Journal of Advanced Research in Applied Sciences and Engineering Technology

Journal homepage:
https://semarakilmu.com.my/journals/index.php/applied_sciences_eng_tech/index
ISSN: 2462-1943

Analysis the Effect of Operating Variables of the Nozzle on Spray Volume Distribution Patterns

Nasir Salim Hassen[1,2,*], Nor Azwadi Che Sidik[3]

[1] Department of Thermo fluid Engineering, Fakulti Kejuruteraan Mekanikal, Universiti Teknologi Malaysia, 81310 Skudai, Johor, Malaysia
[2] Agricultural Machinery unit, Faculty of Agriculture, University of Diyala, Iraq
[3] Universitas Pendidikan Indonesia, Indonesia

ARTICLE INFO

Article history:
Received 9 November 2023
Received in revised form 25 March 2024
Accepted 24 June 2024
Available online 25 July 2024

Keywords:

Nozzle size; Nozzle height; Operating pressure; Spray width

ABSTRACT

Transverse spray volume distribution experiments for commercially available nozzles could help technicians and applicators select correct combinations of the operating variables suitable with different field conditions. The aim of this study is to generate numerous spray patterns are suitable for different weather conditions. Spray distribution patterns from three Tee Jet nozzle sizes XR11002, XR11003 and XR11004 at three operating pressures 1, 2 and 3bar at three spray heights 0.50, 0.75, and 0.90m were generated with spray pattern analysis system (patternator). The results suggest that numerous and clear changes in the nature of the spray patterns were noted depending on operating variables. Working width values increased as operating pressure increased resulting in more uniformity of spray distribution patterns. Further, interaction of operating variables impacted spray width and volume distribution of the spray pattern. The spray peak direct under the nozzle centre decreased linearly as the nozzle height increased. The use of smaller nozzle sizes and higher operating pressure improve the spray uniformity. Correct selection of operating variables suitable to the field conditions could provide optimal and effective performance of the spray nozzle. Producing of nearly identical spray patterns from different operating variables has made the spray system easy to use in a wide range of field conditions.

1. Introduction

The requirements of protection the environment and the high cost of agrochemical are incentives for applicators and users of spraying systems to do their very best in spraying processes. The productivity of a crop per unit area increases as a result of the use of accurate spraying for

* *Corresponding author.*
E-mail address: nasirsalimhassen@gmail.com

https://doi.org/10.37934/araset.49.1.110

agrochemical and organic fertilizers. Use and operation of a sprayer to achieve optimum results of spray application and economic use of agrochemical, a sprayer must be calibrated such as nozzle output, pressure and the swath width to avoid inaccurate application of chemicals [1, 2].

Uniformity of spray pattern is critical for an optimum spray application to increase the effectiveness of agrichemicals and to reduce plant injury [3]. The most important operating variables that affect spray pattern are nozzle size, spray height and operating pressure. All flat fan nozzles present similar spray volume distribution pattern with a peak of volume collected in the central region below the tip of the spray nozzle, with a gradual volume reduction towards the end of the two sides of the spray[4].

There is a direct relationship between nozzle height and spray coverage in which greater spray coverage is as spray height on the targets reduced [5]. Several spray applications were carried out to study effect release height on spray deposition, it was noticed that spray nozzle must be at an optimum height [6]. The use of the minimum nozzle height remains a significant part of any spray application [7]. These nozzles can be operated at higher operation pressures. As operation pressure increased the swath width was increased [8]. In addition, spray nozzle height and the operating pressure have a significant effect on the spray width and the uniformity of the spray distribution [9-11]. The best distribution of nozzle can be achieved at higher heights and medium operation pressures [12].

Hydraulic nozzles are carefully designed to use to deliver agrochemicals to targeted areas by achieving the desired spray coverage under certain conditions. One of the difficult decisions faces sprayer users in the agricultural fields is selection of the nozzle that gives optimal spray patterns among a large numbers of nozzle types and suitable with weather condition in the spray time[13]. Selection and testing a lot of nozzle types is time consumption and costly spray way and the results may be not positive and it is not guarantee. Therefore, to reach to the effective and efficient spray application in the field, the easy and optimal way to generate nearly similar spray patterns in volume and spray quality by different operating variables settings of the nozzle.

