Studies on effect of electrostatic spraying in orchards

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Abstract: Evaluation of an electrostatic sprayer (Make ESS, USA) was conducted on a pear orchard planted at 2.5 m row spacing and distance between plant to plant was 1.5 m. The water sensitive paper stripes were placed on each test plant at the upper and underside of the leaves at the different heights of the plant. Effect of charging on droplet density, area covered by droplets, volume of spray deposition, uniformity coefficient and droplet size were observed during the evaluation of the electrostatic sprayer and comparison was made between two different types of nozzle i.e. twin and single nozzle. It was found that droplet density on the upper and under sides of leaves by twin nozzle (Charged) was significantly (p = 0.0005) higher than twin nozzle (Uncharged) by 57.53% and 59.60% respectively. Droplet density on the upper and underside of leaves by single nozzle (Charged) was significantly (p = 0.0011) higher than single nozzle (Uncharged) by 58.15% and 54.65% respectively. The maximum droplets, i.e. 45 numbers were of size 44 microns observed for the twin nozzle (Charged). But in case of twin nozzle (Uncharged), the maximum droplets, i.e. only 13 numbers of drops were of 44 microns. Similarly maximum droplets, i.e. 32 numbers were of size 44 microns observed for the single nozzle (Charged) and in case of single nozzle (Uncharged), the maximum droplets, i.e. only 11 numbers of drops were of 44 microns. Area covered by droplets on the upper and under sides of leaves by twin nozzle (Charged) was significantly (p = 0.0017) higher than twin nozzle (Uncharged) by 50.19% and 67.86% respectively. Area covered by droplets on the upper and under sides of leaves by single nozzle (Charged) was significantly (p = 0.0007) higher than single nozzle (Uncharged) by 45.07% and 67.53% respectively. Volume of spray deposition on the upper and underside of leaves by twin nozzle was not significantly different from single nozzle. Overall results showed that charging of nozzles has increased spraying efficiency significantly than the spraying done by uncharged nozzles for orchards.

Keywords: Electrostatic spraying, droplet density, volume of spray deposition, uniformity coefficient

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1 Introduction

Protection of field crops, and orchards, is critically important for ensuring safe cultivation. While relatively effective, chemical pesticides add over $25 billion annually to the World's crop-production costs; and with over 2.25 billion kilograms of active ingredients annually dispensed into our ecosystem, environmental monitoring groups have implicated them as being among the top ecological and human health risks Worldwide (Law, 2001).

In India total area under orchard crops was 6.4 million hectares in 2010 and in the same year there was 0.06 million hectares area under orchard crop in the Punjab state alone (Anonymous, 2012). Protection of orchards is critically important for ensuring safe cultivation. There have been many approaches to reduce the amount of pesticide applied in agricultural spray. Small-scale farmers usually apply dilute pesticide solution using a knapsack sprayer with hydraulic nozzles of different shape. By using this sprayer spray distribution is poor (Heijne, 1980) and labour costs are high along with several disadvantages. These are inefficient in

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depositing pesticides onto target-plant surfaces, often resulting in up to 60%-70% off-target losses (Zhou and He, 2010). It is imperative to improve not only the droplet-deposition efficiency, but also the spatial distribution of deposited droplets throughout the plant canopy- especially under leaves where pests preferentially reside. There are many types of pesticide application machines for decreasing of the pesticide drift and increasing deposition of it, electrostatic sprayer one of them.

Electrostatic spraying is a new technology which generally used for the wider leaf crops, orchards and green houses. Thus, strong rationale exists for incorporating the unique benefits of electrostatic forces to attract and deposit pesticide particulates evenly onto plant surfaces where the conventionally used gravitational and inertial forces are ineffective. The application of chemicals through electrostatic sprayer is being claimed to be simple, safer, and easy to use without any material loss with increasing the deposition level of spray (Elmoursi, 1992). More of the material is attracted to and adheres to the target, and less material is lost in the surrounding environment. Charged sprays also increased spray depositional efficiency (Babu et al., 1990). Spray atomization should be of approximately 30-50 μm volume median diameters in order to ensure electrostatic (Law, 2001). The analysis of the deposits with air assistances showed a good uniformity of distribution at different heights and also a sufficient biological efficacy (Ade et al., 2005).

Hence, the present study was undertaken to evaluate the performance of an engine operated electrostatic sprayer on the pear orchard. The purpose of this research is to compare the performance of electrostatic sprayer with single and twin nozzle of charged or uncharged conditions at pear orchards. Spray deposition on leaves at different parts of tree canopy were also investigated.

