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Optimizing Vane Number for Enhanced Performance of Mist Blower Nozzle in Agricultural Spraying

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ABSTRACT

The objective of this study is to optimize the number of vanes equipped in the propeller of a mist blower's nozzle. Performance tests were conducted on the approved sprayer test bed, also known as a patternator, to measure several parameters, including effective spraying discharge, effective spraying width, spraying angle, effective spraying height, effective spraying range, droplet diameter, and droplet density. The vane number was optimized using the weighting method. The results indicate that increasing the number of vanes used is directly correlated with higher values of effective spraying width (ESW), spraying angle, effective spraying range (ESR), and droplet density. Conversely, it is inversely correlated with the value of effective spraying discharge (ESD), effective spraying height (ESH), and droplet diameter. The vane number was optimized using the weighting method. The most effective results in the mist blower performance test are achieved by using 12 vanes. This configuration produces droplets with a diameter of 195.44 ±9.68 µm and a density of 320 ± 17.44 droplets/cm^2. The mist blower also has ESW of 136 ± 1.73 cm, ESH of 68.14 ± 4.19 cm, ESD of 4.41 ± 0.14 L/min, and ESR of 5.76 ± 0.04 m.

1. INTRODUCTION

The process of fertilization has a crucial role in facilitating plant growth and enhancing agricultural productivity. According to Purba *et al*. (2021), plants can receive manure or granules through soil absorption by their roots, whereas liquid fertilizer applied through a sprayer to generate a fine spray (droplet) capable of penetrating the plant stomata. Furthermore, liquid organic fertilizer is widely acknowledged for its rapid nutrient delivery and minimal soil degradation despite its regular application (Alex, 2015).

A sprayer is a device that disperses liquid into a mist or small particles of the appropriate size to ensure uniform distribution. In addition to fertilization, sprayers are also employed for pest and disease management during plant cultivation. Sprayers are utilized to apply liquid of active substances directly onto plants through spraying. The efficacy of the sprayer is contingent upon the suitability of the droplet size. This application can be initiated within a designated time period to guarantee adherence to the regulations for applying the recommended quantity of pesticide (Guntur *et al*., 2016). Furthermore, Mustafid *et al*. (2022) asserted that the precision of spraying is contingent upon factors such as droplet size, spraying time, and the accuracy of the spraying target.

Currently, the sprayers commonly utilized by the community are predominantly manual, resulting in a significant time investment (Anafiyah *et al*., 2021). Furthermore, there are limitations on both the intensity and spraying distance.

The dispersion of droplets becomes asymmetrical (Rahman & Yamin, 2014). The process of spraying is affected by various elements, including the discharge of spray from the nozzle, the distribution and pattern of the spray, the direction of the spray, the influence of the surrounding air, and the behavior of the droplets (Zhai *et al*., 2015). Droplets can be generated through the utilization of fluid pressure and air pressure. The fundamental mechanism of fluid pressure involves the compression of a liquid by a pump, followed by its passage through a nozzle, resulting in the formation of droplets. The fundamental mechanism of air pressure involves the generation of airflow by a blower, which propels liquid droplets via a nozzle, resulting in the formation of droplets (Jamaluddin *et al*., 2018).

Examples of sprayers that operate based on the principle of air pressure include electric sprayers, air blowers, and mist blowers. According to Pramuhadi *et al*. (2019), electric sprayers maintain a consistent pressure for the liquid being sprayed, mist blowers cover a vast distance, and air blowers offer a significant spraying range. The mist blower is ideal for efficiently spraying expansive regions as a result of its extensive misting range, consistent pressure, and substantial spraying width. Mist blowers have the capability to disperse liquid in the form of small droplets that range in size from 51 to 380 µm, or as a mist (SNI 8650:2018). Mist blowers are capable of distributing droplets uniformly due to the mist-like formation of the liquid being sprayed. Mist blowers are equipped with a nozzle that has a propeller-shaped design. The vane number of the propeller can be an important factor that significantly affects the performance of the mist blower.

To achieve a more refined liquid, the number of vanes on the nozzle's propellers should be determined to attain the smallest droplet size, highest droplet concentration, widest effective spraying area, longest spraying distance, and lowest spraying discharge. Hence, this study was conducted to optimize the misting efficiency for plant fertilization in cultivation by regulating the vane count of the nozzle's propeller.

2. MATERIALS AND METHODS

The research was conducted in the Agricultural Machinery and Infrastructure Testing Laboratory at IPB University. Tools and measuring instruments used are a mist blower Tasco MBS 650 Turbo, which has detailed specifications as shown in Table 1, a unit of sprayer testing bed (patternator), measuring tapes, measuring cups, stopwatches, arcs, scales, and ImageJ (open-source software for image processing and analysis). The materials used are clean water and ink solution. Other materials include concords sensitive paper and supporting bars.

