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RESEARCH ARTICLE

Upper Bounds on real-time Spot Spraying of Tree and Bush Crops

[version 1; peer review: 1 approved with reservations, 1 not approved]

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Abstract

Background

Reducing pesticide use in specialty crops is a major societal and challenge. Although high-end sprayers can achieve up to 25% *plant protection product* (PPP) savings through detailed calibration, the EU's Farm-to-Fork strategy targets a 50%. Many simple tree and bush crop sprayers remain inefficient, with up to half of the applied PPP lost to drift, run-off, and ground deposition. However, advanced sensing technologies combined with precision spraying systems, offer opportunities for substantial additional PPP savings.

Methods

Field trials were conducted in commercial citrus, almond, and olive orchards across Spain. A *Fede Smartomizer H3O* sprayer was used as baseline. Further, a real time spot spraying system - comprising 3D stereo vision cameras and individual nozzle control - was mounted to collect real-time canopy geometry data. This information was transmitted to a spot spraying enabled sprayer with independently actuated nozzles. Nozzle activity was logged. Spray deposition was evaluated using hydrosensitive paper. Savings of the spot spraying system, commercially referred to as "AIs", were computed relative to the constant rate baseline application.

Results

Across all test sites, *AIs-enabled* spot spraying significantly reduced PPP use without compromising canopy coverage. Spray volume savings were 43% in citrus, 48% in almond, 56% in intensive olive, and 67% in extensive olive orchards. Moreover, mathematical closed-form

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expressions are derived to indicate the potential savings associated with the application of spot spraying.

Conclusion

Concluding, real time spot spraying in tree and bush crops, like implemented thought the *AIs system,* enables substantial additional PPP savings beyond what is achievable with well-calibrated constant-rate sprayers. Savings depend on canopy variability and the relationship between canopy structure and sprayer resolution. Closed-form upper bounds are derived indicating savings potential of an ideal spot sprayer with infinite resolution.

Keywords
3D Computer Vision, Spot Spraying, Bush and Tree Crops, Specialty Crops, pesticide use reduction, drift reduction, Smartomizer, EU LIFE Programme, Life-AIs.

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Author roles: Berger LT: Conceptualization, Project Administration; **Perales P**: Data Curation; **Esteve E**: Validation; **Alarcón J**: Software

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Introduction

According to the *World Health Organization* (WHO), low fruit and vegetable intake causes approximately 1.7 million deaths per year.[1] Globally, studies predict serious fruit shortages up to 2050, with the world population reaching 9 billion,[2,3] while pests and diseases are responsible for 25% to 40% yield loss before harvest.[4] Moreover, pesticide residues are the most important food-related concern for EU citizens,[5] and the *European Food Safety Authority* (EFSA) announced that more than 45% of the food products analysed (apples, head cabbage, lettuce, peaches, spinach, strawberries, tomatoes, barley, oats, wine grapes, swine fat, and milk) contain pesticide residues.[6]

Thus, reducing the use of pesticides in fruit production is a major global societal challenge, and it is in line with European Directive 2009/128/EC,[7] which demands *Integrated Pest Management* (IPM), as well as 2016/2031/EC,[8] which requires that a proportionate and effective response to plant health threats is established through a combination of technological, ecological, and institutional management. However, large parts of the conventional spraying equipment are currently highly inefficient. The size of the problem was quantified in the 3-year study '*Save Spray'*, directed by the *Valencian Institute of Agriculture Research* (IVIA) in collaboration with *Pulverizadores Fede* (FEDE), the *University of Lleida* (UDL), and the *Polytechnical University of Catalonia* (UPC).[9] The study revealed that 50% of *plant protection product* (PPP) do not reach the plants but are lost owing to drift, run-off, and ground losses when using conventional spraying equipment. As a result, many pesticides are found in ambient air, contaminating the environment,[10] with considerable negative effects on biodiversity, bee life, bystanders,[11] and the ecosystem as a whole. Addressing this serious environmental problem, the EU's *Life-F_3 project*[12] demonstrated, in the case of the Spanish vineyard (*Viñas del Vero*) and the Portuguese olive plantation (*Do Outeiro Sociedade Agricola, S.A.*), that reduction of over 25% of biocidal products and/or pesticides is possible simply through the correct set-up and use of existing high-end spraying equipment.[13,14] Similarly, the recent case study in[15] indicates even higher savings with constant rate high-end equipment in combination with *Best Management Practice* (BMP). While these are already significant advancements, the work presented here as part of the Life-AIs project[16] takes the developments one step further by adding the capability to individually switch all nozzles based on input commands from a 3D stereo vision system with artificial intelligence edge processing capabilities (AIs). The AIs system can be considered as growers' "eyes on the ground." Edge processing algorithms, with a well-balanced degree of detail and temporal resolution, provide information on crop dimensions, which facilitates real-time sprayer adjustments, *i.e.* important enablers to pesticide and foliar fertilizer reduction under the umbrella of *Precision Agriculture* (PA).