The feasibility of using the test-bench methodology is to demonstrate the spray volume distributions [14, 15]. The objective of this study is to evaluate and analyses spray patterns of the flat-fan XR110 nozzle for broadcast spraying based on spray width and volume distribution under effect different operating variables using a spray test bench in controlled environmental conditions, in an effort to provide spray pattern data for users of spray systems according to the field needs.

2. Methodology

2.1 Spray system

A conventional spraying system equipped with a pressurized tank, pressure regulator, pressure gauge, and a spray boom with single nozzle in the Aeronautical laboratory of Faculty of Mechanical Engineering at University Technology Malaysia was used to test a group of nozzles. Numerous spray nozzle setups were carried out to assess the effect of three TeeJet XR nozzle sizes of XR11002, XR11003 and XR11004 (Spraying Systems Co, Inc. Wheaton, Illinois, USA) at three boom heights 0.50, 0.70 and 0.90 m and at three operating pressures of 1, 2 and 3bar on spray pattern width and spray distribution[16, 17]. For the spray distribution validation, the reference nozzle behavior was defined as that obtained using flat fan TeeJet XR11003 nozzle operated at 3bar and at a boom height of 0.50 m[18]. Table 1 shows specification of the spray nozzles.

In order to validate the discharge rate of the nozzles, a group of tests were conducted by collecting amount of water directly from the nozzle at three operating pressures 1, 2, and 3 bar on a container for one minute using tap water. The tests were repeated three times. The deviation between the actual flow and the target flow is stable at ± 2.5%.

Table 1
Specification of the nozzles

Nozzle Code	Pressure (bar)	Flow Rate (l/m)	[1]Droplet Category	Symbol	[2]Approximate VMD Range (microns)
XR11002	1	0.46	Medium	M	236–340
	2	0.65	Fine	F	106–235
	3	0.75	Fine	F	106–235
XR11003	1	0.68	Medium	M	236–340
	2	0.96	Fine	F	106–235
	3	1.18	Fine	F	106–235
XR11004	1	0.91	Medium	M	236–340
	2	1.29	Medium	M	236–340
	3	1.58	Medium	M	236–340

[1]ASABE (American Society of Agricultural & Biological Engineers) Standard 572. 2
[2]VMD = Volume median diameter

2.2 Swath width

Theoretical swath width of the XR nozzle with spray angle 110° at spray heights 50, 75 and 90 are 143,214.5 and 257cm respectively. In order to validate the practical swath width of the tested nozzles was presented as the distance between two spray ends of the nozzle for three XR110 nozzle sizes 02, 03 and 04 at three nozzle heights of 0.50 and 0.75 and 0.90 m above the spray table at three operating pressures 1, 2, and 3bar [19]. Tests was repeated three times. The randomized complete block design with three replications was used to analyze the test data. Differences among means were determined with LSD test using Genstat version 10 Software at the 0.05 level of significance.

2.3 Static spray volumetric distribution

The volumetric distributions measurements of the spray from individual nozzle have been investigated using repeatable and precision assessment method and according to the official standards of spray pattern analyzing system or spray table under laboratory conditions [20-23]. This spray table was manufactured in the workshop with an area of 300 cm length × 100 cm width and contains fifty V-shaped gutters of 6 cm width ×3 cm depth. The spray table was inclined 6° from the horizontal plane [19, 24]. A vertical movable stand was used to support the nozzle above the center of the spray table on the heights of 0.50, 0.75 and 0.90 m to spray at operating pressure of 1, 2 and 3bar. In front of the table, a set of 250 mL tubes was used to collect the liquid from each channel as shown in Figure 1. For all the tests, the average of the temperature and the relative humidity in the laboratory was 30C° and 79% RH respectively. The weighting method (a precision electric balance) was used to determine the transversal volumetric distributions collected during one minute. The spray volumetric distribution data were presented as (ml/min).

