Chapter

Advancements of Spraying Technology in Agriculture

Fiaz Ahmad, Aftab Khaliq, Baijing Qiu, Muhammad Sultan and Jing Ma

Abstract

Plant protection activities are most important practices during crop production. Application of maximum pesticide products with the sprayer. The application of fungicides, herbicides, and insecticides is one of the most recurrent and significant tasks in agriculture. Conventional agricultural spraying techniques have made the inconsistency between economic growth and environmental protection in agricultural production. Spraying techniques continuously developed in recent decades. For pesticide application, it is not the only sprayer that is essential, but all the parameters like the type and area of the plant canopy, area of a plant leaf, height of the crop, and volume of plants related to plant protection product applications are very important for obtaining better results. From this point of view, the advancement in agriculture sprayer has been started in last few decades. Robotics and automatic spraying technologies like variable rate sprayers, UAV sprayers, and electrostatic sprayers are growing to Increase the utilization rate of pesticides, reduce pesticide residues, real-time, cost-saving, high compatibility of plant protection products application. These technologies are under the "umbrella" of precision agriculture. The mechanized spraying system, usually implemented by highly precise equipment or mobile robots, which, makes possible the selective targeting of pesticide application on desire time and place. These advanced spraying technologies not only reduces the labour cost but also effective in environmental protection. Researchers are conducting experimental studies on the design, development and testing of precision spraying technologies for crops and orchards.

Keywords: Protection, Ground Sprayer, Aerial Sprayer, Variate Rate Sprayer

1. Introduction

Pesticide applications are considered significant during the plant protection practices in current agriculture. Efficient use of pesticides can helpful to control plant pests and diseases to increase the crop yields [1]. The use of agrochemicals can effectively enhance the quantity and quality of crops, however, it increases the environmental risks in recent years [2]. Pesticide application utilizes the to a significant percentage of the production cost [3]. During chemical plant protection practices, over application of pesticide or inefficient spraying equipment may cause serious issues on human health and the environment [4]. Effective pesticide application is a critical activity during crop production season that requires efficient spraying machinery with proper calibration as well as relevant regulations to reduce off-target spray deposition. Thus, the significant among all the factors which are influencing the degree of off-target spray deposition is the design and application spraying technology [5]. Spray drift is not only the loss of spray but also risk for the environment and residents [6]. Spray drift may influenced of many factors such as equipment and technology, spray characteristics and operator skill and performance [7]. Some other microclimatic factors which also influence the degree of drift such as wind speed, direction, relative humidity and temperature [8]. Spraying technology aims to effectively and economically application of the precise quantity of the chemical to the set target with minimum threat for the environmental pollution [9]. Conventional agricultural pesticide application practices have developed a contradiction among the yield enhancement, cost effectiveness and environmental protection [10]. Therefore, pesticides have to be applied using suitable spraying systems to avoid adverse effects on environment as well as human health [11]. Thus, in recent decades, spraying methods and technologies have been undergoing continuous evolution [1]. Conventional sprayers were very laborious and require very heavy machinery to operating them in the field. They increase the application amount because of no proper application method for spraying nozzles, crop foliage detection, and weather parameters. The canopy and foliage vary from plant to plant and crop to crop. There were very serious issues in spray uniformity and spray loss in the form of spray drift which was not measured with conventional sprayers like backpack sprayers, and PTO driven boom sprayers. Geometric and structural parameters of plants and crops are conventionally attained using time-consuming and costly manual measurements approaches. But with the advancement in spraying technologies measurement of these parameters becomes very easy with using sensors technology. Advancement in spraying shifts the pesticide application technology on Variate rate sprayers, electrostatic sprayers, and UAV sprayers. These technologies change the pesticide application scenario with the use of IoT sensors for pest and weeds detection, plant canopy and foliage measurement, leaf structure calculation, and weather parameters sensing and apply measure amount of pesticide on required part of plant and crops. With the use of advanced sprayers, the effect of pesticide exposure on the environment, water, and soil contamination reduces with the reduction of spray drift and overdose of pesticide application by the control pesticide applied spray nozzles and quick detection of structure and geometry of crops and plants canopy. In conventional sprayers these flow control nozzles, sensor technology would not be used because of this these sprayers are not working efficiently in the field and produce more amount of drift and increase pesticide amount and less effective for pests, and insects. By changing this technology with sensor base variate rate and aerial spraying technology the life of agriculture framer improves with good production of crops, less and effective pesticide use, and real-time application of pesticides.