2 Materials and methods

2.1 Electrostatic sprayer and working

A back pack type electrostatic sprayer (Make ESS, USA) powered by a 6.5 HP engine with an on-board compressor and spray gun (Figure 1) was used in the study. The specifications of electrostatic sprayer are given in the Table 1. The engine powered the air compressor and the compressor produces pressurized air which passes through conducting hose and used to atomize and propel the liquid spray. The electrostatic sprayer is equipped with a 15 L (about four gallons) tank which is worn on the operator's back. The liquid passes through a different pipeline and atomize by air in nozzle assembly. Electrostatic sprayer comprised different sub-assemblies like nozzle, trigger, liquid filter, air filter and a battery pack. For charging the spray particles in the nozzle, two 9 V rechargeable batteries have been provided. The nozzle assembly is located at the end of the spray gun wand. The spray gun was hand triggered by the operator during spraying. Air and liquid entered separately at the rear of the nozzle. Just before leaving the nozzle, the air hit the liquid stream to atomize it into spray droplets that passed through the charging ring.

Figure 1 Engine operated electrostatic sprayer with operational view

Table 1 Specifications of electrostatic sprayer

Particulars	Specification
Nozzle	1
Engine	6.5 HP
Tank	4 Gallon
Weight full	69 kg
Dimensions	1.1 × 0.6 ×1.8 m
Flow rate	9.5 L/h
Drop size	40 microns
Spray range	4.6 - 6.1m
Air line Pressure	60-70 PSI (4.2 - 4.9 kg/cm^2)

2.2 Field evaluation protocol

Electrostatic sprayer was evaluated on a pear orchard grown at the New Orchard of Department of Fruit Science, Punjab Agricultural University, Ludhiana (India). Row to row and plant to plant spacing for the crop were 2.5 and 1.5 m respectively. Evaluation of the sprayer was done in May month of the year 2012 at pear trees.

The environmental conditions during the evaluation are reported in Table 2. It can be observed that the leaf area index (LAI) values in the section of the row have the same shape. At every tested plant, water sensitive paper stripe of size 76×26 mm were attached at four places of the plant canopy at pre decided locations. The water sensitive paper stripes were attached on the surfaces of plant leaves. Stripes were placed on each test plant at the Top, middle, bottom and dense levels (Table 3).

Table 2 Pear orchard LAI and environmental conditions during tests

Trial date	May 16th, 2012
Temperature, ℃	39.1
Wind speed, m/s	0.27
Relative humidity, %	26
Leaf area index, m^2/m^2	2.3

Table 3 Different locations of water sensitive paper strip at pear plant

Sl No.	Strip position	Distance from Stem, mm	Height from ground, mm
1	Top canopy	2000	2500
2	Middle canopy	1400	1700
3	Dense canopy	200	1800
4	Bottom canopy	1600	800

Two water sensitive paper stripes were placed each at the upper side and underside of leaves at each selected location using steel paper clips (Figure 2). After treatment, the water sensitive paper stripe was collected in separate labeled plastic bags. Spray coverage and size distribution of spots on water sensitive paper stripe determined by using droplet analyzing system. Average diameter of each droplet and its density was calculated. The droplet analyzing system consisted of a Stereo zoom microscope with CCD camera (Make Radical Scientific Equipments), PC and monitor to control the analyzed image. USB digital scale software was used in laboratory to analyze the droplet on water sensitive paper strips. During the evaluation of the electrostatic sprayer effect of charging on spray pattern parameter like droplet density and size, area covered by droplets, volume of spray deposition and uniformity coefficient were measured for single and twin nozzles (Table 4). The effect of the types of nozzles i.e. twin and single was also observed on droplet density and size for orchard.

Figure 2 View of water sensitive paper stapled on the canopy

Table 4 Different treatment of experimental plan

Treatment 1	Treatment 2	Treatment 3	Parameters
1. Charged 2. Uncharged	1. Single nozzle 2. Twin nozzle	1. Top canopy (Upper side) 2. Top canopy (Underside) 3. Middle canopy (Upper side) 4. Middle canopy (Underside) 5. Dense canopy (Upper side) 6. Dense canopy (Underside) Bottom canopy (Upper side) 8. Bottom canopy (Underside)	1. Droplet density and size 2. Area covered by droplet 3. Volume of spray deposition 4. Uniformity coefficient

2.3 Statistical analysis

The factorial experiment was conducted using randomized block design. General Linear Model (GLM) procedure was used for statistical analysis with the help of SAS 9.3 software. Tukey method was used for multiple comparisons of variables. Least Squares Means and p values were calculated for comparison of effect of charging on twin nozzles and single nozzle variables. The statistical analysis of different parameters has been discussed in results and discussion.

