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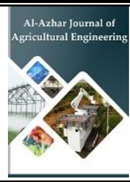


Full length article

# Laboratory evaluation of a locally manufactured pesticides spraying robot

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## ABSTRACT

Accurate pesticide application from sprayers is essential in modern farming practice. Evenness of flow characteristics of liquid from a sprayer nozzle is one of the requirements of accurate pesticide application. Hence, a study aimed to evaluate the flow characteristics of liquid from four different spray nozzles 422HCC02, 422HCC025, 422HCC03, and 422HCC05 on a horizontal spray patternator. The discharge rate, spray distribution pattern, spray swath of all types of nozzles were measured with a pressure range of 6.0 and 9.5 bar at three different nozzle height (30, 40 and 50 cm). The results showed that, Distribution uniformity of spraying machine ranged between (95.88 to 99.17 %), spray overlap varies from 7.5 to 47.5 cm, depending on spraying height and pressure, maximum spray angle was 89.59 ° at 30 cm height and 9.5 bar. Also, the results indicated that maximum spray angle 96.77 when the spraying pressure was 9.5 bar.

## 1. Introduction

In this agriculture sector there is a lot of field works, such as weeding, reaping, sowing etc. Apart from these operations, spraying is also an important operation to be performed by the farmer to protect the cultivated crops from insects, pests, funguses, and diseases for which various insecticides, pesticides, fungicides and nutrients are sprayed on crops for protection. The growing concern to control plant diseases, insects and weeds for qualitative yield of agricultural products is increasing speedily in many developing countries (Singh et al., 2018).

Pesticides are an integral part of the worldwide agriculture. Between 30 and 35% of crop losses can be prevented when harmful insects and diseases are eliminated by spraying pesticides (Cho and Ki, 1999). Although pesticides are needed in modern agriculture, they are poisonous and are dangerous for humans and the environment (Dasgupta et al., 2007; Rogan and Chen, 2005; Pimentel and Lehman, 1993; Reus et al., 2002). The use of pesticides will always involve some degree of risk, because of the poisonous character of these chemicals (Damalas and Koutroubas, 2016).

Farmers and their family members run the highest risks, as they can easily come into contact with the pesticides when mixing the chemicals or when applying them to the crop. Acute poisoning with pesticides is a global public health problem, accounting for as many as 300,000 deaths worldwide every year (Damalas and Koutroubas, 2017). Many of these pesticide poisonings, particularly in the developing world, are intentional (Mewa et al., 2017). Apart from target organisms, other organisms (e.g., beneficial insects, birds, earthworms, and fish) can be affected by pesticides in or around fields, resulting in death of

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wildlife, death of farm animals, and loss of biodiversity (Damalas and Koutroubas, 2011).

Developing a target-specific pesticide robot sprayer can reduce the amount of pesticides used in modern agriculture and potentially remove the human from the pesticide spraying process. Studies show that up to 60% of pesticide use can be reduced by using selective sprayers (Elkabetz et al., 1998; Goudy et al., 2001; Gil and Garg, 2014).

Robotic technology is an alternative method for spraying in agriculture, which provides multiple benefits, such as safety, sustainability and environmental impact. In terms of safety, it removes the farmer from the exposure to dangerous chemicals (Horrigan et al. 2002). In addition, less pesticide means healthier food products for the consumer (Williams and Hammitt, 2001).

In terms of agriculture sustainability, robotic technology can provide a way to reduce inputs (e.g., by reducing the quantity of pesticides used) and make the most efficient usage of pesticide controls (e.g., by targeted spraying). Furthermore, targeted spraying can have a significant reduction on environmental impact (Gill and Garg, 2014; Popp et al., 2013).

In pesticide application, accuracy and uniformity of application is most important to avoid adverse effects of pesticides on environment and crop injury, and reduced pest management. Flow rate, operating pressure and pressure losses, nozzle material, nozzle spray angle, nozzle positioning, spray height, spray width, spray thickness, breakup length, atomization degree or droplet size, impact, spray drift, velocity, spray pattern, etc. are some parameters that affect the nozzle performance. Each nozzle type has specific characteristics and is designed to be used for different applications. Selecting a nozzle based on the spray pattern and other spray characteristics that are required generally yields good results (Padhee et al., 2019).

Keeping in view of the above discussions, an attempt was made to evaluate the spray characteristics with different nozzles used in agricultural sprayers in a horizontal spray patternator which could help in selecting the appropriate nozzle for plant protection of any agricultural crop. The data from this study could be used by the nozzle manufactures to recommend spacing of their nozzles on the booms, operating pressure and other spray parameters that farmers use to treat their field crops during spraying using different hydraulic sprayers.

## 2. Materials and methods

The prototype spraying machine was tested in the faculty of Agriculture and Natural Resources – Aswan University - Aswan - Egypt. Tests were carried out to evaluate the machine performance in terms of the laboratory. The laboratory tests are conducted to assess the discharge rate, spray distribution pattern, and spray angle. The sprayer was operated at different heights of (30, 40, and 50 cm) at different operating pressures of (6.0, 7.0, 8.0, 8.50, and 9.5 bar).

### *2.1. Distribution uniformity*

Distribution uniformity is a ratio expressed in a percent of the average low-quarter amount of water caught or infiltrated to the average amount caught or infiltrated as expressed in the following equation (James, 1988).

$$DU = \frac{X_{LO}^{-}}{X^{-}} \times 100$$

where:

$X_{LO}^{-}$ = The average low-quarter amount of water caught or infiltrated (mm) (the 25% of the collections with the lowest collection amount)

$X^{-}$ = The average amount caught or infiltrated (mm).

