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REVIEW ARTICLE

Studies on Electrostatic Sprayer – A Review

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ABSTRACT

Pesticides plays an critical complement to modern cultivating. It gives most viable and convenient way to oversee creepy crawlies. Chemical pesticides plays noteworthy part within the advancement of rural generation and these are showered through sprayers. There are a few sorts of sprayers like hand sprayer, backpack sprayer, fog blowers, rocker sprayer, bucket sprayer, foot sprayer, control sprayer, boom sprayer, plantation sprayer, electrostatic sprayer, etc. Each sort of sprayer has it's possess preferences, impediments and uniqueness for operation. The choice of showering method depends up on sort of vegetation, kind of bothers and approach to the field. Separated from all, electrostatic sprayer is best to apply pesticides accurately and subsequently diminishes the issue of soil and water contamination. This study has been carried out to know the diverse parameters influencing the performance of electrostatic sprayer conjointly its method.

Keywords: *Pesticides, chemical, sprayer, vegetation and field.*

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INTRODUCTION

Application of pesticides is an critical complement to modern cultivating. They give the foremost effective and cost-effective implies of overseeing numerous species of creepy crawlies, organisms and nematodes competing for our food and fiber. India contains a cultivable locale of 160 million hectares, 80 million hectares of which are protected from bothers by the utilize of chemical pesticides. Be that as it may, yearly edit misfortunes due to bothers are evaluated at around Rs. 6,000 crores, counting grain misfortunes amid capacity [32]. Therefore, chemical pesticides play a significant part in the development of agricultural production and will continue to provide it. The chemicals are being sprayed with the help of sprayers.

Plant assurance apparatus is developing each year in India and around 4.5 lakh plant security apparatuses were fabricated amid 1996-97 [35]. These are of several types viz. hand sprayer, knapsack sprayer, mist blowers, rocker sprayer, bucket sprayer, foot sprayer, power sprayer, boom sprayer, orchard sprayer, electrostatic sprayer, etc.. Even based up on the volume of liquid to be handled, sprayers may be classified into High volume sprayer (more than 400 l ha^{-1}), Low volume sprayer (5 to 400 lha^{-1}) and Ultra low volume sprayer (ULV) spray (less than 5 l ha^{-1}). Each sort of sprayer has it's claim focal points, impediments and uniqueness for operation. The choice of showering method depends up on sort of vegetation, kind of bugs and approach to the field. Knapsack sprayer is the foremost common and flexible pesticide application in developing countries such as India since of it is more extensive scope, comparatively made strides effectiveness of usage, ease of utilize, improved consolation and cost-effectiveness. But these sprayers still need to address testimony, dispersal and entrance issues within the crop canopies [6]. Each type of sprayer generates certain amount of droplet size, which depends upon many parameters like-nozzle type, viscosity of liquid, nozzle pressure, flow rate, spray angle, etc. Droplets smaller than 100 μm (knapsack mist-blower produces 50-100 μm) are proven to be more efficient for insecticide and fungicide sprays in laboratory tests [30], but are considered undesirable for field spray applications due to high drift susceptibility under most meteorological conditions [2].

BEHAVIOUR OF DIPOLE MOMENT ON PLANT

Most agricultural chemicals are used as formulations based on water. Water has a polar molecular structure and has large value of the electric dipole moment. On the basis of electro-chemistry of polar molecules, fine water droplets can be charged electrostatically. The crops rooted to the earth will have zero potential, although the metabolic processes of the living plant body will induce a slight positive charge on the plant. However, this charge was discovered to be asymmetrically distributed on the surface of the plant, focused close the sharp protruding components of the body such as tips of the leaf, spikes and particularly floral sections.

ELECTOSTATIC SPRAYERS

Electrostatics means the study of static electricity, the surface phenomenon that governs the accumulation of electrical charges on a body is explained by the Law of Coulomb. It has important potential for the implementation of agricultural fluid formulations as charged particles can achieve uniform spray coverage with significantly lower quantities. Hence, the electrostatic force fields can be used to direct and control the droplet trajectories of charged droplets.The implementation of electrically charged sprays for agricultural use can provide higher control over droplet transport with imminent waste reduction. Using electrostatic spraying can improve the effectiveness of the application by approximately 80% with 60% less spray chemical ingredient [19]. Electrostatic forces on tiny droplets are more prominent than gravitational forces and therefore electrostatic charging of spray droplets drift can provide higher deposition with decreased [1].