In recent years variable spray technology has attract researchers as well as farmers and showed great advancement in the development and utilization of technology variable rate sprayers in terms of target detection technology, based on real-time sensors. Sensors are (Ultrasonic sensor, Infrared sensor, LiDAR sensor) used in variable sprayers for the feature detection of the target area. The process of spray device control unit adjusts the real-time application of spray rate and allows accurate sprays which are essential on canopy [10]. To enhance the spraying efficiency and droplet deposition for tree crops, the measurement of the plant canopy is a critical consideration because the geometry of the plant canopies variable in height and width [12]. Variable spraying technologies are most useful for orchard and vineyards as this technology increases the spray deposition rate in the target zone and reduces the off-target application. Variable-rate spray technology is growing rapidly because it reduces pollution during spray application. Electrostatic spraying system was firstly designed and developed in the early 1930s. The aim of Electrostatic sprayers to increase spray deposition and penetration in the canopy. Electrostatic sprayers technology consists of static electric charge in every drop which emits from the tip of the nozzle, which develop the force of attraction between the droplet and plant that has a neutral charge. In this spraying system air injects into the spray nozzle to the high energy charge of the drops causes them to reach the plant very fastly, before the volatilization of the drop. In addition, all the drops which emit from the spray nozzles have the same charge which causes repulsion between the drops and safely uniformly reached the plant leaf even in more hidden regions. This due to electrostatic sprayers has high spraying efficiency and save the amount of pesticide requirement. Electrostatic method of pesticide spraying decreases drift, environmental pollution, and human health risks. Electrostatic sprayers are also called ultra-low volume sprayers because it uses 5 L/ha pesticide solutions and produces fine drops with a diameter between 50 and 120 microns but on the other side in high volume spraying, the application rate is >400 L/ha, droplet sizes vary from 300 to 500 μm and gun sprayers are used and low volume spraying, the application rate is 50 to 400 L/ha and droplet sizes vary 125 to 250 μm. Electrostatic spraying in agriculture is not a new technique but is promoted to work on electrostatic spraying technique development in the technology of production and environmental concerns [13]. Thus, electrostatic spraying system is considered as most advanced spraying machinery for efficient application of pesticides to crops and orchards.

To avoid the health problems of humans with the manual spraying mechanism Unmanned aerial vehicles (UAV) aircraft are used. The equipment and labors difficult to operate but UAVs can be used easily operated in the field. UAVs now widely applied in field for purpose of precision agriculture in the developed countries. Before that, a variety of UAV models are utilizing for civilian and military purposes [14]. Addition of vision and sensor systems are also increase the potential of the UAVs [15] and reduces the spray loss in form of spray drift by accurate spray application on the required field with perfect target detection sensors and a good handling system. Advancement in spray application technologies increase crop production and increase pesticide efficiency on weed and insects in the field. Spray loss in the form of spray drift, weather effects, target detection, and control flow nozzles problem solved by advanced pesticide application technologies. The time-consuming problem for tank refilling is reduced with ultra-low volume sprayers and fine droplet spray nozzles. With time the crop maintaining technology advance from weeds and pest, detection to spray application nozzles. The objective of this chapter to highlight the advanced spraying technologies use for the agriculture pesticide application to improve the spray deposition penetration in the plant canopy, reduces the spray drift, and provide a comprehensive understanding of the spraying process from machine to target for improving fruits, vegetables, and cereals crop production.

2. Ground sprayers

2.1 Crop sprayers

The use of herbicides and pesticides has made sure to improve the yields from crops until now have been an overdose of pesticides and herbicides causing herbicide-resistant weeds and a very big decrease in biodiversity. At the early stage of the crop, when herbicide application takes place the detection of weeds is very difficult to identify because they are so small especially. Using conventional spraying (Knapsack, Boom sprayers) technology for the crops (**Figure 1(a)** and **(b)**), farmers lose money on herbicides and pesticides that are sprayed ineffective. Over spraying, of pesticides and herbicides put a squeezing impact on the agriculture farmers. Farmer spends a lot of money on pesticides, but a huge volume of these chemicals never reaches weeds and pests with the use of conventional sprayers. The maximum amount of spray not reached at the target and spray loss in the form of spray drift and field turns because of no path planning and GPS survey of the field. The reason for this inefficiency lies in the poor precision of broadcast sprayers. In old times farmers were in difficulty because the weeds a pest was damage the crop production. The technologies were not so fast to detect the accurate weed and pest target and apply the plant protection product inefficient way which causes the spray loss in the form of spray drift and environmental contamination. In recent past, a smart spraying technology (Variable sprayer, Drones Sprayers) has been introduces that uses sensors and artificial intelligence technology. This technology has a number of advantages such as when it detects plants, weeds, and pests, then selectively apply chemicals where needed. Firstly, the image is recorded using camera or detected plant by using the sensor, after that deep learning algorithms are used for identification of different plants and diseases which helps to decision support system to fix the target. The algorithms automatically choose the plant/herbicide to spray. **Figure 1(c)** shows a schematic diagram of a smart sprayer. The advance sprayer technologies are designed keeping in future crop production requirement under the sustainable agricultural goals along with protecting the environment and reducing costs for farmers and food production. The current technology (4G LTE, and 5G cellular) in agriculture protection change the conventional methods for crop monitoring and applications of pesticides and weedicides on the target area with high accuracy. In the spread field crops like (vegetables, wheat, rice, and cotton), weeds and pests have very good conditions to grow.

2.2 Orchard sprayers

For the orchards and vineyards, a powerful and effective plant-protection method is extensively adopted to attain higher quantity and quality of the production [16]. For the orchard and vineyard, it was difficult to apply spray on the whole

Figure 1.
Cotton filed using Knapsack sprayer (a) wheat field using boom sprayer (b) schematic diagram of smart sprayer (c).

area of the plant because of the shape and size change from plant to plant. It was very difficult in old times when no proper sprayers design for orchard spraying. By the advances in mechanical equipment during the period from the 1890s to 1940, some improvement in sprayers such as steam power, gasoline engines, pressure regulators, and the adjustable spray gun use to apply pesticide sprays to trees [17] as shows in **Figure 2**. Tree structure such as size, shapes and density of canopy significantly vary during different growth periods and different locations [18] thus, it need special operating parameters of sprayer (flow rate and air flow) along the adjustment facilities to match the geometry of the plant [19]. These parameters cannot be calculated with conventional spraying equipment because Conventional orchard sprayers applied pesticides continuously and do not have variable rate capability which causes environmental pollution [20] and human health hazards with producing a huge amount of spray drift.

