

Transverse distribution of working fluid in a micron rotary sprayer

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Abstract

The quality of agricultural production is most significantly affected by the application of pesticides. In accordance with modern quality requirements, it is necessary not to exceed the norms that cause pollution and, at the same time, protect plants from diseases and insects. This necessitates the search for a spraying system providing optimal droplet coverage. Droplet coverage can be controlled with the use of rotary sprayers. They have the advantage that, by changing the rotation speed and/or the flow rate of the working fluid, a predictable drop size can be obtained.

Key words: plant protection, rotary sprayers, working fluid distribution, droplet size

Introduction

Efficient pesticide application is crucial for reducing waste in agriculture, where nearly half of farm inputs (e.g., water, pesticides) are lost due to overuse or misapplication (Prospectuses from companies). Recent studies highlight the importance of precision spraying technologies for improving uniformity and reducing environmental impact. Rotary sprayers, which utilize centrifugal forces to control droplet size, have shown potential in achieving uniform coverage. However, optimizing their transverse distribution remains a challenge to meet regulatory standards

for efficiency and coverage.

This study aims to evaluate the transverse distribution of working fluid across the spraying width of rotary sprayers to ensure uniform coverage, while adhering to normative requirements. Specifically, we assess the performance of the Micromax III rotary sprayer (Micron Sprayers Ltd.) and a modified version, proposing optimal sprayer arrangements along the boom to enhance spraying efficiency.

The research focuses on rotary sprayers, with experiments conducted on an original Micromax III and a modified version developed by the

authors.

Micron rotary sprayer

The Micromax III rotary sprayer (fig. 1) of the English company Micron Sprayers Ltd. is driven by an electric motor (3). The movement is transmitted by means of a belt drive (4) (Prospectuses from companies). It makes it possible to change the speed of the sprayer by means of three belt positions. At low rotations per minute, large droplets are produced, and at higher rpm, small droplets are obtained. The motor is DC, which allows the speed to be changed from the control panel. The rotating elements are lubricated by means of a lubricating device (2). The electric motor, the belt drive, and the spreader are connected to the machine frame via the carrier (1).

The sprayer's operation is illustrated in fig. 2. The working fluid is delivered through a dispenser (1), with adjustable nozzles controlling flow rate. The fluid enters a stationary beaker (2), flows through openings, and passes between the stationary and rotating parts of the sprayer. Centrifugal forces propel the liquid along the inner toothed surface of the rotating cup (3), forming thin streams that break into droplets upon reaching the periphery (Doble, et al., 1985).

Two sprayer variants were tested (BCPC, 1986): the factory-produced Micromax III (fig. 2A) with a toothed periphery, and a modified version (fig. 2B) with a smooth periphery, achieved by removing the factory ribs to widen the gap between the plate and the rotating cup.

Methodology and devices for researching the quality of spraying systems

The research employs a comprehensive scientific methodology, utilizing comparative and formal methods alongside a priori factor ranking. The comparative method evaluates the effectiveness of experimental setups, while the formal approach involves mathematical modeling and analysis of the transverse distribution of the working fluid.

Experimental conditions

Tests were conducted in a windless indoor environment at 20° C using water as the working fluid, with physical properties listed in Table 1.

Study of the transverse distribution of the working fluid

The study of the distribution of the working fluid over the working width of the sprayer is performed with the help of a stand made for this purpose, the general appearance of which is shown in figure 3. It is a gutter tray with the dimensions and depth of the gutters 100 mm shown in figure 4. It is made according to the requirements of ISO 5682-1/1996. The total number of gutters is 40. The liquid from the gutters is collected in plastic containers. The amount of liquid collected from each gutter was measured by weight using a Bimco B3P balance with an accuracy of $d = 0.1$ g. The values obtained depending on the duration of the experiment are given in ml/min. The value for each chute (x_i) was obtained on the basis of three experiments (Ru, et al., 2014).