TECHIQUES USED IN ELECTROSTATIC CHARGING

Generally three techniques are adapted to charge the fluid spray which are as follows:

- **Conduction charging:** It includes direct application by conduction of high voltage potential to the spray fluid. But this technique needs a greater power supply and has the risk of the operator being shocked by high voltage.
- **Corona charging:** It utilizes the corona discharge field to charge the spray particles that pass through it, which also has life risk hazards and can cause chemical changes to the spray material being subjected.
- **Induction charging:**The "Electrostatic Induction Charging" (EIC) method works on the induction of non-contact charge on the spray fluid that passes through the electrical high voltage field. Since this technique has no direct contact with the working fluid, the chances of having the operator a high voltage shock are negligible and the power consumption is also significantly smaller than the other techniques. This allows the charging of electrostatic induction the best technique for charging agricultural spray liquids. Because of its recognized benefits over other charging techniques such as elevated charge transferability, less dangerous to life and simplicity in development, this technique is, therefore, adopted for research on electrostatic sprayers.

The performance of electrostatic sprayer was affected by electrodes type, shape, material along with distance from nozzle, nozzle type, spray angle, nozzle pressure, EC and other properties of liquid to be sprayed, voltage on electrode, distance of nozzles from target, etc. Thus, a review of research work was carried out based on the different parameters affecting the performance of electrostatic spraying system presented under following subheadings:

Static Electricity Present in the Plants and Electrostatic Spraying

Lane and Law [19] performed an electrostatic spraying research on transient charge transfer in living crops. An electric field generator was used in the vicinity of grounded cotton plant to generate time-varying electrical field. The high voltage (HV) electrode was built from 1.04 mx 1.04 m sheet of galvanized steel with its corners coated by copper tube to decrease undesirable corona discharge and put with Teflon insulation at a horizontal distance of 1.45 m from the floor. For measuring the transfer of charge through the factory, an electrometer with operating mode was used. The electrometer output was fed into the oscilloscope of storage to record the time fluctuating charge flow through the plants. The electrode potential for the whole experiment was kept constant at 15 kV. Cotton crops were stressed by drought and reduced charge

Jorg and Launter [15] conducted study about electrical signals in plants, the measurement techniques and their physiological significance. They performed experiments on Mimosa pudica and Dionea muscipula with artificial generation of electrical signals to resemble the environmental stimuli, such as light, temperature, touch or wounding etc. which generated Action Potential (AP) and Variation Potential (VP) within the plant organ. In which APs were fast and propagated very rapidly at speed of 10 – 20 mm s^{-1}, whereas VPs were relatively slower wave potentials. These may be generated due to wounding, organ excision or flaming and was studied in cucumber and pea seedlings. Physiological effects in Dionea revealed that, catching starts with release of Calcium-ion into cytosol by mechanical pressure of one of trigger hairs and subsequently APs generated without any response of trap. If any trigger hair get bent no later than 40 s after the first, a second fast AP evoked to close the trap transfer compared to plants in normal conditions, in the range of 3.0 to 4.0 with respect to time.

Mouel *et al.*[30] studied the electric potential variations in a standing tree and electricity present in the atmosphere. The investigations were done on the trunk of the standing poplar tree equipped with electrodes along its height of 0.5 m to 10.5 m. The results were noticed by Keithley Electrometer for amplitude andduration which gradually increased with the heights 0.5 m to 10.5 m from ground at increments of 50 cm between two consecutive stainless-steel electrodes (6 mm dia.). Electrodes were hammered gently into the trunk up to a depth of 15mm with sampling interval in measurements of one minute using Keithley 2701 electrometer with input impedance larger than 100 MΩ. They observed that there was no difference between the plots of positive and negative signals, plotted against the height respectively. In few cases the plot was straight with a slope of 0.1 to 5.0 $mV.m^{-1}$.

Oyarace and Luis [31] investigated the electrical signals in Avocado trees against light and water availability. Electrical potentials generated within Avocado trees were monitored continuously using non-polarizable Ag/AgCl micro-electrodes inserted at different positions along the trunk. These electrodes included silver wire of 0.35 mm diameter in stainless steel needle of 0.5 mm diameter. Electrodes were connected to 20-channel multi-voltmeter digital data logger (Keithley 2701) with compatible switching board (Keithley 7700). The measurements were taken during dawn, morning, afternoon and at night with irrigated and non-irrigated conditions. It was observed that negative polarity voltage potential developed in the range of 77.85 to 109.68 mV during dawn, 74.37 to 109.16 mV during morning, 68.13 to 106.91 mV during afternoon and 72.70 to 108.25 mV during night.

