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# [F] PhD Extended Abstract Form *(Please select the Calibri 10 typeface)*

**Towards a sustainable use of plant protection products in orchards: Implementation of canopy-adapted spray technology and new developments for spray efficiency evaluation**

by LU XUN

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**Extended Abstract**

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## 1. Chapter 1–Introduction

The application of plant protection products (PPP) is one of the most widely used solutions to effectively control pests and diseases during orchard management, guaranteeing the yield and production of fruits. Farmers normally tend to overdose spray with a high application volume to assure biological efficacy, despite big variability in canopy structure and vegetation volume due to crop type and growth stage. This inefficient conventional application produces huge off-target losses, which causes not only the waste of PPP and applied water but also adverse effects on human health and the environment. The adverse effects of agrichemical applications have raised great public concerns about the safe use of pesticides. To address this issue, the EU proposed the regulation of the sustainable use of pesticides to reduce the risks and impacts of pesticide use, which was also included in the recently published Farm to Fork Strategy. Considering the large PPP usage in orchards and the complexity of canopy characteristics, the optimization of spray application in orchards will be an important part and also a major challenge in achieving the sustainable use of PPP.

Conventional spray application in orchards can be improved in different aspects for safer and more effective use of PPP. Appropriate dose adjustment to determine the actual amount of applied PPP is an important measure to increase application efficiency. Additionally, following the best management practices, to optimize sprayer structure and working parameters to match the target canopy can enhance canopy deposits and mitigate off-target losses. Benefiting from the precise detection and characterization of target canopy by different sensors, variable-rate spraying technology has made significant advancements in recent years, allowing for real-time adjustments of applied liquid rate based on detected canopy characteristics. Furthermore, the use of various spraying support software and tools for decision support, spray quality evaluation, and risk assessment can greatly benefit farmers and operators in practice.

Though a number of available methods and tools can be used to optimize PPP application, more research is needed to explore optimal spray application for specific application scenarios considering the complexity of orchard canopies and the diversity in the distribution and habits of pests and diseases. It is necessary to evaluate and quantify the potential improvement in spray quality and PPP savings of these different optimization measures compared to the conventional application. The obtained data from laboratory and field tests can serve as an important reference and guidance to achieve the sustainable use of pesticides. In this context, the main objective of this doctoral thesis is to improve spray applications in orchards from two major aspects: a) to evaluate and quantify the potential improvement of canopy-adapted spray technology (optimized spray application to match overall canopy characteristics and variable rate application to adapt to variation of vegetation within the orchard) in PPP use, spray quality and biological efficacy through field tests, and b) to develop new methodologies for spray quality evaluation. The main objective of this thesis was achieved through three studies, each of which was described in subsequent chapters.

**2. Chapter 2–The first study**: Xun, L., Garcia-Ruiz, F., Fabregas, F.X., Gil, E., 2022. Pesticide dose based on canopy characteristics in apple trees: Reducing environmental risk by reducing the amount of pesticide while maintaining pest and disease control efficacy. Sci. Total Environ. 826, 154204.

The first study evaluated the spray distribution and biological efficacy of a conventional application and four optimized spray applications with dose adjustments based on tree row volume (TRV) and parameter adjustments following the best management practices in a commercial apple orchard at three growth stages. The results showed that conventional mist-blower with a high application volume (800 L $ha^{-1}$ ) exhibited an excessive coverage with a high risk of contamination at the early crop stage (BBCH19), whereas other treatments using different application techniques, with a reduced volume rate and pesticide dose of 75%, were equivalent with good uniformity, revealing the great importance of suitable adjustment for the sprayers. For the middle and late stages (BBCH64 and 75), the orchard sprayer equipped with vertical booms provided the maximum coverage, and the pneumatic sprayer achieved significantly higher impacts density, which revealed their advantages and high efficiency for dense apple trees. The newly developed multi-fan sprayer and pneumatic sprayer achieved consistent coverage during the entire crop stage, independent of the changes in canopy structure (TRV). This indicates that a suitable setting and adjustment of the sprayer can contribute to a consistent spray quality. In general, benefiting from these new spraying technologies, an average reduction of 60.7% in pesticide dose and volume rate were achieved within the entire season, maintaining the same threshold of pest and disease control as that of the higher reference dose normally applied. These results demonstrate the importance of an alternative dose adjustment method to meet the requirements of the Farm to Fork strategy.

**3. Chapter 3–The second study**: Xun, L., Campos, J., Salas, B., Fabregas, F.X., Zhu, H., Gil, E., 2023. Advanced spraying systems to improve pesticide saving and reduce spray drift for apple orchards. Precis. Agric. 24, 1526–1546.