Using the tray, the liquid collected from a sector of size $\frac{1}{4}$ from the torch received from the sprinkler is measured (fig. 4). For half of the spray bloom, the amount of liquid is obtained by equation 1:

$$A_i = 2 \times x_i \quad (i=1, \dots, 20) \quad (1)$$

From here, through a mirror image of this vector, the values for the other half of the spray bloom h are obtained, and finally for the entire width of the spreader according to equation 2:

$$B_i = 2 \times A_i \quad (2)$$

The relative distribution of the working fluid (C_i) over the width of the torch is determined on the basis of expression 3:

$$C_i = (B_i - \bar{B}) / \bar{B} \times 100, \% \quad (3)$$

where $\bar{B}$ is the average amount of liquid in the gutters.

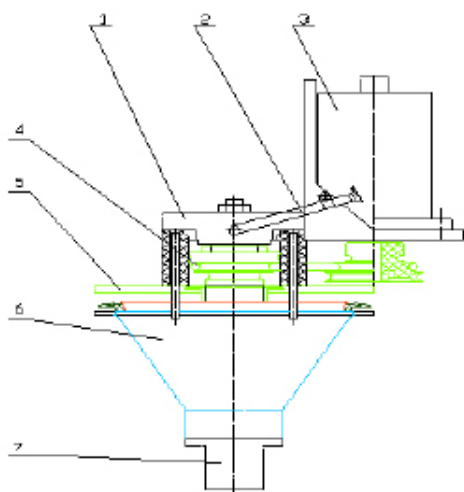


Fig. 1. Scheme of Micron rotary sprayer 1. Carrier, 2. Lubrication device, 3. Electromotor, 4. Belt gear, 5. Plank, 6. Sprinkler, 7. Cap

Since the working width of the torch obtained from one rotary sprayer in the studied variants is up to 4 m, it is possible to overlap the working widths of several sprayers during the simulation (Hart, et al., 1987). To speed up the process of processing the results, we use a C++ program, which simulates the process of possible mutual arrangement between the rotary spreaders and gives as a starting result the obtained distribution of the working fluid across the width of the rod (Miller, et al., 1989, Hadfield 1984, Kostadinov, et al., 2011). It is assumed that the minimum distance between two sprinklers in the simulation is 0.75 m. The simulation was performed in steps of 0.05 m. The possible placement steps of the sprayers are determined by the condition that the variation of the distribution of the working fluid along the length of the rod is not more than 10%.

Variation in the amount of liquid in the individual gutters is determined by equation 4:

$$C = (\bar{x}_i / \bar{X} - 1) 100, \% \quad (4)$$

where $\bar{X}$ is the average amount of liquid in the gutters determined by expression 5:

$$\bar{X} = \sum \bar{x}_i / n \quad (5)$$

$\bar{x}_i$ - the amount of fluid in the i gut determined by simulation

n - number of gutters

Results of Micromax III and modification studies

In order to assess the power supply capacity of the rotary sprinklers, their starting current and operating current were measured. The drive of both tested sprinklers is the same. The results shown in figure 5 indicate that the starting current is about twice as high as the current used in operating mode. From the graph in figure 6, it is seen that the strength of the current consumed is most strongly influenced by the speed of rotation of the nozzle and much less by the flow rate of the working fluid.

The influence of the used flow rate on the rotational speed was also studied. From figure 7, it can be seen that the speed of rotation of the sprayer given by the manufacturer is the theoretically possible speed without working fluid. When using a working fluid, it can be seen that when using the highest gear, the speed is most strongly influenced by the flow rate used. Its use is justified at flow rates up to 3 l/min. The linear approximation of the obtained data shows their suitability to be used in the selection of the theoretical speed in accordance with the required flow rate of the sprayer. It can be seen that if you need to work with higher flow rates and with a smaller diameter of the resulting drops, it is better to work with the middle gear.