Electrostatic Induction Spray Charging

Smith *et al.*[36] conducted study on AC charging of agricultural sprays and its effectiveness. A controllable DC voltage supply unit and three different charging annuli were used with charging voltage stepped in 4.3, 8.2, 12.5 and 16.5 kV with frequency range of 1040 to 1975 Hz. The spray nozzle operated at three constant pressures viz. 173, 276 and 380 kPa and for charging 0.8, 11.5 and 15 kV potentials were used in a square wave form. The 15-kV square wave form AC charging produced more number of small droplets under 50, 20 and 10 µm, so that charge per droplet could be higher and droplet voltage was measured with Keithley 614B Electrometer which showed values in the range of 50 mV to 175 mV for charging voltage 5 kV to 15 kV.

Anantheswaran and Law [3] developed an electrostatic spray charging nozzle for charging pesticide spray droplets by induction. The charging unit was operated by 12V DC battery, which gave an output voltage of 30 kV. For experimental analysis voltage given to the metal plate electrode varied from 0 to 30 kV, in steps of 10 kV. Also, a dielectric barrier type precipitator was evaluated, made of polythene sheet stretched over a square plexi-glass, which accumulated negative charges on its surface. Later these charges would repel spray droplets downward towards the turf grass. The deposition was found to be increased significantly on increasing inclination angle. In conjunction with dielectric barrier, deposition was observed to be increased by 3.6 folds compared to uncharged spray.

Carlton and Bouse [8] designed, developed and evaluated an electrostatic spray charging spinning nozzle for aircraft. The rotational speed of the spinner and hence the droplet size was altered by regulating motor voltage. Spray charging efficiency increased with increase in spinner speed and CMR about 2×10^{-2} $C.kg^{-1}$. The experiments showed that electrostatically charged spray deposition may exceed that of uncharged spray counterpart by 800 per cent.

Gupta *et al.*[12] designed and developed a knapsack type electrostatic spinning disc sprayer, consisting of charging system having 12 V DC wet cell rechargeable battery and HVDC power supply (Model-C30, Venus Scientific Inc., NY). Field applications were conducted with 1.2 kV charging potential, 50 $ml.min^{-1}$ liquid flow rate and 2000 to 3000 rpm spinning disc speed. The results gave CMR from the charging system in the range of 1.0 to 1.2 $mC.kg^{-1}$ with 169 µm mean droplet size. It was observed that, operator's contamination due to drifting chemical was reduced significantly due to rear mounted spray boom.

Luciana and Cramariuc [26] conducted experiments on electro-hydrodynamic (EHD) spray injector including direct injector conduction charging, direct charging through open electrode and charging by induction with insulated electrode and grounded injector. DC high voltage ranging from 0 to 6 kV was used to charge the spray particles with liquid flow rate between 0.1 to 0.4 $mls^{-1}$and two-stage Faraday cage and collector were used to measure the cloud current. They found induction charging as the most efficient method, which showed optimum charge to mass ratio of 5 μCg^{-1} at 3 kV with flow rate at 0.3 ml s^{-1}, with no electrical hazards and power loss.

Maynagh *et al.*[28] evaluated the electrostatic induction charging sprayer with ultrasonic (30 kHz) nozzle for different parameters such as electrode radius, voltage level, air velocity and electrode placement. The tests were performed with varying flow rate (5 to 25 $ml.min^{-1}$), voltage levels (1.5 to 7 kV), airflow speeds, electrode radius (10 and 15 mm) and its horizontal position (1 to 10 mm) from nozzle tip. They found optimum CMR of 1.032 μC g^{-1} at 7 kV voltage; 23 $m.s^{-1}$ airflow speed, electrode radius and placement of 15 mm and 10 mm respectively, while liquid flow rate was kept at 5 $ml.min^{-1}$ to reduce electrode wetting.