### *2.2. Spray swath width*

The spray angle for each nozzle was calculated based on working width and nozzle height and was stated in whole degrees. It is also described as the angle subtended at the final orifice by the edges of the spray pattern. The spray angle of the hollow cone nozzle was calculated using the formula (Jassowal, 2016).

$$W = 2h \tan\left(\frac{\theta}{2}\right)$$

where:

W = Width of spray cone, mm.

h = The height of the spray, mm.

θ = The spray angle in degrees.

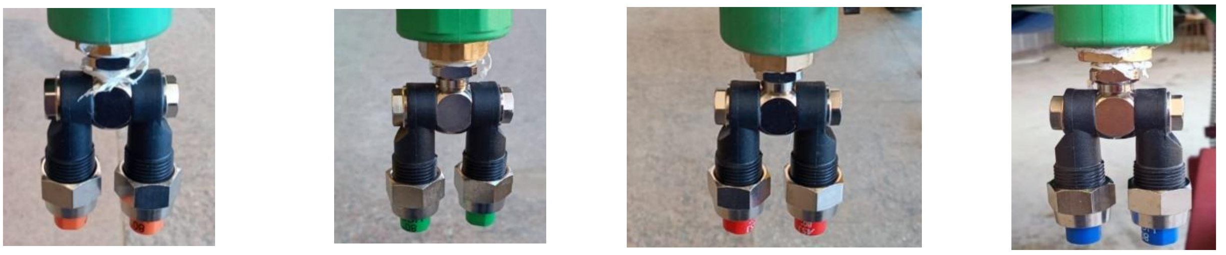
### *2.3. Spray overlap*

The overlap is defined as the width covered by two adjacent nozzles divided by the width covered by a single nozzle, expressed in the present. It mainly affects the spray pattern of the sprayer, and it depends on the boom height and nozzle spacing. The test was done on a test track. First, the test track was cemented was used as water shown on track to get a good contrast between the track and the spray solution. The sprayer was tested for 30, 40, and 50 cm boom height and 50 cm each nozzle spacing spray (Carroll, 2017).

### *2.4. Statistical analysis*

The statistical analysis was carried out using IBM SPSS statistics 25, PC statistical software. Each experiment in triplicate was repeated at least twice and the values were presented in terms of coefficient of variance (S´anchez-Hermosilla et al., 2011).


**Figure 1.** Shows a patternator consists of a number of channels during the uniformity test.



422HCC02 422HCC025 422HCC03 422HCC05

**Figure 2.** The different types of hallow cone ceramic nozzles are used in the current study.

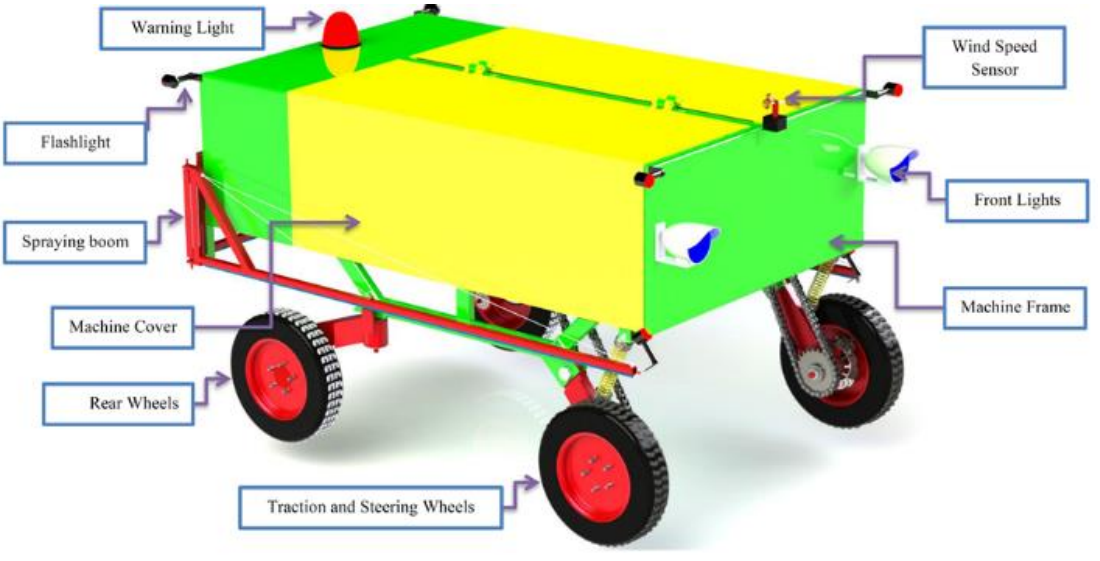



**Figure 3.** The isometric view of the spraying robot shows the main components with a non-spraying position.

**Figure 4.** The spraying robot with a non-spraying position.

## 3. Results and discussions

The tests were carried out in the Agricultural and Bio-Systems Engineering Department – Faculty of Agriculture and Natural Resources – Aswan University – Aswan- Egypt, during the period from 9 to 31 October 2020.

The laboratory tests include**:**

1. Estimation of spraying conditions.
2. Distribution uniformity of spraying machine.
3. Spray overlap test.
4. Effect of operating pressure on spray angle of nozzles.
5. Determination of optimal spray height.

### *3.1. Estimation of spraying conditions*

The laboratory spraying conditions are one of the main factors affecting the performance of the spraying machine. Environmental and testing conditions were monitored and logged during the entire application period. Data were collected in October (29 - 30), 2020 from 7.00 to 18.00. Figures 5 and 6 provide summary statistics of all laboratory spraying conditions during testing of the spraying system.

