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Spray droplet characteristics of agricultural hollow cone nozzles

Himanshu Tripathi, PM D'Souza and Ashok Tripathi

Himanshu Tripathi
PhD Scholar, Department of Farm Machinery & Power Engineering, Vaugh Institute of Agricultural Engineering & Technology, Sam Higginbottom University of Agriculture, Technology and Sciences, Uttar Pradesh, India

PM D'Souza
Department of Farm Machinery & Power Engineering, Vaugh Institute of Agricultural Engineering & Technology, Sam Higginbottom University of Agriculture, Technology and Sciences, Uttar Pradesh, India

Ashok Tripathi
Department of Farm Machinery & Power Engineering, Vaugh Institute of Agricultural Engineering & Technology, Sam Higginbottom University of Agriculture, Technology and Sciences, Uttar Pradesh, India

Corresponding Author:
Himanshu Tripathi
PhD Scholar, Department of Farm Machinery & Power Engineering, Vaugh Institute of Agricultural Engineering & Technology, Sam Higginbottom University of Agriculture, Technology and Sciences, Uttar Pradesh, India

Abstract
The size of droplet affects the plant surface coverage, uniformity and most importantly drift of spraying material from target plant area. The droplet size ranging 140 to 200 µm diameter are recommended for best control of pest in crops. Droplet size less than 140 µm have very much drift and more than 200 µm does not perform well for controlling pest. A study was conducted in plant protection laboratory of ICAR-Central Institute of Agricultural Engineering, Bhopal. The three commercially available hollow cone nozzles i.e. N1, N2 and N3 having orifice diameter of 2.4, 3.5 and 4.7 mm respectively, were tested at predefined spray pressure levels of 0.2, 0.3, 0.4 and 0.5 MPa. The result shows the spray droplet size is higher (309.4 µm) at pressure level 0.2 MPa while the smallest droplet size of 147.3 µm was observed at pressure level 0.5 MPa. The maximum relative span factor (RSF) of 1.288 was recorded for N2 at spray pressure level of 0.3 MPa while minimum RSF of 0.896 was recorded for N1 at 0.3 MPa. The maximum droplet size percent value of 52.59 was detected for nozzle N1 at 0.4 MPa spray pressure. The interaction of nozzle and pressure shows significant effect on spray droplet size at 1% significance.

Keywords: Spray droplet size, droplet size distribution pattern, Malvern Spraytec system, VMD, relative span factor

Introduction
The performance of agrochemical application system should be defined by droplet size and droplet size distribution of nozzles. For application of herbicides fine droplets may be useful for uniform spray deposition on surface of small target plants. Fine droplets are also used for targeting insects and pests. While for penetrating in the plant canopy coarser droplets are used. In sprayer, to achieve the required accurate droplet size and its correct distribution the main component is nozzle. A wide range of nozzles are commercially available which produces different sizes of droplets. Spray droplet size is the most important parameter which affects the transport ability and penetration of spray. The size of droplet affects the plant surface coverage, uniformity and most importantly drift of spraying material from target plant area (Kepner *et al*., 2000) [6]. The droplet size ranging 140 to 200 µm diameter are recommended for best control of pest in crops. Droplet size less than 140 µm have very much drift and more than 200 µm does not perform well for controlling pest (Smith *et al*., 1975) [9]. Each nozzle has specific characteristics which can be used for specific application. It is necessary to select a nozzle based on spray characteristics and spray pattern for optimised spraying efficiency (Lipp, 2012) [7].
Size of droplet and velocity of droplet affects the arrangement of deposition of spray and also affects the drift ability of droplets (Taylor *et al*., 2004) [10]. The droplet size influences the efficiency of applied chemical also hazards the environment. The combination of pressure and nozzle improves the efficacy of spray deposition and transport the chemical to the target, at the same time reduces the losses due to off targeting i.e. drift of spray and chemical contact to the operator. The efficacy of chemical application influenced by spray characteristics i.e. spray droplet size and distribution (Miller & Butler Ellis, 2000) [8]. There is very much effect of pressure on type, size of nozzle and the spray uniformity (Tripathi and Dsouza, 2020). The nozzle type, size and pressure have the effect on the droplet size and velocity spectra (Nuyttens *et al.* 2007) [7]. Malvern laser diffraction techniques had been developed using laser instrumentation to determine droplet characteristics (Barnett & Matthews, 1992; Butler Ellis & Bradley, 2002) [2, 3]. The Malvern Spraytec laser diffraction system provides a dynamic, quick method for assessing the particle size produced by atomizer, assisting to develop new agrochemical devices and interpretations (Anonymous, 2016) [1].