Table 1. Detailed specification of the mist blower Tasco MBS 650 Tubo

Specification	Value
Engine type	2 Cycle, Single Cylinder, Air Cooled
Power	2.5 Kw
Chemical tank capacity	14 L
Fuel tank capacity	0.75 L
Rotation	7500 rpm
Chemical spray discharge rate	5 L/min
Range	15 m
Ignition system	CDI
Net weight	11.5 kg

2.1. Design of Experiment

Mist blower performance testing in the laboratory was used as a reference for testing liquid fertilization performance in the experimental field. The performance test was conducted using a completely randomized design on four different numbers of propellers' vanes on the nozzle as the factor, namely 6 vanes, 8 vanes, 10 vanes, and 12 vanes. The propeller type is shown in Figure 1. The research parameters consisted of spraying discharge, effective spraying width, spraying degree, effective spraying height, effective spraying range, droplet diameter, and droplet density; each was conducted in triplicate. Statistical comparison was made by one-way analysis of variance (ANOVA) using the general linear model procedure.

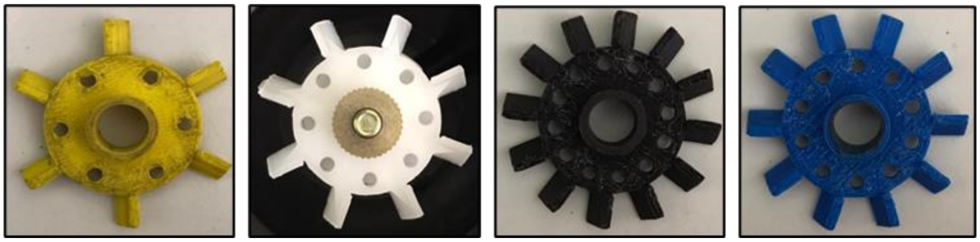

Figure 1. The type of propeller used as treatment in mist blower performance test

2.2. Mist Blower Performance

A spraying test was carried out using a patternator (Figure 2). The patternator was designed based on the Indonesia National Standard for plant cultivation tools, an electric knapsack sprayer, quality requirements, and test methods (SNI 8485:2023), with the specifications shown in Table 2. Spraying discharge measurements are carried out to determine the amount of liquid that comes out in a unit of time. Spraying discharge (L/min) can be determined by spraying droplets in the patternator and then measuring the volume of water held in the container (L) within a particular time (minute) (Barid & Yakob, 2007).

Effective spraying width (*ESW*) is determined by spraying liquid at 60 cm above the surface plane of the patternator. The volume of liquid filled the glass containers was measured, and the original droplet volume chart was made. The charts were then overlapped each other so that the lowest coefficient of variation (CV) was the result. The *ESW* is the horizontal distance of the intersection of the points between the original graph and the selected overlapping chart with the lowest CV value (Pramuhadi *et al*., 2023).

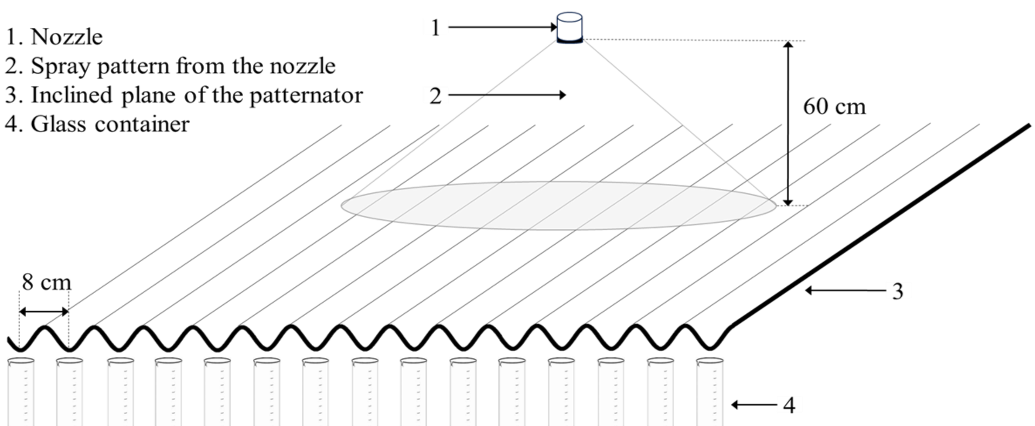

Figure 2. Scheme of the spraying test of the mist blower using patternator

Table 2. Specification of the patternator

Specification	Description
Type/Model	Corrugated roof sheet
Construction material	Wooden
Plane material	Polycarbonate
Dimension	Total length: 800 cm Total width: 425 cm Total height: 113 cm
Distance between waves	8 cm
Waves amount	100

Effective spraying height (*ESH*) becomes the basis or reference for determining the optimum spraying distance to plants. This value was determined based on the width of the *ESW* and the spraying angle, which was calculated using Equation (1).

$$ESH = \frac{\frac{1}{2}ESW}{\tan(\frac{1}{2}\theta)} \quad (1)$$

where *ESH* is effective spraying height (m), *ESW* is effective spraying width (m), and θ is spraying angle (°).

