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Investigation of Nozzle Characteristics for a Hollow Cone Nozzle in Spray Patternator

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ABSTRACT: There is evidence that weeds and pest combinedly can decrease crop production by 33% if left untreated. Chemical application is the most effective and efficient method to overcome this issue. The current practice preferred by the farmers leads to excessive application of the chemical to the crop to reduce the loss of production. The excessive application of chemical affects the human health, environment, soil and it also increase the cost of cultivation. Therefore, selection of right nozzle is crucial for ensuring effective and efficient spray application with minimum ill effects. Hollow cone nozzles are widely used in spray applications, and it is important to understand the operational parameters of these nozzles to optimize their design and performance. In this study, the effect of different nozzle pressure (215.74, 245.17, 274.59, 304.01 and 333.45 kPa) and orifice diameters (1, 1.3, 1.6 and 2 mm) on the discharge rate, spray angle, and spray distribution of hollow cone nozzles was investigated using a spray patternator. The nozzle pressure and orifice size had a significant effect on the discharge rate, spray angle. The discharge rate and spray angle varied from 536 to 1500 ml/min and 52 to 90° with variation in pressure and orifices diameter for selected range of variables. The spray pattern of the nozzle at all four orifices diameters was also studied. The study could help in determining the optimum orifice diameter and nozzle pressure for required discharge rate and spray angle.

Keywords: Spray discharge, Spray distribution, Hollow cone nozzle, Nozzle orifice size.

INTRODUCTION

Spraying is a crucial practice in agriculture that involves the application of liquids such as water, pesticides, herbicides, and chemicals to crops. It plays a vital role in promoting the growth and health of crops, controlling pests and diseases, and increasing yields (Srivastava *et al.,* 1993). The application of these liquids through a spray nozzle is an essential part of the spraying process. The nozzle's design, pressure, and other operational parameters determine the efficiency and effectiveness of the spray application (Shirwal *et al.,* 2020). The hollow cone nozzle consists of a circular orifice with a conical shape, which creates a cone-shaped spray pattern. The design of the hollow cone nozzle allows a large coverage area and efficient use of the spray liquid, making it a popular choice for spray application in agriculture. On all the hydraulic nozzles, the pressure of liquid at the orifice affect the flow rate, spray angle and the droplet spectra produced. Nozzle height above the target influence the distribution pattern. It is important to define nozzle performance because of its ultimate effect on the efficiency of the pesticide application process (Miller and Ellis 2000). The characteristics of each nozzle type vary, and they are intended for various purposes. Choosing a nozzle that matches the desired spray pattern and other spray characteristics typically leads to successful outcomes (Lipp, 2012). In agriculture irrigation, the spraying performance of a sprinkler is mainly influenced by the structure of the nozzle (Li *et al.,* 1994) operating pressure (Cerruto *et al.,* 2021) and environmental conditions. The orifice shape of the nozzle has a significant influence on the characteristics of water droplets (Nuyttens *et al.,* 2007). Other important spray characteristics influencing the efficacy of spray particle is spray angle, spray shape and volume distribution pattern (Minov *et al.,* 2014). Therefore, the study of nozzle characteristics is of prime importance in order to reduce the excessive chemical spraying and increase in the efficiency of the spraying system. Considering the aforementioned discussions, an effort was made to assess the spray characteristics of different orifice diameter nozzles in agricultural sprayers that produce a horizontal spray pattern. This could aid in selecting the appropriate nozzle for protecting any agricultural crop.

MATERIALS AND METHODS

This study was conducted at Farm Machinery Laboratory of Agricultural and Food Engineering Department, IIT Kharagpur. One commercially available hydraulic hollow cone nozzle (Fig. 1) with four different orifice diameters (1, 1.3, 1.6 and 2 mm) (Fig. 2) were used for this study and operational parameters (Discharge rate, spray angle and spray distribution) were measured at different pressure *viz.* 215.74, 245.17, 274.59, 304.01 and 333.45 kPa. Each treatment was replicated thrice.