In figure 8, the relative distribution of the working fluid over the width of the nozzle is shown. At the same time, the distribution is shown for two steps of placement of the sprinklers from each other – 120 cm and 150 cm. You can see the differences at the different steps.

The transverse distribution of the working fluid across the sprayer's torch width is measured for the original Micron sprayer at sprayer spacings of 1.2 m and 1.5 m, demonstrating variations in coverage uniformity.

In figure 9, the general view of the distribution when using the modified sprayer is shown.

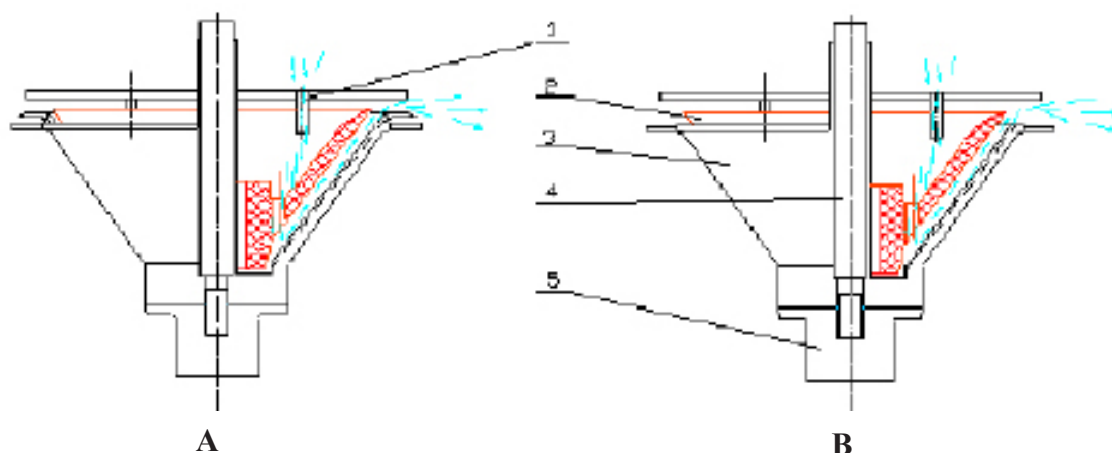


Fig. 2. Sprayer deposition technology

Table 1. Physical properties and indicators of water used as working fluid

Density, kg.m^{-3}	Dynamic viscosity, Pa.s	Kinematic viscosity, $\text{m}^2.\text{s}^{-1} \cdot 10^{-6}$	Surface tension, $\text{mN.m}^{-1} \cdot 10^{-3}$	Temperature, $^{\circ}\text{C}$
998.2	0.001004	1.006	72.9	18

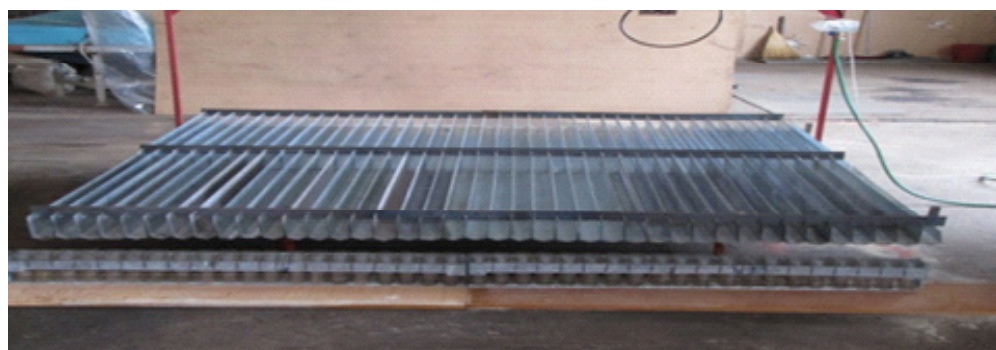


Fig. 3. General view of the stand for the study of the transverse distribution

It can be seen that in this version of the sprayer, the shape of the distribution is different from the original sprayer and allows a uniform coating at a distance between the sprayers of 2.8 m. The use of two such sprayers allows covering a working width of 5.8 m.