Materials and methods

AIs sprayer technology

The *AIs* system, as shown in Fig. 1, was fitted on a tractor and contained two stereo vision cameras per side. Mounting *AIs* on tractors enables the collection of sprayer-independent crop statistics. However, collecting data with *AIs* also presents significant technical challenges; for example, *e.g.* the timing for spray nozzle actuation is dependent on information captured from another vehicle, with the sprayer and tractor only loosely coupled. Furthermore, establishing a reliable high-speed data connection between vehicles that are frequently disconnected and reconnected under harsh field conditions is challenging. Here, *AIs* provide a robust Ethernet solution.

Moreover, the issue of keeping camera lenses clean is addressed with a pressurized air curtain system that shields off the lenses from dust, rain, *etc.* Pressurized air is also used to cool the cameras and the *AIs*' edge processing unit at its core.

The data collected can be directly used to act on the sprayer, *e.g.* to open and close spray nozzles, as a function of the detected tree dimensions and density. To do so, sprayers must be "*AIs-enabled*," which means, they need a connection into the *Sprayer Control System* (SCS) over which to receive proprietary *AIs* commands, and they must be fitted with actuators, *i.e.* the *Nozzle Control Unit* (NCU), to open and close nozzles individually, while maintaining spray pressure constant (Fig. 2).

Turning to the high-level system deployment view in Fig. 3, it becomes apparent that the *Life-AIs* material is much more than a sprayer. It is a specialized crop agricultural management environment that brings digitalization and precision to 3D crops. The lower part of Fig. 3 shows a sprayer with a Fede *Sprayer Control System* (SCS) connected *via* Wi-Fi with a *Terminal Application in the tractor's cabin* (TAPP).

The tractor carries a *speciality crops gateway* (SCG) that guides the sprayer operator and connects the tractor and sprayer via a cellular modem to the Internet and from there to Fede's Cloud, referred to as *Speciality Crops Platform* (SCP). Farmers and agronomic advisors have access to the *Speciality Crops Platform via* web *graphical user interfaces* (GUIs). In this way, they can perform actions such as sending prescriptions or work orders to the sprayer operator as well as monitoring and documenting results. Moreover, through a GUI, back-office staff can process the data. For example, it can



Fig. 1. **Fede's *AIs* system connected to an *AIs-enabled* sprayer in almond field.**