Figures 5 and 6 illustrate the operating condition during the laboratory tests of the spraying system, Results showed that the maximum ambient temperature during all tests was 33 °C, also the minimum relative humidity was 22 %. The dew point temperature decreased from 14 to 8 °C during all tests. The maximum light intensity inside the laboratory was 625 W/m². Little changes were found in atmospheric pressure where it was ranged between 1014.2 to 1012.41 mbar, while the wind speed was maintained at zero during all tests, and also, the altitude was 194 m above the sea level.

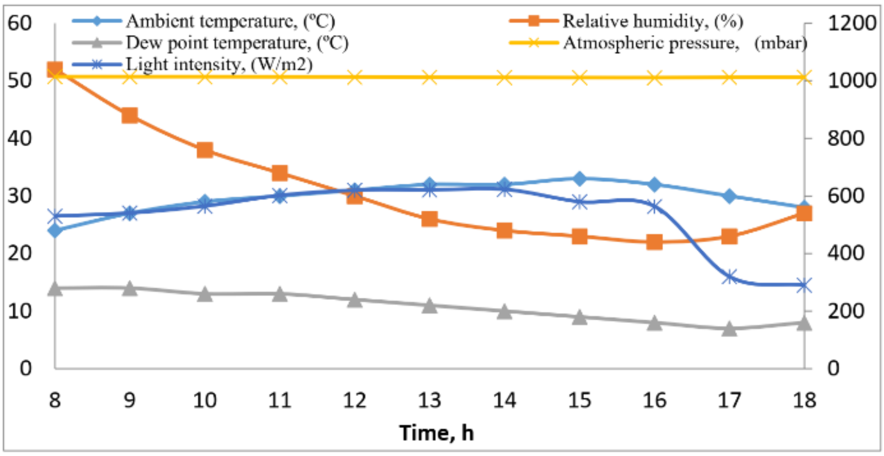



**Figure 5.** Operating conditions stored with time and position of measurement (29 October 2020).

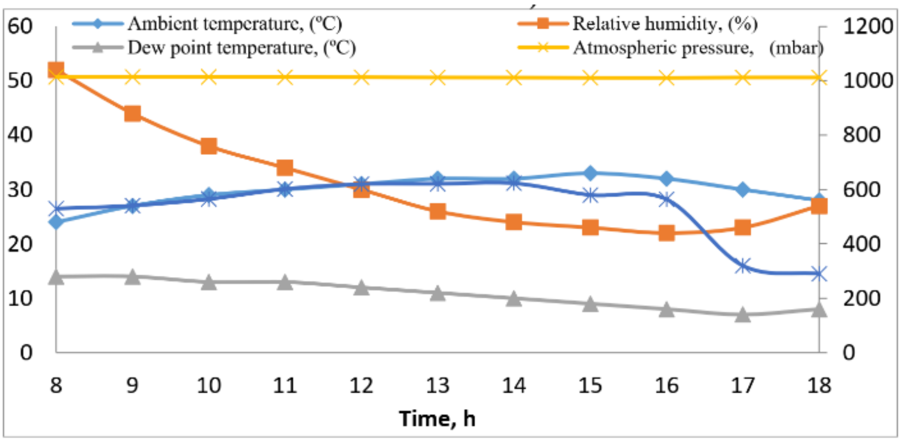



**Figure 6.** Operating conditions stored with time and position of measurement (30 October 2020).

### *3.2. Distribution uniformity of spraying machine*

The discharge rate of the spraying machine was determined under laboratory conditions with static position by estimating the discharge rate of each nozzle on the spraying boom (13 nozzles) for 20 s at different heights of (30, 40, and 50 cm) and pressures of (9.5, 8.5, 8, 7 and 6 bar) for four different hollow cone ceramic nozzles (422HCC02, 422HCC025, 422HCC03, and 422HCC05), as shown in Table 1.

The distribution uniformity of spraying machine ranged between (95.88 to 99.10 %) for 422HCC02, (97.76 to 98.54 %) for 422HCC025, (96.99 to 98 %) for 422HCC03 and (96.67 to 99.17 %) for 422HCC05 which shows the uniform coverage of the spraying obtained. Uniformity coefficient of 85% or more is considered to be satisfactory (Michael, 2008).

The maximum coefficient of variation (C.V) for the average of nozzle discharges was 3.39, 1.91, 2.48, and 2.98 % for hollow cone ceramic nozzle types 422HCC02, 422HCC025, 422HCC03, and 422HCC05 respectively, which showed that the variation in discharges of the nozzle was below an acceptable variation of 10 % as per the recommendation (Gomez and Gomez, 1984).

**Table 1**

Distribution uniformity of spraying machine (422HCC02 and 422HCC025).