Alamuhanna and Maghirang [1] developed and evaluated a charge measuring device for measuring the net CMR induced on the filter with an electrometer. The device was tested using different kinds of airborne particles viz. corn starch, sodium bicarbonate, positively and negatively charged water spray and uncharged water spray. The device consisted of two conducting enclosures, one enclosed and insulated from another. It was electrically connected to the electrometer input and having particle filter with backup metal screen. Calibration circuit was made and used to generate known charges with variable DC voltage supply with 1, 2, 3 V DC fixed voltages and three different capacitors of 0.1μf, 0.01μf and 0.001μf. Electrostatic Spraying Systems (ESS, Watkinsville) sprayer was used to charge the water spray. The device showed reliable readings and good repeatability. With induction charging, significantly large CMR values (i.e. 6.5 mC kg^{-1} for negatively charged water spray and +7.2 mC kg^{-1} for positively charged water spray) were observed by the developed CMR measuring device, which were close to CMR value (-6 mC kg^{-1}) specified by the manufacturer (ESS, Watkinsville, GA).

Yu *et al.*[41] developed an axial flow air assisted ultra-low volume electrostatic sprayer with high voltage (20 kV) corona charging device. The sprayer was evaluated in laboratory as well as field for the parameters like CMR to corresponding voltage levels, droplet size, deposition uniformity and pest mortality against micro-melalopha troglodyte fungi on roadside forestry trees. Spraying was performed with charge as well as without charge on both sides of row along 10 km length. Performance of electrostatic spray was reported in terms of pest mortality, which was observed to be higher (95.40 %) over non-electrostatic spray (74.80 %), while CMR value observed to be 2.35 $mC.kg^{-1}$ with 80.80 μm droplet size at 20 kV.

Mamidi *et al.* [27] developed an electrostatic hand pressure swirl nozzle knapsack sprayer for small crop growers and evaluated different parameters as electrode position, charge to mass ratio, spray deposition and effect of applied pressure on droplet size and breakup length. Twin hole swirl disc with 0.8 mm orifice and copper ring electrode connected to programmable 10W HVDC module (EMCO-F101) ranging from 0 to 10 kV was used. The placement of ring electrode was varied from 1 to 6 mm and manual hand pressure knapsack pump with output pressure from 0 to 2.82 $kg.cm^{-2}$ was used to drive the swirl nozzle. Cloud current (A) and mass flow rate ($kg.s^{-1}$) were measured at 2.11 $kg.cm^{-2}$ pressure and 3.3 kV voltage which by which they found optimum CMR value and droplet size as 0.37 $mC.kg^{-1}$ and 100 μm respectively, while electrode placed at 4.5 mm from orifice.

Robson *et al.*[33] conducted a study on charge to mass ratio and liquid deposition efficiency of electrostatic spraying method. ESS-MBP 4.0 induction charging sprayer model was used for the experiment and Faraday cage equipped with digital multi-meter was used for chargeability analysis. The sprayings were done at distances 0, 1, 2, 3, 4 and 5 m from the Faraday cage and charge readings were obtained from digital multimeter. Liquid discharge rate (lpm) was measured with graduated cylinder with precision of 5 ml. The highest charge-to-mass ratio was found to be 4.11 $mC.kg^{-1}$ for the closest distance and it gradually decreased to 1.38, 0.64, 0.31, 0.017 and 0.005 $mC.kg^{-1}$ for the corresponding distances 1, 2, 3, 4 and 5 m respectively.

Patel *et al.*[34] developed and analyzed an air assisted electrostatic spray charging nozzle for agricultural pesticide application in liquid form. Experiments were conducted to assess the parameters viz. charge to mass ratio (CMR), spray pattern, uniformity of deposition and coverage by using Water Sensitive Paper (WSP) method. Chargeability was tested with Faraday cage and digital multimeter under +20 kV High Voltage DC power supply. Plants were sprayed electrostatically as well as non-electrostatically under all other identical conditions with WSPs mounted on front and back side of leaves at random locations in canopy. After 20 minutes of spraying, WSP samples were collected and analyzed with IMAGE-J Scanner based system. Analysis showed that 2 to 3 times increase in leaf top deposition in electrostatic spray over non-electrostatic spraying, also observed that under leaf deposition has been enhanced by 4 to 5 times.