Fig. 1. Hollow Cone Nozzle.

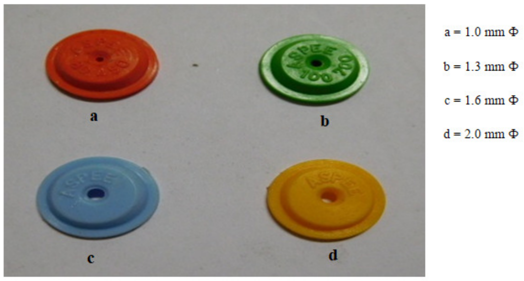

Fig. 2. Orifice discs used for test.

Discharge rate (ml/min). The experiment of estimation of discharge rate (ml/min) was conducted on horizontal spray patternator (Fig. 3) available at Farm Machinery Laboratory. The spray patternator base has channel slots. The total width of the patternator was 165 cm and length were 140 cm. the discharge collecting mechanism has 66 graduated test tubes of 20 ml capacity. The boom height is adjustable from 45 cm to 100 cm. and two nozzles can be tested at a time (Poudel, 2009). The selected all four orifice sizes with nozzle were tested using water as spray liquid. The discharge rate of the selected orifice size with nozzle (A, B, C and D) were tested for different pressure i.e. 215.74, 245.17, 274.59, 304.01 and 333.45 kPa with four replications. To measure discharge rate at different pressure, range the discharge of liquid was collected in a 500 ml capacity measuring cylinder over a given interval of 1 minute.

Spray angle (Degree). Spray angle was measured using a simple two leg protractorat spray patternator. It was measured for different pressures (215.74, 245.17, 274.59, 304.01 and 333.45 kPa) and orifice diameter nozzle and replicated thrice.

Spray distribution. Spray distribution was also measured at different pressures (215.74, 245.17, 274.59, 304.01 and 333.45 kPa) for each orifice size nozzle and replicated thrice. In order to determine spray distribution of a spray nozzle collection tubes was used to collect spray volume. Spray volume was measured and spray distribution curve of each nozzle was plotted.

Fig. 3. Horizonal Spray Patternator.

RESULTS AND DISCUSSION

The results of the experiments on the effect of nozzle pressure and orifice size on discharge rate, spray angle, and spray distribution analyzed using full factorial method and the comparison of the means of each level was compared using tukey's (b) method. The statistical analysis was performed in Design expert-13 and SPSS software.

Discharge rate. The statistical analysis indicated that the both the parameters *i.e.,* nozzle pressure and orifice size had significant effect on the discharge rate at 1% level of significance (Table 1). It was also found that the interaction of the nozzle pressure and orifice diameter was also significant. The Table 2 indicates that the all the five pressure levels are significantly different at 5% level of significance. The means of the four orifices diameters are also significant with each other.

Table 1: ANOVA for effect of pressure and orifice diameter on discharge rate and spray angler.

	Discharge rate		Spray angle	
Source	**F-value**	**Significance**	**F-value**	**Significance**
Pressure	72963.600	.0001**	199.725	.0001**
Orifice diameter	1723797.600	.0001**	2449.800	.0001**
Pressure × Orifice diameter	2331.600	.0001**	.925	.532NS

** indicates significant at 1% level of significance

Table 2: Interaction effect of nozzle pressure and orifice size on discharge rate.

Orifice Size	**Nozzle Pressure**				
	215.74 kPa	**245.17 kPa**	**274.59 kPa**	**304.01 kPa**	**333.45 kPa**
A	536.00^{Aa}	564.00^{Ab}	588.00^{Ac}	620.00^{Ad}	644.00^{Ae}
B	820.00^{Ba}	880.00^{Bb}	920.00^{Bc}	960.00^{Bd}	1000.00^{Be}
C	1060.00^{Cc}	1120.00^{Cb}	1180.00^{Cc}	1240.00^{Cd}	1300.00^{Ce}
D	1240.00^{Dd}	1300.00^{Db}	1380.00^{Dc}	1440.00^{Dd}	1500.00^{De}

**Uppercase subscript represents orifice size and lowercase subscript denotes pressure, numerical in superscript having same alphabetic superscripts are statistically similar

It was observed that both discharge rate followed an increasing trend with the increase in pressure and orifice size (Fig. 4).