Materials and methods
This study was conducted in plant protection laboratory of ICAR-Central Institute of Agricultural Engineering, Bhopal.

The three commercially available hollow cone nozzles i.e. N1, N2 and N3 having orifice diameter of 2.4, 3.5 and 4.7 mm respectively, were used for this study. The volume median diameter (VMD or DV0.5), relative span factor (RSF) and droplet size distribution pattern was measured with the Malvern Spraytec system (Fig 1). This system measures spray droplet and particle size distributions produced by nozzle, using the laser diffraction technique. By measuring the scattered light intensity through spray droplets, laser diffraction system calculates droplet size distribution as they pass through a collimated laser beam. The angle at which light scatters by droplets is inversely proportional to their size. This system can detect and precisely measures a wide range of droplet size from 0.1 to 2000 μm i.e. both fine and coarse droplets in single measurement. This system setup for nozzle test comprises a nozzle 1 m above the center of laser sensors. The system was attached with a computer with pre-installed recommended Spraytec standard operating procedure. The standard operating procedure locks all measuring aspects with configured hardware, analysis settings, triggering options, result parameter reporting and data averaging. From the menu system the desired standard operating procedure should be selected to run measurement. The software measurement manager observes at each stage of the measurement. The nozzle was made start spray at predefined different spray pressure levels of 0.2, 0.3, 0.4 and 0.5 MPa before running program and data were recorded in computer. The software calculates droplet size and display the spray droplet size distribution graph.

Fig 1: Malvern Spraytec system setup for nozzle test

Spray droplet size

Volume Median Diameter (VMD or DV0.5)

Volume median diameter (VMD or DV0.5) is expressed as a sample of droplets in a spray divided into two equal parts by volume in which half volume of droplet having smaller diameter than the VMD and another half volume of droplets have larger diameter droplet than VMD. The Spraytec software calculates DV0.5 (VMD) of all the selected three nozzles and data were tabulated.

Relative Span Factor (RSF)

Relative Span Factor (RSF) is dimensionless parameter which indicates the variability or uniformity of droplet size distribution. The Spraytec software calculates DV0.1, DV0.5, and DV0.9 of all the selected three nozzles. Data obtained from was copied and arranged in tabular form for further evaluation. RSF was calculated by using following equation

RSF= (DV0.9 - DV0.1)/DV0.5

Where,

DV0.1- a value where 10 percent of the total volume of liquid sprayed is made up of drops with diameters smaller or equal to this value.

DV0.9- a value where 90 per cent of the total volume of liquid sprayed is made up of drops with diameters smaller or equal to this value.

Droplet size distribution pattern

Droplet size distribution pattern of specific nozzles is categorized based on droplet size of smaller than 140 µm, 140 to 200 µm and larger than 200 µm at predefined pressure level of 0.2, 0.3, 0.4 and 0.5 MPa. Spray droplet size distribution pattern of all selected hollow cone nozzles was measured with the Malvern Spraytec system. The software calculates and displays the spray droplet size distribution graph. The particle size distribution graph which shows relation between particle diameter vs. cumulative volume and volume frequency of the droplets was studied.

Results and discussion

Spray droplet size

Volume Median Diameter (VMD or DV0.5)

The spray droplet size in terms of volume median diameter (VMD) at different spray pressure levels of 0.2, 0.3, 0.4 and 0.5 MPa for hollow cone nozzles was calculated. The result shows the spray droplet size is higher (309.4 µm) at pressure level 0.2 MPa while the smallest droplet size of 147.3 µm was observed at pressure level 0.5 MPa (Fig 2). This is clearly observed that as pressure level was increased from 0.2 to 0.5 MPa there was decrease of 21.78, 19.06 and 22.18 percent was recorded for nozzle N1, N2 and N3 respectively. The continuous decrease of spray droplet size with increase of pressure is recoded for all nozzles (Fig 2). Nozzle N1 sprayed liquid within recommended spray droplet size of 140 to 200 µm for all pressure level.