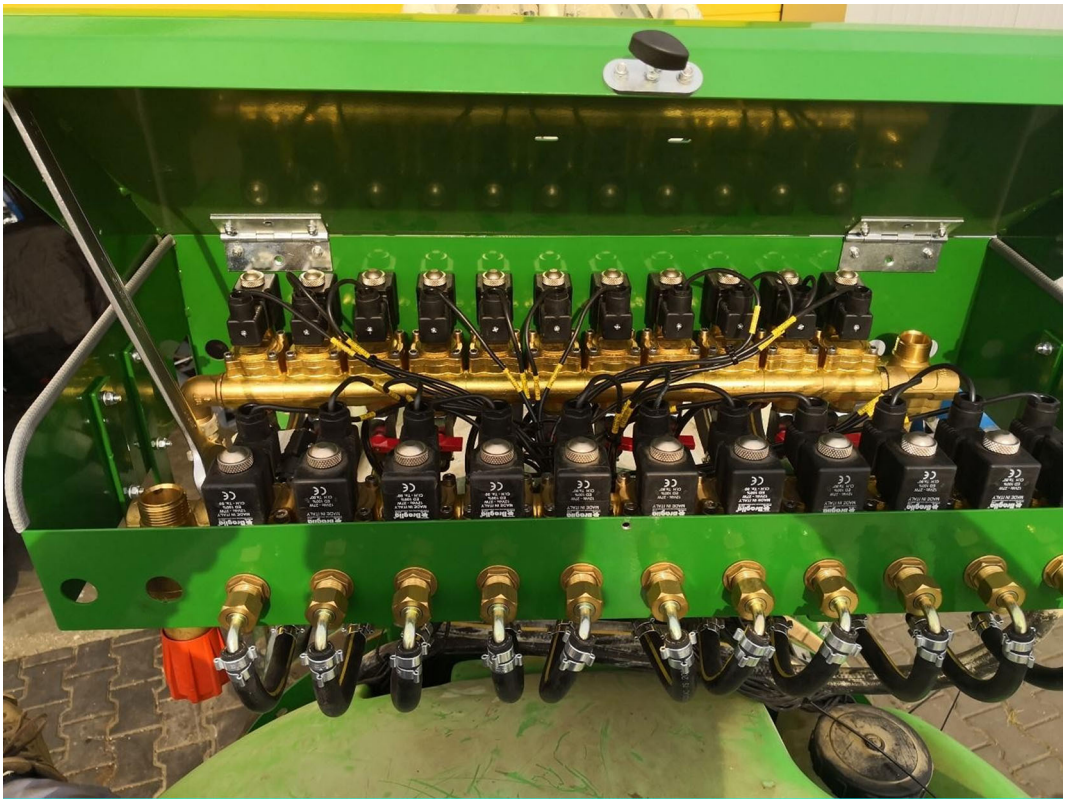

Fig. 2. **Nozzle Control Unit (NCU) to open and close nozzles individually, while maintaining spray pressure constant.**

automatically produce a farm book that records all treatments for plant protection products. Moreover, interoperability with third-party service providers is ensured through *Application Programming Interfaces* (APIs) bundled in the *Specialty Crop Integration Centre* (SCIC).

AIs and baseline reference set-up

The baseline sprayer was a *Smartomizer* H_3O of 2000 l, with $n = 26$ identical individual switchable nozzles, $n/2$ per side. The test results were obtained for traditional citrus, almond, and olive groves under spraying conditions, as outlined in Fig. 4. Fig. 4. (a) shows the baseline situation, where the sprayer is configured manually in a conventional manner by selecting the baseline spray volume Q (L ha^{-1}) with respect to the *Tree Row Volume* (TRV),[17] *i.e.,*