Fig. 1. Spray pattern analysing system

3. Results and Discussion

3.1 Spray pattern width

The results in table 2 show that the working width of the tested Tee jet XR1100 nozzle can help determine how the nozzle size, pressure and height should be installed to get specific spray pattern width. The spray widths ranged from 1.26 - 2.99m at nozzle heights in the range of 0.50-0.90 m and operating pressures 1-3 bars. It is clear that there are significant effects for nozzle height and operating pressure on the working width. Spray pattern width increased as nozzle height and operating pressure increased for all nozzle sizes. The widest spray width was obtained from XR11003 nozzle of 2.99m from interaction of the nozzle height 0.90 m and operating pressure 3bar[8]. There was no clear effect of the nozzle size on spray width .

Table 2
Spray pattern width (m) of different nozzles sizes of 02, 03and 04, nozzle heights of 50, 75 and 90cm, and operating pressure of 1, 2 and 3 bar

Nozzle size	Nozzle height (cm)	Operating pressure (bar)			Height * Size
		1	2	3	
	50	1.2633	1.7267	1.9067	1.6322
XR11002	75	2.0133	2.4467	2.4900	2.3167
	90	2.2733	2.6333	2.7933	2.5667
	50	1.3800	1.7333	1.9067	1.6733
XR11003	75	2.2467	2.4967	2.7000	2.4811
	90	2.6167	2.9033	2.9933	2.8378
	50	1.3767	1.7300	1.9100	1.6722
XR11004	75	2.2267	2.5867	2.7133	2.5089

	90	2.6033	2.8633	2.9500	2.8056
LSD 0.05		0.03770			0.02177
					Average size
	XR11002	1.8500	2.2689	2.3967	2.1719
Pressure* Size	XR11003	2.0811	2.3778	2.5333	2.3307
	XR11004	2.0689	2.3933	2.5244	2.3289
LSD 0.05		0.02177			0.01257
					Average Height
	50	1.3400	2.1622	2.4978	1.6593
Pressure* Height	75	1.7300	2.5100	2.8000	2.4356
	90	1.9078	2.6344	2.9122	2.7367
LSD 0.05		0.02177			0.01257
Average pressure		2.0000	2.3467	2.4848	
LSD 0.05		0.01257			

3.2 Effect nozzle height spray volume distribution

In this study, the effect of different nozzle heights on spray volume distribution was suggested. Figure 2 shows that the spray peak direct under the nozzle centre decreased linearly as the nozzle height increased. In addition, the spray volume at the two spray ends increased. The results conformed to the results of [5].

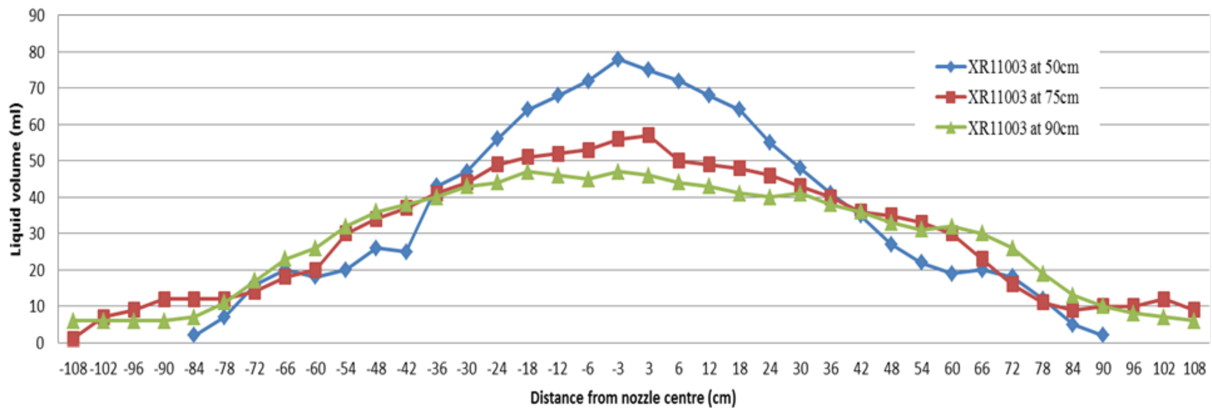

Fig. 2. Spray volume distribution of reference nozzle XR11003 at different nozzle heights 0.50, 0.75 and 0.90 m and at operating pressure 3bar

3.3 Effect operating pressure on spray volume distribution

Figure 3 shows as operating pressure increased, the spray uniformity increased, this may be as result to a correlation between operating pressure with spray width and flow rate values in which increase the pressure increase the spray width and in the same time increase the spray volume at the two spray ends in which reduced the number of peaks at the spray periphery because of the turbulent spray nature. In addition. Increasing of operation pressure tend to give a good distribution of spray [25].

