Orchard Target-Oriented Spraying Systems

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Pests in orchards are mainly controlled through the use of chemical pesticides, which decrease fruit loss by 66% to 90%. Orchard air-assisted spraying technology is recommended as highly effective by the Food and Agriculture Organization (FAO) of the United Nations, and this method has been widely used for orchard pest control. Traditional orchard air-assisted spraying methods involve spraying a pesticide solution in a continuous and uniform manner. This not only requires a large amount of pesticide, but also causes environmental pollution due to the drift of excess spray into the air and onto the ground. To address this problem, orchard air-assisted target-oriented spraying systems with various sensors have been developed, thus enabling variable-rate spraying based on information such as tree location, canopy profile and leaf density, and significantly reducing the amount of pesticides used.

Keywords: orchard spraying ; target-oriented sprayer ; photoelectric sensor ; ultrasonic sensors ; off-target deposition

1. Overview

Orchard pesticide off-target deposition and drift cause substantial soil and water pollution, and other environmental pollution. Orchard target-oriented spraying technologies have been used to reduce the deposition and drift caused by off-target spraying and control environmental pollution to within an acceptable range. Two target-oriented spraying systems based on photoelectric sensors or ultrasonic sensors were developed. Three spraying treatments of young cherry trees and adult apple trees were conducted using a commercial sprayer with a photoelectric-based target-oriented spraying system, an ultrasonic-based target-oriented spraying system or no target-oriented spraying system. A rhodamine tracer was used instead of pesticide. Filter papers were fixed in the trees and on the ground. The tracer on the filter papers was washed off to calculate the deposition distribution in the trees and on the ground. The deposition data were used to evaluate the systems and pesticide off-target deposition achieved with orchard target-oriented sprayers. The results showed that the two target-oriented spraying systems greatly reduced the ground deposition compared to that caused by off-target spraying. Compared with that from off-target spraying, the ground deposition from photoelectric-based (trunk-based) and ultrasonic-based (canopy-based) target-oriented spraying decreased by 50.63% and 38.74%, respectively, for the young fruit trees and by 21.66% and 29.87%, respectively, for the adult fruit trees. The trunk-based target-oriented detection method can be considered more suitable for young trees, whereas the canopy-based target-oriented detection method can be considered more suitable for adult trees. The maximum ground deposition occurred 1.5 m from the tree trunk at the back of the tree canopy and was caused by the high airflow at the air outlet of the sprayer. A suitable air speed and air volume at the air outlet of the sprayer can reduce pesticide deposition on the ground.

2. Pests in Orchards

Pests in orchards are mainly controlled through the use of chemical pesticides, which decrease fruit loss by 66% to 90% [1][2][3][4]. Orchard air-assisted spraying technology is recommended as highly effective by the Food and Agriculture Organization (FAO) of the United Nations, and this method has been widely used for orchard pest control. Traditional orchard air-assisted spraying methods involve spraying a pesticide solution in a continuous and uniform manner. This not only requires a large amount of pesticide, but also causes environmental pollution due to the drift of excess spray into the air and onto the ground [5][6][7][8]. To address this problem, orchard air-assisted target-oriented spraying systems with various sensors have been developed, thus enabling variable-rate spraying based on information such as tree location, canopy profile and leaf density, and significantly reducing the amount of pesticides used [9][10][11].

Currently, orchard air-assisted target-oriented spraying systems mainly use photoelectric, ultrasonic and light detection and ranging (LiDAR) sensors. Among them, photoelectric sensors are the easiest to use in terms of applying target-oriented pesticide spraying in orchards. They allow control of the nozzle opening by detecting the position of the tree trunk or tree canopy to achieve target-oriented spraying [12][13][14][15]. Based on the photoelectric target-oriented detection technique, He et al. [16] developed a precise target-oriented spraying control system for orchards. This system has photoelectric sensors mounted at levels matching the upper, middle and lower portions of canopies to detect trees at different heights, and this system can decrease pesticide use by 50%–75%. Zhai et al. [17] located the canopy by detecting the tree trunk and used this information to design a photoelectric-based target-oriented controller for young trees. Zou et al. [18] used photoelectric sensors to detect fruit canopy positions in real time, and target-oriented spraying was realised by controlling the opening time of the nozzle according to the position of the fruit tree canopy. Because target-oriented spraying with a photoelectric sensor can only selectively spray based on the presence or absence of a tree and cannot perform variable-rate spraying based on information such as canopy profile and denseness, a target-oriented spraying system equipped with an ultrasonic sensor has been developed [11][19][20][21]. Maghsoudi et al. [22] acquired the volume of fruit tree canopies in real time through ultrasonic sensors and achieved variable-rate spraying according to the change in canopy volume, cutting pesticide use by 34.5% on average to achieve spraying effectiveness similar to that of conventional spraying methods. Gail et al. [23] developed an orchard sprayer equipped with ultrasonic sensors capable of variable-rate spraying according to changes in the volume of fruit tree canopies, and this sprayer reduced pesticide usage by 21.9%. Petrović et al. [24] examined the effects of a conventional spraying system and a target-oriented spraying system equipped with ultrasonic sensors on spray deposition and drift on a pear tree canopy. They found that in comparison to the conventional spraying system, the target-oriented system reduced ground drift by 48.74% and air drift by 59.16%. Compared with photoelectric and ultrasonic sensors, LiDAR sensors can obtain more information about the characteristics of fruit trees, but LiDAR point cloud data processing requires high controller performance. Osterman et al. [25] designed a target-oriented spraying system equipped with a LiDAR sensor that enables real-time sensing of the canopy shape at different tree heights and achieves form spraying by controlling the angles and positions of the upper, middle and lower spraying nozzle arms. Li et al. [26] designed a target-oriented spraying system equipped with a LiDAR sensor capable of variable-rate spraying according to the change in the volume of fruit tree canopies. Compared to traditional air-assisted sprayers and directional air-assisted sprayers, this sprayer decreased droplet drift by 23.2% and 42.7%, respectively, and ground loss by 67.4% and 58.8%, respectively. Zhu et al. [27] developed a laser-guided variable-rate sprayer for managing insects in ornamental nurseries, and field tests in the three studied nurseries with three different insect pests showed that the sprayer reduced spray volume rates by 25% to 80%.