3 Results and discussion

3.1 Effect of charging on spray pattern

3.1.1 Effect of charging on droplet density and size

The results of droplet density (No. of drop/cm^2) measured by water sensitive paper for twin nozzle and single nozzle are shown in Figure 3. The droplet density measured in the laboratory on the upper side of the leaves at the top, middle, bottom and dense levels of the plant were 1,638, 1,285, 911 and 807 drops/cm^2 respectively for the twin nozzle (Charged). The droplet densities for twin nozzle (Uncharged) on the upper side of the leaves at the top, middle, bottom and dense levels of the plant were 834, 512, 384 and 298 drops/cm^2 respectively. The droplet density 306, 247, 160 and 131 drops/cm^2 were observed at the underside of the leaves at the top, middle, bottom and dense levels of the plant for twin nozzle (Uncharged), but the twin nozzle (Charged) deposited 754, 605, 457 and 291 drops/cm^2 at the underside of the leaves at the top, middle, bottom and dense levels of the plant respectively. The droplet density at the top, middle, bottom and dense levels of the plants by twin nozzle (Charged) was significantly higher than twin nozzle (Uncharged) by 49.05%, 60.19%, 57.83% and 63.02% respectively. Similarly, droplet density on the underside of top, middle, bottom and dense levels of the plant leaves by twin nozzle (Charged) was 59.36%, 59.20%, 65% and 54.42% more as compared to twin nozzle (Uncharged) respectively. The overall results revealed that droplet density on the upper and under sides of leaves by twin nozzle (Charged) was significantly (p = 0.0005) higher than twin nozzle (Uncharged) by 57.53% and 59.60% respectively. It may be attributed to the fact that the charging of spray has increased the no. of droplets on leaf surface by 58% as explained earlier. But there was non-significant difference (p = 0.6875 and 0.9997) of charging on droplet density at underside leaves attached at bottom and dense level of the plant respectively (Table 5).

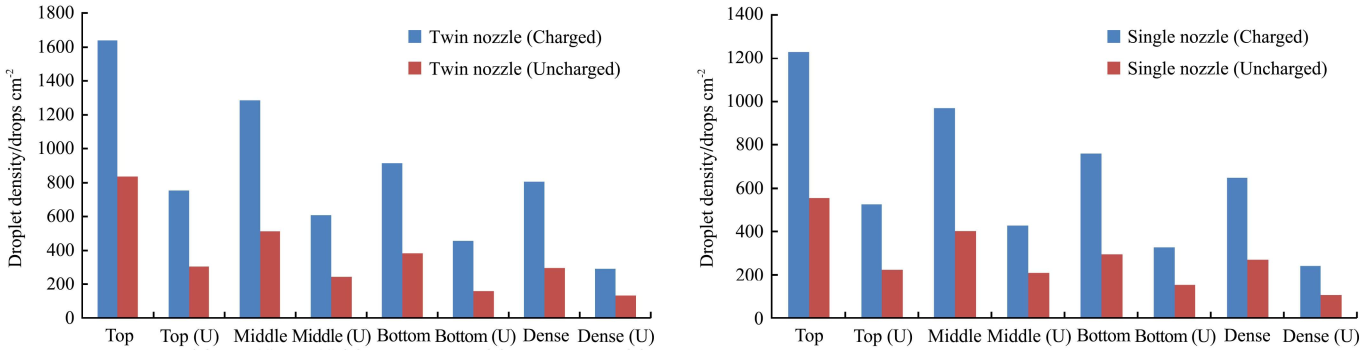

Figure 3 Effect of charging on droplet density

Table 5 *p* value of comparison between effect of charging on nozzles twin and single nozzle for droplet density

Place	Droplet density	
	Twin	Single
Top	0.0001	0.0001
Top (U)	0.0085	0.0001
Middle	0.0002	0.0005
Middle (U)	0.0020	0.0043
Bottom	0.0104	0.0001
Bottom (U)	0.6875	0.4992
Dense	0.0001	0.0001
Dense (U)	0.9997	0.9838
Over all	0.0005	0.0011

The droplet density measured on the upper side of the leaves at the top, middle, bottom and dense levels of the plant were 1,231, 968, 758 and 646 drops/cm^2 respectively for the single nozzle (Charged). The droplet densities for single nozzle (Uncharged) on the upper side of the leaves at the top, middle, bottom and dense levels of the plant were 557, 402, 295 and 270 drops/cm^2 respectively. The droplet densities 224, 208, 152 and 106 drops/cm^2 were observed at the underside of the leaves at the top, middle, bottom and dense levels of the plant for single nozzle (Uncharged), but the single nozzle (Charged) deposited 527, 425, 327 and 242 drops/cm^2 at the underside of the leaves at the top, middle, bottom and dense levels of the plant respectively. The droplet density at the top, middle, bottom and dense levels of the plants by single nozzle (Charged) was significantly higher than single nozzle (Uncharged) by 54.77%, 58.47%, 61.05% and 58.29% respectively. Similarly, droplet density on the underside of top, middle, bottom and dense levels of the plant leaves by single nozzle (Charged) was 57.61%, 51.14%, 53.47% and 56.39% more as compared to single nozzle (Uncharged) respectively. The overall results revealed that droplet density on the upper and under sides of leaves by single nozzle (Charged) was significantly (p = 0.0011) higher than single nozzle (Uncharged) by 58.15% and 54.65% respectively. It may be attributed to the fact that the charged spray droplets bend upward the underside of the leaf surface as explained earlier. But there was non-significant difference (p = 0.4992 and 0.9838) of charging on droplet density at underside leaves attached at bottom and dense level of the plant respectively.