| Nozzle type | Pump Pressure, (bar) | Nozzle flow rate, (L/min) | | | | | | | | | | | | | D.U, % | C.V, % |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | $N_1$ | $N_2$ | $N_3$ | $N_4$ | $N_5$ | $N_6$ | $N_7$ | $N_8$ | $N_9$ | $N_{10}$ | $N_{11}$ | $N_{12}$ | $N_{13}$ | | |
| 422HCC02 | 9.5 | 1.39 | 1.4 | 1.42 | 1.38 | 1.41 | 1.36 | 1.39 | 1.42 | 1.37 | 1.39 | 1.35 | 1.41 | 1.38 | 99.10 | 1.58 |
| | 8.5 | 1.22 | 1.23 | 1.2 | 1.21 | 1.25 | 1.21 | 1.23 | 1.26 | 1.27 | 1.24 | 1.22 | 1.19 | 1.18 | 97.85 | 2.18 |
| | 8 | 1.11 | 1.12 | 1.15 | 1.16 | 1.18 | 1.18 | 1.19 | 1.23 | 1.19 | 1.24 | 1.18 | 1.19 | 1.13 | 96.11 | 3.31 |
| | 7 | 1.07 | 1.06 | 1.11 | 1.09 | 1.15 | 1.12 | 1.12 | 1.14 | 1.13 | 1.12 | 1.09 | 1.11 | 1.04 | 96.48 | 2.92 |
| | 6 | 0.94 | 1.01 | 0.98 | 1.04 | 1.02 | 1.05 | 1.03 | 1.04 | 1.06 | 1.02 | 1.04 | 0.97 | 1.02 | 95.88 | 3.39 |
| 422HCC025 | 9.5 | 1.65 | 1.61 | 1.66 | 1.64 | 1.67 | 1.66 | 1.68 | 1.69 | 1.63 | 1.66 | 1.65 | 1.63 | 1.64 | 98.54 | 1.33 |
| | 8.5 | 1.49 | 1.48 | 1.49 | 1.52 | 1.54 | 1.49 | 1.54 | 1.55 | 1.56 | 1.52 | 1.51 | 1.54 | 1.55 | 97.76 | 1.80 |
| | 8 | 1.44 | 1.41 | 1.43 | 1.41 | 1.45 | 1.4 | 1.45 | 1.46 | 1.47 | 1.42 | 1.46 | 1.44 | 1.45 | 98.25 | 1.53 |
| | 7 | 1.26 | 1.24 | 1.22 | 1.24 | 1.27 | 1.21 | 1.26 | 1.28 | 1.29 | 1.28 | 1.27 | 1.24 | 1.26 | 97.78 | 1.91 |
| | 6 | 1.2 | 1.16 | 1.17 | 1.15 | 1.18 | 1.13 | 1.16 | 1.18 | 1.21 | 1.18 | 1.16 | 1.17 | 1.19 | 98.10 | 1.81 |
| 422HCC03 | 9.5 | 1.81 | 1.77 | 1.76 | 1.84 | 1.8 | 1.75 | 1.8 | 1.79 | 1.83 | 1.79 | 1.75 | 1.7 | 1.76 | 97.71 | 2.12 |
| | 8.5 | 1.63 | 1.61 | 1.62 | 1.66 | 1.65 | 1.64 | 1.63 | 1.72 | 1.7 | 1.67 | 1.6 | 1.62 | 1.64 | 98.00 | 2.11 |
| | 8 | 1.49 | 1.57 | 1.56 | 1.5 | 1.54 | 1.51 | 1.55 | 1.56 | 1.54 | 1.5 | 1.49 | 1.48 | 1.55 | 97.79 | 2.08 |
| | 7 | 1.41 | 1.39 | 1.35 | 1.38 | 1.41 | 1.35 | 1.39 | 1.43 | 1.39 | 1.36 | 1.33 | 1.37 | 1.31 | 97.12 | 2.48 |
| | 6 | 1.18 | 1.21 | 1.24 | 1.27 | 1.26 | 1.19 | 1.23 | 1.25 | 1.27 | 1.24 | 1.27 | 1.23 | 1.21 | 96.99 | 2.44 |
| 422HCC05 | 9.5 | 1.95 | 2.11 | 2.02 | 2.08 | 2.05 | 2.09 | 2.01 | 2.1 | 2.06 | 2.1 | 2.06 | 2 | 2.08 | 99.17 | 2.31 |
| | 8.5 | 1.81 | 1.86 | 1.8 | 1.85 | 1.87 | 1.81 | 1.84 | 1.85 | 1.86 | 1.84 | 1.81 | 1.82 | 1.83 | 98.52 | 1.25 |
| | 8 | 1.71 | 1.77 | 1.73 | 1.79 | 1.77 | 1.74 | 1.76 | 1.75 | 1.77 | 1.75 | 1.73 | 1.71 | 1.74 | 98.42 | 1.38 |
| | 7 | 1.54 | 1.56 | 1.6 | 1.56 | 1.51 | 1.51 | 1.54 | 1.56 | 1.55 | 1.54 | 1.52 | 1.54 | 1.55 | 98.41 | 1.56 |
| | 6 | 1.34 | 1.3 | 1.35 | 1.42 | 1.4 | 1.31 | 1.37 | 1.37 | 1.42 | 1.37 | 1.34 | 1.36 | 1.3 | 96.67 | 2.98 |

