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Droplet spectrum of spray from nozzles of a wheel operated boom sprayer used in agriculture

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ABSTRACT: The aim of the study was to evaluate the droplet spectrum of commonly used agricultural nozzles i.e., Flat fan, Hollow cone and Flood jet nozzle with the change in height of spraying and number of nozzles on the boom of awheel operated boom sprayer. The experimental study was carried out using water sensitive papers (WSP) laid on the ground in line to the sprayer nozzle. The droplet spectrum parameters like number of droplets, droplet diameter, $DV_{0.1}$, $DV_{0.5}$ and $DV_{0.9}$ were measured using mobile based software namely Dropleaf. The software captured the stained image of the water sensitive paper after spraying operation using water was completed. The study revealed that the height of spraying and number of nozzles on a boom have a significant effect on droplet spectrum. The droplet diameter increases with the corresponding decrease in the number of the droplets by increasing the height of spraying. The span factor was found to be ideal at the maximum height and among the nozzles the flood jet was better in terms of uniformity of the spray.

Keywords: Spray spectrum, Droplet diameter, VMD, $DV_{0.1}$, $DV_{0.9,}$ Span factor Water sensitive paper,

INTRODUCTION

Pesticides play a crucial role in agricultural development by decreasing the losses of agricultural products and increasing the affordable yield and quality of the food. The spraying of pesticides is usually done using a pump attached with the nozzle so to use the pressure energy for converting fluid into fine droplets (Beyaz *et al*., 2017). Nozzle is the most critical component for the application of the pesticide and directly controls by breaking the liquid into fine droplets to form the suitable spray pattern. The size of the spray droplets formed by the nozzles is crucial because it affects the efficacy of the application of an herbicide, insecticide, or fungicide (Bari *et al.,* 2019). The droplet size is a measure of atomization efficiency and a guide for nozzle design and selection. The studies have revealed that if the droplet size is not optimum the problems like waste loss or drift and inefficacy occurs. Only when the droplet size is in the optimal range, the target crop can capture the droplets and the best control effects can be achieved.

MATERIALS AND METHODS

The present study was carried out using a wheel operated boom sprayer developed at Sher-e-Kashmir University of Agricultural Sciences and Technology of Jammu (Zaffar, 2020). The droplet spectrum of three commonly used agriculture nozzles namely fan type, hollow cone and flood jet nozzle at three types of booms i.e., boom carrying two, three and four nozzles respectively at three heights of spraying (0.4, 0.5 and 0.6 m)

Description of a wheel operated boom sprayer

The wheel operated sprayer consisted of a bicycle wheel of 640 mm diameter attached at the front end of the main frame. On the rear end of the main frame, a sprayer pump is mounted and the sprayer consisted of an eccentric mechanism by which the rotational motion of the front wheel is converted into the reciprocating motion of the pump. The pump is attached with the hose pipe which in turn is connected with the boom carrying nozzles for the spraying operation. The main components of the wheel operated sprayer are main frame, sprayer tank cum pump, boom stand, boom and nozzles (Fig.1)

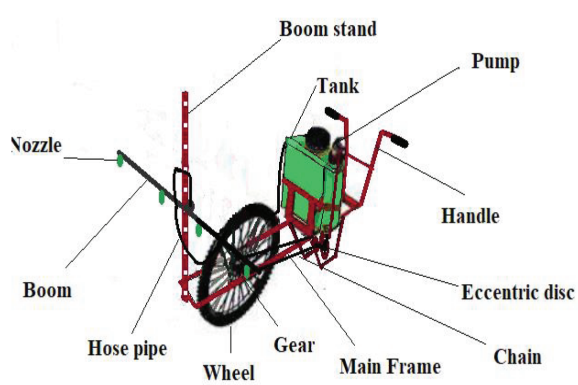

Fig. 1. Various components of a wheel operated boom sprayer

Study area

The study was conducted at Sher-e-Kashmir University of Agricultural Sciences and Technology of Jammu (SKUAST J) on the open flat concreate surface under open atmospheric conditions. The area of the concreate plot was 50 × 50 m^2 in which a straight line of 30 m was marked for straight running of the wheel operated boom sprayer. The surface was also marked with dots where the water sensitive paper's (WSP) were laid on every treatment to find the spectrum of the sprayer from all three types of nozzles.