Sprayer performance based upon the droplet size of two type of nozzle is depicted in Figure 4. As evident, the maximum droplets, i.e. 45 numbers were of size

44 microns observed for the twin nozzle (Charged). The droplet size for 96% droplets were below 120 micron for twin nozzle (Charged), but in case of twin nozzle (Uncharged), the maximum droplets, i.e. only 13 number of drops were of 44 microns and the droplet size was ranging from 9 to 226 microns. The maximum droplets, i.e. 32 numbers were of size 44 microns observed for the single nozzle (Charged). The droplet size for 95% droplets were below 120 micron for single nozzle (Charged), but in case of single nozzle (Uncharged), the maximum droplets, i.e. only 11 number of drops were of 44 microns.

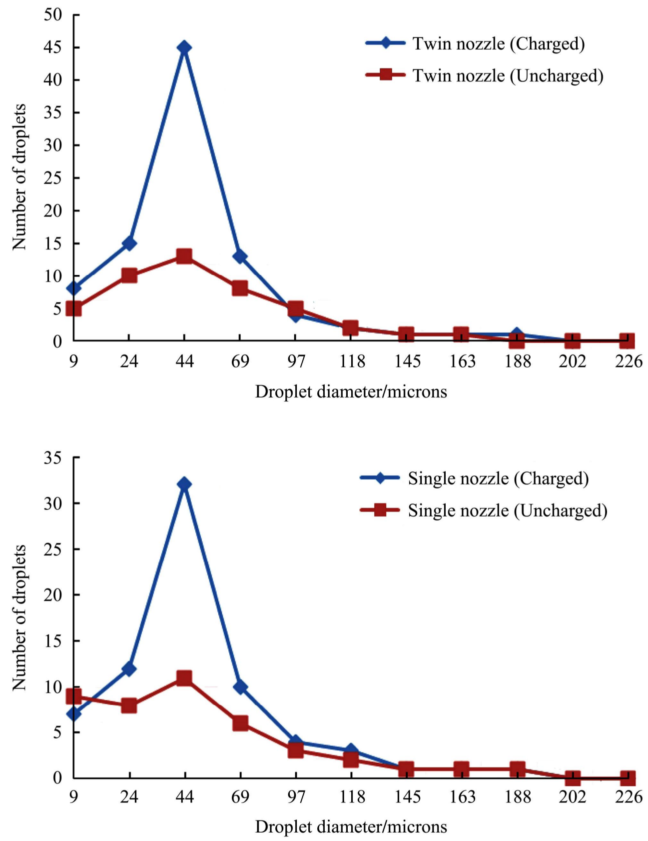

Figure 4 Effect of charging on sprayer performance

3.1.2 Effect of charging on area covered by droplets

The results of area covered by droplets measured by water sensitive paper are depicted in Figure 5. The area covered by droplets measured in the laboratory for the twin nozzle (Charged) on the upper side of the leaves at the top, middle, bottom and dense levels of the plant were 60.53, 48.79, 30.88 and 23.76 mm^2/cm^2 respectively. The area covered by droplets for twin nozzle (Uncharged) on the upper side of the leaves at the top, middle, bottom and dense levels of the plant were 36.75, 22.37, 14.30 and 11.02 mm^2/cm^2 respectively. The area covered by droplets 8.66, 6.43, 1.83 and 1.19 mm^2/cm^2 were observed at the underside of the leaves at the top, middle, bottom and dense levels of the plant for twin nozzle (Uncharged), but the twin nozzle (Charged) covered 21.90, 16.96, 5.97 and 5.81 mm^2/cm^2 at the underside of the leaves at the top, middle, bottom and dense levels of the plant respectively. The area covered by droplets at the top, middle, bottom and dense levels of the plants by twin nozzle (Charged) was significantly higher than twin nozzle (Uncharged) by 39.28%, 54.16%, 53.70% and 53.62% respectively. Similarly, area covered by droplets on the underside of top, middle, bottom and dense levels of the plant leaves by twin nozzle (Charged) was 60.46%, 62.11%, 69.44% and 79.45% more as compared to twin nozzle (Uncharged) respectively. The overall results revealed that area covered by droplets on the upper and under sides of leaves by twin nozzle (Charged) was significantly (p = 0.0017) higher than twin nozzle (Uncharged) by 50.19% and 67.86% respectively. But there was non-significant difference (p = 0.0558, 0.9925 and 0.9855) of charging on area covered by droplets at underside leaves attached at middle, bottom and dense level of the plant respectively (Table 6).

