer relative to the surface being processed. An analytical relationship for calculating the required limits for the root spray angle of the adaptive sprayer is derived. The limits are calculated according to the distance l of the sprayer projection relative to the vertical axis passing through the sprayer support point. The root spray angles for the deflectors of adaptive spray nozzles are determined within the limits of sprayer oscillations, ranging from −18° to +11° in the transverse–vertical plane.

ADDITIONAL INFORMATION

Authors' contribution. S.A. Rodimtsev — editing the text of the manuscript, creating figures; expert assessment, approval of the final version; I.A. Dembovsky — search for publications on the topic of the article, writing the text of the manuscript; creating figures. Authors confirm the compliance of their authorship with the ICMJE international criteria. All authors made a substantial contribution to the conception of the work, acquisition, analysis, interpretation of data for the work, drafting and revising the work, final approval of the version to be published and agree to be accountable for all aspects of the work.

Competing interests. The authors declare that they have no competing interests.

Funding source. This study was not supported by any external sources of funding.

ДОПОЛНИТЕЛЬНАЯ ИНФОРМАЦИЯ

Вклад авторов. С.А. Родимцев — редактирование текста рукописи, создание изображений; экспертная оценка, утверждение финальной версии; И.А. Дембовский — поиск публикаций по теме статьи, написание текста рукописи; создание изображений. Авторы подтверждают соответствие своего авторства международным критериям *ICMJE* (все авторы внесли существенный вклад в разработку концепции, проведение исследования и подготовку статьи, прочли и одобрили финальную версию перед публикацией).

Конфликт интересов. Авторы декларируют отсутствие явных и потенциальных конфликтов интересов, связанных с публикацией настоящей статьи.

Источник финансирования. Авторы заявляют об отсутствии внешнего финансирования при проведении исследования.

REFERENCES

1. Kireev IM, Koval ZM, Danilov MV. Distribution of droplet liquid between sprayers for plant spraying technology. *Agro Forum.* 2019;4:18–20. (In Russ). EDN: XMWMUE

2. Kovalenkov VG, Tyurina NM, Pavlova LI. Resistance of the rapeseed flower beetle as an indicator of the restructuring of the genetic structure of populations of harmful species under the influence of insecticides. *Agrochemistry.* 2018;5:54–62. (In Russ). EDN: XMZHQT doi: 10.7868/S0002188118050083

3. Sukhoruchenko GI, Belyakova NA, Ivanova GP, et al. Methods for assessing the toxicity of pesticides for arthropods used in the fight against pests of protected soil crops. *Entomological Review.* 2018;4:649–657. (In Russ). EDN: YOOYXJ doi: 10.1134/S0367144518040056

4. Pobedinskaya MA, Plutalov PN, Romanova SS, et al. Resistance of potato and tomato Alternaria pathogens to fungicides. *Mycology and Phytopathology.* 2012;46(6):401–408. (In Russ). EDN: PILZBT

5. Popov YuV. Protection of grain crops from diseases must be justified. *Protection and quarantine of plants.* 2009;7:42–45. (In Russ). EDN: KYBEBT

6. Lysov AK, Kornilov TV. Improving technologies for using plant protection products by spraying. *Bulletin of plant protection.* 2017;2(92):50–53. (In Russ). EDN: ZFHRHD

7. Nikitin NV, Spiridonov YuYa, Abubikerov VA, et al. Anti-drain technology for the application of new generation herbicides. *Bulletin of plant protection.* 2008;3:47–55. (In Russ). EDN: KAUMIT

8. Markevich AE, Nemirovets YuN. *Basics of effective pesticide use. A guide to questions and answers on mechanization and quality control of pesticide use in agriculture.* Gorki: Mogilev State Training Center for Training, Advanced Training, Retraining, Consulting and Agrarian Reform; 2004. (In Russ).