** $N_1$, $N_2$, …, $N_{13}$ are thirteen Hollow Cone nozzles fitted on the boom at 50 cm spacing.

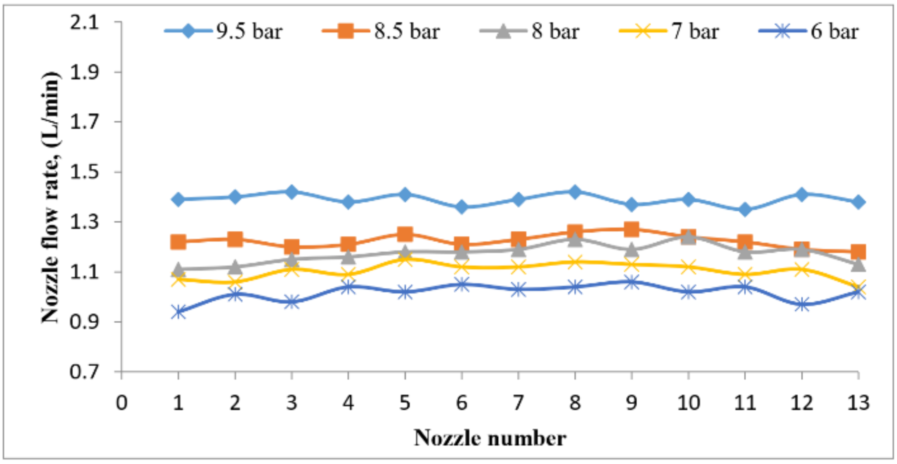



**Figure 7.** Distribution Uniformity of spraying machine for nozzle type (422HCC02).

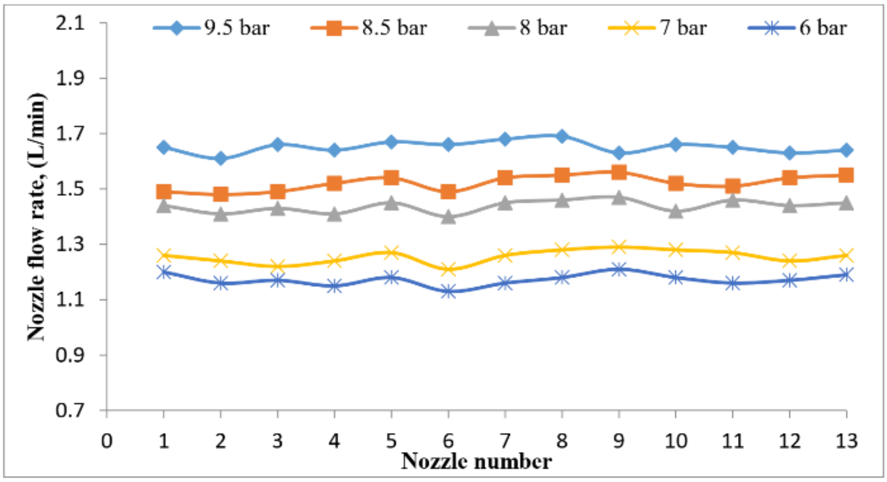



**Figure 8.** Distribution Uniformity of spraying machine for nozzle type (422HCC025).

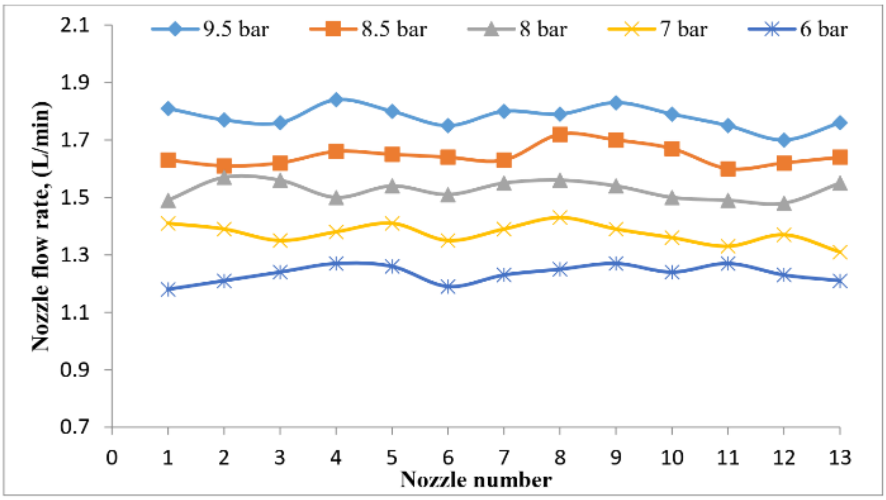



**Figure 9.** Distribution Uniformity of spraying machine for nozzle type (422HCC03).

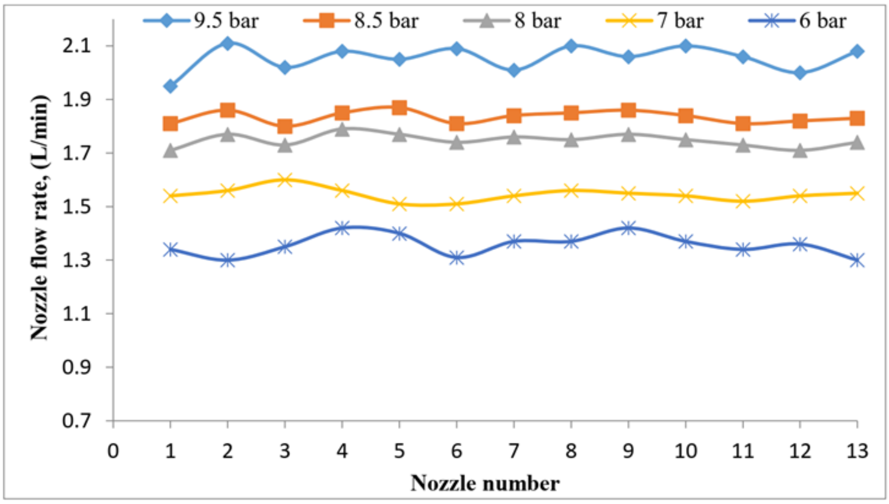



**Figure 10.** Distribution Uniformity of spraying machine for nozzle type (422HCC05).

### *3.3. Spray overlap test*

The spray overlap was estimated at different heights (30, 40, and 50 cm) and pressures of (9.5, 8.5, 8, 7, and 6 bar) for four different hollow cone ceramic nozzles (422HCC02, 422HCC025, 422HCC03, and 422HCC05).

