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Review Article

Electrostatic Spraying System: A Revolution in Agricultural Spraying

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Abstract

Electrostatic spraying is a recent and essential technique used in crop production for efficient and practical application of plant protection products. The spraying process involves charging the droplets from the sprayer with an electrical charge. The charged droplets are attracted to the plant surfaces, resulting in a more uniform and complete coverage than traditional spraying methods. Compared to hydraulic sprayers, electrostatic sprayers produce ultra-fine droplets that are up to 900 times smaller, achieving more than twice the deposition efficiency while reducing water consumption by up to tenfold. This improved coverage lowers pesticide usage by 25–50%, decreases costs, and enhances control of major pests and diseases such as downy mildew, late blight, thrips, aphids, and weeds. Ultimately, this technology offers several benefits, including decreased pesticide usage, reduced drift, reduced pesticide exposure, and improved efficiency. By reducing the amount of pesticide used, electrostatic spraying helps to promote environmentally friendly farming practices. Hence, the utilization of electrostatic spraying has emerged as an essential step towards efficient and sustainable agricultural practices, ensuring the safety of the environment and farmers.

Keywords: Electrostatic Spraying; Agriculture; Pesticides; Human Exposure; Environment

Introduction

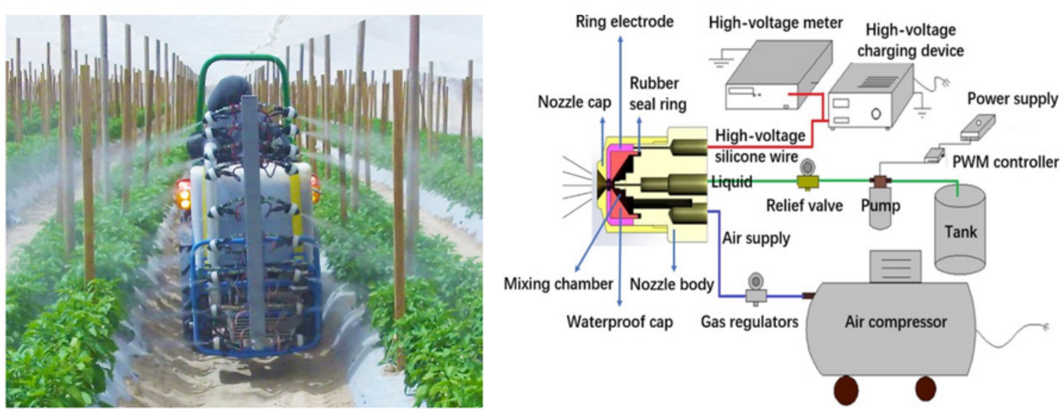
Spraying pesticides plays a crucial role in improving agricultural production and crop quality. However, overuse of pesticides and inadequate spraying equipment can pose serious risks to human health and the environment [1,2]. Appropriate spraying technologies are essential to reduce off-target deposition [3,4]. Traditional application methods, such as backpack sprayers and PTO-driven boom sprayers, present several challenges, including spray drift, non-uniform coverage, and excessive pesticide use. These limitations increase production costs, reduce efficiency, and raise concerns for environmental safety. Appropriate application strategies, including the consideration of crop canopy structure, leaf characteristics, and climatic conditions, can help to address these challenges.

Electrostatic spraying technology, developed in the early 1930s, offers a promising solution. This method charges droplets with static electricity, creating an attraction between the spray droplet and plant surfaces. As a result, the droplets achieve better adhesion and penetration, even on hidden leaf surfaces. Electrostatic sprayers improve deposition efficiency, reduce pesticide consumption, and minimize drift. Consequently, they reduce environmental contamination and human health hazards. For crops and orchards, electrostatic spraying is now recognized as one of the most advanced and practical application techniques.

What is electrostatic spraying?

Electrostatic spraying using air-assisted sprayers provides a much more effective use of chemicals than conventional spray equipment and is highly efficient in controlling insects and diseases while reducing waste. Electrostatic sprayers produce negatively charged droplets as they pass by an electrode, causing them to be attracted by the target (plant) due to its negative charge. This electrostatic attraction is about 75 times stronger than gravity, allowing droplets to wrap around leaves and coat all sides, including undersides where most insects reside. Small droplets with high charges have a strong electrostatic attraction towards the plant surface. They can reverse their flow direction and move upward against gravity to coat under leaves and hidden surfaces.