In figure 10, the relative deviation from the average of the original sprayer at different flow rates and average speed is shown. It can be seen that within the studied range of flow rates, which

are typical for the sprayer, changes in flow rate practically do not affect the nature of the distribution. Doubling the flow rate increases the spray width by only 5% at the specified placement height and disc speed. This indicates that changes in flow rate do not lead to significant changes in droplet diameter, which would affect the parameters of the spray pattern at the same rotation frequency.

Within the operational flow rate range (1.5–3 l/min), flow rate changes have minimal impact on

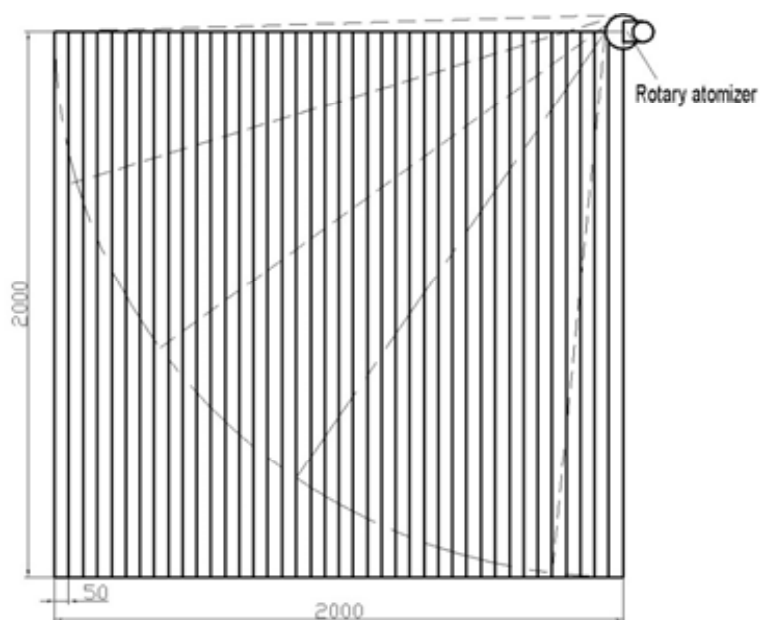


Fig. 4. Diagram of the sector from which the working fluid is collected

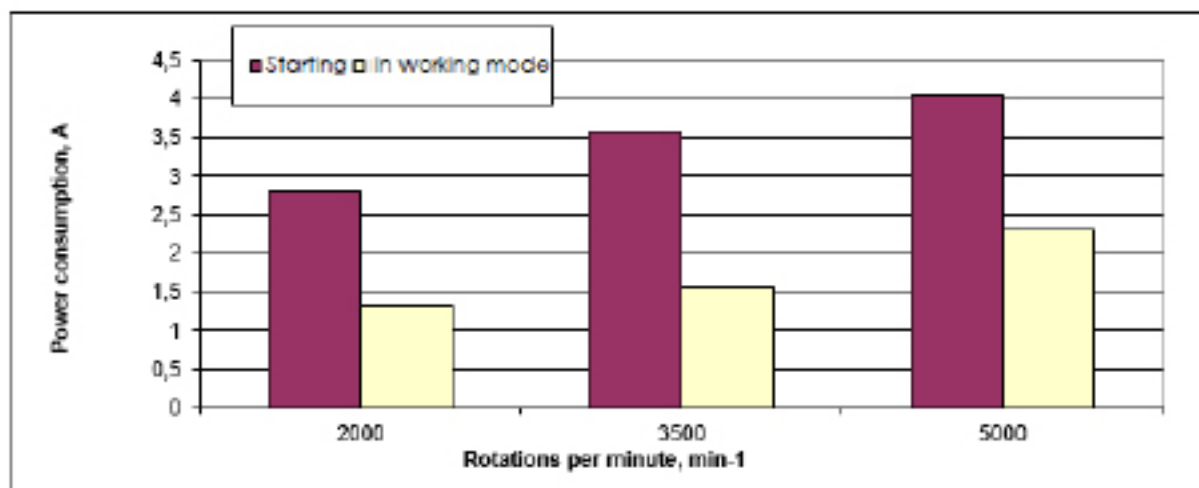


Fig. 5. Current consumption during start-up and operation at different speeds

the transverse distribution for the original sprayer. Doubling the flow rate increases the spray width by approximately 5% at fixed placement height and rotation speed, indicating stable droplet size.