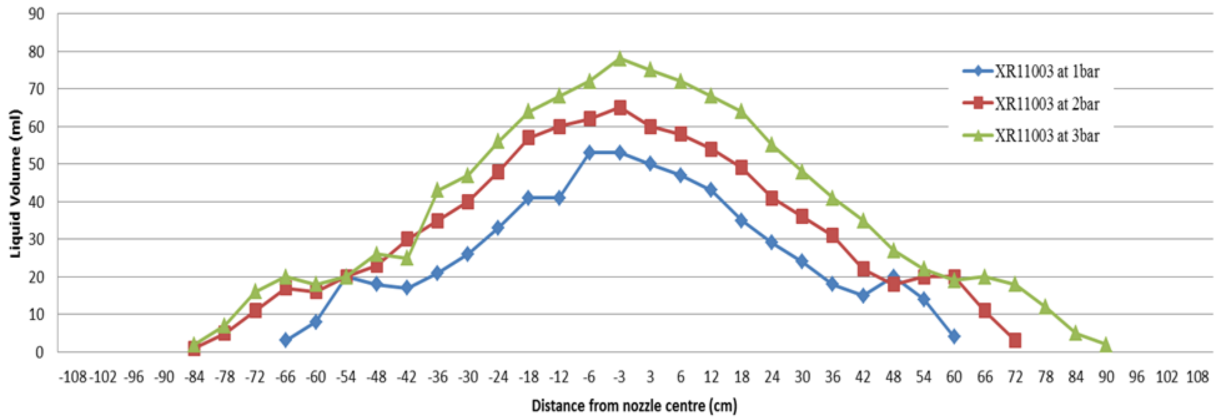

Fig. 3. Spray volume distribution for reference nozzle XR11003 at different operating pressures 1, 2 and 3bar and at nozzle height 0.50m

From Figure 4, it is very clear that increasing of nozzle size increase the spray peak under the nozzle centre more than at the two sides of the spray because the number of big droplets in the spray increases in which they fall direct under the nozzle centre under effect their weight.

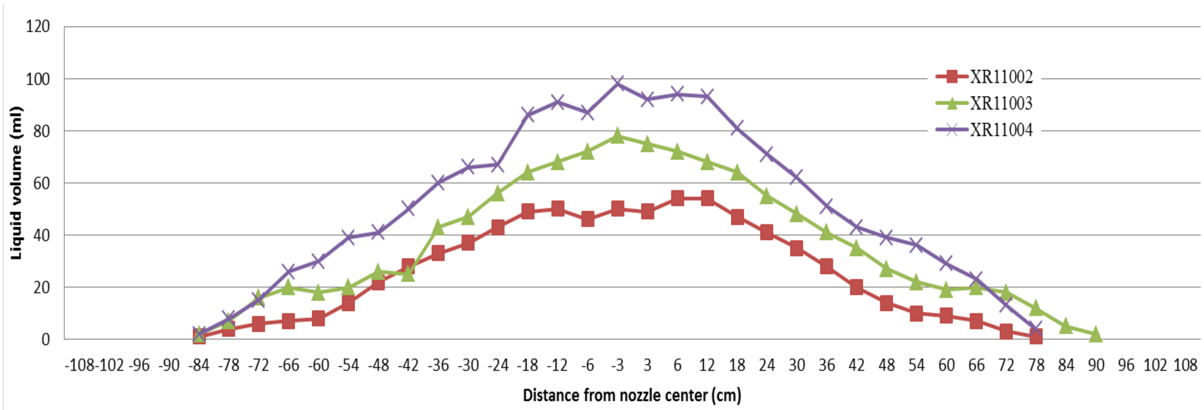

Fig. 4. Spray volume distribution at of different XR110 nozzle sizes 02, 03 and 04 and at operating pressure 3bar and at nozzle height 0.50m