Figure 1 illustrates how charged droplets envelop plant surfaces to achieve uniform coverage. The field sprayer deposits droplets evenly across the crop canopy (Figure a), improving pesticide coverage on both top and underside of leaves, while reducing chemical loss and environmental contamination. Figure 1b illustrates the Schematic diagram of an air-assisted electrostatic spraying system. The setup consists of a liquid supply unit, an air compressor with regulators, and a high-voltage charging device connected to the nozzle. Liquid is pumped into the nozzle and atomized by high-speed airflow, while the ring electrode charges the droplets through induction. A PWM controller regulates flow rate, and a high-voltage meter monitors charging conditions for safe and efficient operation. The air stream carries charged droplets to plant surfaces. This technique improves adhesion, reduces spray drift, and ensures target surface coverage.



a. Application of chemicals using an electrostatic spraying system

b. Schematic diagram of an air-assisted electrostatic spraying system

Figure 1: Electrostatic spraying system [5].

Working of electrostatic spraying

An electrostatic sprayer operates on the principle of Coulomb's law. According to Coulomb's law, "If the two charges have the same sign, the electrostatic force between them is repulsive; if they have different signs, the force between them is attractive". A negative charge is imparted to the droplets as they exit the nozzle. These charged droplets are attracted to the positively charged leaf surface, ensuring thorough coverage of the leaf. Once the droplet lands, it loses its charge immediately.

During operation, the liquid is first atomized by a hydraulic nozzle or air-shear nozzle for the formation of optimum-size droplets. As the droplets pass by an electrode, electrons are induced into the liquid stream, leaving the droplets highly negatively charged.

These droplets are carried in an air stream toward the target. Small droplets (30-40 microns) with high charges exhibit a strong electrostatic attraction towards the plant surface. They can reverse their flow direction, moving upward against gravity to coat underleaf and hidden surfaces. The working of the electrostatic sprayer is shown in figure 2.

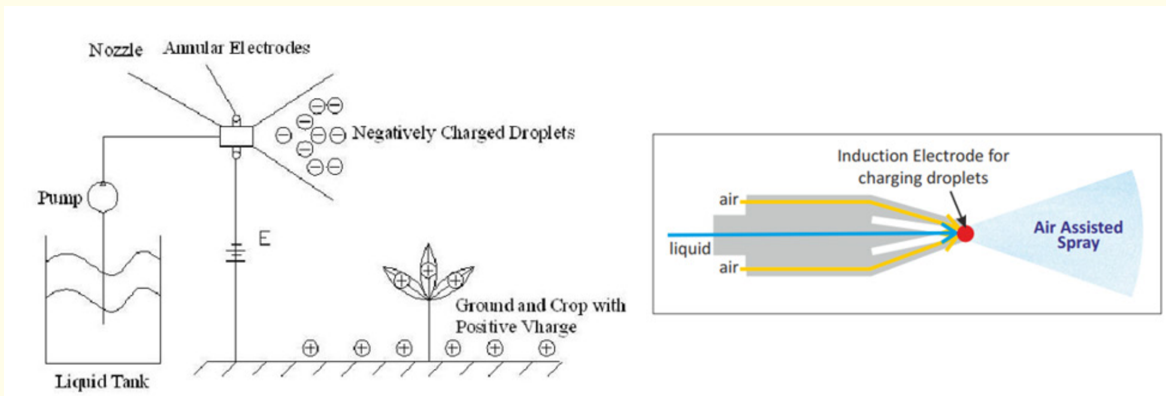


Figure 2: Working of electrostatic sprayer [6].

Methods of charging the spray

There are three ways to charge the liquid

- **Induction charging-** When a high-voltage electrode, positioned close to where spray liquid is emitted from a nozzle, is positively charged, a conductive water-based pesticide spray at earth potential has a negative charge induced on its surface by the attraction of electrons. This method involves applying a non-contact charge to a spray fluid that is moving through a high-voltage electrical field. The operator has a minimal risk of receiving a high-voltage shock from this method because it doesn't come into direct contact with the working fluid, and it also uses less power than other methods. This is the most suitable method for charging agricultural spray liquids. The configuration of the inductive electrostatic sprayer is shown in figure 3.

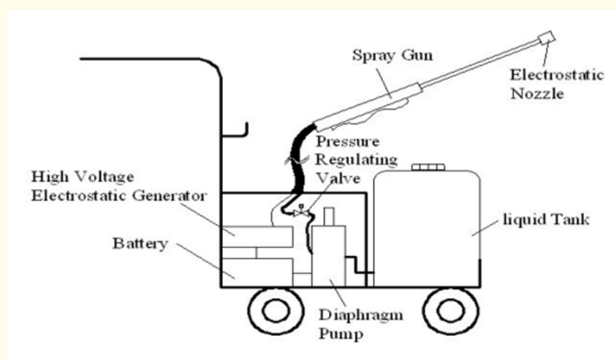


Figure 3: Configuration of the inductive electrostatic sprayer [7].