Currently, compared with LIDAR sensors, photoelectric and ultrasonic sensors are low in cost and more mature in their application in orchard target-oriented spraying systems. However, different types of sensors detect the characteristics of fruit tree canopies in different ways, which affects spray deposition and drift on the canopy and ground. The objectives of the research were to evaluate a developed photoelectric-based target-oriented spraying system and a developed ultrasonic-based target-oriented spraying system and to compare pesticide off-target deposition and drift from traditional spraying with those from the two target-oriented spraying systems. Meanwhile, the target-oriented detection accuracy of the sensor-based detection methods for different target detection positions is affected by fruit tree types and canopy structure. The photoelectric-based target-oriented spraying system enables target-oriented spraying by locating the canopy position through the detection of tree trunks. Further, the ultrasonic-based target-oriented spraying system enables target-oriented spraying by directly detecting the canopy position. Young cherry trees and adult apple trees were selected to verify the influence of the target detection position (trunk-based detection and canopy-based detection) on the target-oriented detection effect for different fruit tree types and canopy structures.

3. Conclusions

Two target-oriented spraying systems, one based on photoelectric sensors and one based on ultrasonic sensors were developed in this study. Three spraying treatments were applied to young cherry trees and adult apple trees and revealed that the two target-oriented spraying systems can greatly reduce the ground deposition caused by off-target spraying. Compared with that from the commercial sprayer without any target-oriented spraying system, the ground deposition from the sprayers with the photoelectric-based target-oriented spraying system (trunk-based target-oriented detection) and the ultrasonic-based target-oriented spraying system (canopy-based target-oriented detection) was decreased by 50.63% and 38.74%, respectively, for the young fruit trees and by 21.66% and 29.87%, respectively, for the adult fruit trees. The trunk-based target-oriented detection method can be considered more suitable for young trees, whereas the canopy-based target-oriented detection method can be considered more suitable for adult trees.

Along the spray pathway, as the distance from the sprayer nozzle increased, the ground deposition first increased and then decreased, peaking 1.5 m from the tree trunk. The highest deposition occurred at the back of the canopy and was caused by the high airflow at the air outlet of the sprayer. To reduce ground deposition and improve pesticide deposition in fruit tree canopies, it is necessary to control the sprayer to provide a suitable air speed and air volume.