To enhance orchard sprayer performance a number of new mechanisms have been introduced such as, an automatic variable-rate (VAR), Electrostatic, air-jet, air assisted and air blast systems. Which facility the effective spray penetration in the plant canopy and reduced the spray loss [19]. Real-time sensor are used for the detection of canopy features (density, size, shape and height) for proper spraying fluid control [21]. Thus, the characterization of the plant and crop is the basic concern for pesticide applications. As the true information of the geometrical features of the crop allows enhancing spraying performance and to reduce environmental and economic impact [22]. For the detection of plant geometry, many sensors are used like ultrasonic sensors, Infrared sensors, LiDAR sensors, and computer vision-based technology used. Ultrasonic sensor detects the target distance from the sprayer however it is sensitive to environmental conditions such as humidity and temperature, and [19]. The infrared sensor is an electronic sensor that detects the target area with measures infrared light radiating from objects in its field of view [23]. LIDAR sensor technology is an accurate remote sensing technique for distance measurements It has good accuracy for the detection and quantification of biological and nonmetallic objects [24]. LIDAR sensor measures the distance of the elapsed time between the transmission of a pulsed laser beam and the reception of its echo from a reflecting object [23]. In computer vision-based technology, the cameras are inserted on sprayers which segregate the physical parameters of the plant-like area, height, density, and color of the plants as shown in **Figure 3.**

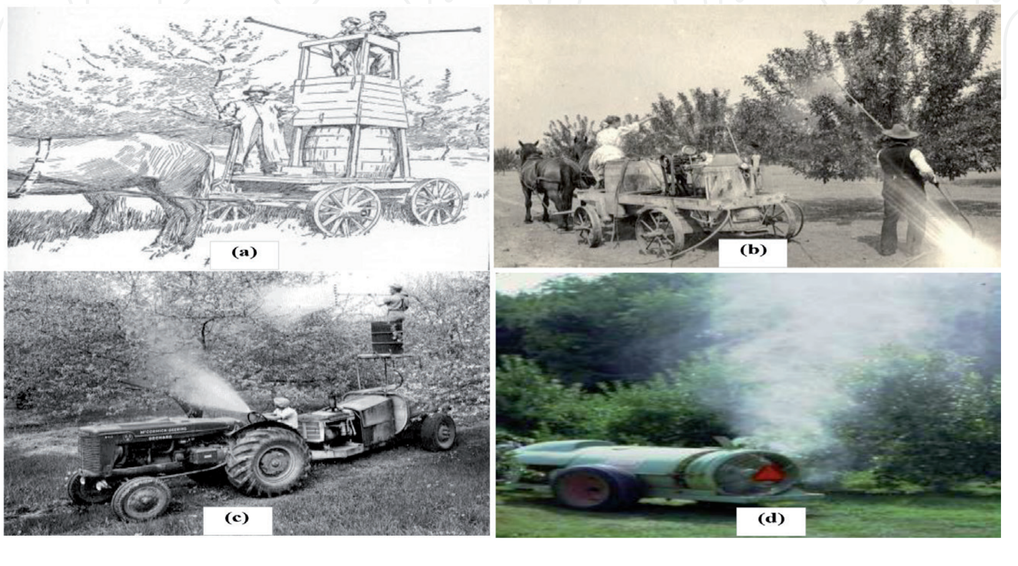

Figure 2.
Old sprayers for orchard spraying (a) hand operated sprayer (b) steam power sprayer (c) pressure regulator engine sprayer (d) conventional VRT sprayer [16].

Several types of variable rate sprayers use for orchard sprayings like air-assisted variate rate sprayer, Tunnel sprayer, tower sprayers, axialf fan air blast sprayers, canon air blast sprayers, and Electrostatic sprayers are shown in **Figure 4**. These sprayers apply a measurable amount of pesticide with proper target detection and save the number of pesticides by reducing spray drift. Air assisted sprayers are mostly used for the fruit trees. Variable air assistance (VAA) system consists of incessant real-time air volume control attached on both sides of the sprayer. A double axial fan arrangement is used which permits remote adjustment of air volume. These sprayers apply pesticide parallel to the plant and cover the maximum area of the target but throw the spray with fan circulation away from the target which produces some airborne drift. Variable sprayers are not used in high humidity and temperature conditions. Tunnel sprayers are very famous in small fruit trees (apple,