- **Ionized field charging-** A high voltage applied to a pinpoint can create an intense electric field around it that suffices molecules of the surrounding air. A positively charged conductor will repel the positive ions created. At the same time, the electrons that are released in the ionization process will be attracted to the conductor and neutralize some of its charge. This method requires a higher power supply (30 to 70 kV) and poses the hazard of high-voltage shock to the operator.
- **Direct charging -** When a semi-conductive spray liquid, with an electrical resistivity in the range 104- 106 Ω m, is

exposed to a high voltage (15-40 kV) as the liquid emerges through a narrow slit, mutual repulsion between different portions of the liquid overcomes surface tension and ligaments are formed. These ligaments break up into droplets due to axisymmetric instabilities. The level of charge on the droplets represents the maximum that can be attained and is called the Rayleigh limit.

Comparative analysis of various charging methods is given in table 1.

Criteria	Induction Charging	Ionized Field Charging	Direct Charging
Principle	High-voltage electrode induces opposite charge on conductive spray liquid without direct contact.	High-voltage point creates an intense field, ionizing air molecules, which charge droplets.	Spray liquid is directly exposed to high voltage; ligaments are formed and break into charged droplets.
Power requirement	Low (5-15 kV)	High (30-70 kV)	Medium to High (15-40 kV)
Safety	Very safe No direct liquid-voltage contact. Low shock risk.	Risky Strong ionized field. Higher chance of operator shock.	Moderate risk Liquid in direct contact with high voltage.
Suitability	Highly suitable for agriculture.	Less suitable for agriculture. Mainly used in industrial or specialized spraying.	Suitable for agriculture but less preferred.

Table 1: Comparative analysis of various spray charging methods.

Benefits of electrostatic spraying

- **Enhanced coverage:** In the electrostatic sprayer, droplets are uniformly distributed on both the front and back surfaces of the leaf, ensuring better coverage, including hidden areas. In contrast, the conventional sprayer shows uneven deposition with larger droplets mainly concentrated on the upper surface, leaving the underside insufficiently covered (Figure 4). The electrostatic sprayer provides 4 times better coverage on leaves than conventional spraying.
- **Improve application efficiency:** Electrostatic spraying reduces overspray, runoff, and drift, resulting in more efficient use of chemicals. Net chemical savings of 40-50% (Anonymous, 2018) [7] and 6 times better penetration into the canopy.
- **Reduction in soil deposition:** The deposition of liquid in the foliar part increased by 2 to 3 times when using an elec-

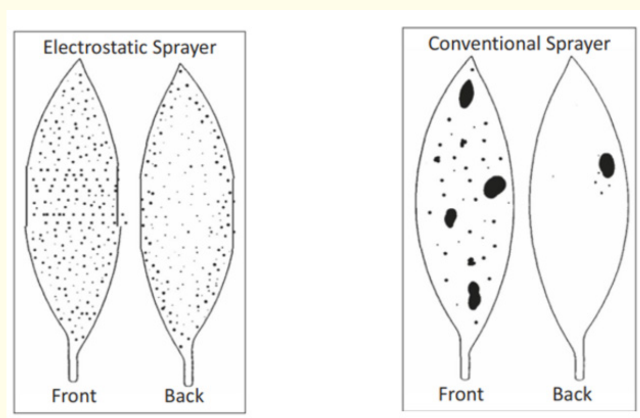


Figure 4: Comparison of spray deposition.

trostatic application, compared to a non-electrostatic nozzle under the same conditions. As shown in figure 5. Electrostatic spraying resulted in significantly higher foliar deposition (1.38 ng cm^{-2}) compared to hydraulic spraying (0.31 ng cm^{-2}). In contrast, soil deposition was considerably lower with electrostatic spraying (0.19 ng cm-2) compared to hydraulic spraying (1.65 ng cm-2), indicating reduced chemical loss to the ground and improved application efficiency. It is also reported that electrostatic spraying reduces soil deposition by 9 times compared to a conventional nozzle.