Measurement of Spray Charge Acquisition

Law [22] studied on charge measurement of agricultural particles and developed an electrostatic induction instrument for tracking and charge measurement of airborne particles. Water held in variable-head glass reservoir was allowed to slowly drip from the blunt end of the hypothermic needle at the rate of 1 drop per 5 seconds. A negative charge was imparted on droplets by maintaining the needle at selected negative high voltage potential. A smooth induction electrode of 14 mm inner diameter and 3 mm thickness was positioned concentrically with and 6 mm below the tip of the needle. Keithley 600B electrometer was used for charge measurements and connected vertical deflection oscilloscope. A small Faraday's cage was positioned in a Teflon insulator at the of the apparatus. The average charge (- q) was determined experimentally by collecting and counting the number of drops acquired by Faraday's cage. Particle charge as high as - 4.25 x 1010 and - 2.45 x 1010 coulombs were attained and corresponded to CMR values as -2.5 x 10-5 C.kg^{-1} and -6 x 1010 C.kg^{-1} with – 2.5 kV needle potential.

Bode and Bowen [7] conducted study on spray distribution and charge-mass ratio of electrostatically charged agricultural sprays. Spray droplet size was analyzed with Fleming Particle Size Analyzer at flow rates of 25, 50 and 75 ml.min^{-1} and spinner disc speed of 2000, 3000, 4000 and 5000 rpm for both charged and uncharged particles. For charged application a positive (0.5 to 3.0 kV) high voltage (HV) potential from HV power supply Model H-30 Ferrant Int., N.Y. was used. An aluminium cup with 75 cm diameter and 50 cm height was used to intercept all the spray. Charged spray imparted an equal and opposite charge on the cup and was measured by Keithley 614 Electrometer. The measured droplet size was in the range of 115 to 203 µm without charging and 109 to 183 µm with charging. At all conditions studied, droplet size reduced by 1 to 10 per cent due to charging was observed. CMR was achieved in the range of 1.0 mC.kg^{-1} to 2.5 mC.kg^{-1} at spinner speed 3000 to 4000 rpm at peak level of charging from 0.5 kV to 3.0 kV. The spray deposition efficiency was in the range of 55 to 94 per cent and relative increase of 1.6 to 2.0 fold over uncharged spray was observed due to charging.

Kihm *et al.*[16] conducted both laboratory as well as field experiments on bipolarly charged aircraft sprays in order to assess the deposition characteristics with DC motor driven serrated cup atomizers with induction charging ring electrode. Laboratory experiment was consisted of 40 hp motor driven blower at 175 km.h^{-1} air velocity, 55 mm diameter serrated cup atomizer with ring electrode having outer diameter of 63 mm and thickness of 1.6 mm. The clearance between Aluminium ring electrode and spinning cup edge was 2 mm axially and 2.4 mm radially. Malvern 2600D Aerosol sizer and charge collector Faraday's cage comprising of needle, plane mesh and concave mesh collector were used for droplet size analysis and spray cloud charge measurement respectively. Whereas field apparatus was consisted of 60 m long movable stand with 40 WSPs and Cessna Model P206B agricultural aircraft with 10 atomizers cruising altitude 3 m at 175 km.h^{-1} speed. CMR values were observed at 9000 and 12000 spinner rpm as 0.008 C.kg^{-1} and 0.01 C.kg^{-1},respectively. Field experiments showed increase of 45 percent in charged spray. However, the droplet size with bipolarly charged spray showed higher value than uncharged one.

Carlton *et al.*[9] investigated an electrostatic charging of aerial spray to determine its depositional advantages. Three spray charging treatments were employed as, the use of dual power supply which provided bi-polar charge polarities of one wing-boom vs. the opposite one, low frequency alternating direct current which provided along the flight path alternating (+) and (-) sectors of unipolar charged spray and No-charging but maintaining all other parameters identical to first and second treatments. The spray deposition data was obtained by using the Leaf-wash method with fluorescence tracer. Statistical analysis indicated bi-polar charging to be superior over other two treatments, enhancing the spray deposits. The plant canopy penetration was achieved by horizontal drift forces. The research established that a level of Q/M = 2.64 mC.kg^{-1} (CMR) was required to achieve expected improvement in spray deposition on targets.

Law and Scherm [25] conducted an experiment on electrostatic application of plant disease bio-control agent against fungal infection on Blueberry. Electric characters of plant flower were determined in terms of resistance and resistivity. Application tests were carried for three setups as, hydraulic nozzle, electrostatic nozzle with charge-off and electrostatic nozzle with charge-on. Where, applied induction voltage for spray charging was set at 1.09 kV and corresponding CMR of -7.8 mC.kg^{-1}. Electrostatic charged spray application showed 4.5 times more deposition on target than other two methods and better viability for colony forming units.