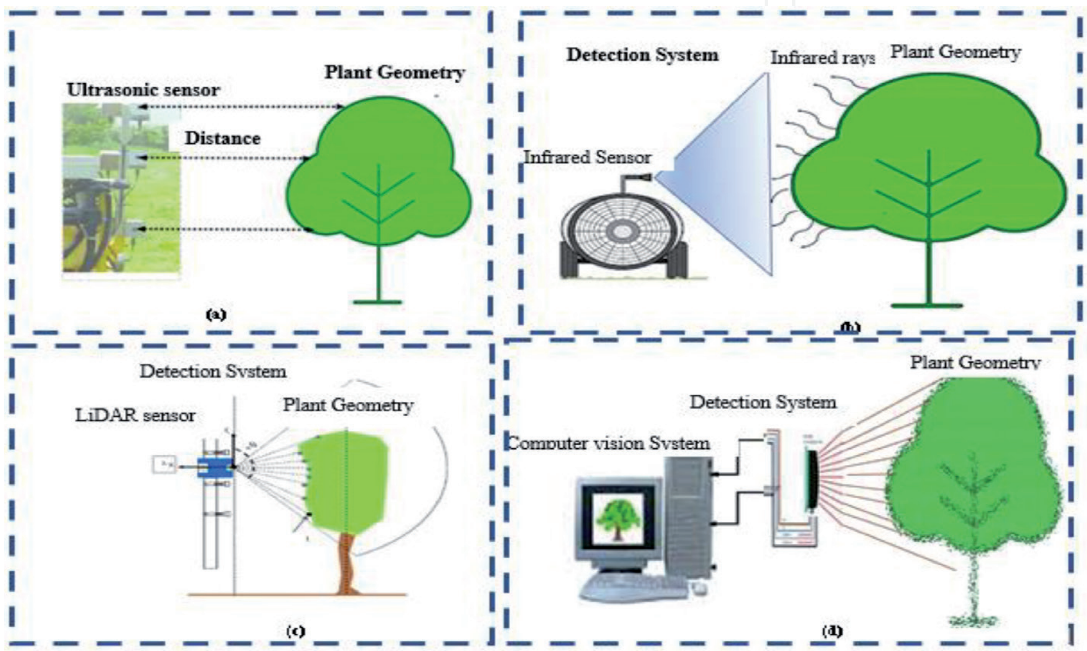

Figure 3.
Sensor based VR sprayers. Ultrasonic sprayer (a) infrared sensor sprayer (b) LiDAR sensor sprayer (c) computer vision based spraying technology (d).

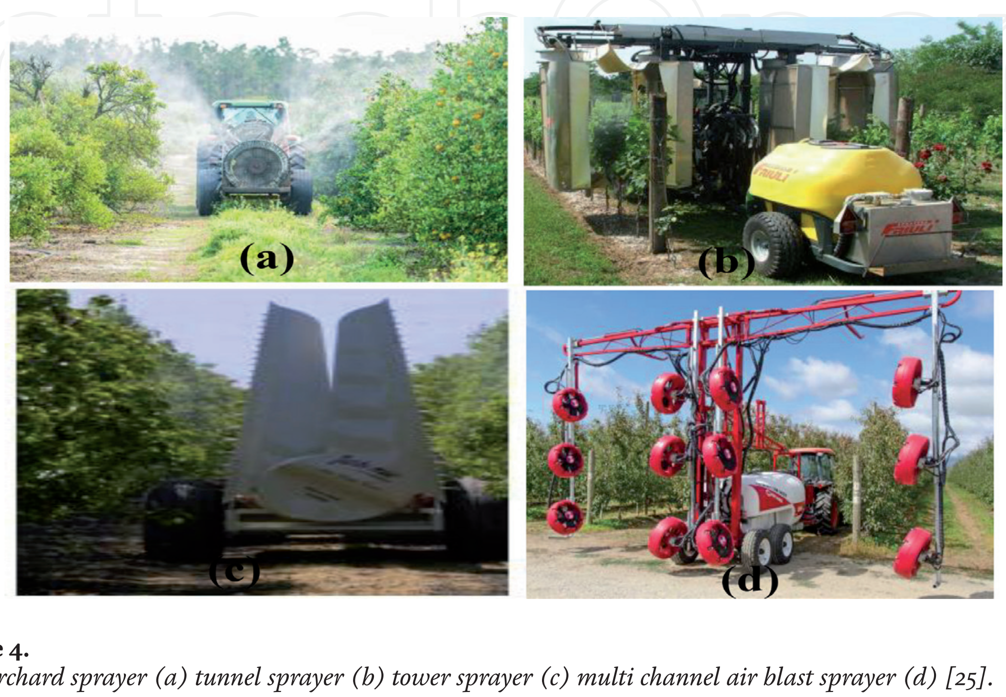

Figure 4.
VAA orchard sprayer (a) tunnel sprayer (b) tower sprayer (c) multi channel air blast sprayer (d) [25].

vineyard) growth for the last few decades. Tunnel sprayer technology has long been recognized as an important tool to reduce both airborne drift and soil contamination [26]. Tunnel sprayer is enclosed target spray application technology. Some tunnels sprayer work on the recirculation principle to recycle the extra spray from the target area. Tunnel sprayers are feasible for working in every weather condition. Tower sprayers are air assisted type sprayers that discharge the spray horizontally with the direction of airflow from the fan into horizontal conductus on the vertical level. Tower sprayers are used for very high plants. Canon air blast sprayers consist of cylindrical outlets that create high air velocity jets that break spray mixture into fine droplets and penetrate the spray into the canopy. The canon sprayer can cover the maximum spray area and often use in orchards where the conventional air blast sprayers are not feasible for the spray to the crops. Due to high air velocity in the air blast sprayer, throw spray can enter into the canopies and improve spray deposition on the plant leaf and reduce the spray drift. Variable rate sprayers produce very fine (150 to 250 μL/m) mist of spray from the nozzles which reduce the pesticide amount and increase spray coverage area, but this size of the droplet is very sensitive to weather parameters and air velocity. In high humidity and low temperature condition very, fine droplets not reached to the target and hanging in the air which cause airborne spray drift, and in low humidity and high temperature conditions these droplets are evaporate into the air before reaching to the target area and cause spray loss and increase pesticide amount which is hazardous for environmental and human health.