Tables 2 to 5 indicated that the spray overlap test for 422HCC02 nozzle varies from 8.5 to 36 cm, for 422HCC025 nozzle varies from 12 to 38.5 cm, for 422HCC03 nozzle varies from 14 to 47 cm, and for 422HCC05 nozzle varies from 16 to 47 cm, depending on spraying height and pressure

**Table 2**

Spray overlaps between nozzles for nozzle type (422HCC02).

| Average pump pressure, (bar) | Spraying height, (cm) | Overlap, (cm) | | | Average Overlap, (cm) | C.V, (%) | Spraying angle, (degree) | C.V, (%) |
|---|---|---|---|---|---|---|---|---|
| | | $N_1$-$N_2$ | $N_2$-$N_3$ | $N_3$-$N_4$ | | | | |
| 9.5 | 30 | 24.5 | 26.5 | 25.0 | 50.33 | 2.07 | 80.26 | 2.67 |
| | 40 | 30.0 | 30.0 | 30.5 | 55.17 | 0.52 | 68.89 | 1.37 |
| | 50 | 31.0 | 32.5 | 36.0 | 58.17 | 4.41 | 59.63 | 3.63 |
| 8.5 | 30 | 23.0 | 26.0 | 28.0 | 50.67 | 4.97 | 78.87 | 4.39 |
| | 40 | 24.5 | 26.5 | 24.0 | 50.00 | 2.65 | 64.40 | 3.39 |
| | 50 | 24.5 | 27.5 | 28.5 | 51.83 | 4.02 | 54.32 | 5.33 |
| 8 | 30 | 17.0 | 17.5 | 16.0 | 41.83 | 1.83 | 68.65 | 6.42 |
| | 40 | 19.5 | 21.5 | 21.0 | 45.67 | 2.28 | 59.35 | 3.83 |
| | 50 | 23.0 | 23.5 | 24.5 | 48.67 | 1.57 | 50.63 | 5.90 |
| 7 | 30 | 13.5 | 15.5 | 15.5 | 39.83 | 2.90 | 66.81 | 4.28 |
| | 40 | 16.5 | 17.5 | 18.0 | 42.33 | 1.80 | 55.23 | 3.41 |
| | 50 | 19.5 | 21.5 | 23.0 | 46.33 | 3.79 | 48.76 | 4.06 |
| 6 | 30 | 8.5 | 7.5 | 11.0 | 34.00 | 5.30 | 58.74 | 6.01 |
| | 40 | 12.0 | 12.5 | 10.0 | 36.50 | 3.62 | 49.39 | 5.03 |
| | 50 | 15.5 | 17.5 | 15.0 | 41.00 | 3.23 | 44.91 | 4.54 |

** $N_1$-$N_2$, $N_2$-$N_3$, and $N_3$-$N_4$ are the adjacent four hollow cone nozzles fitted on the boom at 50 cm spacing.

Table 2 illustrates the effect of spraying pressures on the overlaps and coefficient of variation of 422HCC02 at 30, 40, and 50 cm spraying height, Results showed that increasing the spraying pressure leads to an increase in the overlap by (8.5 to 24.5 %) at 30 cm height and during tests the coefficient of variation variety between (1.83 to 5.30 %). Results also, show that the maximum overlap was 30.0 cm at 9.5 bar at 40 cm height, and the maximum coefficient of variation was 3.66 at 6 bar and generally, we can conclude that the increase of the spraying pressure or spraying heights led to increasing the overlap.

Table 3 represents the effect of spraying pressures on the overlaps and coefficient of variation of 422HCC025 at 30, 40, and 50 cm spraying height, Results show that decreasing the spraying pressure led to a decrease in the overlap from (35.5 to 12.0 cm), (36.0 to 16.5 cm) and (38.5 to 18.5 cm) at 30, 40 and 50 cm height and during tests when the spraying pressure was decreased from 9.50 to 6.00 bar. The maximum coefficient of variation was (11.47 %) with 8.5 spraying pressure and 50 cm boom height while the minimum coefficient of variation was (1.10 %) with 8.5 spraying pressure and 30 cm boom height.

**Table 3**

Spray overlaps between nozzles for nozzle type (422HCC025).

| Average pump pressure, (bar) | Spraying height, (cm) | Overlap, (cm) | | | Average Overlap, (cm) | C.V, (%) | Spraying angle, (degree) | C.V, (%) |
|---|---|---|---|---|---|---|---|---|
| | | $N_1$-$N_2$ | $N_2$-$N_3$ | $N_3$-$N_4$ | | | | |
| 9.5 | 30 | 35.5 | 35.0 | 32.5 | 59.33 | 2.71 | 89.59 | 2.04 |
| | 40 | 32.5 | 35.5 | 36.0 | 59.67 | 3.17 | 73.21 | 4.17 |
| | 50 | 35.0 | 36.5 | 38.5 | 61.67 | 2.85 | 63.03 | 3.32 |
| 8.5 | 30 | 27.0 | 28.0 | 27.0 | 52.33 | 1.10 | 82.88 | 2.72 |
| | 40 | 32.5 | 31.0 | 30.0 | 59.50 | 1.68 | 70.48 | 2.73 |
| | 50 | 33.5 | 35.5 | 37.0 | 47.83 | 11.47 | 61.91 | 3.58 |
| 8 | 30 | 18.5 | 21.0 | 20.0 | 44.83 | 2.81 | 73.20 | 4.09 |
| | 40 | 22.5 | 24.5 | 22.0 | 48.00 | 2.76 | 61.89 | 4.93 |
| | 50 | 26.5 | 28.5 | 26.5 | 52.17 | 2.21 | 54.93 | 4.36 |
| 7 | 30 | 15.5 | 17.5 | 19.5 | 42.50 | 4.71 | 69.94 | 4.74 |
| | 40 | 19.5 | 17.5 | 16.0 | 42.67 | 4.12 | 57.60 | 4.02 |
| | 50 | 24.0 | 22.0 | 18.0 | 46.33 | 6.59 | 50.65 | 5.69 |
| 6 | 30 | 12.0 | 15.5 | 14.0 | 38.83 | 4.52 | 65.41 | 7.51 |
| | 40 | 16.5 | 15.5 | 14.5 | 40.50 | 2.47 | 53.07 | 7.87 |
| | 50 | 17.5 | 18.5 | 18.0 | 43.00 | 1.16 | 45.91 | 5.44 |