$$Q = (H \cdot W \cdot k \cdot 10\,000)/\mathrm{R} \qquad \text{(equ. 1)}$$

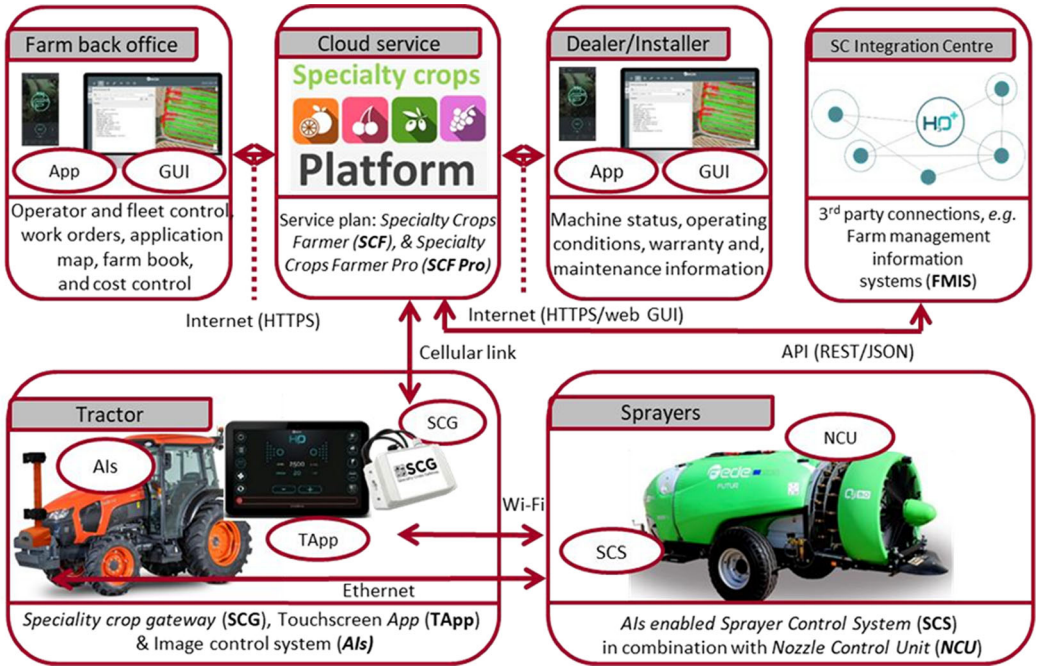

Fig. 3. Fede's AIs system embedded into the *Specialty Crops Platform* (SCP).

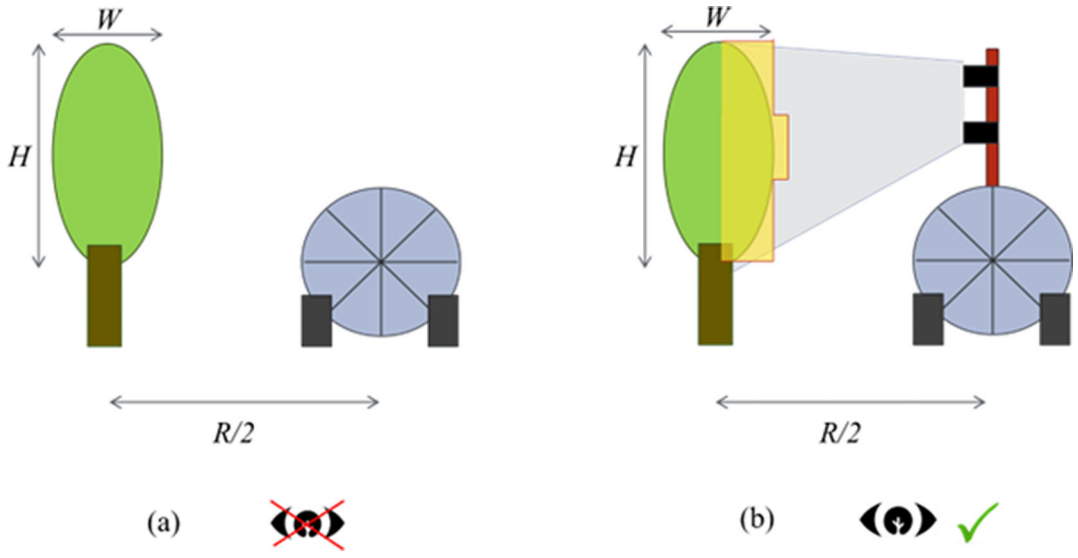

Fig. 4. Spraying situation. (a) baseline without *AIs.* (b) with *AIs* scanning of tree dimensions.

where H is the tree height excluding the bare trunk (m), W is the tree width (m), R is the interrow distance (m), and k is the unit volume (L m^{-3}).

The flow rate per nozzle q is then calculated as in,[17] *i.e.*

$$q = (Q \cdot R \cdot v)/(600 \cdot n) \quad \text{(equ. 2)}$$

where additionally v is the driving velocity in km h^{-1}.