2.3 Ultra-low volume sprayers

Ultra-low volume (ULV) spraying is a common and advanced spraying method [27] and considered a most effective and standard technique control of locust using chemicals and is also extensively used by farmers of cotton crops to control pest and insects. ULV sprayer is designed to create very small droplets (50 to 150 $\mu L/m^2$), which help for uniform coverage with low spray volumes. Ultra-low volume (ULV) fungicide application sprayer was first developed as thermal fogging [28]. The objective of ULV sprayer to reduce the fluid application rate, drift, and wastage of chemicals while increasing insect and diseases control. Conventional tractor-mounted boom sprayers apply spray on the upper side of the leaves, However, mostly the sucking insects (aphid, whitefly, jassid, thrips, etc.) have their shelter houses on the bottom side of leaves of the upper half section of the cotton plant which not only get shield from sprays but also attain the shadow of leaves shadow as of umbrella coverage. Therefore, the chemical spray using conventional sprayer do not reach the definite target and cause wastage of the spray material to the ground and air. Various pests and insects need a different droplet numbers per cm2 [29] which can only apply using a ULV sprayer. Vehicle mounted ULV sprayer shows in **Figure 5**. Pesticide droplets deposit on the upper side of the leaf using conventional sprayers may be washed off by rain or in some cases by overhead irrigation. Some researchers have concluded that up to 80% of the total pesticide applied to the plant may finally reach the soil [30].

Thus, conventional spray approaches are considered as mostly inefficient due to higher spectrum of the droplet size (150 to 250 $\mu L/cm^2$) which do not go to the target surface and ultimately become the part of waste substance. Nevertheless, the use of ULV sprayers has drastically transformed spray technology as they develop relatively small droplets [29]. Due to this Volume Application Rate (VAR) of ULV sprayers utilize fluid less than 5 L/ha for field crops or less than 50 L/ha for tree/bush [29]. Electrostatic sprayers are the most emerging technology for ultra-low-volume pesticide application.

Figure 5.
Vehicle mounted ultra-low volume sprayer.

Air-assisted electrostatic sprayers are new development in plant protection machinery which enhanced the pesticides application efficiency to crops, vineyards, orchards, plants, and trees. Electrostatic spraying method spray decreases off-target drift, environmental issues, and human health risks [31]. It is assumed that electrostatic spraying technique has revolutionized the spraying machinery through higher droplet deposition and retention on the plant leaf [32]. It is assumed as one of the appropriate methods to overcome complications associated with agrochemical spraying in the conventional system such as volatility and drift of spray droplets from temperature and wind effects [33]. Electrostatic space charge and induced image charge forces increase the spray uniformity on the target surface, enhance the transfer efficiency, bio-efficacy and adhesion. These electrostatic forces minimize the effect of gravitational force which is the main cause of spray drift [34] as shown in **Figure 6**. The electrostatic spray application increases the spray retention time on leave. There is an interaction between formulation effects on the tenacity of a deposit and the surface of the leaf to which it adheres. Droplets often bounce on waxy leaves (a property that is often influenced by age) and poor retention may occur with water-based formulations, especially those with high dynamic surface tensions. But with the ULV electrostatic sprayers the droplet gets negative charge from the nozzles with air injection and repel each other and reached at the target separately without bonding each other and create a charge on plant leaf which produce adhesion force to the drops for retain for long time on the leaf and reduce spray drift.

2.4 Aerial spraying

Although the aerial spraying has been used since middle of 20th century however, the innovation on unmanned aerial vehicle is assumed as most of are one important development in the field of agricultural spraying and plant protection engineering because of its tremendous merits over the conventional ground sprayers. The crop monitoring and the assessment of pesticide and fertilizer requirement at accurate time and location of crop area is an important parameter to effective utilization of the inputs for the purpose of yield enhancement [35]. Aerial spraying using UAV has gained great interest worldwide [36]. Thus, currently Unmanned aerial vehicles (UAVs) are known as most advanced spraying technology that is helpful for

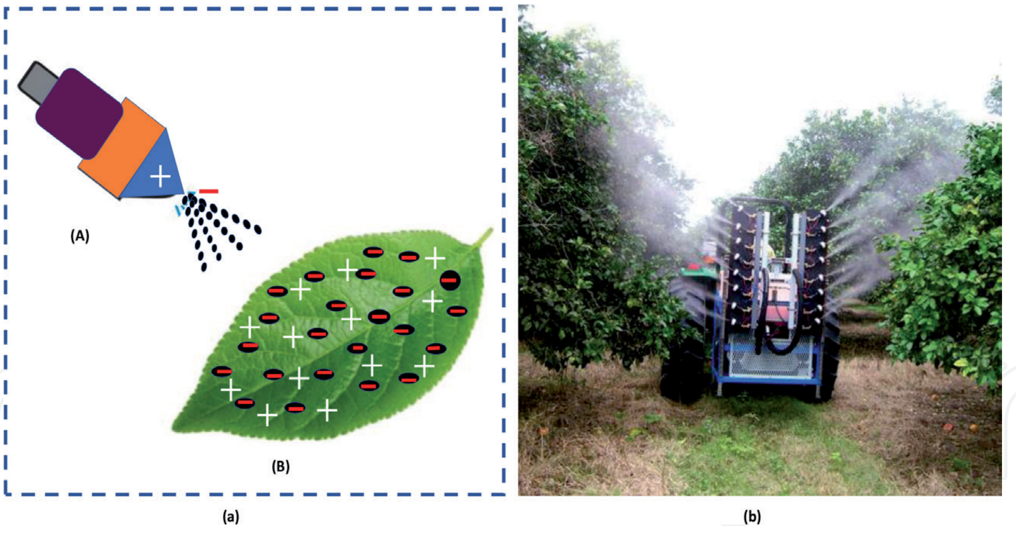

Figure 6.
Electrostatic spraying mechanism (a) variate rate multichannel electrostatic sprayer (b).