Experimental Setup

During the experimental study the calibration of the speed for spraying operation was done so to maintain the constant speed of 3.2 km/h in all the treatments assuring that the speed will have constant effect on the spray pattern. The study involved the use of water sensitive papers (WSP) which were laid on the flat surface during spraying operation for all types of the nozzles. A total of 81 trials were performed to determine the droplet spectrum of all three nozzles. All stained WSP's were analysed using mobile software namely Drop leaf and to calculate the droplet characteristics like Number of droplets, droplet diameter, $D_{V0.1}$, $D_{V0.5}$, $D_{V0.9}$ and span factor.

Type of Nozzles

Flat fan nozzle

The flat fan nozzle is used for most of the broadcast spraying of herbicides and for certain insecticides when foliar penetration and coverage are not required. The nozzle has elliptical shaped orifice type in nozzle tip by which the spray pattern is formed. The components of the nozzles are; body, filter, washers, nozzle tip and nozzle head as shown in Fig. 2.

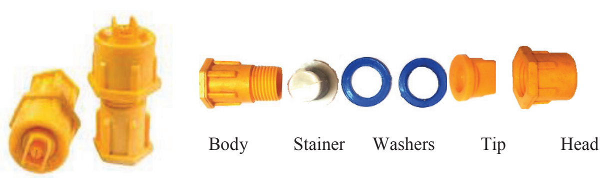

Fig. 2. Components of a nozzle

Hollow cone nozzle

The hollow cone nozzles are primarily used when plant foliage penetration is essential for effective insect or disease control and when drift is not a major concern. The hollow cone contains a whirl chamber inside it which sets the whirl motion to the fluid. The resulting turbulence breaks up the fluid into the droplets which are then shaped into a hollow cone as they exit the orifice. The components of the hollow cone nozzles are; body, whirl chambers, washers and nozzle head as shown in Fig. 3.

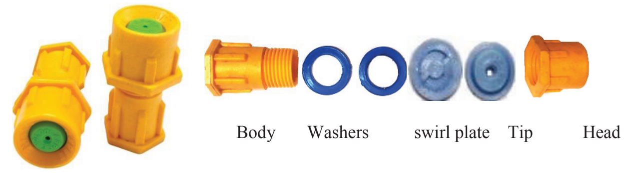

Fig. 3. Hollow cone and its components

Flood jet nozzle

The flood jet nozzles also called solid stream nozzles has a little more than a circular orifice at the end of a funnel. The flood jet nozzles give the highest impact of any spray pattern as the full momentum of liquid is concentrated into a small area. The various component of flood jet are; Body, washer, nozzle tip and head as shown in figure 4.

Fig. 4. Flood jet and its components

Dropleaf

In order to calculate the parameters like droplet diameter, Number of droplets, $D_{V0.1}$, DV0.5 and DV0.9 drop leaf was used which is simply a mobile based software used to measure the quality of pest control spraying machine via image analysis. (Zaffar and Khar, 2022a).

Number of droplets

The number of droplets is the total count of the stained dots on the water sensitive paper after the spraying operation is completed. The number of droplets was calculated using the Drop leaf software.