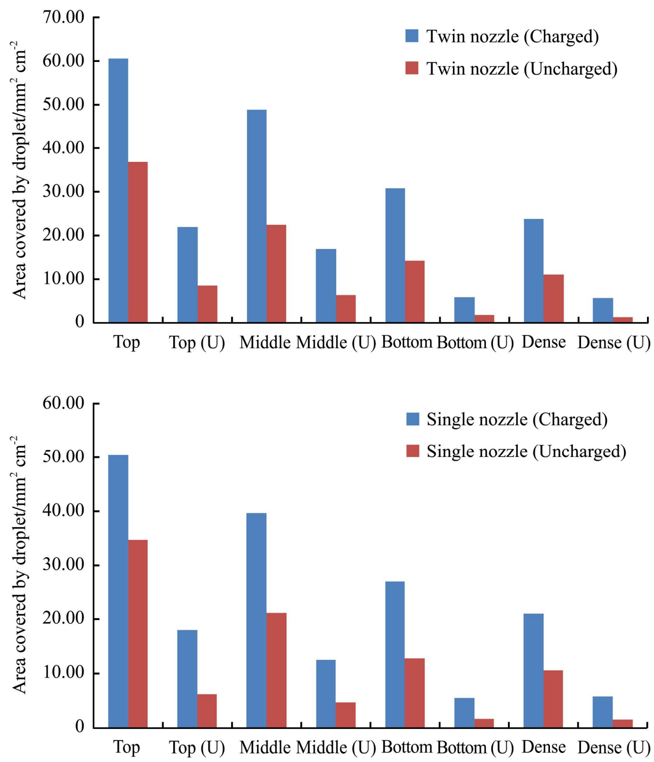

Figure 5 Effect of charging on area covered by droplets

Table 6 *p* value of comparison between effect of charging on nozzles twin and single nozzle for area covered by droplets

Place	Area covered by droplet	
	Twin	Single
Top	0.0001	0.0001
Top(U)	0.0098	0.0004
Middle	0.0001	0.0001
Middle(U)	0.0558	0.0058
Bottom	0.0002	0.0001
Bottom(U)	0.9925	0.9817
Dense	0.0005	0.0043
Dense(U)	0.9855	0.9701
Over all	0.0017	0.0007

The area covered by droplets measured for the single nozzle (Charged) on the upper side of the leaves at the top, middle, bottom and dense levels of the plant were 50.46, 39.48, 27.07 and 20.93 mm^2/cm^2, respectively. The area covered by droplets for single nozzle (Uncharged) on the upper side of the leaves at the top, middle, bottom and dense levels of the plant were 34.68, 21.17, 12.74 and 10.56 mm^2/cm^2 respectively. The area covered by droplets 6.21, 4.72, 1.67 and 1.60 mm^2/cm^2 were observed at the underside of the leaves at the top, middle, bottom and dense levels of the plant for single nozzle (Uncharged), but the single nozzle (Charged) covered 18.04, 12.50, 5.59 and 5.74 mm^2/cm^2 at the underside of the leaves at the top, middle, bottom and dense levels of the plant respectively. The area covered by droplets at the top, middle, bottom and dense levels of the plants by single nozzle (Charged) was significantly higher than single nozzle (Uncharged) by 31.28%, 46.52%, 52.94% and 49.56% respectively. Similarly, area covered by droplets on the underside of top, middle, bottom and dense levels of the plant leaves by single nozzle (Charged) was 65.59%, 62.19%, 70.13% and 72.20% more as compared to single nozzle (Uncharged) respectively. The overall results revealed that area covered by droplets on the upper and under sides of leaves by single nozzle (Charged) was significantly (p = 0.0007) higher than single nozzle (Uncharged) by 45.07% and 67.53% respectively. But there was non-significant difference (p = 0.9817 and 0.9701) of charging on area covered by droplets at underside leaves attached at bottom and dense level of the plant respectively.