3.5 Effect of interaction of nozzle size and operating pressure on spray volume distribution

It is noticed in Figure 5 that the interaction of nozzle size and operating pressure effected on nature of the spray periphery volume. Increasing of the nozzle size and reducing operating pressure at constant nozzle height increase the spray peak under the centre of the nozzle and reduce the spay volume at the two ends of the spray, and in the same time there is similarity in spray volume in the middle of the distance between the nozzle centre and the end of the spray at the two side of spray pattern. Further, increased operating pressure and decreased the nozzle size improve the uniformity of spray by increasing the spray width and reduce the peak of spray volume under the nozzle center, while in figure 6, at the nozzle height of 75cm, when the operating pressure increased from 2 to 3 bar and nozzle size decreased from 04 to 03, spray volume next to the two ends of the spray increased and the spray peak under the nozzle center decreased. And still there is similarity in spray volume in the points in the middle of the distance between the nozzle centre and the end of the spray.

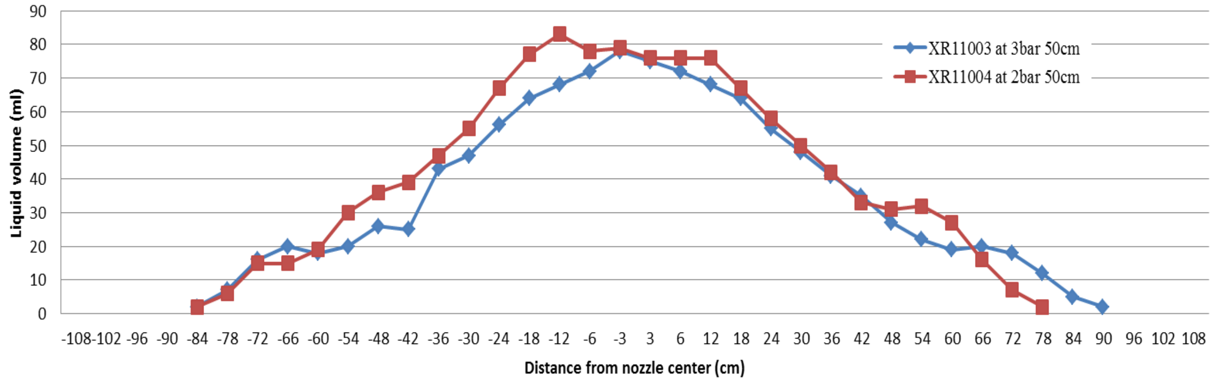

Fig. 5. Spray volume distribution of different XR110 nozzle sizes 03 and 04 and at operating pressures 2 and 3 bar and at nozzle height 0.50 m