effective and precision spraying. Unmanned aerial sprayers are potentially supportive in decreasing negative effect pesticides to the environment and human during the application process of agrochemical at farm level [37]. The use of unmanned aerial vehicles (UAVs) is facilitating the to ease plant production practices and also provide the conform to spray on the tall stalk crop such as maize, cotton and water ponding crop such as rice. In fact, UAV aerial spraying capability is not only limited to crop protection but it has also utilize for the fertilization practices [38]. The idea of aerial spraying by means of UAV is firstly developed founded on the technology of unmanned helicopters that had been developed by Yamaha Corporation (Japan) for rice cultivation [39]. Mostly, chemicals application such as pesticide and fertilizer is applied by using ground sprayers, chemigation, aircraft aerial spraying, and broadcasting method without the real time assessment of the specific conditions, [40]. Unmanned aerial vehicle (UAV) sprayer develops the downwash airflow by the UAV rotor which interacts with the crop canopy and creates a conical vortex shape in the crop plant [41]. The droplet deposition efficiency is one of the major concerns in UAV spraying operation. During the spraying with UAV sprayer, the droplets pervade to the crop canopy However, some droplets drift often occurs, which wastes pesticides, decreases the control effect, and even causes environmental pollution and poisoning [42]. Spray system arrangements equipped on UAV have not yet been optimized to accompaniment spray pattern based on the proper nozzle selection, [43]. Droplet size, weather conditions, and operational parameters of sprayers influence the spray coverage, absorption, and attachment to the target [44]. The effect of climatic condition (temperature, wind direction, wind speed, humidity, etc.) on UAV spraying efficiency should clearly be understood to the applicators [45]. Unmanned aerial vehicles (UAV's) are operated remotely either by using telemetry, where the operator holding visual contact with the aircraft, or autonomously along planned paths using GPS and inertial guidance [39]. UAV sprayers working on the proper path planning with GPS, 4G, or 5G network technology to the target area which provide the proper path to the drone to apply a precise amount of pesticides on plants which reduces the spray drift, save pesticide application amount, and high accuracy results. Old UAV sprayers were very large which was difficult in handling, transport issues, landing problems, and produces more downwash pressure with high air guests by the large size of wings which produce more off-target spray deposition as shows in **Figure 7**. Due to their large size, these types of sprayers do not use in trees and orchards, it was only used in broad field crops.

In comparison, small-size unmanned aerial vehicle (UAV) crop protection operations provides the advantages of a low flight altitude, a flight velocity control, and well field adaptability, mainly for small fields and diversified crop planting zones [48]. Many small sizes of drones like Four-rotor, six-rotor, and eight rotors are used nowadays as shown in **Figure 8** which is easily handled, transport, use senor technology more easily, use in orchards, trees, and crop very sufficiently. Based on the current UAV models, crop protection operation requirements, UAV loading capability, and flight duration, under an identical load, a six-rotor UAV is thought more stable than a four-rotor UAV and consumes less energy than an eight-rotor UAV. Small size drone sprayers provide us the efficient spray deposition on the target, reduce the airborne drift, and easily operate between the orchards and crops. UAVs have high control precision and fast response speed when using a variable spray system. Spray drift is a practical reality during the pesticide spraying operations. **Figure 9** shows the flow field during the spraying operation of unmanned aerial vehicle. Recent studies on UAV sprayer application and spray deposition performance shows in **Table 1**.

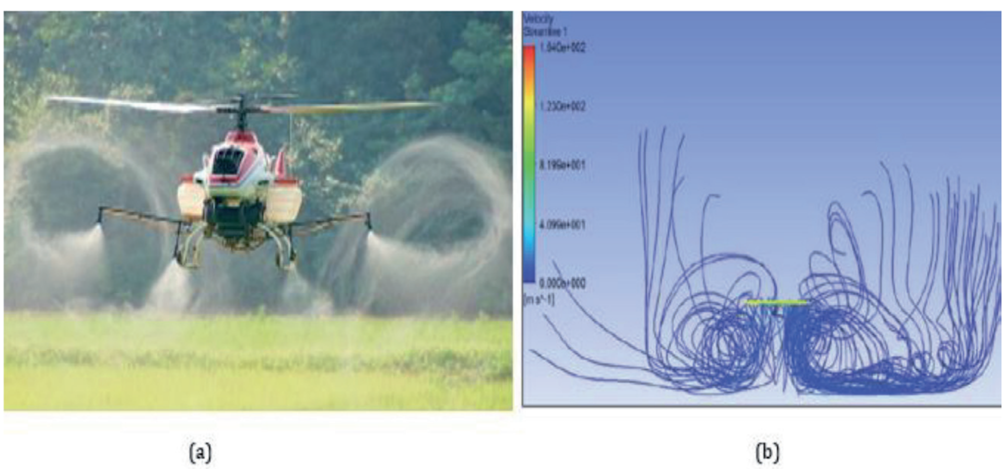

Figure 7.
Rotor wings effect on spray drift (a) [46] streamlines of the flow field under the rotor (b) [47].