Droplet diameter

The droplet diameter or droplet size is generally referred to the mean diameter of the droplets present in spray and was measured in microns. The droplet size was measured using Drop leaf software with the help of WSP (Zaffar and Khar, 2022b)

Table 1. Droplet Spectrum of fan type nozzle

Spraying Height (cm)	No. of droplets	Droplet diameter (µm)	$D_{V0.1}$ (µm)	$D_{V0.5}$ (µm)	$D_{V0.9}$ (µm)	Span factor
Boom carrying two fan nozzles (B1)						
40	1693	305.3	92.3	228.2	566.0	2.08
50	1244	367.1	89.5	269.7	777.6	2.55
60	1225	370.6	126.0	283.6	669.2	1.92
Mean	1387	347.6	102.6	260.5	670.9	2.18
Boom carrying three fan nozzles (B2)						
40	1117	375.5	90.20	286.6	768.8	2.37
50	1039	400.2	157.30	271.0	594.5	1.86
60	966	411.0	89.52	288.2	652.3	1.72
Mean	1040	395.5	112.34	281.9	671.8	1.98
Boom carrying four fan nozzles (B3)						
40	1006	402.8	89.50	349.2	1020.7	2.67
50	901	436.8	88.81	210.3	431.4	1.63
60	826	440.7	156.3	300.3	565.9	1.36
Mean	911	426.7	111.5	286.6	627.6	1.88

Table 2. Droplet Spectrum of Hollow cone type nozzles

Spraying Height (cm)	No. of droplets	Droplet diameter (µm)	$D_{V0.1}$ (µm)	$D_{V0.5}$ (µm)	$D_{V0.9}$ (µm)	Span factor
Boom carrying two hollow cone nozzles (B_1)						
40	1406	379.5	90.02	201.1	836.24	3.71
50	1284	393.0	90.32	287.7	782.82	2.41
60	913	469.2	126.30	357.3	927.51	2.24
Mean	1201	413.9	102.60	282.03	848.85	2.79
Boom carrying three hollow cone nozzles (B2)						
40	1354	384.5	127.00	299.8	722.96	1.99
50	1171	391.8	127.20	271.6	683.33	2.05
60	1135	398.8	90.51	271.3	626.13	1.97
Mean	1220	391.7	114.90	280.9	677.47	2.00
Boom carrying four hollow cone nozzles (B3)						
40	1225	494.4	90.15	284.2	1088	3.51
50	863	487.6	89.34	297.7	1053.2	3.24
60	553	537.4	126.80	360.1	1289.2	3.23
Mean	880	506.4	102.09	314.0	1143.4	3.32

$D_{V0.1}$

$D_{V0.1}$ refers to the value where 10 percent of the total volume of liquid sprayed is made up of drops with diameters smaller or equal to this value. In order to reduce the losses due off target spraying or drift the $D_{V0.1}$number should be near or above 200 microns (NSDU, 2017).

Volume mean diameter ($D_{V0.5}$)

The volume median diameter also known as VMD or MVD expresses drop size in terms of the volume of liquid sprayed. The VMD refers to a value where 50 percent of the total volume of liquid sprayed is made up of drops with diameters larger than the median value and 50 percent smaller than the median value.

$D_{V0.9}$

$D_{V0.9}$ refers to the value where 90% of the total volume (or mass) of liquid sprayed is made up of drops with diameters smaller or equal to this value. This diameter is best suited when complete evaporation of the spray is required and used to determine the efficiency of spraying i.e., with large increase in $D_{V0.9}$ value results in poor leaf coverage or droplets lost to non-target areas such as soil (Bari *et al.,* 2019).

Related span factor (RSF)

Relative span factor (RSF) refers to a dimensionless parameter indicative of the uniformity of the drop size distribution. (Bari *et al.,* 2019). The closer this number to one, more uniform the spray will be and is expressed as

$$\textbf{Relative span factor(RSF)} = \frac{\textbf{DV0.9} - \textbf{DV0.1}}{\textbf{DV0.5}}$$

RESULTS AND DISCUSSION

The observations recorded regarding various droplet characteristics are presented below.