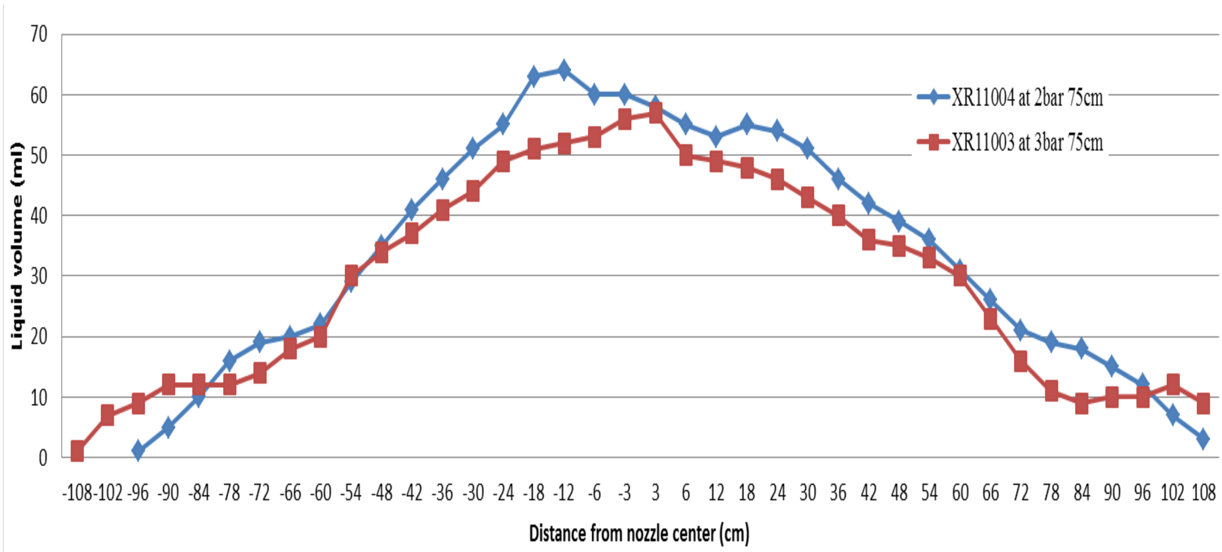

Fig. 6. Spray volume distribution of different XR110 nozzle sizes 03 and 04 at working pressures 2 and 3bar and at nozzle height 0.75 m

3.6 Effect of interaction of nozzle size, pressure and height on spray distribution

Generally, the best way to control the uniformity of spray patterns is by interaction operation variables (nozzle size, height and pressure) to gather. Figure 7 and Figure 8 show that similarity in spray patterns can be achieved along the spray periphery although of changing operating variables.

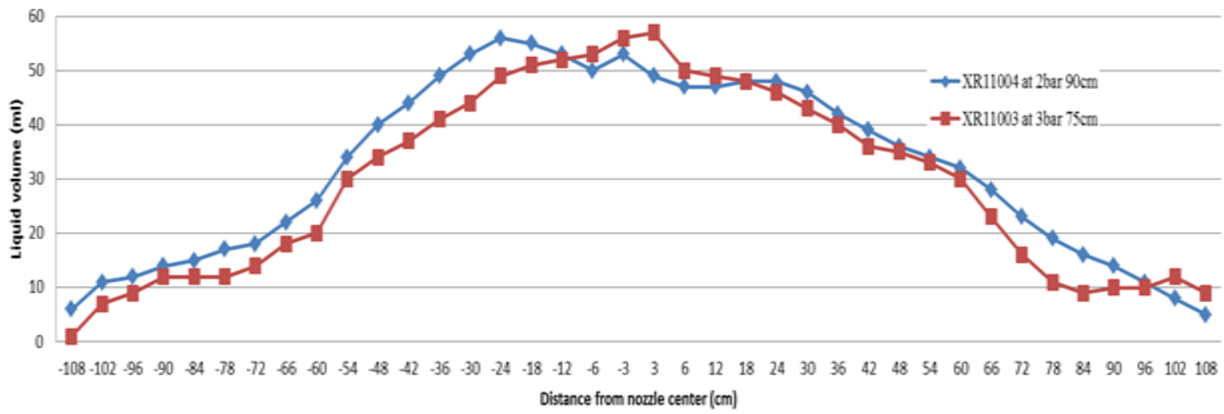

Fig. 7. Spray volume distribution of different XR110 nozzle sizes 03 and 04 at operating pressures 2 and 3bar and at nozzle heights 0.75 and 0.90 m

