Anti-Drift Technology of Plant Protection Machinery

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In orchard plant protection application, an anti-drift strategy can effectively reduce drift in the non-target area, reduce spray drift in the environment, and avoid spray leakage and overspraying.

Keywords: orchard ; spraying ; drift ; pesticides

1. Introduction

Drift prevention and control technology is an important part of precision agriculture that can improve pesticide utilization and reduce the amount of pesticide drift when combined with modern information technology based on the realization of the precise application of pesticides. Thus, promoting the innovation of plant protection machinery industry is of great significance. At present, orchard plant protection spraying technologies mainly include air-assisted spraying technology, recycling spraying technology, electrostatic spraying technology, profiling spraying technology, and target variable spraying technology.

2. Air-Assisted Spraying Technology

Air-assisted sprayers can improve the efficiency of application and reduce pesticide waste [1]. Currently, sprayers using air-assisted technology can be divided into multi-fan air-assisted sprayers [2][3]. Researchers worldwide have researched various types of air-assisted sprayers to solve the problems of insufficient droplet penetration and large drift by using air-assisted spraying technology [4][5]. tower-type air-assisted sprayers [6], multi-conduit air-assisted sprayers [7], multi-fan air-assisted sprayers [8], and centrifugal plus agro-cannon sprayers [9].

Air-assisted sprayers can also solve the problem of drift due to the improper application of pesticides and can overcome the limitations of conventional sprayers used in traditional and intensive orchards by enhancing droplet deposition and droplet deposition uniformity, as well as significantly reducing ground drift. This suggests that air-assisted spraying systems are effective in reducing spray drift [6][7][8]. For example, Wei et al. [7] designed a multichannel directional air-assisted sprayer for orchards of the air-assisted type that can perform an independent adjustment of the height of airflow in each channel. The sprayer solved the problems of difficult droplet penetration and severe drift in air-assisted application of pesticides for fruit trees, improved droplet deposition in the canopy by 47.6%, reduced the coefficient of variation by 34%, and reduced the amount of ground deposition and air drift by 29.9% compared to traditional air-assisted sprayers.

In the spraying process, the air-assisted flow can weaken the influence of ambient airflow on droplet movement. However, the type of air-assisted airflow has a significant effect on droplet movement. Thus, researchers worldwide have studied the effect of application parameters on droplet deposition and drift, and the results show that optimizing application parameters such as pressure, spray medium, and airflow rate can reduce the amount of drift without affecting the amount of droplet deposition [10].

The application parameters mainly include spray pressure, spray distance, and airflow rate [1][6][7][8][9]. Air-assisted spraying technology can improve the uniformity of droplet deposition, but the unreasonable setting of application parameters can lead to an increase in drift [11][12], which is closely related to droplet particle size, airflow rate, and spraying distance. Moreover, drift gradually increases with the increase in spraying distance, spraying pressure, and airflow rate [13]. Thus, studying the mechanism of the reciprocal effect of spraying parameters on drift can reduce drift, improve the efficiency of application, enhance the effectiveness of pest control, and have important theoretical and practical significance for agricultural production. Increasing the spray pressure will lead to a decrease in droplet particle size, increase the application cost, and reduce the application efficiency, resulting in a large amount of deposition in the non-target area [14].

However, the above studies only considered the use of single air-assisted spraying, which has the problem of very high or very low airflow rate during the spraying process, generating problems such as pesticide drift or poor penetration [15]. Moreover, they did not consider the use of multiple air-assisted solutions and did not propose an improvement plan for the traditional air-assisted spraying structure.

When the unit is traveling against the ambient airflow, the main turbine generates airflow B, which sends the droplets to the canopy of the fruit tree. The front secondary turbine generates airflow A, and airflow B flips the branches and leaves to make the back side face upward and weaken the influence of ambient airflow on the droplets. The rear secondary turbine forms an air curtain along the plant height direction (i.e., the anti-drift airflow C), which reduces the non-target area of the droplets to be drifted and improves the amount of droplet deposition in the canopy of the fruit tree [16].

To improve the orchard affected area deposition and reduce the fruit tree rows of drift, Fan et al. [17] designed a multi-airflow synergistic V-shaped anti-drift spraying device for conventional air-assisted spraying. Compared to a single airflow, the multi-airflow synergistic effect of droplet deposition increased by 17.4%, and the amount of drift was reduced by 21.8%. This kind of air-assisted flow is an innovative form in orchard plant protection application, and the use of active air-assisted flow to offset the influence of ambient airflow on the movement of droplets can effectively reduce the amount of drift, which can greatly contribute to environmental protection.