Depositional Characteristics of Electrostatically Charged Spray

Law and Michael [23] conducted chargeability evaluation in laboratory with field sprayer simulator, which dispensed charged spray as it passed over stationary plants. The morphologies tested were mature cabbage, broccoli, mature cotton plants and corn plants. Three embedded-electrode spray charging nozzles were used for evaluation purpose with 73 ml.min^{-1} flow rate per nozzle, which corresponded to

9.4 $l.ha^{-1}$. The area density values of tracer particles deposited on foliar target was observed between 150 to 200 $kg.cm^{-2}$, with cloud current ranged 6 to 8 µA for electrostatic sprayer. Whereas, the depositional density was observed in the range of 50 to 75 $kg.cm^{-2}$ for conventional sprayer.

Lake and Merchant [25] conducted wind tunnel experiments for the development of mathematical model for spray deposition in barley crop with an electrostatic sprayer. They reported that charging increased deposits on vertical target and tended to decrease deposits on upper surface of horizontal targets. Both the effects were significant with the smaller nozzles and independent of nozzle height.

Law and Cooper [22] studied on mass transfer of fluorescent tracer onto front and back sides of the target deployed through a large scale grid. Mass transfer was determined for comparison between charged and uncharged spray from air-atomizing electrostatic nozzle and conventional hydraulic nozzle respectively. Depending on target location, electrostatically charged spray achieved higher deposition (1.5 to 2.4 fold over uncharged spray). The highest electro-deposition benefit was achieved on target back surfaces. Deposition of charged droplets did not surpass that achieved with 370 µm VMD droplets from conventional hydraulic orchard spraying nozzles.

Gupta *et al.*[13] conducted experiments on a prototype of hand held electrostatic spray charging unit with spinning disc atomizer. Charging system consisted of Venus C-30 power supply unit having maximum output of 3 kV and 500 µA current with 5 to 12 V DC input. The spray liquid used was deionized water with 2 g l^{-1} of fluorescent tracer (Fluorescent Sodium). The standard solvent of 2% ethanol was used to wash-off the tracer from targets. Air gap of 1.8 mm was kept between spinning disc and Aluminium ring electrode. A two-fold increase in deposition was found with charged spray than compared to uncharged one.

Walker *et al.*[41] evaluated of different pesticide spray atomizers for weed control in soybean cultivation. Research plots were consisted of 4 rows of soybean spaced at 102 cm and 18.3 m long under study period of 6 years. The spray atomizers taken into the study were rotary atomizer from Micron Corp., Sprayrite Mfg. Inc., Spraying Systems Co., Electrostatic prototype by FMC Corp., Air-atomizing nozzle by Spraying Systems Co. and Air-atomizing electrostatic prototype by Parker-Hamifin Corp. These different nozzles were compared with the conventional fan-type spray nozzle. They observed that non-conventional atomizers did not out-perform significantly as compared to conventional hydraulic sprayers based on broad leaf weed control over foliar applied chemicals.

Gupta *et al.*[13] compared the deposition pattern of charged and uncharged sprays. The charged spray was applied with a hand-held electrostatic spinning disc sprayer and uncharged spray with spinning disc sprayer and standard knapsack sprayer with hydraulic nozzle. Fluorometric analysis was followed for quantifying tracer deposition at different elevations of the plant. Droplet density was observed with WSPs placed at different elevations of plant canopy. Electrostatic charged spray application was done with 3kV charging potential, 3500 – 4500 rpm spinning disc speed and 50 ml.min-1 flow rate. The charging system provided CMR of 2.5 $mC.kg^{-1}$ approximately, with droplet size in the range of 115 – 140 µm measured by collecting droplet on MgO glass slide and analyzer. The result showed the deposition of tracer increased in 3.5 to 4.9 folds in rice crop with electrostatic spraying and 1.1 to 1.19 in soybean.