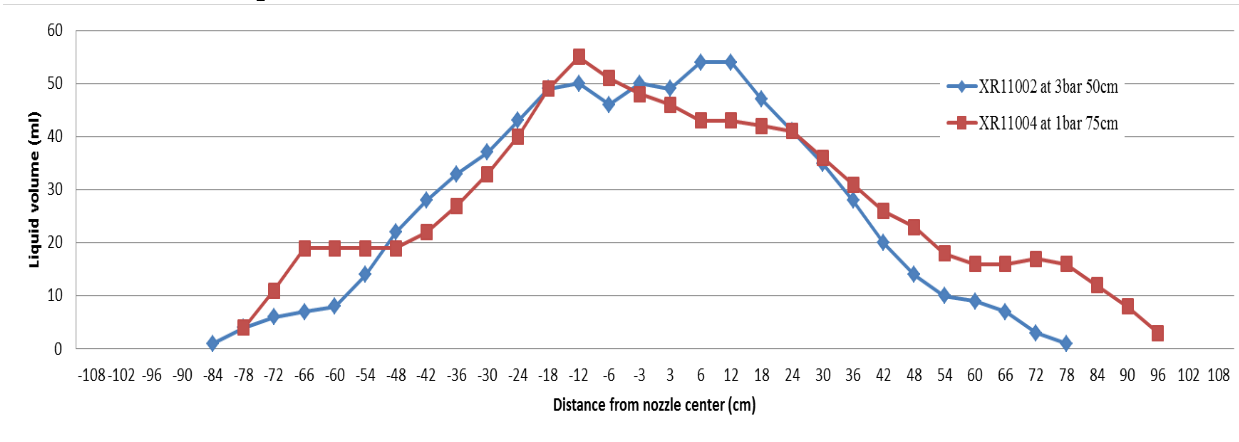

Fig. 8. Spray volume distribution of different XR110 nozzle sizes 02and 04 at operating pressures1 and 3 bar and at nozzle heights 0.50 and 0.75m

4. Conclusions

Study of uniformity of spray volume distribution is so important for any successful control. Tests were carried out to evaluate the effect of operating variables: nozzle size, pressure and spray height on transverse spray volume distribution. The results showed that working width of the nozzle could not simply be calculated by using the spray angle given by the manufacturers. Nozzle height and operation pressure significantly influenced working swath while nozzle size has no clear influence working swath. Numerous spray volume distribution patterns can be achieved accurately and rapidly based on the experimental data of controlled operating variables. Spray volume distribution measurements in the laboratory allowed use of the most optimal nozzle size, pressure and height to generate nearly identical spray patterns to the reference nozzle and according to the requirements of the field. The spray volume distribution and the similarity in the shapes of spray patterns can be adjusted by changing operation variables settings. In order to avoid uneven spray volume distribution patterns, selection of operating variable data should be according to the field requirements and needs.

Acknowledgement
We would like to thank members of the aeronautical laboratory of the faculty of mechanical engineering, university technology, Malaysia.

References

[1] Hofman, Vern, and Elton Solseng. "Spray equipment and calibration." (2004).
[2] Andersen, P. G., and M. K. Jørgensen. "Calibration of sprayers." (2010): 143-152.
[3] Butts, Thomas R., Joe D. Luck, Bradley K. Fritz, W. Clint Hoffmann, and Greg R. Kruger. "Evaluation of spray pattern uniformity using three unique analyses as impacted by nozzle, pressure, and pulse-width modulation duty cycle." *Pest Management Science* 75, no. 7 (2019): 1875-1886. https://doi.org/10.1002/ps.5352
[4] Negrisoli, Matheus Mereb, Diego Miranda de Souza, Danilo Morilha Rodrigues, Patrick Julio de Jesus, and Carlos Gilberto Raetano. "Effect of angled spray nozzle designs on spray distribution and droplet spectrum." *Revista Ciência Agronômica* 52 (2021): e20197043. https://doi.org/10.5935/1806-6690.20210029
[5] Guler, Huseyin, Heping Zhu, H. Erdal Ozkan, and Peter Ling. "Characterization of hydraulic nozzles for droplet size and spray coverage." *Atomization and Sprays* 22, no. 8 (2012).
[6] Arvidsson, Tommy, Lars Bergström, and Jenny Kreuger. "Spray drift as influenced by meteorological and technical factors." *Pest management science* 67, no. 5 (2011): 586-598. https://doi.org/10.1002/ps.2114
[7] Miller, P. C. H., Mc Butler Ellis, A. G. Lane, C. M. O'sullivan, And C. R. Tuck. "Methods for minimising drift and off-target exposure from boom sprayer applications." (2011): 281-288.
[8] Sanchavat, H. B., H. S. Chaudhary, G. Bhautik, and S. N. Singh. "Field evaluation of a tractor mounted boom sprayer." *Agricultural Engineering Today* 41, no. 4 (2017): 67-71.
[9] Hassen, Nasir Salim, and Nor Azwadi Che Sidik. "Laboratory investigation of nozzle type, size and pressure effects on spray distribution." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 61, no. 1 (2019): 140-146.
[10] Abd Kharim, Muhammad Nurfaiz, Seri Intan Mokhtar, Fatimah Kayat, Ikarastika Rahayu Abdul Wahab, Raimi Mohamed Redwan, Mohd Mahmud, Syed Muhammad Al Amsyar et al. "Agrotechnology Students' Acceptance on Agriculture Drones Spraying as Practical Tool in Class using the Knowledge, Attitude and Practice (KAP) Model." *International Journal of Advanced Research in Food Science and Agriculture Technology* 1, no. 1 (2024): 31-44.
[11] Martin, Daniel E., Wayne E. Woldt, and Mohamed A. Latheef. "Effect of application height and ground speed on spray pattern and droplet spectra from remotely piloted aerial application systems." *Drones* 3, no. 4 (2019): 83. https://doi.org/10.3390/drones3040083
[12] Višacki, Vladimir V., Aleksandar D. Sedlar, Emilio Gil, Rajko M. Bugarin, Jan J. Turan, Todor V. Janic, and Patrik Burg. "Effects of sprayer boom height and operating pressure on the spray uniformity and distribution model development." *Applied Engineering in Agriculture* 32, no. 3 (2016): 341-346. https://doi.org/10.13031/aea.32.11376
[13] Sumner, Paul E. "Sprayer nozzle selection." (2009).
[14] Balsari, Paolo, Emilio Gil, Paolo Marucco, Jan C. van de Zande, David Nuyttens, Andreas Herbst, and Montserrat Gallart. "Field-crop-sprayer potential drift measured using test bench: Effects of boom height and nozzle type." *Biosystems engineering* 154 (2017): 3-13. https://doi.org/10.1016/j.biosystemseng.2016.10.015
[15] Choudhary, Mukesh Kumar, Mohit Kumar, Gopal Carpenter, Annu Rani, Malkhan Singh Jatav, and E. V. Thomas. "Investigation of Nozzle Characteristics for a Hollow Cone Nozzle in Spray Patternator." In *Biological Forum–An International Journal*, vol. 15, no. 1, pp. 638-642. 2023.
[16] TeeJet Technologies. "TeeJet® catalog 50A-M." (2015).
[17] Grisso, Robert D., Shawn D. Askew, and David S. McCall. "Nozzles: selection and sizing." (2019). https://doi.org/10.21061/442-032_BSE-262P
[18] Kluza, Paweł A., Izabela Kuna-Broniowska, and Stanisław Parafiniuk. "Modeling and prediction of the uniformity of spray liquid coverage from flat fan spray nozzles." *Sustainability* 11, no. 23 (2019): 6716. https://doi.org/10.3390/su11236716