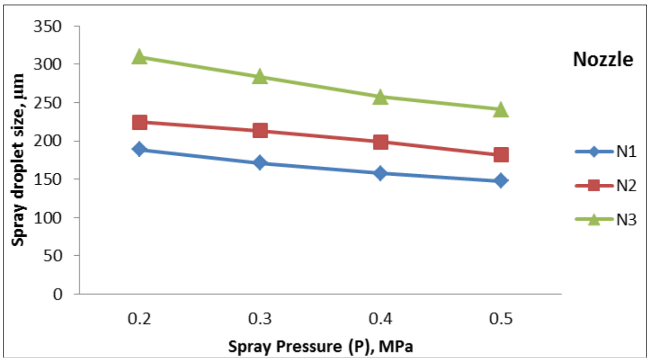

Fig 2: Spray droplet size (VMD) at different pressure level

Relative Span Factor (RSF)

The relative span factor (RSF) of all three hollow cone nozzles at different spray pressure levels of 0.2, 0.3, 0.4 and 0.5 MPa was calculated and provided in Table 1. The maximum RSF of 1.288 was recorded for N2 at spray pressure level of 0.3 MPa while minimum RSF of 0.896 was recorded for N1 at 0.3 MPa (Table 1). In this study the hollow cone nozzles will be optimized on the basis of uniform coefficient of droplet size distribution which can be recognized by relative span factor closer to unity. It is observed that the nozzle N1 revealed a relative span factor of 0.965 at spray pressure of 0.4 MPa which was close to unity (Table 1).

Table 1: Relative span factor (RSF) for different nozzles

S. No.	Spray pressure, MPa	RSF		
		N1	N2	N3
i.	0.2	1.117	1.214	1.139
ii.	0.3	0.896	1.288	1.184
iii.	0.4	0.965	1.210	1.275
iv.	0.5	0.936	1.125	1.145

Spray droplet size distribution pattern

The Malvern Spraytec laser diffraction system generates a graph of the distribution of droplets size over a wide range of values for nozzle. The generated graph for nozzle N1, N2 and N3 are shown in Fig 3. The histograms and a curved line in graph are showing cumulative result of cumulative volume frequency and cumulative volume of the droplet distribution of spray. Bar in graph represents a particle size band i.e. 101 to 110 and the height of bar represents spray percentage within that band. The curve in graph represents the droplets cumulative volume frequency and the percentage of droplets above and below that particular size.