** N1-N2, N2-N3, and N3-N4 are the adjacent four hollow cone nozzles fitted on the boom at 50 cm spacing.

Table 4 illustrates the effect of spraying pressures on the overlaps and coefficient of variation of 422HCC03 at 30, 40, and 50 cm spraying height, Results show that increasing the spraying height from (30 to 50 cm) led to increasing the overlap from (37.0 to 41.0 cm) by about 9.76 % at 9.5 bar. The increasing the spraying pressure led to an increase in the overlap from (14.0 to 47.0 cm) at 30 cm height and during tests when the spraying pressure was increased from 6.0 to 9.5 bar. Also, we found that the maximum coefficient of variation was (6.85 %) with 8.0 spraying pressure and 40 cm boom height while the minimum coefficient of variation was (1.42 %) with 8.5 spraying pressure and 30 cm boom height.

**Table 4**

Spray overlaps between nozzles for nozzle type (422HCC03).

| Average pump pressure, (bar) | Spraying height, (cm) | Overlap, (cm) | | | Average Overlap, (cm) | C.V, (%) | Spraying angle, (degree) | C.V, (%) |
|---|---|---|---|---|---|---|---|---|
| | | $N_1$-$N_2$ | $N_2$-$N_3$ | $N_3$-$N_4$ | | | | |
| 9.5 | 30 | 37.0 | 38.5 | 41.0 | 63.83 | 3.17 | 93.25 | 2.92 |
| | 40 | 41.5 | 44.5 | 41.0 | 67.33 | 2.81 | 80.47 | 3.48 |
| | 50 | 41.0 | 43.0 | 47.0 | 68.83 | 4.45 | 68.14 | 3.51 |
| 8.5 | 30 | 28.0 | 29.5 | 28.5 | 53.67 | 1.42 | 84.36 | 3.00 |
| | 40 | 31.0 | 33.5 | 33.0 | 57.50 | 2.30 | 71.23 | 3.24 |
| | 50 | 34.5 | 36.0 | 38.0 | 61.17 | 2.87 | 63.00 | 5.37 |
| 8 | 30 | 21.5 | 24.0 | 26.5 | 49.00 | 5.10 | 76.77 | 3.70 |
| | 40 | 22.0 | 23.5 | 28.5 | 49.67 | 6.85 | 62.43 | 6.06 |
| | 50 | 24.5 | 27.5 | 26.5 | 51.17 | 2.99 | 54.32 | 5.33 |
| 7 | 30 | 19.0 | 18.0 | 17.0 | 43.00 | 2.33 | 72.48 | 3.61 |
| | 40 | 20.0 | 20.5 | 21.5 | 45.67 | 1.67 | 59.91 | 4.64 |
| | 50 | 21.5 | 24.5 | 23.0 | 48.00 | 3.13 | 51.57 | 5.77 |
| 6 | 30 | 15.5 | 15.0 | 14.0 | 39.83 | 1.92 | 66.81 | 4.28 |
| | 40 | 17.5 | 18.0 | 21.0 | 43.83 | 4.32 | 56.72 | 4.16 |
| | 50 | 20.0 | 20.5 | 21.5 | 45.67 | 1.67 | 47.79 | 6.40 |

** $N_1$-$N_2$, $N_2$-$N_3$, and $N_3$-$N_4$ are the adjacent four hollow cone nozzles fitted on the boom at 50 cm spacing.

**Table 5**

Spray overlaps between nozzles for nozzle type (422HCC05).

| Average pump pressure, (bar) | Spraying height, (cm) | Overlap, (cm) | | | Average Overlap, (cm) | C.V, (%) | Spraying angle, (degree) | C.V, (%) |
|---|---|---|---|---|---|---|---|---|
| | | $N_1$-$N_2$ | $N_2$-$N_3$ | $N_3$-$N_4$ | | | | |
| 9.5 | 30 | 42.5 | 44.0 | 41.0 | 67.50 | 2.22 | 96.77 | 1.55 |
| | 40 | 44.5 | 45.0 | 43.0 | 69.17 | 1.50 | 81.81 | 1.27 |
| | 50 | 47.5 | 47.0 | 45.5 | 71.67 | 1.45 | 70.97 | 1.47 |
| 8.5 | 30 | 35.5 | 35.5 | 36.5 | 60.83 | 0.95 | 89.77 | 0.64 |
| | 40 | 35.5 | 34.0 | 38.5 | 61.00 | 3.76 | 73.97 | 3.10 |
| | 50 | 38.5 | 39.0 | 39.0 | 63.83 | 0.45 | 64.68 | 0.45 |
| 8 | 30 | 30.5 | 31.0 | 32.0 | 56.17 | 1.36 | 85.42 | 0.89 |
| | 40 | 33.5 | 35.5 | 35.0 | 59.67 | 1.74 | 72.97 | 1.43 |
| | 50 | 35.5 | 34.5 | 34.5 | 59.83 | 0.96 | 61.35 | 0.94 |
| 7 | 30 | 25.0 | 23.0 | 23.5 | 48.83 | 2.13 | 78.44 | 1.33 |
| | 40 | 25.0 | 26.0 | 25.5 | 50.50 | 0.99 | 64.95 | 0.77 |
| | 50 | 31.0 | 31.5 | 32.5 | 56.67 | 1.35 | 58.19 | 1.31 |
| 6 | 30 | 20.0 | 20.5 | 16.0 | 43.83 | 5.63 | 72.89 | 3.38 |
| | 40 | 19.5 | 23.0 | 21.5 | 46.33 | 3.79 | 60.45 | 2.90 |
| | 50 | 23.5 | 27.0 | 26.5 | 50.67 | 3.74 | 53.41 | 3.54 |

** $N_1$-$N_2$, $N_2$-$N_3$, and $N_3$-$N_4$ are the adjacent four hollow cone nozzles fitted on the boom at 50 cm spacing.