The spraying range was determined by deploying the patternator in a vertical orientation at the height of 60 cm, in accordance with the guidelines set by the Indonesian National Standardization Agency (SNI-8485:2023). The effective spraying range (*ESR*) is the farthest when spraying occurs. The value of the effective spraying range is obtained from the number of initial containers that hold the liquid until the container with the enormous value of the volume of liquid accommodated at the time of spraying multiplied by the distance between the containers, 0.08 m.

Droplets diameter (µm) and droplets density (droplets/cm^2) were measured by spraying the mixture of ink solution and water on sensitive paper (concord) with a nozzle height equal to the *ESH* value. The paper was then scanned and saved in jpg format and then imported into ImageJ software, which can analyze the area of the paper, the wetted area, and the area of each droplet from the RGB 255 or black reading.

2.3. Optimization of the number of propeller's vane nozzle

The optimization aims to determine the optimum spraying performance by setting the number of vanes of mist blower nozzle propellers, which is carried out using experimental data in the laboratory. The method used to optimize the treatment on the mist blower was the weighting method using all of the performance parameters, which have already been evaluated with criteria as mentioned in Table 3. The criteria and the weighting calculation follow the method of Ayu (2022). The percentage of the weighting value shows how important these parameters are in the spraying work. The greater the percentage, the more important the parameter is in using the mist blower. The droplet diameter and density have large values because they are the main components of the solution and can be absorbed well through the leaves.

Table 3. Criteria of weighting parameters for optimizing the vane number of the propeller's nozzle (Ayu, 2022)

Weighting parameters	Order of priority	Weighting percentage	Consideration
Droplet diameter	1	30%	Smaller droplet diameters could make it easier for fertilizer to enter the stomata and be absorbed by the plant. Thus, fertilization would be more optimal and effective.
Droplet density	2	25%	Greater droplet density could increase the plant's liquid fertilizer intake through stomata.
Effective spraying width (*ESW*)	3	20%	A greater *ESW* value indicates wider coverage of the application of liquid fertilizer per area, which means the fertilization time would be more efficient.
Effective spraying discharge (*ESD*)	4	15%	A smaller *ESD* value indicates the effectiveness of using the liquid fertilizer on the field.
Effective spraying range (*ESR*)	5	10%	A greater *ESR* value would make fertilizing faster due to the longer spraying range.

3. RESULTS AND DISCUSSION

3.1. Mist Blower Performance

Mist blower performance tests have been carried out in this research. The test results show that the greater the number of vanes on the nozzle propeller is directly proportional to the *ESW*, spraying angle, *ESR* and droplet density. While it is inversely proportional to the *ESD*, *ESH* and droplet diameter. The mist blower performance test results are shown in Table 4.

Table 4. Performance of mist blower with different numbers of propeller vane

Performance parameters	Number of vane			
	6	8	10	12
ESD (L/minute)	5.33 ± 0.20[a]	5.19 ± 0.19[a]	5.00 ± 0.17[a]	4.41 ± 0.14[b]
ESW (cm)	104.00 ± 1.00[d]	112.00 ± 2.00[c]	120.00 ± 2.65[b]	136.00 ± 1.73[a]
Spraying angle (degree)	60.00 ± 3.46[d]	70.00 ± 2.00[c]	79.00 ± 1.00[b]	90.00 ± 3.46[a]
ESH (cm)	90.35 ± 6.50[a]	80.08 ± 2.98[ab]	71.56 ± 0.02[bc]	68.14 ± 4.19[c]
ESR (m)	5.44 ± 0.08[b]	5.60 ± 0.11[ab]	5.68 ± 0.11[a]	5.76 ± 0.04[a]
Droplet diameter (µm)	250.51 ± 2.28[a]	249.78 ± 3.34[a]	231.82 ± 10.18[a]	195.44 ± 9.68[b]
Droplet density (droplets/cm^2)	122 ± 9.17[c]	212.33 ± 16.26[b]	244.67 ± 9.87[b]	320.00 ± 17.44[a]

ESD: Effective spraying discharge, *ESW*: Effective spraying width, *ESH*: Effective spraying height, *ESR*: Effective spraying range.
Value sharing the same letter means it is not different based on the Tukey comparison test with a confidence level of 95%.