3.1.3 Effect of charging on volume of spray deposition

The results of volume of spray deposition of two types of nozzles measured by water sensitive paper are depicted in Figure 6. The volume of spray deposition ($\times10^{-6}$ cc/cm^2) measured in the laboratory on the upper side of the leaves at the top, middle, bottom and dense levels of the plant were 1,030.47, 887.34, 669.31 and 515.15 respectively for the twin nozzle (Charged). The volume of spray deposition ($\times10^{-6}$ cc/cm^2) for twin nozzle (Uncharged) on the upper side of the leaves at the top, middle, bottom and dense levels of the plant were 531.95, 356.61, 184.46 and 151.28 respectively. The volume of spray deposition ($\times10^{-6}$ cc/cm^2) 187.80, 103.96, 48.42 and 24.08 were observed at the underside of the leaves at the top, middle, bottom and dense levels of the plant for twin nozzle (Uncharged), but the twin nozzle (Charged) deposited 459.51, 228.17, 211.44 and 150.88 at the underside of the leaves at the top, middle, bottom and dense levels of the plant respectively.

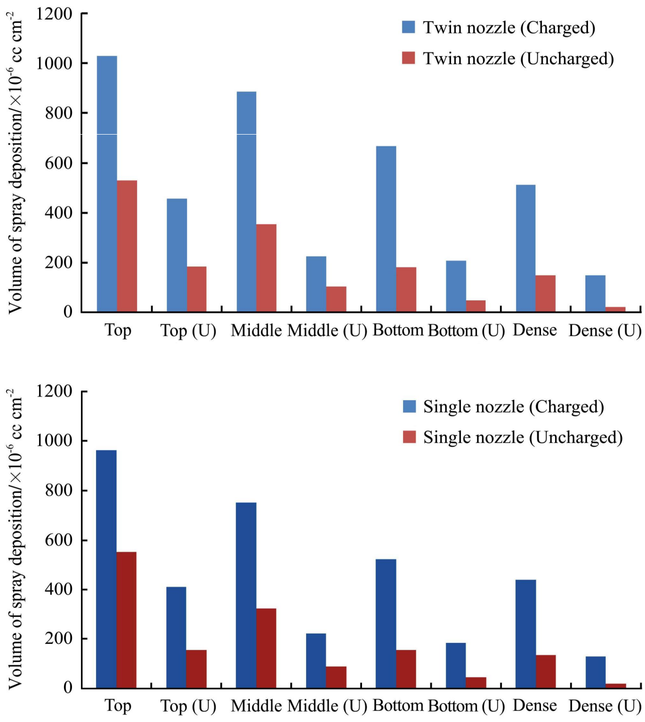

Figure 6 Effect of charging on volume of spray deposition

The volume of spray deposition at the top, middle, bottom and dense levels of the plants by twin nozzle (Charged) was significantly higher than twin nozzle (Uncharged) by 48.38%, 59.81%, 72.44% and 70.63% respectively. Similarly, volume of spray deposition on the underside of top, middle, bottom and dense levels of the plant leaves by twin nozzle (Charged) was 59.13%, 54.44%, 77.40% and 84.04% more as compared to twin nozzle (Uncharged) respectively. The overall results revealed that volume of spray deposition on the upper and under sides of leaves by twin nozzle (Charged) was significantly (p = 0.0033) higher than twin nozzle (Uncharged) by 62.82% and 68.68% respectively. But there was non-significant difference (p = 0.7675, 0.5359 and 0.8680) of charging on volume of spray deposition at underside leaves attached at middle, bottom and dense level of the plant respectively (Table 7).

Table 7 *p* value of comparison between effect of charging on nozzles twin and single nozzle for volume of spray deposition

Place	Volume of spray deposition	
	Twin	Single
Top	0.0001	0.0001
Top(U)	0.0083	0.0001
Middle	0.0001	0.0001
Middle(U)	0.7675	0.0001
Bottom	0.0001	0.0001
Bottom(U)	0.5359	0.0001
Dense	0.0007	0.0001
Dense(U)	0.868	0.0003
Over all	0.0033	0.0035

The volume of spray deposition ($\times10^{-6}$ cc/cm^2) measured on the upper side of the leaves at the top, middle, bottom and dense levels of the plant were 962.27, 754.15, 524.22 and 439.68 respectively for the single nozzle (Charged). The volume of spray deposition ($\times10^{-6}$ cc/cm^2) for single nozzle (Uncharged) on the upper side of the leaves at the top, middle, bottom and dense levels of the plant were 555.30, 325.04, 153.36 and 134.77 respectively. The volume of spray deposition ($\times10^{-6}$ cc/cm^2) 154.82, 87.65, 42.54 and 16.34 were observed at the underside of the leaves at the top, middle, bottom and dense levels of the plant for single nozzle (Uncharged), but the single nozzle (Charged) deposited 411.65, 221.31, 182.83 and 128.25 at the underside of the leaves at the top, middle, bottom and dense levels of the plant respectively. The volume of spray deposition at the top, middle, bottom and dense levels of the plants by single nozzle (Charged) was significantly higher than single nozzle (Uncharged) by 42.29%, 56.90%, 70.75% and 69.35% respectively. Similarly, volume of spray deposition on the underside of top, middle, bottom and dense levels of the plant leaves by single nozzle (Charged) was significantly higher than single nozzle (Uncharged) by 62.39, 60.40, 76.74 and 87.265 respectively. The overall results revealed that volume of spray deposition on the upper and under sides of leaves by single nozzle (Charged) was significantly (p = 0.0035) higher than single nozzle (Uncharged) by 59.82% and 71.69% respectively.