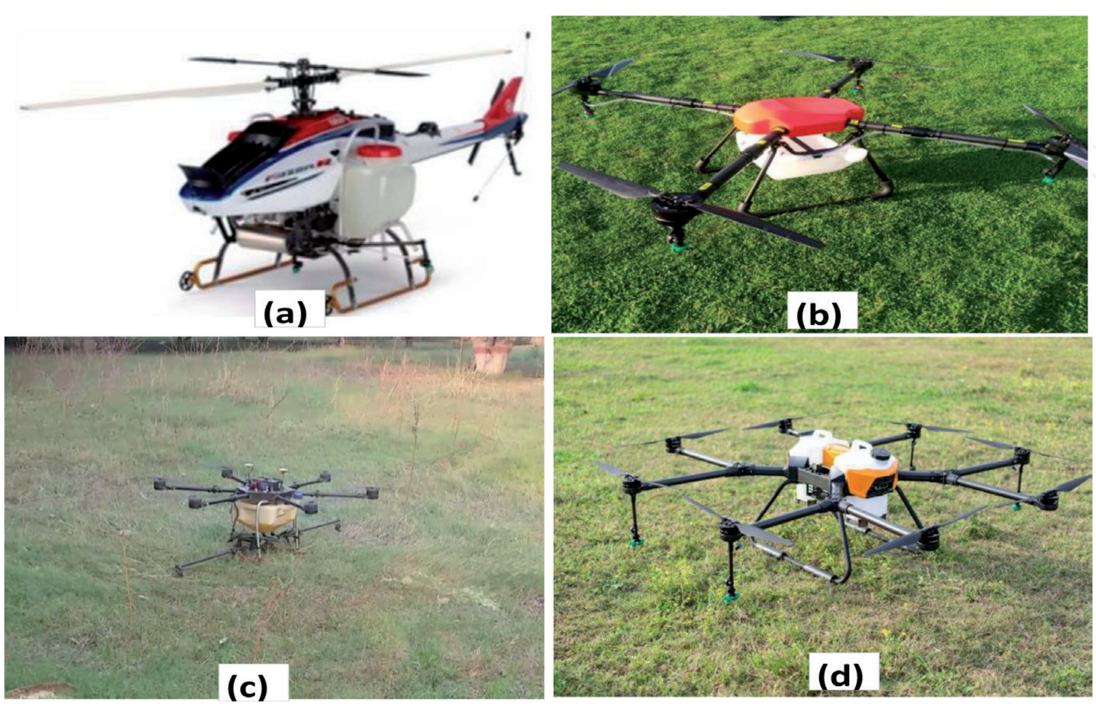

Figure 8.
Single rotor UAV sprayer (a) four rotor UAV sprayer (b) six rotor UAV sprayer (c) eight rotor UAV sprayer (d).

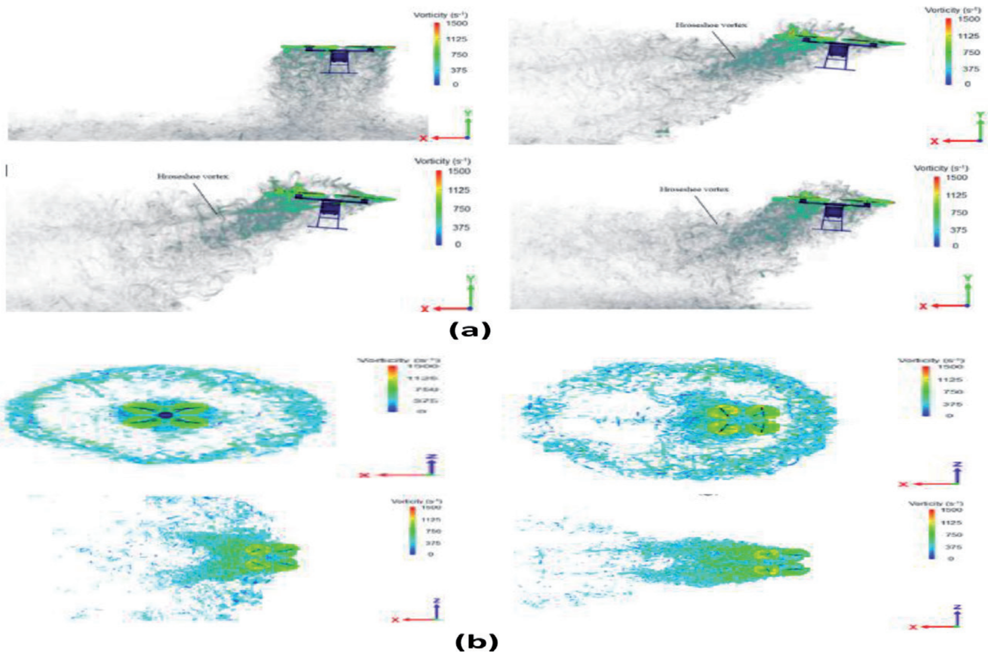

Figure 9.
Quad-rotor drone flow fields with different forward velocities and pitch angles (a) wake structure variations with flight speed (top view) (b) [49].

Reference	Study type	UAV type	Crop	Study Parameters
Shi et al. [47]	Numerical Simulation	Single rotor	—	Flight Hight, Spray deposition
Teske et al. [50]	Numerical Simulation	Single rotor and octocopter		Flow field, Effective drift
Wang et al. [51]	Field study	Single rotor	Wheat	Spray volume, nozzle size, droplet deposition
Wang et al. [52]	Filed and	Multirotor	Rice	Vision based crop detection, fuzzy logic application
Sadam et al. [53]	Field Study	Multirotor		Nozzle opening, Operating height
Liao et al. [54]	Field Study	Multi rotor	Cotton	Volume rate spray adjuvants, flight altitude, flight speed
Lv et al. [55]	Field study	Multi rotor		Flight speed, thermal imaging,
Martin et al. [56]	Field	Multi rotor	Eeed	Spray rate, spray efficiency
Wang et al. [57]	Field	Multirotor	Wheat	Overage area, total deposition
Zhang et al. [58]	Field study	Multirotor	Citrus	Tree shape and flight height
Yanliang et al. [48]	Filed study	Multirotor		Electrostatic spraying, Spray altitude, Spray pressure
Yang et al. [59]	Numerical simulation	Multirotor		CFD simulation, Flow tubulance model

Table 1.
Recent studies on UAV sprayer application and spray deposition performance.