Droplet spectrum for fan type nozzle

The results revealed that with the increase in the height of spraying for a boom carrying two fan nozzles the number of droplets decreased and the mean diameter of the droplet increased in correspondence to it (Table 1). The decrease in number of droplets from 0.4 to 0.5 m and 0.5 to 0.6 m was in the range of 26.5% and 1.52%respectively with the corresponding increase in the mean diameter of 20.2 and 1.0% for the increase height of 0.4 to 0.5 and 0.5 to 0.6 m respectively. Similar trends in number of droplets and droplet diameter was observed for the boom carrying three and four nozzles. The decrease in the number of the droplets due to increase in the height of spraying was due to the decrease in the pressure of the individual nozzle. The decrease in pressure results in less atomization of the fluid and less droplets are formed which in turn results in formation of large sized droplets. In case of type of boom i.e., boom carrying two, three and four nozzles the number of droplets decreases with the increase in the number nozzles with the corresponding increasing in droplet diameter at all spraying heights i.e., 0.4, 0.5 and 0.6 m.

The values of $Dv_{0.1}$ on changing height and number of the nozzles in all cases was observed to be less than 200μm (susceptible to spray drift) but changes with respect to the change in height and number of nozzles on the boom. Which implies that the height and the number of nozzles on boom has significant effect. In case of $D_{V0.9}$ no such general trend was observed however the maximum value was obtained at the lowest height of spraying i.e., 0.4 m which implies that spray was distributed unevenly at the height of 0.4 m. The same non-uniformity of spray at the height of 0.4 m was supported by the estimated span factor which was farthest from the ideal value (1). The span factor or uniformity of spray was observed to be approaching to one with the increase in the height of spraying. The minimum values of span factor i.e., 1.92, 1.72 and 1.36 for boom carrying two, three and four fan type nozzles were obtained at the height of 60 cm.

The $D_{V0.5}$ values of the spray produced by fan type nozzle ranged from 228.3 to 283.6, 286.6 to 288.2 and 300.3 to 349.2μm representing medium spray for all three types boom i.e., boom carrying two, three and four nozzles respectively.

Droplet Spectrum of Hollow Cone Nozzle

The effect on droplet spectrum of a hollow cone nozzles with respect to change in height of spraying and number of the nozzles is given in table 2.

The data related to the droplet spectrum of hollow cone nozzles given in table 3 depicts that with the increase in the height of the spraying the number of droplets decreased with the corresponding increase in the mean diameter of the droplets. The decrease in number of droplets in terms of percentage ranged from 3 to 36 % with the corresponding range in the increase in the mean diameter as 1.5 to 16%. The increase in mean droplet diameter might be due to the merging of droplets with increase in the height of the spraying.

Table 3. Droplet spectrum of flood jet nozzles

Spraying Height (cm)	No. of droplets	Droplet diameter (µm)	$D_{V0.1}$ (µm)	$D_{V0.5}$ (µm)	$D_{V0.9}$ (µm)	Span factor
Boom carrying two flood jet nozzles (B1)						
40	1522	326.56	90.13	221.2	712.2	2.81
50	964	403.1	96.24	236.4	957.9	3.64
60	591	429.04	89.89	353.8	1123.1	2.92
Mean	1025	386.23	92.09	270.47	931.07	3.12
Boom carrying three flood jet nozzles (B2)						
40	1259	411.01	156.40	326.9	813.1	2.01
50	809	434.83	156.00	372.7	895.1	1.98
60	734	461.97	128.10	385.1	896.1	1.99
Mean	934	435.94	146.83	361.57	868.10	1.99
Boom carrying four flood jet nozzles (B3)						
40	607	571.43	202.60	504.2	1213.7	2.01
50	504	647.87	201.40	394.1	828.4	1.59
60	374	704.57	240.40	461.5	913.8	1.46
Mean	495	641.29	214.80	453.27	985.30	1.69

Table 4. Comparison of fan, hollow cone and flood jet nozzles on the basis of droplet spectrum