9. Kuznetsov VV, Kuznetsov AV. Suspension of a wide-reach boom for a field sprayer // *Design, use and reliability of agricultural machines.* 2012;1(11):5–9. (In Russ). EDN: VDUXDT

10. Kruk IS, Karpovich SK, Markevich AE, et al. *Design of load-bearing structures, suspension schemes and stabilization systems for field sprayer booms. Recommendations.* Minsk: BGATU; 2018. (In Russ).

11. Yan J, Xue X, Cui L, et al. Analysis of Dynamic Behavior of Spray Boom under Step Excitation. *Appl. Sci.* 2021;11:10129. https://doi.org/10.3390/app112110129

12. Ghasemzadeh HR, Humburg D. Using variable spray angle fan nozzle on long spray booms. *CIGR Journal.* 2016;18(1):82–90.

13. Borisenko IB, Meznikova MV, Ulybina EI. Theoretical justification for the uniformity of application of the working solution to the object of influence when processing row crops using strip spraying. *News of the Nizhnevolzhsky Agro-University Complex: Science and Higher Professional Education.* 2021;4(64):296–305. (In Russ). EDN: SCTXTD doi: 10.32786/2071-9485-2021-04-31

14. Dembovsky IA, Rodimtsev SA. Determination of the magnitude of vibrations of the barrow sprayer boom in the transverse-vertical plane. In: *State and prospects for the development of the agro-industrial complex. Anniversary collection of scientific works of the XV International Scientific and Practical Conference.* Rostov-on-Don: DSTU-PRINT; 2022:169–173. (In Russ). EDN: EJNWGF doi: 10.23947/interagro.2022.169-173

15. Rodimtsev SA, Dembovsky IA, Panin EN. *Development and justification of the parameters of a mobile sprayer for gardening and landscape construction.* World of transport and technological machines. 2023;2(81):26–34. (In Russ). EDN: HEMKNL doi: 10.33979/2073-7432-2023-2(81)-26-34

16. Avtorskoe svidetelstvo USSR № 1308307 / 07.05.1987, Byul. № 17. Chentsov VV, Frumovich VL, Lagutin AV, et al. Shtangovyy opryskivatel. (In Russ). [cited: 21.10.2023] Available from: https://www.elibrary.ru/download/elibrary_40453392_70180032.pdf

17. Avtorskoe svidetelstvo USSR № 650589 / 05.03.1979. Byul. № 9. Bilyk AI, Maslo IP, Sudak PG. Raspylitel. (In Russ). [cited: 21.10.2023] Available from: https://www.elibrary.ru/download/elibrary_39961347_87563149.pdf

18. Patent RUS № 2515290 / 10.05.2014. Byul. № 13. Dodson M. Ploskostruynye forsunki dlya teku-chey sredy s reguliruemym razmerom kapel, vklyuchayushchie postoyannyy ili peremennyy ugol raspyleniya. (In Russ). [cited: 21.10.2023] Available from: https://www.elibrary.ru/download/elibrary_37797805_91349313.pdf

19. Patent RUS № 2324348 / 20.05.2008. Byul. № 14. Gulko AI. Kombinirovannaya raspylitelnaya golovka. (In Russ). [cited: 21.10.2023] Available from: https://www.elibrary.ru/download/elibrary_37671634_28843972.pdf

20. Yandutova KI, Rodimtsev SA. Optimization of working conditions for the operator of a small-sized boom sprayer for selection purposes. *Labor protection 2011. Current problems and ways to solve them. Materials of the All-Russian Scientific and Practical Conference.* Orel, 2011. Orel: OSAU im NV Parakhina; 2011:128–138. (In Russ). EDN: ZHQNHB

21. Rodimtsev SA, Shapenkova AA. Assessment and control of the position of a wheelbarrow sprayer in a transverse-vertical plane. *Agricultural technology and energy supply.* 2015;3(7):233–238. (In Russ). EDN: YIIUTF

22. Rodimtsev SA, Shapenkova AA, Timokhin OV. and others. Justification of the ergonomic characteristics of a small-sized wheelbarrow-type boom sprayer. *Life Safety.* 2014;12(168):17–23. (In Russ). EDN: TBZKOP