In Fig. 4 (b), the sprayer receives input from the *AIs* system with instructions to switch individual nozzles on and off for segments of the canopy where little or no foliar mass is detected.

The nozzle opening and closing times were digitally logged for post-processing data analysis. To monitor and ensure no negative impact of the *AIs* system on distribution and deposition, water sensitive paper was deployed over the canopy, placing special emphasis on edges and areas close to canopy holes where *AIs* are expected to perform nozzle switching.

The citrus, almond, and olive test fields

Trials were performed in citrus, almond, and olive plantations throughout Spain, with field satellite maps as well as individual tree views, as shown in Fig. 5.

Comparing in the lower part of Fig. 5. the RGB (*Red, Green, Blue*) image to the left and the depth image to the right, one gets an understanding of the type of information the 3D cameras are gathering. In fact, all the grey shadings correspond to different depths that are then converted by *AIs´* processing algorithms into actionable nozzle opening and closing commands.

Furthermore, the olive results are obtained in two different fields, as shown in Fig. 5 (c), in a 7 m × 7 m *intensive* setting and in Fig. 5 (d) in an 11 m × 11 m *extensive* setting. The target spray volumes Q_{target} in the case of constant rate uniform application were selected as 3125 L ha^{-1}, 1000 L ha^{-1}, 1180 L ha^{-1}, and 1100 L ha^{-1} for the citrus, almond, intensive, and extensive olive cases, respectively.

Results

PPP savings due to AIs

Monitoring of the baseline spray parameter shows that the sprayer regulates the spraying processes so that the actual applied spray volume $Q_{applied}$ stays in all four cases within ±2.5% of the target.

For the *AIs* situation, the notion of treatment "*equivalent to*" was devised because many growers are used to define a constant-rate target spray volume per field surface area. However, when *AIs* autonomously closes nozzles, while maintaining the spray pressure approximately constant, the sprayer applies over the whole area a quantity that results in spray coverage "*equivalent to*" having ordered a uniform treatment with Q_{target}, but where due to *AIs* induces savings

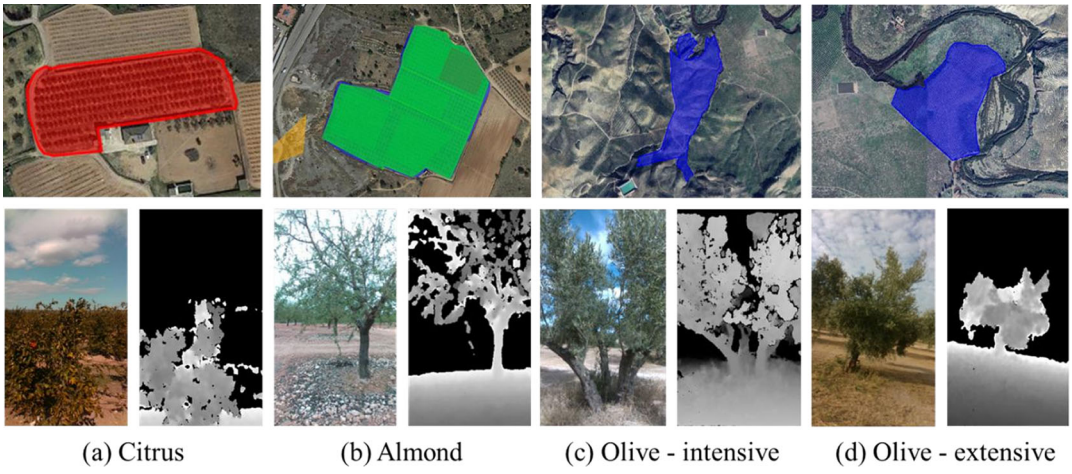

Fig. 5. Satellite, RGB, and depth view of (a) Citrus, (b) Almond, (c, d) Olive test fields/trees.