The combined effect of flow rate and rotation speed influences the spray distribution (fig. 11). At high flow rates and low speeds, the working fluid concentrates in the center of the spray. Higher speeds shift the concentration to a circular band, affecting sprayer placement along the boom.

Two distinct sprayer placement intervals were identified for optimal transverse distribution (fig. 12). A spacing of 0.85 m along the boom ensures uniformity across all operating modes. At 5000 rpm, spacings of 1.05 m or 1.45 m are viable, reducing the number of sprayers by one-third. At 2000 rpm with flow rates of 1.5–2.1 l/min, spacings of 1.05 m or 1.55 m are suitable. In the medium speed range, flow rates of 1.5–2.4 l/min allow spacings of 1.0 m or 1.25–1.45 m.

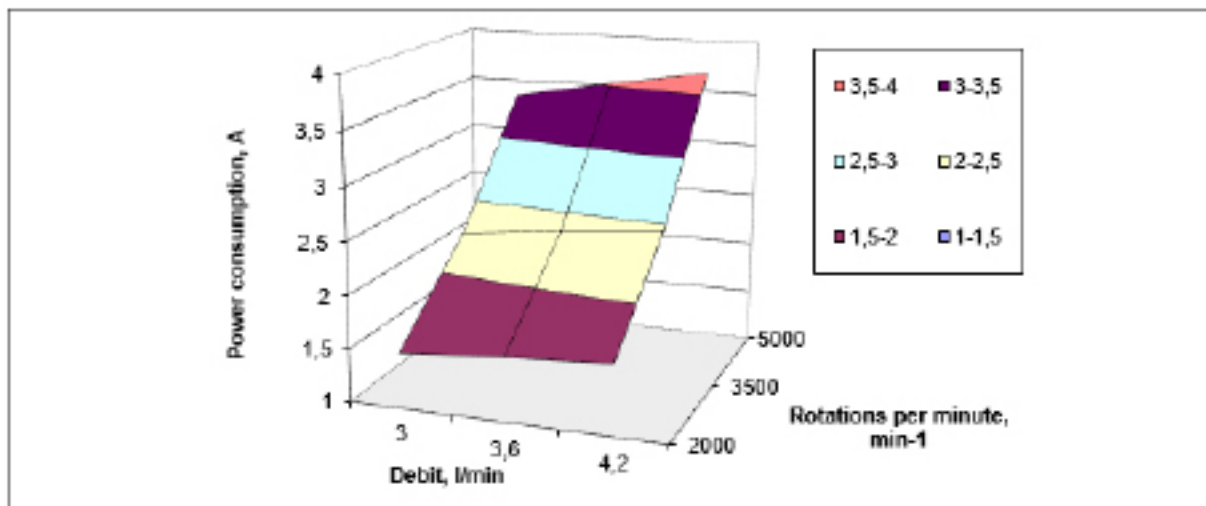


Fig. 6. Dependence of the consumed current on the flow rate of the sprinkler and the speed of rotation (Bachalo et al., 1984)