At present, Europe and the United States, Japan, Korea, and other countries produce an advanced orchard air-assisted spraying technology. Famous manufacturers are Italy CAFFINI company, Denmark HARDI company, and South Korea ASIA TECH company. Overall, Europe and the United States orchards are mostly for traction and suspension, wherein the large- and medium-sized air-assisted sprayer is the main power with a long range, tank volume, high fan air volume, and suitable for wide rows, narrow plants, and high canopy standardized orchards; Japan and South Korea orchard planting is similar to China, being mostly self-propelled and the small- and medium-sized air-assisted sprayer is the main power, which is lower than Europe and the United States, with a compact structure, good trafficability characteristic, etc. [18][19][20][21].

3. Recycling Spraying Technology

To spray pesticides safely and effectively, the sprayer must ensure that sufficient liquid is deposited on the target area while minimizing pesticide loss. Recycling spraying technology is one of the technologies that best meets the requirements of environmentally friendly spraying techniques. Recycling spraying technology uses pesticides recovery devices to intercept and collect undeposited pesticides. Thus, recycling spraying has emerged in a wide variety of types: the “Π” type cover type, collector type, reflective type, and air circulation type.

By the 1990s, the improvement in the traditional orchard sprayer had basically completed. To further increase the pesticide deposit rate, researchers aimed to develop a new type of sprayer, leading to the rapid development of the “Π” type recirculating sprayer. Many studies have aimed to improve the system to further enhance the working performance of the sprayers [22].

The research on recirculating sprayers has mainly focused on droplet deposition, pesticide loss, and the recovery rate. To address the problems of low pesticide utilization, Jianli et al. [23][24] designed and tested the performance of a “Π” type sprayer, and the results show that staggered spraying on both sides of the spray bar could improve the pesticides recovery rate by 44.0% and reduce the amount of ground drift within the drift distance by 99.3% compared with a conventional orchard air-assisted sprayer. Furthermore, Ade et al. [25][26] developed the “Π” type sprayer and showed that it consumed less pesticides and had significantly lower drift than the conventional sprayer. Moreover, Jamar et al. [27] and Soriano et al. [28] compared droplet deposition in orchards under a recirculating spray system, a conventional hydraulic spray system, and a conventional air-assisted spray system and found that the recirculating spray system could effectively reduce the amount of drift compared to other spray systems.

With the development of technology and the integration of multiple technologies, the difference between the sprayer types is no longer clear, and a combination of the “Π” type cover type and airflow circulation types has emerged. Gianfranco et al. [29] designed a tunnel-type air-assisted spraying machine that reduced the drift rate by 8.1% and could recover at least 30% of the drift. Moreover, Qiu et al. [30] designed a recirculating air-assisted sprayer adapted to low-growth orchards, and the average coverage of droplets on the front side of canopy-rifled blades was increased by 42.9%, while that on the back side of blades was increased by 40.4%, reducing the pollution of pesticides to the environment.

Nestor cyclic sprayer is one of the typical recycling sprayers, which is connected to the back of the tractor by traction, with a tank capacity of 2000 L, an operating width of 0.94–2.70 m, and a canopy height of 2.10–2.35 m [31]. In addition, according to LIPCO company, information shows that its production of recycling sprayer in the fruit tree sparse branches and leaves have a liquid recovery rate of 70%, while the branches and leaves also have 20% liquid recovery rate; MUNKHOF company manufactured recycling sprayer according to the degree of dense branches and leaves have a liquid recovery rate from 30% to 60% [32]. In summary, the recirculating sprayer has been found to significantly reduce the amount of drift and ground loss, resulting in effective recovery of droplets and improvement in the utilization rate of pesticides. However, because it is mainly applicable to specific dwarf plantations, the current universality of recirculating spraying technology is poor. Moreover, the technology has a complex structure and a high cost of manufacturing, leaving much room for improvement in its development.

4. Profiling Spraying Technology

To improve the quality of droplet distribution and reduce the deposition in the non-target area, the integrated profiling mechanism of the spraying machinery needs to be increased. Moreover, the manual adjustment of the spray unit folding position can achieve a uniform envelope of the fruit tree canopy to uniformly stabilize the spraying distance and the distribution of the pesticides, thereby improving the effect of spraying.