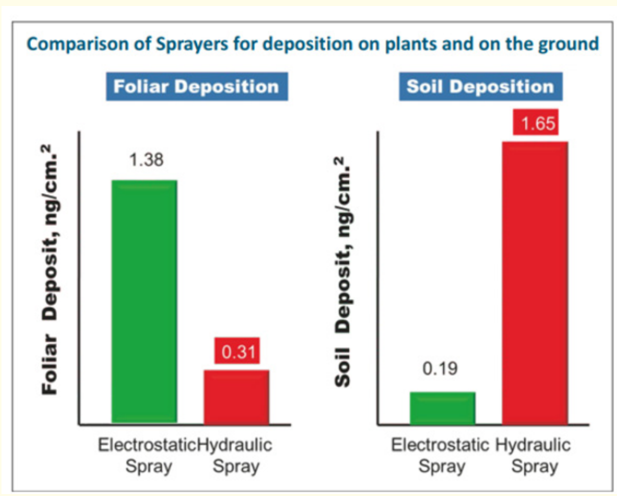


Figure 5: Comparison of sprayers for deposition on plants and on the ground.

- **Reduce labour:** Due to reduced spraying time and fewer tank fills, labour requirements are reduced, as well as more area covered per day. Also, electrostatic spraying can reduce the risk of exposure to chemicals for operators.
- **Environmentally friendly:** By minimizing overspray and drift, electrostatic spraying helps to protect non-target areas and reduce chemical contamination of water bodies
- **Low volume and high yield:** Electrostatic sprayers use less water to dispense a given amount of chemicals. For example, growers use from 1 to 3 gallons of water per 10,000 sq. feet compared to a traditional sprayer that uses 25 to 75 gallons for the same area.
- **Cost saving:** The improved efficiency and reduced chemical usage of electrostatic sprayers can lead to significant cost savings, and no additional expenditure in the use of wetter/spreader/sticker.

Table 2 represents the benefits of electrostatic spraying over conventional spraying.

Benefits	Quantitative result
Chemical saving	40-50%
Increase in foliar deposition	2-3 times
Reduction in soil deposition	9 times
Increase chemical coverage on the leaf	4 times
Increase in canopy penetration	6 times

Table 2: Benefits of electrostatic spraying over conventional spraying.

Limitations of electrostatic spraying

- **Limited range:** The effectiveness of electrostatic spraying diminishes as the distance between the nozzle and the target surface increases. This is due to the dissipation of the electrostatic charge over longer distances. Also, if the target surface is at a considerable distance, then the droplet will be attracted towards the nearest surface available, so it will not reach the target. Sasaki., *et al*. (2013) [8,9] reported that by increasing the spray distance, the charge-to-mass ratio decreases. For the closest distance (0 m) to the target, the Q/M ratio was 4.11 m C kg^{-1}, and at distances of 1, 2, 3, 4, and 5 m, the ratio decreased to 1.38, 0.64, 0.31, 0.17, and 0.005 m C kg^{-1}, respectively.
- **High initial cost:** Electrostatic sprayers tend to be more expensive than traditional sprayers, both in terms of purchase and maintenance.
- **Sensitivity to humidity:** High humidity can reduce the effectiveness of the electrostatic charge. Moist air can cause the charged droplets to clump together, reducing their abil-

ity to coat surfaces evenly. Recent trials in humid tropical regions reported 30% lower electrostatic efficiency due to droplet clumping.

- **Skill labour required:** Operators must have some level of technical expertise to use and maintain the equipment effectively, which may involve additional training and costs.
- **Power requirements:** These sprayers usually need a power source to charge the droplets, making them dependent on batteries or electricity, which might not be available in all agricultural fields.

Conclusion

The key to efficient spraying lies in achieving a uniform and targeted distribution of liquid. Uneven coverage leads to waste, increased costs, and unnecessary environmental contamination. Electrostatic sprayers produce "extremely fine" or "very fine" droplets. Unlike conventional sprayers, which are not able to direct droplets precisely to the target, electrostatic sprayers use a gentle airflow to carry charged droplets directly to the target surface. Hermosilla et al. (2022 reported that handheld electrostatic sprayers increased canopy deposition by 1.48 times, reduced the application rate by 48%, increased the underside leaf deposition by 1.78 times, and decreased ground loss by 36.36% compared to traditional handheld sprayers. Similarly, in controlled conditions, droplet deposition can be increased by 40-50%. Still, in actual field conditions, several factors, such as wind speed, crop canopy density, and humidity, may affect the uniformity of deposition and the penetration of the electrostatic sprayer. Therefore, comprehensive field trials across diverse cropping systems are required to validate the practical efficiency of electrostatic spraying. Apart from several limitations, the electrostatic sprayer has lots of potential in agriculture and can be said to be a revolution in plant protection sprayers.

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