3. Spray drift management

Spray drift is a physical moment of the droplet during the application of spraying liquid to the off target area under influence of climatic factors such as wind speed and temperature [60]. Spray drift may occur to numerous forms as a droplet, dry particles, or vapor. Particle drift enhances when water and other pesticide carriers evaporate rapidly from the droplet lifting tiny particles of concentrated pesticide. Vapor may arise directly from the spray or by evaporation of pesticide from sprayed surfaces [61]. Spray drift is a complex phenomenon due to the accumulative effect of spraying equipment design, crop architecture, atmospheric conditions and the physicochemical properties of the spray mix [62]. Spray drift is occurred due to droplet characteristics infuse by the weather parameters, nozzles types, operating pressure, speed, and height. Drift corresponds to a modification of droplet trajectory induced by the drag force due to external air velocity. The expression of the drag force Fd is given by Eq. (1):

$$Fd \equiv \frac{1}{2}\rho_a C_d A(V_d - V_a)^2 [N] \tag{1}$$

The safe, efficient and efficacious use of pesticides requires the management of pesticide drift and deposition. The sensitivity of drift to numerous factors, including atmospheric conditions and application equipment, makes it difficult to field test the full range of possible meteorological application scenarios. There are two approaches to aerial spray models: empirical and mechanistic [46].

The empirical models do not account for any physical basis and are generally applicable only to situations that are very similar to those for which they are developed. Mechanistic models based on Gaussian dispersion equations and particle tracking models. Gaussian modeling is a classical approach that is used in atmospheric dispersion modeling and lagrangian models track a cohort of droplets in a given drop size category and overlay a random component on the movement of the droplets to account for atmospheric turbulence [63]. Empirical models primarily include field testing and wind tunnel research. Compared with field testing, the wind tunnel environment can accurately control the test conditions, such as the wind speed, airflow direction, temperature. Mechanistic model include CFD, Gaussian modeling and Lagrangian model (AGDISP) [46]. The CFD model provides whole-flow field data, fast and reproducible results, repeatable and controllable conditions, reliable data, and rapid, economical and accurate means, but at the expense of incompatibility [64].

For the drift estimation three models use the German drift curve, Dutch IMAGE drift Calculator, and the Model Proposed by Meli. The equations of these models are discussed below.

German Drift

$$\%\text{Drift} = 60.36 \text{ x z} (-1.2243) (\text{z} < 15 \text{ m}) \tag{2}$$

$$\%\text{Drift} = 298.83 \text{ x z} (-1.8672) (\text{z} > 15 \text{ m}) \tag{3}$$

IMAGE Model

$$\%\text{Drift} = 48 \text{ x e} (-\text{z}/2.7) + 0.45 \text{ x e} (-\text{z}/0.091) \tag{4}$$

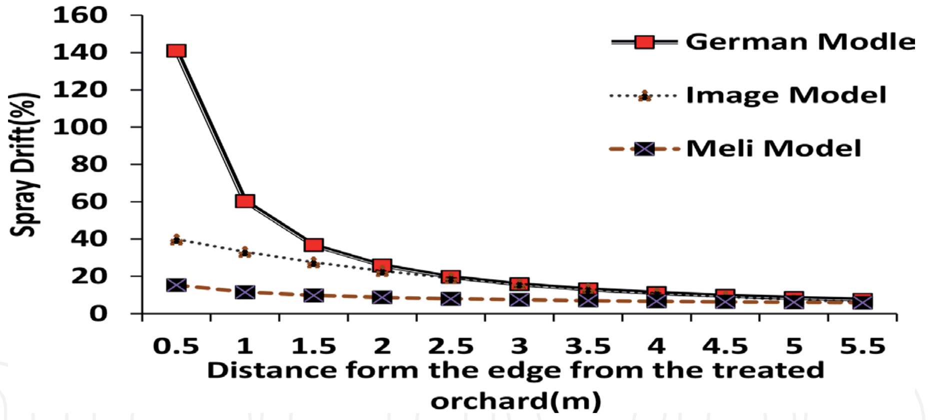

Figure 10.
Graphical representation of drift model values with distance.

Meli Model

$$\%\text{Drift} = 11.45 \text{ x } z\left(-0.4026\right) \tag{5}$$

The graphical representation of drift model values shows in **Figure 10**. Its shows that which parameters should adopted for pesticide application for the spray drift man agent.

From the result it shows that spray drift increases with increasing the application distance, height and angle. By reducing the application distance drift reduce immediately and drift curve of three model's constant after 5 m.

4. Conclusion

Plant protection practices are most important activities during crop production. Progress in spraying technology has been increase in recent past. Robotics and automatic spraying technologies like variable rate sprayers, UAV sprayers, and electrostatic sprayers has gained more attention to enhance. These advanced spraying technologies not only reduces the labor cost but also effective in environmental protection. Researchers are conducting experimental studies on the design, development and testing of precision spraying technologies for crops and orchards. Simulation modeling studies are also conducting by the researcher to increase the sprayer's efficiency and to improve the design for better utilization. However, there is still needed to conduct further studies to reduce the spray loss and health risks during the pesticide application to the orchards.

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