The spraying discharge (*ESD*) is mostly determined by the nozzle type and the spraying pressure (Dharmawan & Soekarno, 2020). *ESD* is a parameter that determines the amount of liquid that comes out of the nozzle per unit of time. The amount of spraying discharge is influenced by the cross-sectional area of the flow and the flow speed. Smaller spraying discharge indicates better nozzle performance due to the smaller solution applied. The spraying discharge value is influenced by the speed of the water flow coming out of the mist blower and the difference in the number of nozzle vanes. According to Candrago *et al.* (2018), there is a direct correlation between the flow rate of a nozzle and the requirement for the solution being utilized. Based on the result, vane number 12 had the smallest *ESD* value and was the most different, which means this treatment is the most effective compared to the others.

The operator must have information about the width of the nozzle spray in order to accurately adjust it to the desired region for spraying. To effectively spray the plant near the growing medium, it is advisable to choose a nozzle with a wide spray coverage. This ensures that the primary plants receive a sufficient amount of spray solution (Sari & Prasetio, 2021). *ESW* value is utilized as a basis for adjusting planting patterns and spacing so that fertilization is more optimal and the waste of fertilizer solution can be minimized. *ESW* was determined based on the overlapping graph obtained from observation data, and the original data was shifted to obtain the overlapping graph. The original graph is shifted right and left to get the intersection between the original and overlapping graphs. Overlapping graph 1 is the original graph shifted left and right by half the number of containers filled during spraying. Overlapping graph 2 is the original graph that is shifted one cup to the left, and overlapping graph 3 is the original graph that is shifted one cup to the right. The overlap graph for each treatment is shown in Figures 3 to 6.

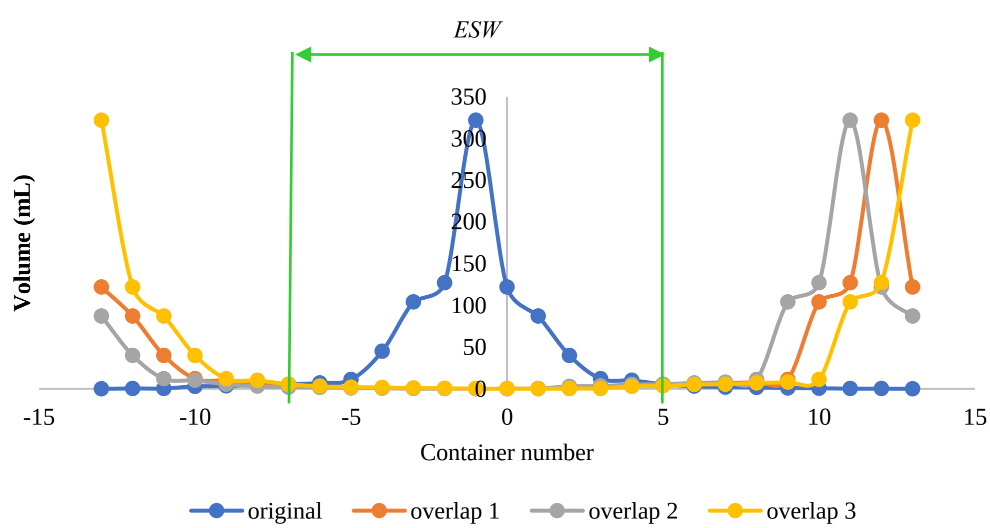

Figure 3. Overlapping graph of mist blower performance with 6-vaned nozzle propeller

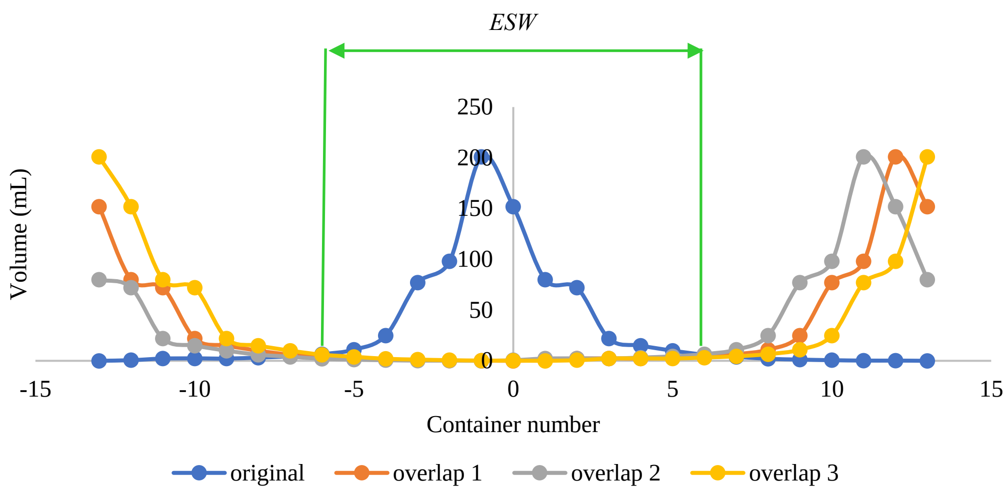

Figure 4. Overlapping graph of mist blower performance with 8-vaned nozzle propeller