	FB1	HB1	JB1	FB1	HB1	JB1	FB1	HB1	JB1
Number of droplets	1387	1201	1025	1040	1220	934	911	880	495
Droplet diameter	347.6	413.9	386.2	395.5	391.7	435.9	426.7	506.4	641.3
$D_{V0.1}$	102.6	102.60	92.1	112.3	114.9	146.8	111.5	102.9	214.8
$D_{V0.5}$	260.5	282.03	270.5	281.9	280.9	361.6	286.6	314.0	453.3
$D_{V0.9}$	670.9	848.85	931.0	671.8	677.5	868.1	627.6	1143.4	985.3
Span factor	2.18	2.79	3.12	1.98	2.00	1.99	1.88	3.32	1.69

FB1, FB2, FB3 stands for fan nozzle with boom carrying two, three and four nozzles
HB1, HB2, HB3 stands for hollow cone nozzle with boom carrying two, three and four nozzles
JB1, JB2, JB3 stands for flood jet nozzle with boom carrying two, three and four nozzles

The values of $D_{V0.1}$ ranged from 90.0 to 127.0µm in all treatment combination which implies that ten percent of volume contribution was of size less than 127µm i.e., ten percent of spray volume which are in the form very small spray pattern are susceptible to the spray drift.

The $D_{V0.5}$ values of the spray produced by hollow cone type nozzle ranged from 201.1 to 357.3, 271.3 to 299.8 and 284.2 to 360.1µm representing medium spray for all three types boom i.e., boom carrying two, three and four nozzles respectively.

In terms of $D_{V0.9}$ no such general trend was observed however maximum value was obtained at the higher height of spraying i.e., 60 cm which might be due to increase in the size of droplets with the increase in the height of spraying. The span showed same trend as in case of fan nozzle i.e., The span factor or uniformity of spray was observed to be approaching to one with the increase in the height of spraying.

Droplet Spectrum of Flood Jet Nozzles

The effect on droplet spectrum of a flat fan nozzles with respect to change in height of spraying and number of the nozzles is given in table 3.

The number of droplets decreased significantly with the corresponding increase in mean diameter at the higher height of spraying. The $D_{V0.1}$ value in flood jet nozzle are comparably better than the flat fan and hollow cone nozzle. In case of boom carrying four flood jet nozzles the $D_{V0.1}$ values are higher than 200μm values which clearly depicts the flood jet nozzle have less spray drift. On the basis of $D_{V0.5}$, the values ranged from 221.2 to 461.5μm which lies in the large sized spray category which are mostly uniform in distribution. The span factor in the flood jet nozzle was found to be approaching to one with the increase in the height of spraying and the number of the nozzles on the boom.

Comparison of Agricultural nozzles on the basis of droplet spectrum

On comparing various droplet characteristics (Table 4) for the boom carrying two nozzles, the number of droplets and $D_{V0.1}$was found maximum for fan type nozzle with span factor near to one. The droplet diameter and $D_{V0.5}$ (VMD) was found maximum for hollow cone nozzle with two nozzles. In case of boom carrying three nozzles, the maximum droplet diameter, $D_{V0.1}$, $D_{V0.5}$ was found for flood jet nozzle with span factor of 1.99. Similar results were found for the boom carrying nozzle with the span factor 1.69.

CONCLUSION

As per the results obtained, it can be concluded the height of the spraying has a significant effect on the droplet spectrum of all three types of nozzles. The droplet diameter increases with the increase in the height of the spraying by merging of various droplets due to decrease in the pressure. The droplet diameter in all cases were found maximum in flood jet nozzles with minimum number of the droplets. Also, the span factor in flood jet nozzles was near to ideal value i.e., 1 for flood jet nozzles in all treatment combinations except that in boom carrying two nozzles. The study directs that the flood jet nozzles have an ideal droplet spectrum in terms of drift, uniformity etc. However, the wide range of application of flat fan and hollow cone nozzles like foliar application to the crops cannot be ignored.

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