The first research demonstrated the effectiveness to reduce PPP usage using dose adjustments based on the orchard characteristic at different growth stages. However, there is significant spatial variability in canopy characteristics even in the same orchard at a specific time. In order to adapt to the changes in vegetation along the crop row to achieve site-specific management, a variable rate spraying system was developed. This precision system used ultrasonic sensors to characterize canopy vegetation and proportional valves to adjust the output liquid rate of spray nozzles in real-time. In the second study, this system was compared with two typical spraying systems (conventional system and optimized system following the best management practices) in the applied volume/PPP and spray drift when applied in an apple orchard at two growth stages following the ISO22866-2005 protocol. Compared to the conventional system, the other two advanced systems significantly reduced the amount of ground drift (>60%) at most of the sampling distances at the growth stage BBCH 72, while the precision system demonstrated the best drift mitigation (57.3% reduction) at the stage BBCH 99. For the airborne drift, a remarkable drift reduction was also achieved with the two advanced systems. Specifically, the optimized spraying system exhibited a drift reduction by approximately 80% at the first growth stage, and the precision application demonstrated its considerable advantages in minimizing drift loss for the sparse canopy at the stage BBCH 99. Moreover, the saving of applied volume/pesticide was achieved by 12% with the optimized system and 43% with the precision system. This study revealed the necessity and prospect of the advanced spraying systems to reduce the environmental contamination and health risk from pesticide applications in fruit tree production.

**4. Chapter 4–The third study**: Xun, L., Gil, E., 2024. A novel methodology for water-sensitive papers analysis focusing on the segmentation of overlapping droplets to better characterize deposition pattern. Crop Prot. 176, 106492.

In the two previous studies, the potential improvements of advanced spray applications in PPP usage, spray quality, and biological efficacy were evaluated and quantified through field tests, and the third study focused on the development and optimization of spray quality evaluation tools. Water-sensitive papers (WSPs), as an artificial target, have been generally used to evaluate spray quality in pesticide applications. Though many tools were available to analyze WSPs, they were not effective in processing the presented overlapping droplets, which prevented accurate quantification of spray quality. Here, a novel methodology was proposed to analyze WSPs, focusing on the segmentation of overlapping droplets based on

concave point detection and ellipse fitting. Up to 553 WSPs obtained from field trials in apple trees were used to validate this methodology. A high overall segmentation accuracy of 77.8% was achieved for the WSPs with coverage below 25%, which allowed to precisely characterize the corresponding deposition pattern. A universal linear relationship was observed between the droplet density and coverage, independent of the sprayer and canopy characteristics. In addition, the droplet size distributions for all spray applications showed a similar trend. As the proposed methodology was not effective to segment the complex overlapping spots on the WSP with high coverage (>25%), simulated WSPs were generated to estimate the deposition pattern of high coverage based on the droplet size distribution deposited on the WSPs with low coverage. A linear relationship with a much higher slope was observed between droplet density and coverage for the high deposition, which enabled an approximate estimation of the corresponding droplet density. In general, the proposed approaches allowed to obtain more accurate spray quality indicators from the WSP collectors and could be widely used for spray application evaluation to promote precision spraying.

**5. Chapter 5–General conclusions**

For the application of PPP in orchards, the canopy-adapted technology (optimized application to match the overall canopy characteristic and variable rate application to adapt the intra-orchard variation) with dose adjustments can effectively reduce the use of water and PPP compared to the conventional high-volume application. In most cases, the canopy-adapted application achieved equal or better spray quality within the tree canopy and remarkably lower spray drift than the conventional application while maintaining the effective control of pests and diseases. The promotion and adoption of the canopy-adapted technology can be an effective solution to achieve the remarkable reduction of chemical pesticides set in the Farm to Fork Strategy and sustainable use of PPP. In addition, the proposed approaches in the third study allow to obtain more accurate spray quality indicators from the WSP collectors and can be widely used for spray application evaluation to promote precision spraying.

**Final remarks concerning benchmarks and strength points of the Pellizzi Prize 2024**

*[compulsory chapter to fill with 1000 characters max, spaces included]*

This thesis can be classified within category 1.2 Agricultural Machines and Mechanization, or 1.4 Automation and Electronics. The starting point was the conventional spray application in orchard plantations with high spray volume. To reduce the PPP use, a new “smart sprayer” with variable rate application (VRA) has been developed. The precise spraying was implemented using the latest technology combined with the PPP dose adjustment based on canopy characteristics.

Transfer to the market is guaranteed. This VRA sprayer, developed within Optima H2020 EU project, was honored with Bolonia Fair Award in 2022. This smart sprayer has been launched into the market and is already in use-phase in several commercial orchards.

Benefits for farmers are manifold. This thesis gave a solution of ready-to-use VRA technology to sprayer manufacturers to accomplish EU standards. Farmers can effectively reduce the amount of PPP used and mitigate environmental contamination, consequently cutting expenses.