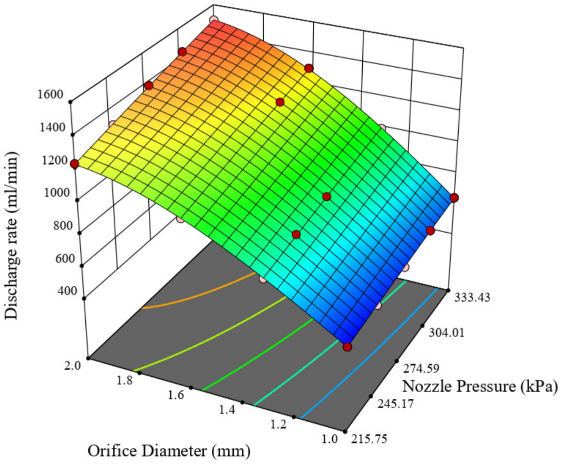

Fig. 4. Effect of pressure and orifice diameter on discharge rate.

The effect of orifice size was more compared to the nozzle pressure. As pressure increased 10% the discharge rate was increased 4.65, 4.59, 5.00 and 4.88% for orifice A, B, C and D respectively. Whereas, as orifice diameter increased from 1 to 2 mm the discharge rate increased by 33.08, 33.12, 33.89, 33.37 and 33.55% at the operating pressures 215.74, 245.17, 274.59, 304.01 and 333.45 kPa respectively. The effect of orifice diameter was higher on the discharge rate due to increase in the cross-sectional area of the passage for the liquid. Similar results were reported by Li and Wang (2017); Chen *et al.,* 2022).

Spray angle. It was observed that pressure and orifice size of nozzle had significant effect on the spray angle at 1% level of significance. The interaction of the orifice and pressure on spray angle was non-significant at 5% level of significance (Table 1). However, the tukey's(b) analysis showed that spray angle at all the pressure level are significantly different with each other (Table 3).

It was observed that as pressure and orifice size of nozzle increased the spray angle of nozzle also increased. When the orifice size was increased the whirl velocity of liquid also increased. Therefore, the spray angle increased due to increase in velocity of liquid coming out of the nozzle. Increase in spray angle was more with increase in the orifice size than pressure. As pressure increased 10% the spray angle increased 4.32, 4.42, 3 and 2.89% for orifice A, B, C and D respectively. As the orifice diameter increased from 1 to 2 mm the spray angle increased by 15.68, 14.85, 14.81, 13.71 and 13.31% at the operating pressure 215.74, 245.17, 274.59, 304.01 and 333.45 kPa respectively. Similar findings were confirmed by Dafsari *et al.* (2020); Penaloza *et al.* (2016).

Table 3: Mean value of spray angle (degree) affected by pressure and orifice diameter.

Pressure	**P1**	**P2**	**P3**	**P4**	**P5**
Mean Comparison of pressures	66.75^{a}	69.50^{b}	72.50^{c}	74.75^{d}	77.00^{e}
Orifice	**A**	**B**	**C**	**D**	
Mean Comparison of orifice diameter	57.20^{A}	66.20^{B}	79.60^{C}	85.40^{D}	

**Uppercase subscript represents orifice size and lowercase subscript denotes pressure, numerical in superscript having same alphabetic superscripts are statistically similar

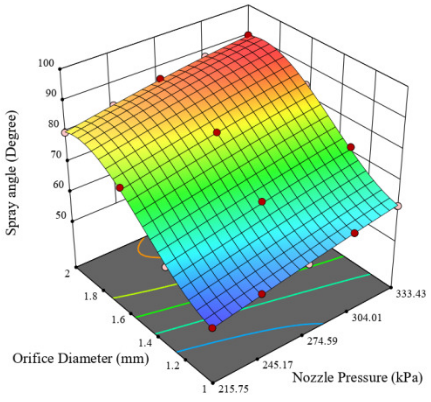

Fig. 5. Effect of pressure and orifice diameter on spray angle.