3.1.4 Effect of charging on Uniformity Coefficient (UC)

The results of uniformity coefficient measured by water sensitive paper are depicted in Tables 8 and 9. The uniformity coefficient measured in the laboratory on the upper side of the leaves at the top, middle, bottom and dense levels of the plant were 1.25, 1.47, 1.63 and 1.66 respectively for the twin nozzle (Charged). The uniformity coefficient for twin nozzle (Uncharged) on the upper side of the leaves at the top, middle, bottom and dense levels of the plant were 1.85, 2.02, 2.10 and 2.11 respectively. The uniformity coefficient 2.05, 2.11, 2.28 and 2.31 were observed at the underside of the leaves at the top, middle, bottom and dense levels of the plant for twin nozzle (Uncharged), but uniformity coefficient by the twin nozzle (Charged) 1.53, 1.68, 1.76 and 1.78 at the underside of the leaves at the top, middle, bottom and dense levels of the plant respectively.

Table 8 Effect of charging on uniformity coefficient for twin nozzle

Place	Twin nozzle (Charged)	Twin nozzle (Uncharged)
Top	1.25	1.85
Top (U)	1.53	2.05
Middle	1.47	2.02
Middle (U)	1.68	2.11
Bottom	1.63	2.10
Bottom (U)	1.76	2.28
Dense	1.66	2.11
Dense (U)	1.78	2.31
Average	1.60	2.10

Table 9 Effect of charging on uniformity coefficient for single nozzle

Place	Single nozzle (Charged)	Single nozzle (Uncharged)
Top	1.63	1.96
Top (U)	1.80	2.38
Middle	1.67	2.15
Middle (U)	1.84	2.42
Bottom	1.79	2.29
Bottom (U)	1.92	2.58
Dense	1.80	2.32
Dense (U)	1.96	2.61
Average	1.80	2.34

The uniformity coefficient measured in the laboratory on the upper side of the leaves at the top, middle, bottom and dense levels of the plant were 1.63, 1.67, 1.79 and 1.80 respectively for the single nozzle (Charged). The uniformity coefficient for single nozzle (Uncharged) on the upper side of the leaves at the top, middle, bottom and dense levels of the plant were 1.96, 2.15, 2.61 and 2.32 respectively. The uniformity coefficient 2.38, 2.42, 2.58 and 2.29 were observed at the underside of the leaves at the top, middle, bottom and dense levels of the plant for single nozzle (Uncharged), but uniformity coefficient by the single nozzle (Charged) were 1.80, 1.84, 1.92 and 1.96 at the underside of the leaves at the top, middle, bottom and dense levels of the plant respectively. The average UC for charged twin and single nozzle was 1.6 and 1.8 respectively as compared to 2.1 and 2.34 for uncharged nozzle. It means the charge nozzles are providing more uniform spray on the plant. As the droplet size becomes more uniform, the uniformity coefficient (VMD/NMD) becomes nearer to unity (Singh, 2005).

3.2 Effect of type of charged nozzles on spray pattern

3.2.1 Effect of type of nozzle on droplet density

The effects of two types of nozzle on droplet density are shown in Figure 7. The droplet density of upper side of the leaves at the top, middle, bottom and dense levels of the plant by twin nozzle (Charged) was significantly higher than single nozzle (Charged) by 24.87%, 24.66%, 16.76% and 16.77% respectively. Similarly droplet density of underside of the leaves at the top, middle, bottom and dense levels of the plant by twin nozzle (Charged) was 30.07%, 29.71%, 28.44% and 16.77% higher as compared to single nozzle (Charged) respectively. On an average, droplet density of the upper and under sides of leaves by twin nozzle (Charged) was significantly (p = 0.0279) higher than single nozzle (Charged) by 21.55% and 26.24% respectively. But there was non-significant difference (p = 0.8482 and 1.0000 respectively) of nozzle type on droplet density at underside leaves attached at bottom and dense level of the plant (Table 10).