References

1. He, X. Research progress and developmental recommendations on precision spraying technology and equipment in China. Smart Agric. 2020, 2, 133–146.
2. Wandkar, S.V.; Bhatt, Y.C.; Jain, H.K.; Nalawade, S.M.; Pawar, S.G. Real-time variable rate spraying in orchards and vineyards: A review. J. Inst. Eng. Ser. A 2018, 99, 385–390.
3. Zhai, C.; Zhao, C.; Wang, N.; Long, J.; Zhang, H. Research progress on precision control methods of air-assisted spraying in orchards. Trans. Chin. Soc. Agric. Eng. 2018, 34, 1–15.
4. Zhang, Z.; Wang, X.; Lai, Q.; Zhang, Z. Review of variable-rate sprayer applications based on real-time sensor technologies. Autom. Agric. Secur. Food Supplies Future Gener. 2018, 4, 53–79.
5. Hassen, N.S.; Sidik, N.A.C.; Sheriff, J.M. Advanced techniques for reducing spray losses in agrochemical application system. Life Sci. J. 2014, 11, 56–66.
6. Eugen, M.; Mihai, M.; Mihaela, N.; Gabriel, G. Experimental researches regarding assessment of coverage degree obtained by orchard spraying machine. In Proceedings of the 16th International Scientific Conference: Engineering for Rural Development, Jelgava, Latvia, 24–26 May 2017.
7. Michael, C.; Gil, E.; Gallart, M.; Stavrinides, M.C. Influence of Spray Technology and Application Rate on Leaf Deposit and Ground Losses in Mountain Viticulture. Agriculture 2020, 10, 615.
8. Michael, C.; Gil, E.; Gallart, M.; Stavrinides, M.C. Evaluation of the effects of spray technology and volume rate on the control of grape berry moth in mountain viticulture. Agriculture 2021, 11, 178.
9. Brown, D.L.; Giles, D.K.; Oliver, M.N.; Klassen, P. Targeted spray technology to reduce pesticide in runoff from dormant orchards. Crop Prot. 2008, 27, 545–552.
10. Llorens, J.; Gil, E.; Llop, J. Ultrasonic and LIDAR sensors for electronic canopy characterization in vineyards: Advances to improve pesticide application methods. Sensors 2011, 11, 2177–2194.
11. Miranda-Fuentes, A.; Rodríguez-Lizana, A.; Cuenca, A.; González-Sánchez, E.J.; Blanco-Roldán, G.L.; Gil-Ribes, J.A. Improving plant protection product applications in traditional and intensive olive orchards through the development of new prototype air-assisted sprayers. Crop Prot. 2017, 94, 44–58.
12. Abbas, I.; Liu, J.; Faheem, M.; Noor, R.S.; Shaikh, S.A.; Solangi, K.A.; Raza, S.M. Different real-time sensor technologies for the application of variable-rate spraying in agriculture. Sens. Actuators A Phys. 2020, 316, 112265.
13. Lee, W.S.; Alchanatis, V.; Yang, C.; Hirafuji, M.; Moshou, D.; Li, C. Sensing technologies for precision specialty crop production. Comput. Electron. Agric. 2010, 74, 2–33.
14. Rosell, J.R.; Sanz, R. A review of methods and applications of the geometric characterization of tree crops in agricultural activities. Comput. Electron. Agric. 2012, 81, 124–141.
15. Zhou, L.; Xue, X.; Zhou, L.; Zhang, L.; Ding, S.; Chang, C.; Zhang, X.; Chen, C. Research situation and progress analysis on orchard variable rate spraying technology. Trans. Chin. Soc. Agric. Eng. 2017, 33, 80–92.
16. He, X.; Zeng, A.; Liu, Y.; Song, J. Precision orchard sprayer based on automatically infrared target detecting and electrostatic spraying techniques. Int. J. Agric. Biol. Eng. 2011, 4, 35–40.
17. Zhai, C.; Zhao, C.; Wang, X.; Liu, Y.; Xue, W. Design and experiment of young tree target detector. Trans. Chin. Soc. Agric. Eng. 2012, 28, 18–22.
18. Zou, W.; Wang, X.; Deng, W.; Su, S.; Wang, S.; Fan, P. Design and test of automatic toward-target sprayer used in orchard. In Proceedings of the IEEE International Conference on Cyber Technology in Automation, Shenyang, China, 8–12 June 2015; pp. 697–702.
19. Giles, D.K.; Delwiche, M.J.; Dodd, R.B. Sprayer control by sensing orchard crop characteristics: Orchard architecture and spray liquid savings. J. Agric. Eng. Res. 1989, 43, 271–289.
20. Doruchowski, G.; Swiechowski, W.; Godyn, A.; Holownicki, R. Automatically controlled sprayer to implement spray drift reducing application strategies in orchards. J. Fruit Ornam. Plant Res. 2011, 19, 175–182.
21. Hołownicki, R.; Doruchowski, G.; Świechowski, W.; Godyń, A.; Konopacki, P.J. Variable air assistance system for orchard sprayers; concept, design and preliminary testing. Biosyst. Eng. 2017, 163, 134–149.
22. Maghsoudi, H.; Minaei, S.; Ghobadian, B.; Masoudi, H. Ultrasonic sensing of pistachio canopy for low-volume precision spraying. Comput. Electron. Agric. 2015, 112, 149–160.
23. Gil, E.; Llorens, J.; Llop, J.; Fàbregas, X.; Escolà, A.; Rosell-Polo, J.R. Variable rate sprayer. Part 2-Vineyard prototype: Design, implementation, and validation. Comput. Electron. Agric. 2013, 95, 136–150.

24. Petrović, D.; Banaj, Đ.; Banaj, A.; Barač, Ž.; Vidaković, I.; Tadić, V. The impact of conventional and Sensor Spraying on Drift and Deposit in Cherry Orchard. Teh. Vjesn. 2019, 26, 1211–1217.
25. Osterman, A.; Godeša, T.; Hočevar, M.; Širok, B.; Stopar, M. Real-time positioning algorithm for variable-geometry air-assisted orchard sprayer. Comput. Electron. Agric. 2013, 98, 175–182.
26. Li, L.; He, X.; Song, J.; Liu, Y.; Wang, Z.; Li, J.; Jia, X.; Liu, Z. Comparative experiment on profile variable rate spray and conventional air assisted spray in orchards. Trans. Chin. Soc. Agric. Eng. 2017, 33, 56–63.
27. Zhu, H.; Rosetta, R.; Reding, M.E.; Zondag, R.H.; Ranger, C.M.; Canas, L.; Fulcher, A.; Derksen, R.C.; Erdal Ozkan, H.; Krause, C.R. Validation of a laser-guided variable-rate sprayer for managing insects in ornamental nurseries. Trans. ASABE 2017, 60, 337–345.