[19] Guler, H., Heping Zhu, H. Erdal Ozkan, R. C. Derksen, Y. Yu, and C. R. Krause. "Spray characteristics and drift reduction potential with air induction and conventional flat-fan nozzles." *Transactions of the ASABE* 50, no. 3 (2007): 745-754. https://doi.org/10.13031/2013.23129

[20] Lebeau, Frédéric, E. Hamza, and Marie-France Destain. "Automation of a patternator to measure liquid distribution of nozzles." (2000): 505-509.

[21] Sidahmed, M. M., H. H. Awadalla, and M. A. Haidar. "Symmetrical multi-foil shields for reducing spray drift." *Biosystems Engineering* 88, no. 3 (2004): 305-312. https://doi.org/10.1016/j.biosystemseng.2004.04.006

[22] Vasquez-Castro, Javier A., Gilberto C. De Baptista, CASIMIRO D. GADANHA, and Luiz RP Trevizan. "Effectiveness of the standard evaluation method for hydraulic nozzles employed in stored grain protection trials." *Revista Colombiana de Entomología* 34, no. 2 (2008): 182-187. https://doi.org/10.25100/socolen.v34i2.9285

[23] Douzals, Jean–Paul, Antoine Porte, and Pierre Fernandez. "Simulating CoV from nozzles spray distribution: a necessity to investigate spray distribution quality with drift reducing surfactants." In *CIGR-AgEng2012*, pp. 6-p. CIGR-AgEng, 2012.

[24] Daggupati, Naga Prasad. "Assessment of the varitarget nozzle for variable rate application of liquid crop protection products." PhD diss., Kansas State University, 2007.

[25] Padhee, D., S. Verma, S. S. Rajwade, H. Ekka, S. K. Chandniha, and S. K. Tiwari. "Evaluating the effect of nozzle type, nozzle height and operating pressure on spraying performance using a horizontal spray patternator." *Journal of Pharmacognosy and Phytochemistry* 8, no. 4 (2019): 2137-2141.