Bayat *et al.*[5] experimented on comparison between spray depositions with conventional and electrostatically charged spraying in citrus trees for pest control. Investigations were conducted with code M1 and M4with different configurations of spray application setups. The air carrier sprayer operated by standard PTO speed (540±10 rpm) was used with 2.3 mm orifice diameter nozzles with electrostatic charging system of 17 kV tension. The spraying was done at 3.5 $km.h^{-1}$ travel speed and deposition analysis was carried through fluorescent tracer, WSPs and fluorometric analysis. The relative deposition was calculated by equation

$$\text{RD}=\frac{MS}{AS/_{LAI}}X100$$

Where,
RD = Relative Deposition (%),
AS = Ideal Deposition ($µg.cm^{-2}$),
MS = Mean Stardust deposition determined by filter papers ($µg.cm^{-2}$),
LAI = Leaf Area Index (dimensionless).

The results showed that, the electrostatic application reduces losses in citrus trees by 11.6 per cent to 29.5 per cent, then the conventional spray application.

Wang *et al.*[40] investigated the effects of operating pressure and nozzle height on uniformity of spray distribution pattern under laboratory conditions using five types of $TeeJet^{R}$11004 nozzles. Nozzles were operated over three different heights (45.7 cm, 38.1 cm and 30.5 cm) and three different operating pressures (138 kPa, 276 kPa and 414 kPa). The results showed that effect of nozzle height on distribution uniformity was significant for nozzle height 30.5 cm to 45.7 cm. The results seemed to agree with manufacturer's recommended nozzle heights i.e. 38.1 cm to 45.7 cm with test data. However, effect of operating pressure found to be insignificant on distribution uniformity.

Sumner *et al.*[37] compared different spray techniques for pest management in cotton. Experiments included spray methods as air assisted spray, over the top hydraulic nozzle plus drop nozzles, electrostatic air assisted spray, over the top hydraulic nozzles and over the top plus shielded drop nozzles. Water sensitive cards and Leaf-wash method was used to quantify the droplet deposition in various techniques. WSPs were placed into the canopy, top side and middle portion of canopy on both upper and undersides of leaves. Results have shown that electrostatic air assisted spray technique provided better coverage and lowest standard deviation in spot diameter (77 μm and 60 μm for top and underside respectively) than other methods.

Kirk *et al.*[17] evaluated the performance characteristics of aerial electrostatic spray system with different fields of cotton for control and management of Ball weevil and Whitefly. The prototype was studied at laboratory on the basis of commercial version of aerial electrostatic spraying system. Charge to mass ratio was assessed for corresponding flow rates, spray mixture and pest mortality. The prototype aerial electrostatic spray charging nozzle system was mounted on Cessna T1888C Ag-Husky, agricultural aircraft (231 kW, 12.74 m wingspan), calibrated for 9.4 lit. ha^{-1} at 483 kPa and conventional spray system calibrated for 46.8 lit. ha^{-1} at 193 kPa. Spray droplet deposits with Caracid brilliant flavine dye were collected with six water sensitive papers per plant at random locations and quantified by dye fluorometry. They found higher pest mortality in electrostatic aerial spray as 96.60 percent compared to conventional spraying with 76.60 percent pest mortality.

Laryea and No [20] investigated the spray characteristics of charge injected electrostatic pressure swirl nozzle for oil burner for agricultural product drying. Experiments were conducted with direct nozzle charging of hydrocarbon fuel with negative polarity. A point sharpened tungsten wire with 1.0 mm diameter was used as an electrode and placed concentrically inside fuel supply pipe. Fuel injection pressures ranging between 0.7 to 0.9 MPa with flow rates between 69.0 to 77.6 ml.min^{-1} were used. The electrode was connected to variable DC high voltage from 4 to 12 kV and Faraday pile connected with digital electrometer was used to collect spray charge. Experiments reported that electrical breakdown occurred at 10 kV at injection pressure lower than 0.9 MPa; while at injection pressure equal to 0.9 MPa electrical breakdown of fuel occurred at 12 kV.

Tong-Xian *et al.*[38] conducted experiments on spray deposition over plant foliage with self-adhesive paper targets. Self-adhesive paper micro-slide labels were used as the targets to evaluate spray coverage on tomato and citrus plant foliage. On both, upper and under leaf surfaces, self-adhesive papers were pasted randomly throughout the plant canopy before spray application. The spray solution was consisted of Brilliant blue dye (FD&C No.1) as a tracer in aqueous base. The tracer dye deposited on labels was then subsequently eluted into vials of water (20 ml) after spray application and the concentration of the rinsate obtained therefore was determined by spectrophotometry. Also, the spray coverage was evaluated for comparison with same sized WSPs stapled onto the leaves. Comparatively more dye was recovered from labels than the actual plant leaves and recovery by two methods was correlated using yellow WSPs i.e. r-value = 0.83 to 0.99. Dye recovery was also correlated with the coverage measured using WSPs i.e. r-value = 0.72 to 0.95.