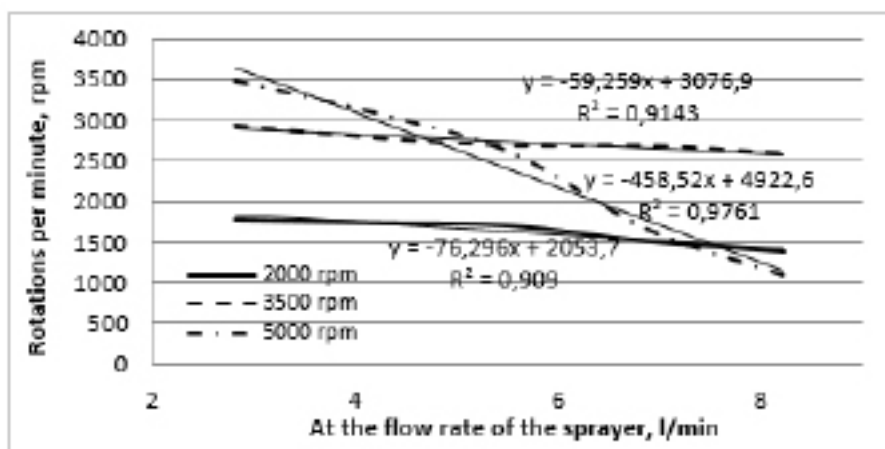


Fig. 7. Flow rate influence on rotation speed across modes

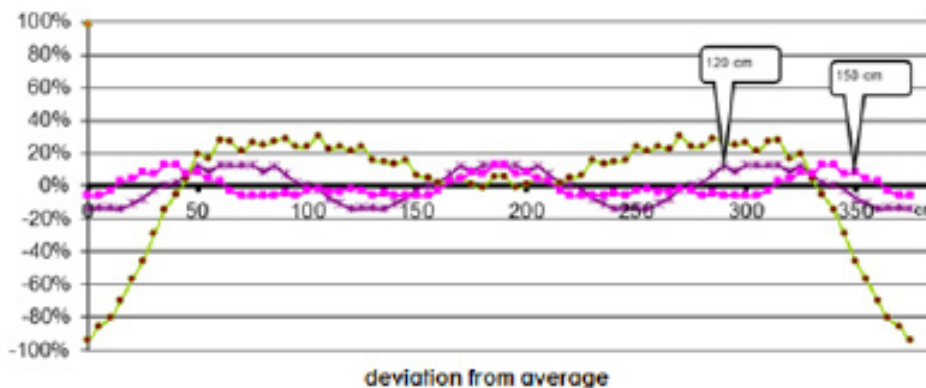


Fig. 8. Transverse distribution of working fluid for the Micron sprayer at 1.2 m and 1.5 m spacing

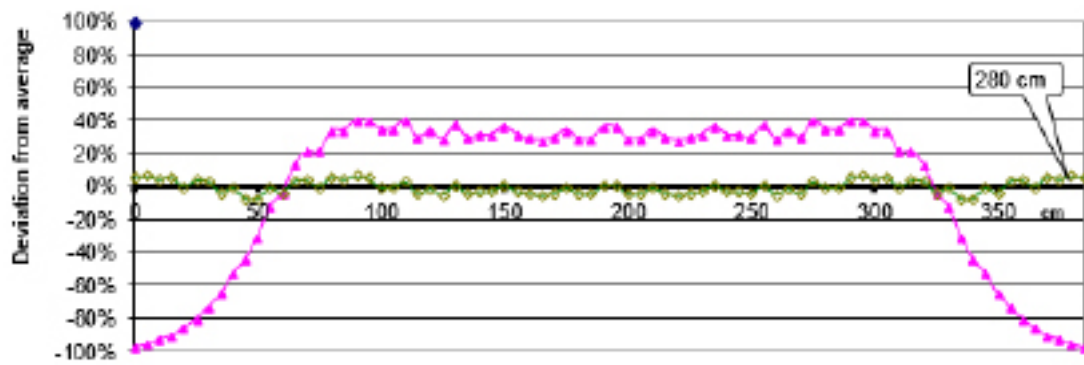


Fig. 9. Transverse distribution of working fluid for the modified sprayer at 2.8 m spacing