the actual applied spray volume stays below, *i.e.* $Q_{applied} \leq Q_{target}$. To express that *AIs* enabled sprayers intentionally stay most of the time below the uniform spray volume, Q_{target} is renamed into "$Q_{equivalent}$," and *AIs* induced spray volume savings are expressed as,

$$S_{AIs} = Q_{equivalent} - Q_{applied} \quad \text{(equ. 3)}$$

which in relative terms delivers the savings ratio,

$$s_{AIs} = \left(Q_{equivalent} - Q_{applied}\right) / Q_{equivalent} \quad \text{(equ. 4)}$$

To ensure that the precision treatment is "*equivalent to*" the uniform baseline treatment, it is of utmost importance that the spray efficacy does not diminish. Although spray efficacy trials were not feasible owing to time constraints in the present work, a visual inspection of water sensitive paper distributed in the canopy was conducted for the baseline cases and the AIs cases, which showed comparable spray distribution and deposition. Water sensitive paper spray impact quantification performed using the *SnapCard* spray APP[18] revealed that, in all situations, the minimum coverage was above 10%.

To obtain a feeling for the nozzle opening and closing processes, Fig. 6. shows the number of nozzles opened over time in the citrus case.

With the baseline sprayer manually adjusted to the maximum tree size, it operates with ten constantly open nozzles per side. However, the *AIs*-enabled sprayer dynamically regulates the number of nozzles, reaching a maximum of ten nozzles open per side. Thus, *AIs* control does not at any moment in time lead to an increase in spray volume, while in many instances, it leads to a spray volume reduction.[19]

The results of the spray volume reductions achieved in the citrus, almond, and olive cases are shown in Fig. 7 rounded to the nearest integer.

Fig. 7 shows that *AIs* induced spray volume savings S_{AIs} are 1329 *L*, 485 *L*, 658 *L*, and 737 *L* in citrus, almond, and intensive and extensive olive fields, respectively. This relates to savings percentages of 43%, 48%, 56%, and 67%, respectively, and is a clear indication that with *AIs* additional savings can be obtained in comparison to a high-end well-adjusted constant-rate sprayer.

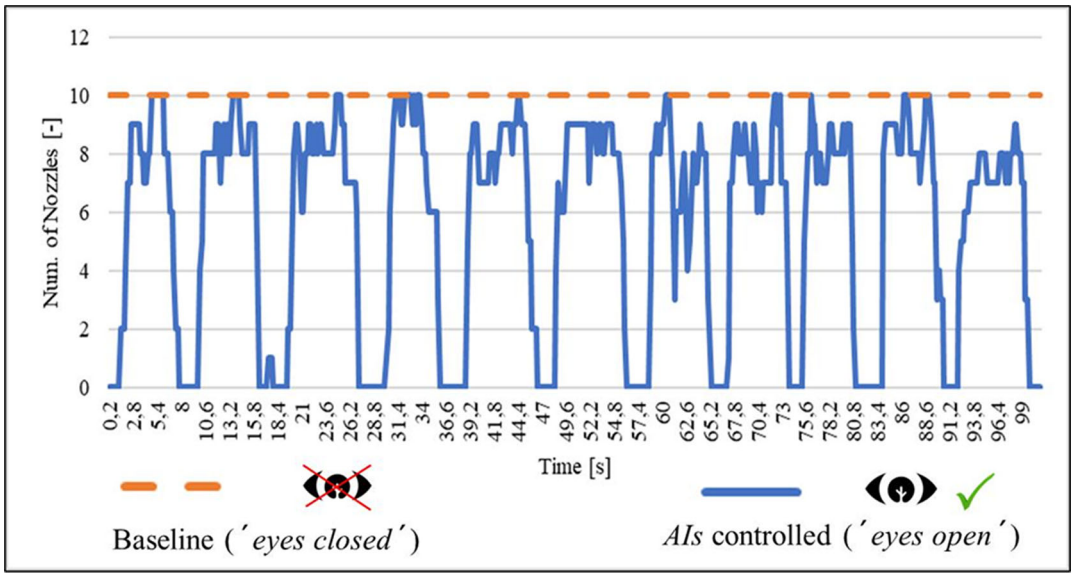

Fig. 6. Time series nozzle opening example in citrus case.