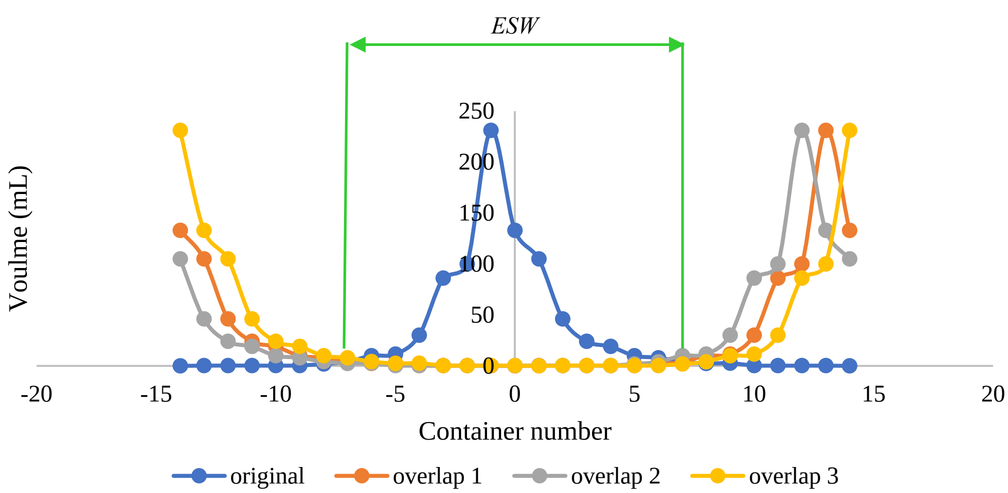

Figure 5. Overlapping graph of mist blower performance with 10-vaned nozzle propeller

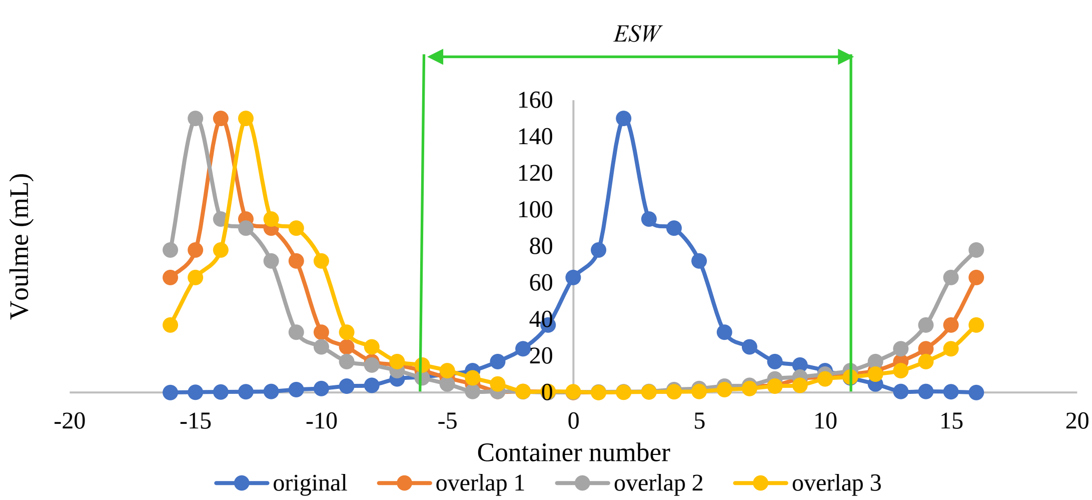

Figure 6. Overlapping graph of mist blower performance with 12-vaned nozzle propeller

Table 5. Summary of CV and *ESW* obtained from each overlapping for each vane

Number of vanes	Overlap	CV	1. *ESW*
6	1	1.1441	2. 104
	2	1.1609	3. 104
	3	1.1930	4. 104
8	1	0.9390	5. 112
	2	0.9414	6. 112
	3	0.9646	7. 104
10	1	1.0367	8. 120
	2	1.0389	9. 112
	3	1.0780	10. 120
12	1	0.7507	11. 136
	2	0.7508	12. 128
	3	0.7644	13. 136

Based on Table 5, the largest *ESW* value is 136 cm when using 12-vaned nozzle propellers, and the smallest value is 104 cm when using 6-vaned propellers. The *ESW* value determines the effective bed width for cultivating plants on the field. Spraying angle measurements are carried out directly by spraying liquid on the protractor. The value of the spraying angle is obtained from the part of the protractor that is wetted with the solution. Based on the result in Table 4, the number of vanes proportionally affects the formed spraying angle. The greater vane number formed a greater spraying angle.