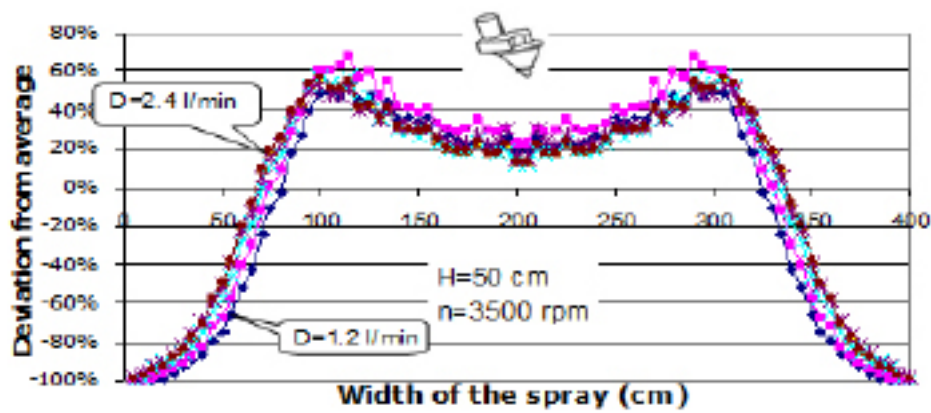


Fig. 10. Relative deviation from average transverse distribution at different flow rates

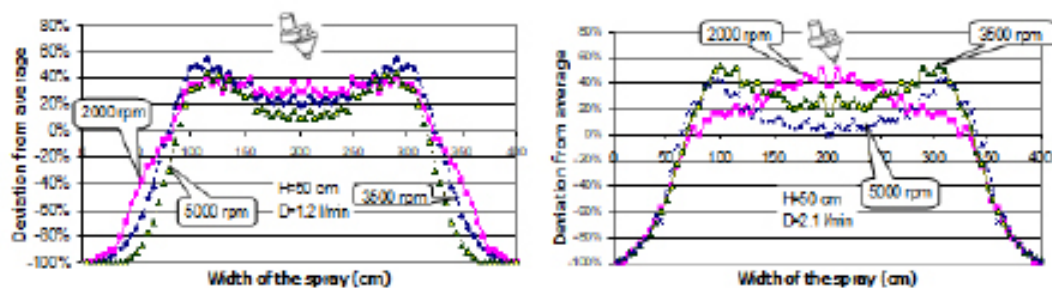


Fig. 11. Influence of rotation speed on transverse distribution at different flow rates