СПИСОК ЛИТЕРАТУРЫ

1. Киреев И.М., Коваль З.М., Данилов М.В. Распределение капельной жидкости между распылителями для технологии опрыскивания растений // Агро Форум. 2019. № 4. С. 18–20. EDN: XMWMUE

2. Коваленков В.Г., Тюрина Н.М., Павлова Л.И. Резистентность рапсового цветоеда как показатель перестройки генетической структуры популяций вредных видов под влиянием инсектицидов // Агрохимия. 2018. № 5. С. 54–62. EDN: XMZHQT doi: 10.7868/S0002188118050083

3. Сухорученко Г.И., Белякова Н.А., Иванова Г.П. и др. Методы оценки токсичности пестицидов для членистоногих, применяемых в борьбе с вредителями культур защищенного грунта // Энтомологическое обозрение. 2018. № 4. С. 649–657. EDN: YOOYXJ doi: 10.1134/S0367144518040056

4. Побединская М.А., Плуталов П.Н., Романова С.С. и др. Устойчивость возбудителей альтернариоза картофеля и томата к фунгицидам // Микология и фитопатология. 2012. Т. 46. В. 6. С. 401–408. EDN: PILZBT

5. Попов Ю.В. Защита зерновых культур от болезней должна быть обоснованной // Защита и карантин растений. 2009. № 7. С. 42–45. EDN: KYBEBT

6. Лысов А.К., Корнилов Т.В. Совершенствование технологий применения средств защиты растений методом опрыскивания // Вестник защиты растений. 2017. № 2(92). С. 50–53. EDN: ZFHRHD

7. Никитин Н.В., Спиридонов Ю.Я., Абубикеров В.А. и др. Противосносная технология внесения гербицидов нового поколения // Вестник защиты растений. 2008. № 3. С. 47–55. EDN: KAUMIT

8. Маркевич А.Е., Немировец Ю.Н. Основы эффективного применения пестицидов. Справочник в вопросах и ответах по механизации и контролю качества применения пестицидов в сельском хозяйстве. Горки: Могилевский государственный учебный центр подготовки, повышения квалификации, переподготовки кадров, консультирования и аграрной реформы, 2004.

9. Кузнецов В.В., Кузнецов А.В. Подвеска широкозахватной штанги полевого опрыскивателя // Конструирование, использование и надежность машин сельскохозяйственного назначения. 2012. № 1 (11). С. 5–9. EDN: VDUXDT

10. Крук И.С., Карпович С.К., Маркевич А.Е. и др. Проектирование несущих конструкций, схем подвесок и систем стабилизации штанг полевых опрыскивателей. Рекомендации. Минск: БГАТУ, 2018.

11. Yan J., Xue X., Cui L., et al. Analysis of Dynamic Behavior of Spray Boom under Step Excitation. Appl. Sci. 2021. Vol. 11. P. 10129. https://doi.org/10.3390/app112110129

12. Ghasemzadeh H.R., Humburg D. Using variable spray angle fan nozzle on long spray booms // CIGR Journal. 2016. Vol. 18, N. 1. P. 82–90.

13. Борисенко И.Б., Мезникова М.В., Улыбина Е.И. Теоретическое обоснование равномерности нанесения рабочего раствора на объект воздействия при обработке пропашных культур способом полосового опрыскивания // Известия Нижневолжского агроуниверситетского комплекса: Наука и высшее профессиональное образование. 2021. № 4 (64). С. 296–305. EDN: SCTXTD doi: 10.32786/2071-9485-2021-04-31

14. Дембовский И.А., Родимцев С.А. Определение величины колебаний штанги тачечного опрыскивателя в поперечно-вертикальной плоскости. В кн.: Состояние и перспективы развития агропромышленного комплекса. Юбилейный сборник научных трудов XV Международной научно-практической конференции. Ростов-на-Дону: ДГТУ-ПРИНТ, 2022. С. 169–173. EDN: EJNWGF doi: 10.23947/interagro.2022.169-173