Table 5 represents the effect of spraying pressures and spraying height on the overlaps and coefficient of variation of 422HCC03, where the overlap was estimated at five pump pressures (9.5, 8.5, 8.0, 7.0, and 6.0 bar) and three spraying heights (30, 40 and 50 cm). The results showed that increasing of overlap is a result of increasing the spraying height from (30 to 50 cm) at constant spraying pressure, and also, due to increasing of spraying pressure at the same height, or due to increase both of them. Also, the results showed that the maximum coefficient of variation was (5.63 %) with 6.0 spraying pressure and 30 cm boom height while the minimum coefficient of variation was (0.45 %) with 8.5 spraying pressure and 50 cm boom height.

### *3.4. Effect of operating pressure on spray angle of nozzles*

The results in Tables 3 to 5 indicated that the spraying angle was calculated at 30, 40, and 50 cm nozzle height and five pump pressures of (9.5, 8.5, 8.0, 7.0, and 6.0 bar) for four different hollow cone ceramic nozzles (422HCC02, 422HCC025, 422HCC03, and 422HCC05).

Tables 3 to 5 showed that as the operating pressure was increased from 6.0 to 9.5 bar, the spray angle for hollow cone nozzle ceramic (422HCC02) increased from (58 to 80.26 °) at 30 cm height and the maximum coefficient of variation was 6.42 at 8 bar and the minimum coefficient of variation was 1.37 at 9.5 bar. It also showed that for hollow cone nozzle ceramic (422HCC025) the maximum spray angle was 89.59 ° at 30 cm height and 9.5 bar. Also, the maximum spray angle for hollow cone nozzle ceramic (422HCC03) was 93.25 at 9.5 bar and 30 cm height while the coefficient of variation varied between 6.40 and 2.92 %. And finally, the spray angle for hollow cone nozzle ceramic (422HCC05) was ranged between (96.77 to 72.89 °) when the spraying pressure increased from (6.0 to 9.5 bar) at a constant height. The less increase in angle may be because the increase in pressure is gradual and hollow cone nozzles work at higher pressures.

### *3.5. Determination of optimal spray height*

The first step was to find the optimal spray height for each nozzle type at various pressures. For each nozzle type, one test was conducted at three different heights (30, 40, and 50 cm), at five different pressures of (9.5, 8.5, 8.0, 7.0, and 6.0 bar) using four types of hollow cone ceramic nozzle (422HCC02, 422HCC025, 422HCC03, and 422HCC05). Four nozzles were used in each test. Water was collected from nine graduated beakers within the target width. Using an excel spreadsheet, the average, standard deviation, and coefficient of variation (C.V) were calculated, as shown in Tables 2 to 5.

## 4. Conclusions

The Distribution uniformity of spraying machine ranged between (95.88 to 99.10 %) for 422HCC02, (97.76 to 98.54 %) for 422HCC025, (96.99 to 98 %) for 422HCC03 and (96.67 to 99.17 %) for 422HCC05 which shows the uniform coverage of the spraying obtained. Results showed that the spray overlap test for 422HCC02 nozzle varies from 7.5 to 36.0 cm, for 422HCC025 nozzle varies from 12 to 38.5 cm, for 422HCC03 nozzle varies from 14.0 to 47.0 cm, and for 422HCC05 nozzle varies from 16 to 47.5 cm, depending on spraying height and pressure. The spray angle for hollow cone nozzle ceramic (422HCC02) increased from (58 to 80.26 °) at 30 cm height. The maximum spray angle for (422HCC025) was 89.59 ° at 30 cm height and 9.5 bar. Also, the results indicated that the maximum spray angle for (422HCC03) was 93.25 at 9.5 bar and 30 cm height. And finally, we found that the spray angle for (422HCC05) was ranged between (96.77 to 72.89 °) when the spraying pressure increased from (6.0 to 9.5 bar) at a constant height.

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# تقييم معملي لروبوت رش مبيدات محلي الصنع

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## الملخص العربي

يعد الرش الدقيق لمبيدات الآفات أمراً ضرورياً في الممارسات الزراعية الحديثة حيث إنه يزيد من مكافحة الآفات ويقلل من تكاليف المبيدات والفواقد ويزيد من السلامة البيئية. ومن ثم، هدفت الدراسة الحالية إلى تقييم خصائص تدفق السائل من أربع أنواع من الفواني المختلفة المستخدمة في رش المبيدات من نوع الرشاشات الخزفية ذات المخروط المجوف وهي 422HCC02 ، 422HCC025 ، 422HCC03 و 422HCC05 على جهاز patternator الأفقي. تم قياس معدل التصريف ونمط توزيع الرذاذ وعرض الرش لجميع أنواع الفوهات بمدى ضغط ٦,٠ و٩,٥ بار عند ثلاث ارتفاعات مختلفة للرش وهي (٣٠ و ٤٠ و ٥٠ سم). أوضحت النتائج أن انتظام التوزيع لآلة الرش تراوحت بين (٩٥,٨٨ إلى ٩٩,١٧٪)، وتراوحت تداخل الرش من ٧,٥ إلى ٤٧,٥ سم، اعتمادا على ارتفاع وضغط الرش، وكانت أقصى زاوية للرش ٨٩,٥٩ درجة عند ارتفاع ٣٠ سم و٩,٥ بار. كما أشارت النتائج إلى أن أقصى زاوية رش ٩٦,٧٧ درجة عند ضغط رش ٩,٥ بار.