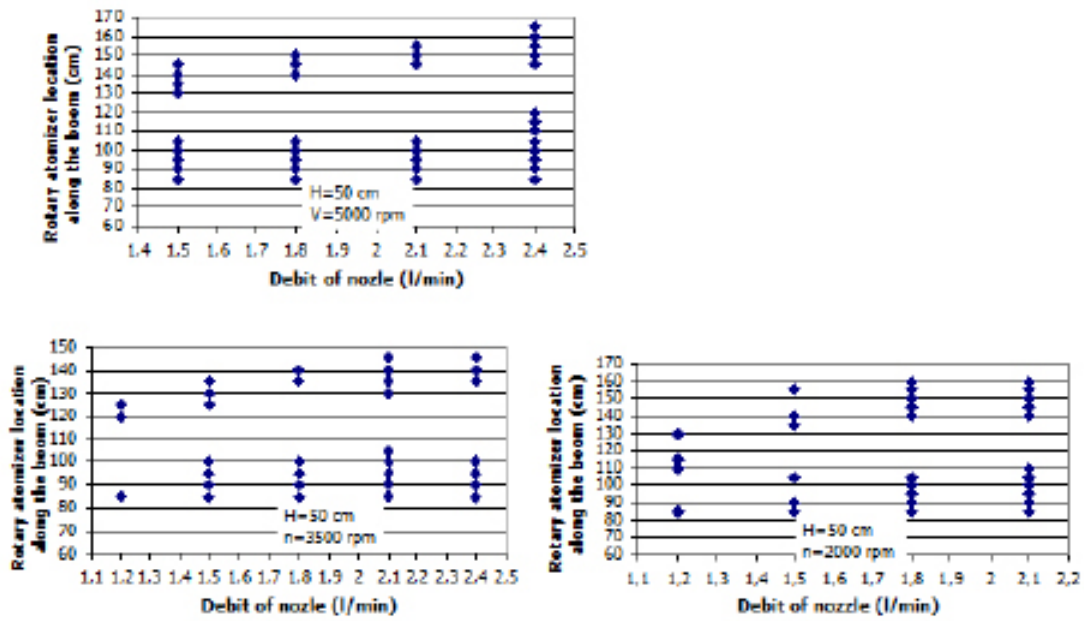


Fig. 12. Sprayer placement along the boom based on flow rate and speed

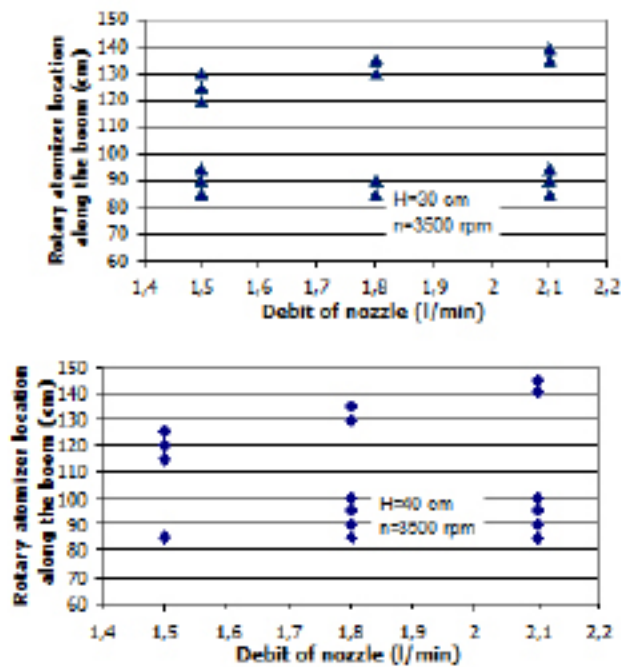


Fig. 13. Sprayer placement along the boom based on height

In the medium speed range, flow rate changes have a greater effect on the second possible spacing interval. This arrangement can be 1 m for flows from 1.5 to 2.4 l/min, and the second possible interval ranges from 1.25 to 1.45 m depending on the flow rate.

In all three speed ranges, there is a tendency for the upper limit of the second possible spacing interval to increase as flow rate increases. Changes in the working height of the sprayer above the treated surface do not affect the uniformity of the working fluid distribution at either placement interval (fig. 13). The uniformity of distribution when choosing the spacing step in the second interval is significantly influenced by the flow rate, almost equally at all three studied placement heights.

It can be observed that as the height above the measuring tray increases, the peak heights decrease, and the distribution becomes more uniform and wider.

Conclusions

1. Flow rate has a negligible effect on current consumption in both sprayer variants.

2. The highest gear is optimal for flow rates up to 3 l/min.

3. The modified sprayer achieves a more uniform transverse distribution, enabling a 2.8 m spacing and a 5.8 m working width with two sprayers.

4. Within operational flow rates (1.5–3 l/min), flow rate changes minimally affect transverse distribution, with a doubled flow rate increasing the spray width by 5% at constant rotation speed.

5. At high flow rates (e.g., 2.4 l/min) and low rotation speeds (e.g., 2000 rpm), the working fluid concentrates in the center of the spray; higher speeds (e.g., 5000 rpm) shift the concentration to a circular band.

6. Two sprayer placement intervals (0.85 m or 1.05–1.55 m) ensure distribution variation below 10%, depending on speed and flow rate.

7. Increasing sprayer height improves distribution uniformity and spray width.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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