To solve the problems of the poor adaptability of the sprayers to the canopy of fruit trees, Yu et al. [33] combined the application requirements of tree profiling sprayer and designed an orchard profiling sprayer that can change the spray angle and spray distance according to the tree's spacing, height, and crown shape, thereby ensuring precise spraying, improving pesticide use efficiency, and reducing drift. Zhang et al. [34] designed a trinity multifunctional sprayer, combined with air-assisted spraying technology to reduce the impact of natural airflow on the drift, forcing droplets into the inner layer of the canopy to improve the amount of deposition and uniform distribution of the droplets, which can reduce the loss of the liquid to protect the environment. Zhou et al. [35] designed a combined disk-type air-assisted sprayer for fruit trees. It can adjust the spraying position according to the shape of fruit trees, thus improving the quality and efficiency of the operation and providing new techniques for the control of fruit tree diseases and pests. Their work can provide a reference for the improvement in the design of the air-assisted sprayer in orchards. Furthermore, Li et al. [36] compared the performance of profiling spray and conventional air spray in orchards, and the experimental results showed that, compared with conventional spraying, the profiling spray effectively improved the pesticide utilization rate. Additionally, the spray drift of the profiling variable spray machine was reduced by 23.2% and the saving of liquid solution was 45.7%.

Thus, the development of profiling spraying technology is important for realizing a precision application, improving pesticide utilization, and reducing production costs in orchards [37]. Profiling spraying technology reduces the averaged spray distance and improves the uniformity of droplets deposition, but drift remains at high levels due to the influence of factors such as large differences in characteristics between nearby canopies and between canopies. Li et al. [38] designed an orchard automatic profiling sprayer based on the variable rate spraying. The sprayer allows the applicator to adjust the airflow rate and nozzle flow rate in real time by detecting the canopy volume of fruit trees so that they can realize the profiling variable application according to the canopy information. The results show that the minimum number of droplets on the left and right sides of apple trees was 46.2 droplets/cm^2, which meets the requirements of application. The results provide a theoretical and methodological reference for the structural design and performance optimization of precision planting and protection implements. Aljaž et al. [39] designed a variable geometry air-assisted sprayer that can be positioned in real time for orchard sprayers, where the nozzles of the profiling spraying device are in the optimal position. To design a real-time adjustable application altitude and spray distance of the profiling spray mechanism, through mathematical modeling and software optimization, the researchers derived kinematic equations of the spraying point. The results show that the average value of the profiling spray droplet coverage reached 43.85%.

5. Target Variable Spraying Technology

Variable spraying has received more attention in recent years as one of the means to realize a precise application. Then, the sprayer comprehensively handles all kinds of information about the crop and spraying device to realize the precise application of target crops according to the demand [40][41][42]. Compared with the traditional large airflow spraying technology, variable spraying technology can alleviate the problem of pesticide overuse, save pesticides while reducing the risk of drift in the spraying process, improve pesticide prevention and control efficiency, save labor and application costs, and promote the sustainable development of agriculture [43][44][45].

Drift during spraying cannot be completely eliminated by plant protection sprayers, but it can be reduced by developing new techniques [46][47][48]. For example, Bayat et al. [49] designed and developed a novel servo-controlled spraying system, which can change the nozzle's directional angle in real time and automatically, opposite to the direction of the airflow, to minimize ground spray drift. Salcedo et al. [50] used a 3D ultrasonic anemometer to dynamically assess the airflow produced by an axial fan airflow delivery system. Studying the interaction of airflow rate with canopy and ambient airflow, predicting the trend of airflow attenuation within the canopy [51], and adjusting the spray angle in real time can ensure the effectiveness of plant protection application without negatively affecting the environment.

Variable spraying is an efficient application technique recommended by the Food and Agriculture Organization of the United Nations, which can effectively improve the deposit rate in the canopy and reduce drift. Aiming at the difficulty of modeling airflow in the canopy of fruit trees and the lack of airflow control models, Gu et al. [52][53] investigated airflow loss modeling in the canopy of fruit trees. Sensors were utilized to measure the number of leaves in the target canopy, and the spray volume was controlled according to the canopy consistency, which could ensure uniform spraying of canopies of different sizes and densities [54]. Moreover, Ryszard et al. [55] designed a variable air-assisted system, which was able to continuously adjust the airflow rate and spraying system in real time, and the targeted airflow adjustments significantly reduced the amount of drifting. Similarly, Dou et al. [56] evaluated the performance of spraying systems with laser and ultrasonic sensors, and the results show that both targeted spraying systems were effective in reducing ground deposition and off-target deposition, with photoelectric (trunk) and ultrasonic (canopy) directed spraying reducing ground deposition on young trees by 50.63% and 38.74%, respectively. Overall, research on variable sprayers for orchards has generally focused on the modular addition of variable spray systems to existing sprayers. At present, orchard variable sprayers have achieved industrialized development and small-scale application in some countries and regions in Europe and America.