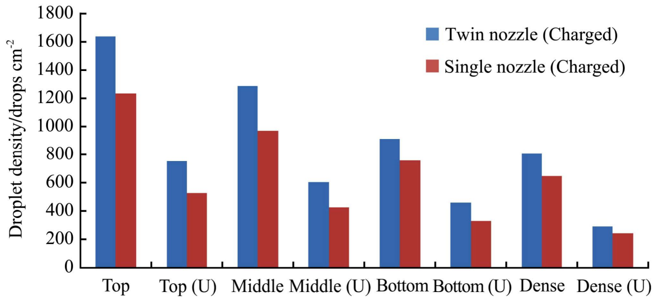

Figure 7 Effect of type of nozzle on droplet density

Table 10 p value of comparison between effects of type of charged nozzle on spray pattern on twin and single nozzle for droplet density

Place	Droplet density
Top	0.0001
Top (U)	0.0207
Middle	0.0001
Middle (U)	0.0014
Bottom	0.0490
Bottom (U)	0.8482
Dense	0.0013
Dense (U)	1.0000
Over all	0.0279

3.2.2 Effect of type of nozzle on volume of spray deposition

The effect of two types of nozzles on volume of spray deposition is shown in Figure 8.

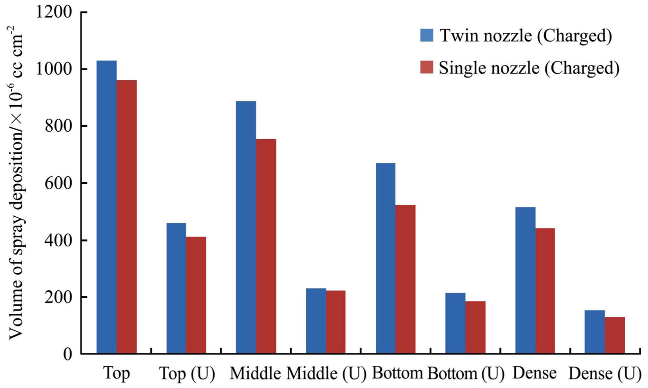

Figure 8 Effect of type of nozzle on volume of spray deposition

The volume of spray deposition of upper side of the leaves at the top, middle, bottom and dense levels of the plant by twin nozzle (Charged) was 6.62%, 15.01%, 21.68% and 14.65% higher respectively but it was not significantly higher as compared to single nozzle (Charged). Similarly volume of spray deposition of underside of the leaves at the top, middle, bottom and dense levels of the plant by twin nozzle (Charged) was

10.42%, 3.01%, 13.53% and 15.00% higher respectively but it was not significantly higher as compared to single nozzle (Charged). On an average, volume of spray deposition of the upper and under sides of leaves by twin nozzle (Charged) was not significantly (p = 0.3123) higher than single nozzle (Charged) (Table 11).

Table 11 *p* value of comparison between effects of type of charged nozzle on spray pattern on twin and single nozzle for volume of spray deposition

Place	Volume of spray deposition
Top	0.9975
Top (U)	1.0000
Middle	0.6371
Middle (U)	1.0000
Bottom	0.5044
Bottom (U)	1.0000
Dense	0.9931
Dense (U)	1.0000
Over all	0.3123

4 Conclusions

The following conclusions are drawn from the study:

1) The results showed that droplet density on the upper and underside of leaves by twin nozzle (Charged) was significantly (p = 0.0005) higher than twin nozzle (Uncharged) by 57.53% and 59.60% respectively;

2) Droplet density on the upper and under sides of leaves by single nozzle (Charged) was significantly (p = 0.0011) higher than single nozzle (Uncharged) by 58.15% and 54.65% respectively;

3) The results showed that on an average, area covered by droplets on the upper and under sides of leaves by twin nozzle (Charged) was significantly (p = 0.0017) higher than twin nozzle (Uncharged) by 50.19% and 67.86% respectively;

4) On an average, area covered by droplets on the upper and under sides of leaves by single nozzle (Charged) was significantly (p = 0.0007) higher than single nozzle (Uncharged) by 45.07% and 67.53% respectively;

5) The results showed that on an average, volume of spray deposition on the upper and under sides of leaves by twin nozzle (Charged) was significantly (p = 0.0033) higher than twin nozzle (Uncharged) by 62.82% and 68.68% respectively;

6) On an average, volume of spray deposition on the upper and under sides of leaves by single nozzle (Charged) was significantly (p = 0.0035) higher than single nozzle (Uncharged) by 59.82% and 71.69% respectively;

7) The average UC for charged twin and single nozzle were 1.6 and 1.8 respectively as compared to 2.1 and 2.34 for uncharged nozzle;

8) It was observed that there was significant difference for different spray pattern parameter like droplet density, area covered by droplets and volume of spray deposition between charging and non-charging of nozzle except at the underside of leaves at bottom of the plant and in some cases at middle of the plant;

9) Volume of spray deposition on the upper and underside of leaves by twin nozzle was not significantly different from single nozzle.

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