Based on the result in Table 4, the largest *ESH* was obtained when using a 6-vaned nozzle propeller. The lowest *ESH* was obtained when using a 12-vaned nozzle propeller. A high value of *ESH* could cause spraying activities to be ineffective because some parts far from the center of the nozzle output will experience a minimal droplet density. The effective fogging height will also affect the droplet density value. The higher the fogging value, the smaller the droplet density, affecting the spraying position further away from the spray medium.

ESR measurements were carried out in a closed room that was not influenced by environmental wind speed. Measurements are carried out by spraying the liquid to the patternator and then calculating the volume that can be accommodated in the glass container filled with liquid. The volume of fluid held is then input into the graph. To make the range pattern, the liquid volume value is divided on the x-axis by ½ so that the result is (positive y), and the value is then mirrored to get negative y. The graph of the extent of spraying in each treatment is shown in Figures 7 to 10.

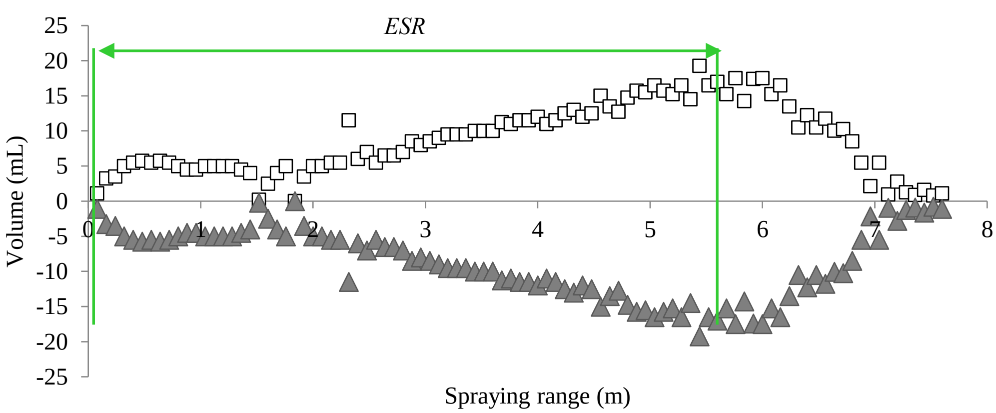

Figure 7. *ESR* of mist blower performance when using 6-vaned propeller nozzle

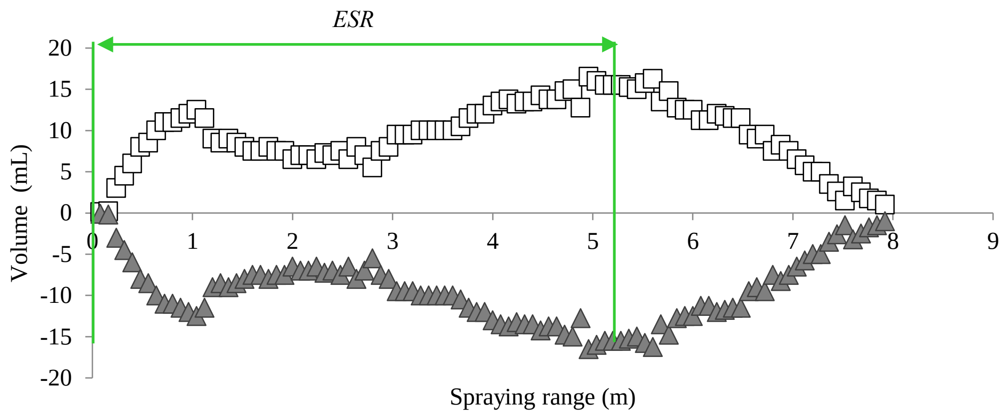

Figure 8. *ESR* of mist blower performance when using a 8-vaned propeller nozzle

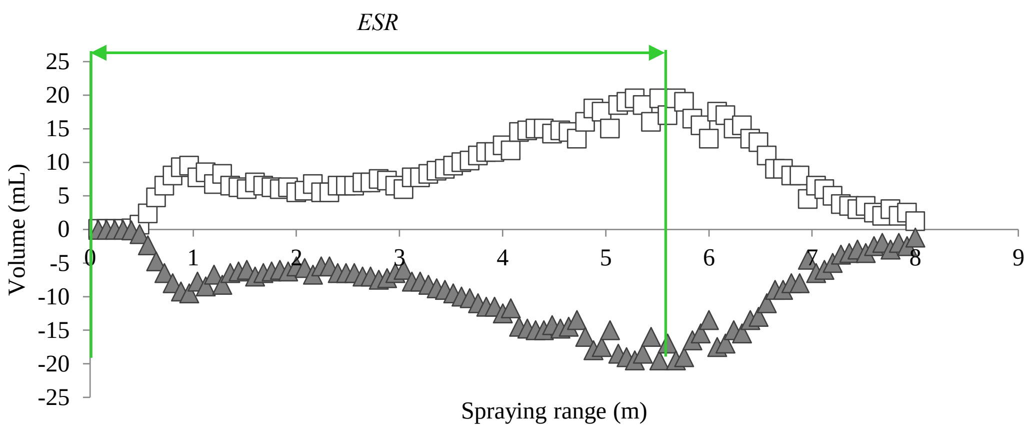

Figure 9. *ESR* of mist blower performance when using a10-vaned propeller nozzle

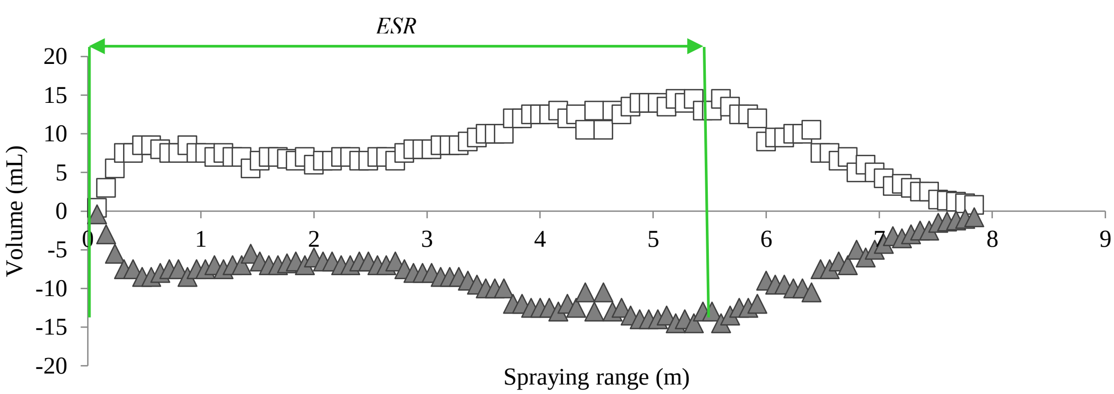

Figure 10. *ESR* of mist blower performance when using a 12-vaned propeller nozzle

Droplet diameter is a parameter that determines the effectiveness of liquid fertilization (Pramuhadi *et al*., 2018). Droplet diameter is the size of the spray droplets that come out of the nozzle vanes when spraying. The smaller the droplet size produced, the easier it is for the plant to absorb liquid fertilizer through the stomata. The size of the droplets throughout