Effect of Pressure and Orifice size on spray distribution. The nozzle with different orifice diameter were tested for spray distribution pattern. The test was carried out as per the IS 10064: (1982). The collection period of spray volume was 15 sec, boom height was 50 cm and pressure were varied from 215.75 to 333.43 kPa. Fig. 6 showed spray pattern of hollow cone nozzles having different orifice size from 1 mm to 2 mm. It was found that as orifice size was increased from 1 mm to 2 mm the swath of spray increased from 65 to 106 cm. This might be due to increase in whirl velocity with increase in orifice size and pressure. The distribution of spray was almost uniform in both side of nozzle from the centre for nozzle A, B and C. However, it was observed that spray volume was more in the left side for orifice D (Fig. 6). It may be due to more drift in orifice D as it has largest diameter. Similar results were reported by Sun *et al.* (2018); Chen *et al.* (2022) for spray distribution on full-cone pressure swirl atomizers.

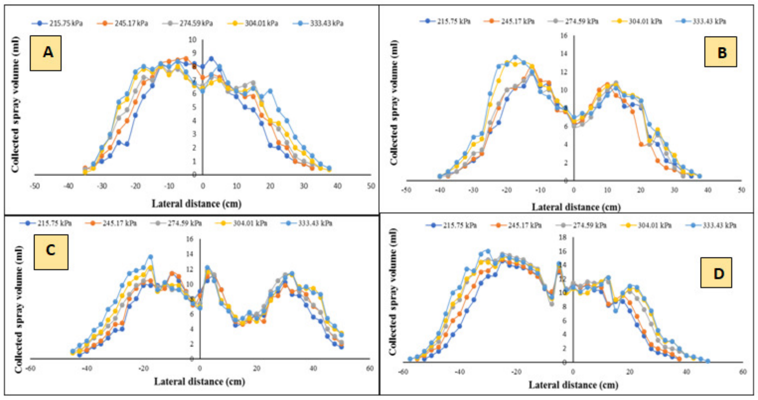

Fig. 6. Spray distribution pattern of hollow cone nozzle at different pressure and orifice; (A) Orifice A, (B) Orifice B, (C) Orifice C and (D) Orifice D.

CONCLUSIONS

The hollow cone nozzles were evaluated for different combination of pressure and orifice diameter. The result indicated that the orifice diameter and pressure of nozzle affect the operational parameters such as discharge rate, spray angle and spray distribution. As pressure and orifice diameter increases the discharge rate, spray angle and spray swath of liquid spray also increased. The increment in the orifice diameter is more effective to get more discharge rate than pressure. The effect of orifice size of nozzle and pressure on spray distribution showed that there is a direct relationship between the orifice size and the spray distribution. An increase in orifice size resulted in a wider spray distribution, while a decrease in orifice size resulted in a narrower spray distribution. Furthermore, the experiments also showed that an increase in pressure resulted in a narrower spray distribution, while a decrease in pressure resulted in a wider spray distribution. These findings are important for the design and optimization of spray systems used in various applications such as agriculture, industrial processes, and fire suppression. In order to achieve a desired spray distribution, it is crucial to carefully consider the size of the nozzle orifice and the pressure used in the spray system.

FUTURE SCOPE

The study further can be performed to test different type of nozzle such as flat fan, solid cone etc. The drift losses can also be assessed at varying nozzle height.

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Conflict of Interest. None.

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