15. Родимцев С.А., Дембовский И.А., Панин Е.Н. Разработка и обоснование параметров мобильного опрыскивателя для садово-паркового и ландшафтного строительства // Мир транспорта и технологических машин. 2023. № 2 (81). С. 26–34. EDN: HEMKNL doi: 10.33979/2073-7432-2023-2(81)-26-34

16. Авторское свидетельство СССР № 1308307 / 07.05.1987, Бюл. № 17. Ченцов В.В., Фрумович В.Л. Лагутин А.В. и др. Штанговый опрыскиватель. Дата обращения: 21.10.2023. Режим доступа: https://www.elibrary.ru/download/elibrary_40453392_70180032.pdf

17. Авторское свидетельство СССР № 650589 / 05.03.1979. Бюл. № 9. Билык А.И., Масло И.П., Судак П.Г. Распылитель. Дата обращения: 21.10.2023. Режим доступа: https://www.elibrary.ru/download/elibrary_39961347_87563149.pdf

18. Патент РФ № 2515290 / 10.05.2014. Бюл. № 13. Додсон М. Плоскоструйные форсунки для текучей среды с регулируемым размером капель, включающие постоянный или переменный угол распыления. Дата обращения: 21.10.2023. Режим доступа: https://www.elibrary.ru/download/elibrary_37797805_91349313.pdf

19. Патент РФ № 2324348 / 20.05.2008. Бюл. № 14. Гулько А.И. Комбинированная распылительная головка. Дата обращения: 21.10.2023. Режим доступа: https://www.elibrary.ru/download/elibrary_37671634_28843972.pdf

20. Яндутова К.И., Родимцев С.А. Оптимизация условий работы труда оператора малогабаритного штангового опрыскивателя селекционного назначения // Охрана труда 2011. Актуальные проблемы и пути их решения. Материалы Всероссийской научно-практической конференции. Орел, 2011. Орел: ОГАУ им. Н.В. Парахина. С. 128–138. EDN: ZHQNHB

21. Родимцев С.А., Шапенкова А.А. Оценка и контроль положения тачечного опрыскивателя в поперечно-вертикальной плоскости // Агротехника и энергообеспечение. 2015. № 3 (7). С. 233–238. EDN: YIIUTF

22. Родимцев С.А., Шапенкова А.А., Тимохин О.В. и др. Обоснование эргономических характеристик малогабаритного штангового опрыскивателя тачечного типа // Безопасность жизнедеятельности. 2014. № 12 (168). С. 17–23. EDN: TBZKOP

AUTHORS' INFO

*** Sergey A. Rodimtsev,**
Dr. Sci. (Engineering),
Professor of the Service and Repair of Machines Department;
address: 77 Moskovskaya street, 302030 Oryol,
Russian Federation;
ORCID: 0000-0003-1849-4224;
eLibrary SPIN: 9469-0125;
e-mail: rodimcew@yandex.ru

Ilya A. Dembovsky,
Postgraduatet of the Technosphere Safety Department;
ORCID: 0009-0006-6975-7708;
eLibrary SPIN: 9359-8042;
e-mail: emilyenn@rambler.ru

ОБ АВТОРАХ

*** Родимцев Сергей Александрович,**
д-р техн. наук,
профессор кафедры «Сервис и ремонт машин»;
адрес: Российская Федерация, 302030, Орел,
ул. Московская, д. 77
ORCID: 0000-0003-1849-4224;
eLibrary SPIN: 9469-0125;
e-mail: rodimcew@yandex.ru

Дембовский Илья Андреевич,
аспирант кафедры «Техносферная безопасность»;
ORCID: 0009-0006-6975-7708;
eLibrary SPIN: 9359-8042;
e-mail: emilyenn@rambler.ru

* Corresponding author / Автор, ответственный за переписку