the mist blower is determined by the spray distance, nozzle shape, air speed coming out of the nozzle, the natural characteristics of the sprayed material, the ambient air condition, and the spraying discharge. The smallest droplet diameter was obtained when using a 12-vaned propeller nozzle, which is 195.44 ± 9.68 µm, and the largest droplet diameter was obtained when using a 6-vaned propeller nozzle, which is 250.51 ± 2.28 µm. The best droplet diameter value for spraying ranges from 150 µm to 250 µm (ASABE S-572).

The number of droplets determines droplet density with a certain expansion. The greater the droplet density, the more contact between the liquid droplets and the plants, so plant growth will be more optimal. The success of spraying is largely determined by the level of coverage, namely the number of spray particles that cover the target field (droplet density). The more spray particles in each unit of the target area, the more likely the object will be sprayed and the greater the spraying success (Prabaningrum, 2017). Small (fine) droplets with large density will easily enter stomata in large quantities. These parameters will greatly determine the quality of spraying liquid fertilizer on crops and become the basis for determining or selecting the type of nozzle used in the sprayer (Hermawan, 2014).

Several elements, including spray height, spray distribution pattern, spray discharge, and external air conditions, influence the density of droplets. In addition, Abd. Kharim *et al.* (2019) assert that various factors can influence the dispersion of sprayed substances. These factors include (1) the composition and type of liquid preparations, as well as their volatility and droplet size; (2) the technology employed in the spraying equipment; and (3) environmental conditions, such as wind speed and direction, temperature, and humidity. The appearance of the distribution of droplets produced by various numbers of propeller nozzle vanes is shown in Figure 11.