Latheef *et al.* [21] conducted experiments on aerial electrostatically charged sprays to find its efficacy against fruitfly on cotton. Cessna AgHusky Agricultural aircraft equipped with spray boom was used for the application with 1.5 to 2.0m boom height above the crop canopy. The spray boom was engineered to achieve application rate of 4.68 l. ha^{-1} and assembled with 82 and 32 nozzles at 482.7 kPa and 193 kPa operating pressure respectively, with bipolar charging system of +5 kV potential. Six leaf samples were collected after application from top and mid-canopy locations randomly from the plot and tracer deposition was measured with Turner Digital Fluorometer (Abbott Diagnostics, C.A.) in terms of kg.cm^{-2}. They observed that there was no significant difference between charged and uncharged sprays.

Barbosa *et al.*[4] conducted study on deposition and canopy penetration of different sprays in soybean (Glycine Max-L). Artificial mylar cards and tetrazine tracer were used to quantify the distribution and penetration performance. The equation used for converting sample concentration results in units of volume per unit area was,

$$Deposit = \frac{C\ x\ V}{\rho\ \mathrm{X}\ \mathrm{A}}$$

where, Deposit is the final concentration, C is the tracer concentration obtained through laboratory analysis (mass.l^{-1}), V is the solvent volume, ρ is the original concentration of solution (mass per unit volume) and ,A is the target surface area. Multiple comparisons on means were made using Fisher's Test of Least Significant Difference (LSD).

Celen *et al.*[10] studied the effect of air assistance on deposition characteristics of tunnel type electrostatic sprayer. The sprayer was attached to a 55 kW tractor and having 0 to 17 kV power supply unit with 12 V DC input. Vineyard sprayer having 50 $l.min^{-1}$ discharge rate at 2 bar pressure and operated on crop position of 3 m × 1.5 m and 1.2 m height. Air support system was used having 710 mm diameter fan and air flow rate of 600 $l.min^{-1}$ at 36 $m.s^{-1}$ air velocity. Tetrazine food dye was used as a tracer. Deposition was increased by 7.8 % with air support and 23.5 % reduction in drift.

Jaworek *et al.*[14] conducted study on electrostatic spraying of nano-thin films on metal surfaces. The electro-spray system was consisted of stainless steel (SS) capillary nozzle and heated stainless-steel table of 120 mm diameter. The distance between nozzle tip and the table was kept 15 mm and 25 mm. The substrate was SS rectangular plate of 500 µm thickness and 25 mm x 30 mm dimensions. The solvent was evaporated from the spray solution by providing an electric heater placed beneath the table. The nozzle was connected to the HVAC-DC generator Model-P04015 TREK, switched to positive polarity while plate and the extractor were grounded. The spray plume was recorded using CCD Camera Model-NG-VS400, Panasonic Inc. Methanol was used as the solvent and MgO particulates of size 100 nm as solute. The DC bias was in the range of 5.7 to 6.3 kV and AC in 1.5 to 4.0 kV at liquid flow rate of 1.5 $ml.h^{-1}$. The results showed homogenous metal-oxide films on substrate of thickness 1 – 2 µm.

Mishra *et al.*[29] evaluated the performance of electrostatic spraying in orchards with USA made ESS-MBP electrostatic sprayer. Tests were carried out with various experimental combinations of WSPs mounted on leaf top and leaf underside at distinct portions of plant canopy as top, middle, bottom and dense parts. Droplet density and uniformity coefficient for corresponding portions were obtained with the help of PC-assisted Stereo zoom microscope CCD camera and compared between electrostatic (single and twin nozzle) spray and conventional non-electrostatic spray. They found that average droplet density on upper and underside of leaves was substantially higher in charged spray i.e. 57.53 percent and 59.60 percent, respectively than uncharged spray method.

The Electrostatic Induction Charging (EIC) system technique has no direct contact with the working fluid, the probability of having high voltage shock to the operator are negligible and the power consumption is also significantly smaller than the other methods. The techniques were studied for the research owing to its highest suitability for charging agricultural spray liquids to be used for spraying.

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