Gil et al. [57] integrated the variable spraying system into the LE-600 sprayer produced by HARDI. The variable spraying system reduced overspray and 22% of application cost. Overall, the research on variable sprayers for orchards is generally fused through the modular addition of variable spraying systems to established sprayers. At present, the orchard variable spray machine in Europe and the United States in some countries and regions has achieved industrial development and small-scale application. However, the relevant experimental research on precision variable spraying is based on an ideal environment due to the complexity of field application, jagged fruit tree canopies, and interactive overlap. Thus, precision spraying technology is still in the theoretical research stage. The reliability of target detection, stability, and other deficiencies presents challenges to the realization of real-time precision sprayer adjustment, which can serve as future research directions.

6. Plant Protection UAVs

Compared with the ground plant protection machinery, plant protection UAV has become an important plant protection machine due to its good adaptability to complex terrain, not restricted by fields and other limitations. However, in the plant protection operation, the researchers found that the problem of drift is very serious. To reduce the environmental pollution caused by spray drift and improve the spray efficiency of orchard, the researchers carried out a series of researches from the aspects of nano-pesticide, spray adjuvants, nozzles, rotor wind field and operation parameters, etc., respectively [58][59][60].

To reduce the pollution of pesticides to the environment and enhance the efficacy of pesticide control, researchers have developed nano-pesticides in combination with nanotechnology. Polymer-based formulations have received the greatest attention, followed by formulations containing inorganic nano-particles and nano-emulsions [61]. Nano-pesticides can be used to combat pest resistance and can be targeted against a specific organism [62][63]. Nano-pesticides also increase toxicity to target organisms and improve the selectivity of pesticides to organisms [64], and have better penetration, adhesion, and degradation capabilities [65]. It can reduce the impact of pesticides on the environment, contribute to the protection of the environment, and provide a new solution to improve the efficiency of pesticides [66].

However, Gao et al. found that nano-pesticides are characterized by smaller droplets size, higher permeability, and higher utilization compared to traditional pesticides [67]. Minor droplets are more likely to be affected by environmental airflow, which puts higher requirements on spraying technology. Therefore, researchers need to combine nano-pesticides with anti-drift technologies to reduce spray drift.

The nozzle types and spray adjuvants can affect the droplet particle diameter, which is the main sector of the UAV plant protection operation of the droplet deposition efficiency, because the minor droplets are more sensitive to the environmental airflow and rotor wind field. To reduce the quantity of minor particles sprayed from the nozzle per unit time and reduce the quantity of spray drift, the researchers designed two methods:

Researchers have developed anti-drift nozzles. US Lechler produced anti-drift nozzle AD, wherein after the relevant spray test, the detected droplet diameter spectrum is narrower than the standard nozzle. Guo et al. [68] utilized the Venturi principle to design anti-drift nozzle (IDK), which showed that the spray drift was significantly lower than the conventional nozzle, and improved droplet penetration in the canopy.

Pesticide adjuvants can change the properties of the liquid, and provide new ideas for reducing spray drift [69]. Some researchers have found that the addition of methylated [70], mineral oil [71], non-ionic adjuvants [72], normaton [73], emulsion [74], and other adjuvants to the liquid can reduce the proportion of minor droplets that are easy to drift, improve the distribution of droplet diameter, and increase the amount of droplet deposition, which has a significant effect on the reduction in pesticide pollution.

Rotor wind field is one of the major factors affecting the effect of deposition. During the operation of multi-rotor and single-rotor UAVs, the wind field has an impact on spray drift [75]. Zhang et al. [76] found that the direction of UAV operation parallel to the airflow direction of environment can effectively reduce the amount of spray drift. Chen et al. [77] found that the airflow field below the rotor has a significant impact on the droplet deposition and spray drift.

In terms of operational parameters, some researchers have designed UAV spraying experiments, and the results show that plant protection UAV has the optimal operating height range [78], the optimal operating velocity range [79], and the droplet deposition density will be significantly reduced when it exceeds or is lower than the optimal range. For the application parameters, choosing the appropriate spray pressure [80] and flight altitude [81] can significantly reduce the amount of spray drift. It can be found that the application parameters of plant protection UAVs are important factors affecting the effect of droplet deposition, and selection of the optimal operating parameters is of great significance in achieving the optimal plant protection efficiency. Some scholars have researched the nozzle, adjuvant, rotor wind field, and operational parameters of plant protection UAVs, and found that plant protection UAV can meet the demand of orchard plant protection, but the problems of spray drift and uneven distribution of droplets need to be further solved.

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