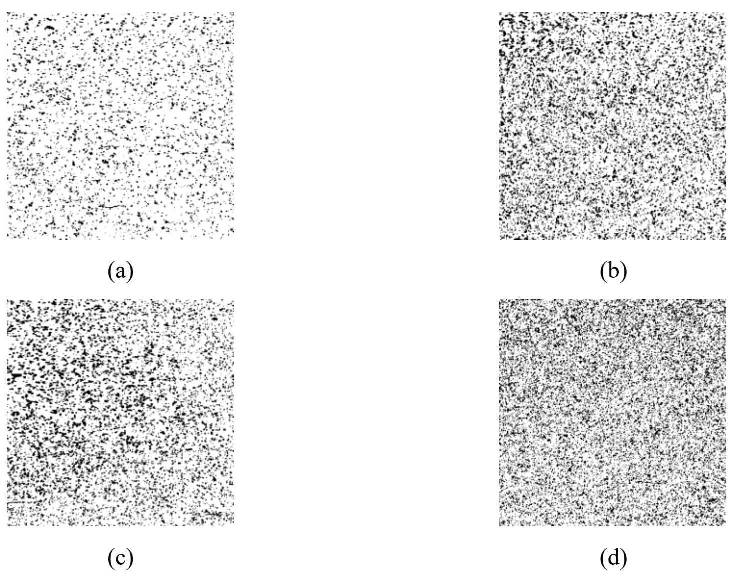

Figure 11. Image of droplet distribution of each treatment: (a) using a 6-vaned propeller nozzle, (b) using an 8-vaned propeller nozzle, (c) using a 10-vaned propeller nozzle, (d) using a 12-vaned propeller nozzle.

The droplets in each treatment are of different sizes, namely small and large. This can occur when the liquid comes out of the mist blower nozzle; some liquids merge and mix, causing the enhancement of the droplet size. Large droplets are a combination of small droplets.

To summarize the correlation between parameters, a correlation analysis was conducted using the Pearson correlation method with a confidence level of 95%. The correlation between parameters is described in Table 6. All of the parameters in this research correlate well with the number of vanes used, characterized by the correlation coefficient value above 0.800. the number of vanes used has a strong positive correlation with the parameters of *ESW*, spraying angle, *ESR*, and droplet density, while inversely, the number of vanes used has a strong negative correlation with the parameters of *ESD*, *ESH*, and droplet diameter.

Table 6. Correlation between parameters in the mist blower performance test

Pearson correlation	Vane number	*ESD*	*ESW*	Spraying angle	*ESH*	*ESR*	Droplet diameter	Droplet density
Vane number	1.000							
ESD	-0.873	1.000						
ESW	0.974	-0.900	1.000					
Spraying angle	0.980	-0.877	0.951	1.000				
ESH	-0.911	0.783	-0.833	-0.956	1.000			
ESR	0.842	-0.701	0.758	0.813	-0.763	1.000		
Droplet diameter	-0.886	0.947	-0.923	-0.848	0.700	-0.728	1.000	
Droplet density	0.974	-0.833	0.953	0.960	-0.891	0.814	-0.837	1.000

ESD: Effective spraying discharge, *ESW*: Effective spraying width, *ESH*: Effective spraying height, *ESR*: Effective spraying range

Table 7. Weighting results for each vane number for the mist blower nozzle propeller

Performance parameters	Percentage	Weighted value			
		W6	W8	W10	W12
Droplet diameter	30%	0.60	0.90	0.30	1.20
Droplet density	25%	0.25	0.50	0.75	1.00
ESW	20%	0.20	0.40	0.60	0.80
ESD	15%	0.15	0.30	0.45	0.60
ESR	10%	0.10	0.20	0.30	0.40
Sum.		1.30	2.30	2.40	4.00
Rank		4	3	2	1

ESW: Effective spraying width, *ESD*: Effective spraying discharge, *ESR*: Effective spraying range

3.2. Optimization of the number of the nozzle propeller's vane

Optimization of mist blower nozzle propeller settings was conducted to determine the optimal number of vanes to support mist blower performance for fertilization. The main criteria for determining mist blower performance are the smallest droplet diameter, the largest droplet density, the largest *ESW*, the smallest *ESD*, and the largest *ESR*. Treatment combinations were optimized by weighting the percentage of each parameter shown in Table 3. The weighting results for each vane number for the mist blower nozzle propeller are shown in Table 7. Based on Table 4, the most optimal treatment (highest value) is the mist blower using a 12-vaned propeller nozzle. Treatment combinations are optimized to determine the optimal performance for liquid fertilization in the field.

4. CONCLUSION

Mist blower performance tests with the treatment of vane number on the propeller nozzle have been carried out. The number of vanes on the propeller nozzle significantly affects the performance of the mist blower. The greater the number of vanes used is directly proportional to the increasing value of effective spraying width (*ESW*), spraying angle, effective spraying range (*ESR*), and droplet density but inversely proportional to the value of effective spraying discharge (*ESD*), effective spraying height (*ESH*), and droplet diameter. The optimum results in the mist blower performance test are when using 12 vanes, which are capable of producing a droplet diameter of 195.44 ±9.68 µm, a droplet density of 320 ± 17.44 droplets/cm^2, an *ESW* of 136 ± 1.73 cm, an *ESH* of 68.14 ± 4.19 cm, an *ESD* of 4.41 ± 0.14 L/min, an *ESR* of 5.76 ± 0.04 m.

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