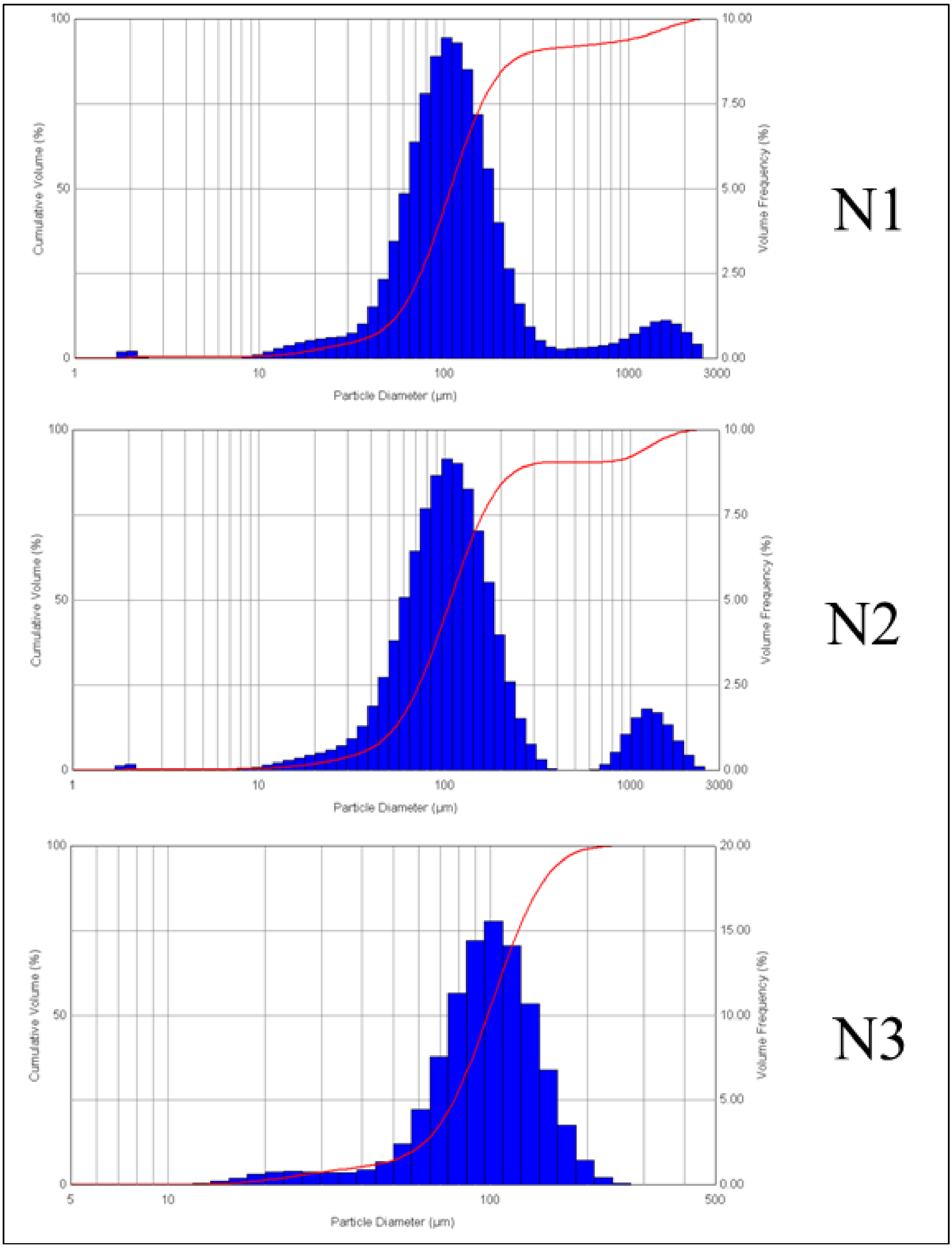

Fig 3: Droplet size distribution histogram graph generated by Spraytec for nozzle N1, N2 and N3

The data observed from Spraytec particle size graph were tabulated. The spray droplet size was classified in three classes less than 140, 140 to 200 and more than 200 µm. The percent value of three classified spray droplet size distribution pattern of hollow cone nozzles at pressure levels of 0.2, 0.3, 0.4 and 0.5 MPa are shown in Fig 4 (a, b, and c). Nozzle N1 shows the maximum percent value for recommended range of pesticide application 140 to 200 µm range at all pressure levels (Fig 4 (a)). The maximum droplet size value of 52.59 percent was identified for nozzle N1 at 0.4 MPa spray pressure. It was observed that as pressure was increasing from 0.2 to 0.5 MPa the percent value of droplet size range of lower than 140 µm was increasing (21.72 to 28.71) and decrease (26.67 to 22.09) in droplet size range of higher than 200 µm was recorded.

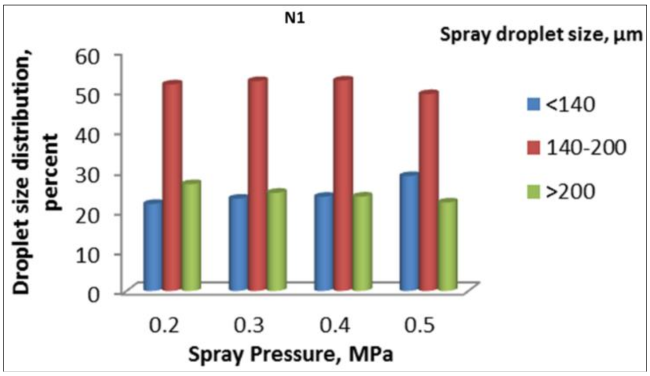

Fig 4(a): Spray pressure effect on droplet size distribution for nozzle N1

Nozzle N2 shows the maximum percent value of 38.93 for the range larger than 200 µm at spray pressure levels 0.2 MPa (Fig 4 (b)). It was observed that as pressure was increasing from 0.2 to 0.5 MPa the percent value of droplet size range of lower than 140 µm was increasing (22.49 to 37.33) and decrease (38.93 to 28.37) in droplet size range of higher than 200 µm was recorded. At spray pressure level 0.4 MPa the minimum value of 33.78 percent was recorded for recommended range of 140 to 200 µm. For range of 140 to 200 µm, from pressure level of 0.2 to 0.3 MPa the percent value was decreased from 38.57 to 36.69 and at 0.5 MPa it was observed 34.31 percent.

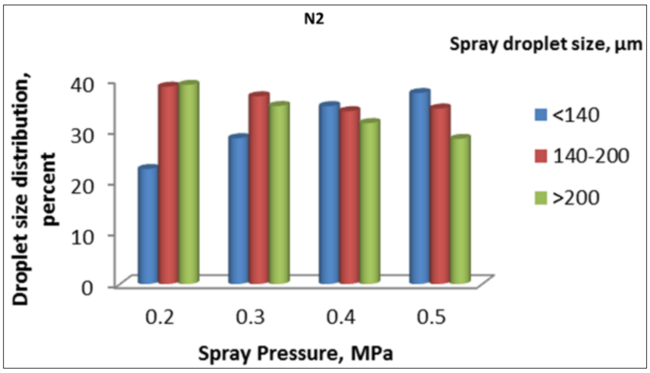

Fig 4(b): Spray pressure effect on droplet size distribution for nozzle N2

Nozzle N3 shows the maximum percent value of 39.90 for the range larger than 200 µm at spray pressure levels 0.2 MPa (Fig 4 (c)). It was seen that as pressure increases from 0.2 to 0.5 MPa the increase in the percent value of droplet size range of lower than 140 µm was observed from 21.94 to 32.41 respectively. While decrease from 38.16 to 33.01 was observed for droplet size range of 140 to 200 µm from 0.2 to 0.4 MPa respectively, and at pressure 0.5 MPa spray droplet size percent value was quite higher of 33.87. In droplet size range of higher than 200 µm the percent value was 39.90, 35.91, 37.99 and 33.73 for pressure level 0.2, 0.3, 0.4 and 0.5 MPa respectively.

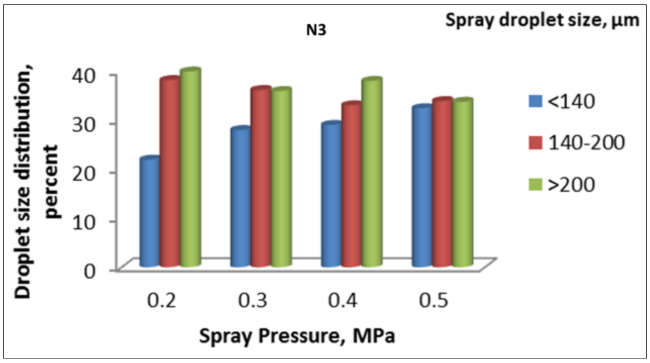

Fig 4 (c): Spray pressure effect on droplet size distribution for nozzle N3

The statistical analysis of variance (ANOVA) was performed to know the significant effect of pressure and nozzle (Table 2). It is seen from Table 2 that nozzle have significant (*P*<0.01) effect on spray droplet size. Pressure also shows significant (*P*<0.01) effect for spray droplet size. The interaction of nozzle and pressure shows significant effect on spray droplet size at 1% significance (Table 2).

Table 2: ANOVA Analysis for spray droplet size

Source	DF	Sum of Square	Mean of Square	F-Ratio	p-Value	Significant
Replication	2	8.8617	4.43	0.19	0.8362	NS
Nozzle	2	70170.07	35085.04	1481.92	<.0001	**
Error(Nozzle)	4	94.70	23.68	.	.	
Pressure	3	13130.11	4376.71	140.03	<.0001	**
Nozzle*Pressure	6	966.80	161.13	5.16	0.0030	**
Error(Pressure)	18	562.58	31.25	.	.	
Total	35	84933.13	.	.	.	

** - Significant at 1%, * - Significant at 5%, NS - Non Significant

Nozzle N1 sprayed liquid within recommended spray droplet size of 140 to 200 µm for all pressure level. It is observed that the nozzle N1 revealed a relative span factor of 0.965 at spray pressure of 0.4 MPa which was close to unity. The percent value of total droplet size for the recommended range of 140 - 200 µm was higher only for nozzle N1 as compared other nozzles for all selected pressure level. It is also observed that except N1 all other nozzles were having variability in droplet distribution for recommended range of droplet size. The maximum percent value of total droplet size of 52.59 was detected for nozzle N1 at 0.4 MPa spray pressure. The interaction of nozzle and pressure shows significant effect on spray droplet size at 1% significance.

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