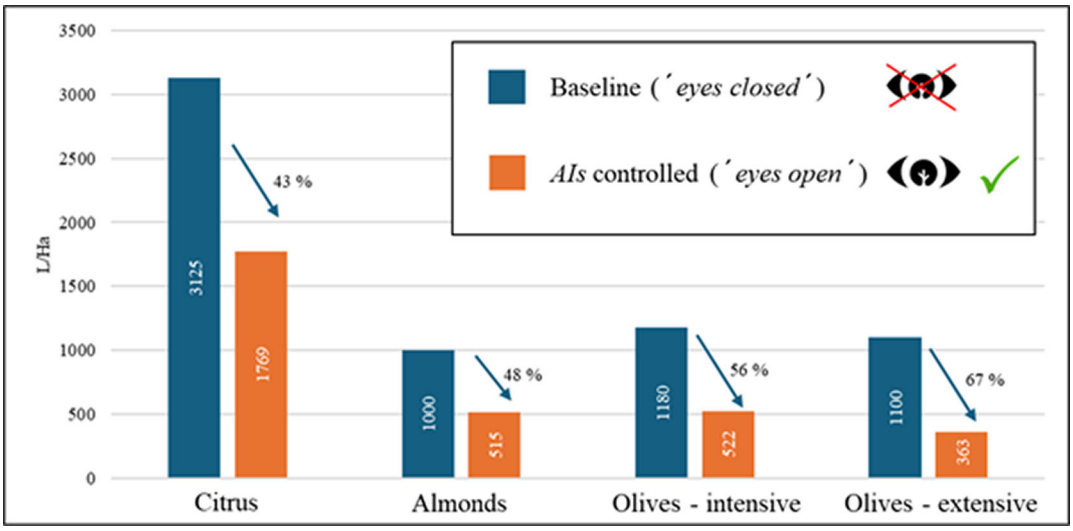

Fig. 7. Spray volume as applied in baseline and *AIs* case in Citrus, Almond and Olive fields.

Discussion

For our health and well-being, pesticide use in crop production needs to be reduced, which is also in line with EU policies such as the *Green Deal* and the *Farm-to-Fork strategy*. A significant percentage can already be gained by following the "*Calibration of Orchard Sprayers*" procedures, as in.[17] Respective trials in the predecessor *Life-F*$_3$ project[12] revealed savings of up to 25% using manually well-adjusted spraying equipment.[14]

This work goes a step further and demonstrates additional savings of up to 67% even over a well-adjusted constant-rate sprayer owing to *AIs* enabled precision spraying.

To approximate and predict savings theoretically, let us make the simplifying assumption that tree crowns seen from the side can be represented by circles of diameter *d*. Denoting the tree spacing from trunk to trunk with *r*, the simplified 2D tree canopy area can then be modelled, as shown in Fig. 8,

where

$$A_{AIs} = \pi \cdot \left(\frac{d}{2}\right)^2 \qquad \text{(equ. 5)}$$

$$A_{US} = d^2 \qquad \text{(equ. 6)}$$

$$A_{BL} = r \cdot d \qquad \text{(equ. 7)}$$

are the expressions for the surface under the ideal case. In Fig. 8, the light red rectangular area corresponds to the ideal area of a single tree sprayed with uniform constant rate *baseline* (BL) equipment, *i.e.* with *eyes closed* (equ. 7)). The medium red quadratic area corresponds to the ideal area sprayed when a single *ultrasound sensor* (US) per side is used to detect the presence of the canopy, which triggers the entire left or right side of the spray nozzles to turn on (equ. 6)).[1] The dark red circular area indicates the ideal sprayed area using the *AIs* system (equ. 5)). Forming the quotient of these areas, the mathematical expressions for the savings upper bounds are

$$\widehat{s}_{US} = \frac{(r \cdot d) - d^2}{r \cdot d}$$

[1]Note that while the *ultrasound* (US) system is not core of this publication, it is included in the discussion as it helps to visualize and understand some of the underlying effects.

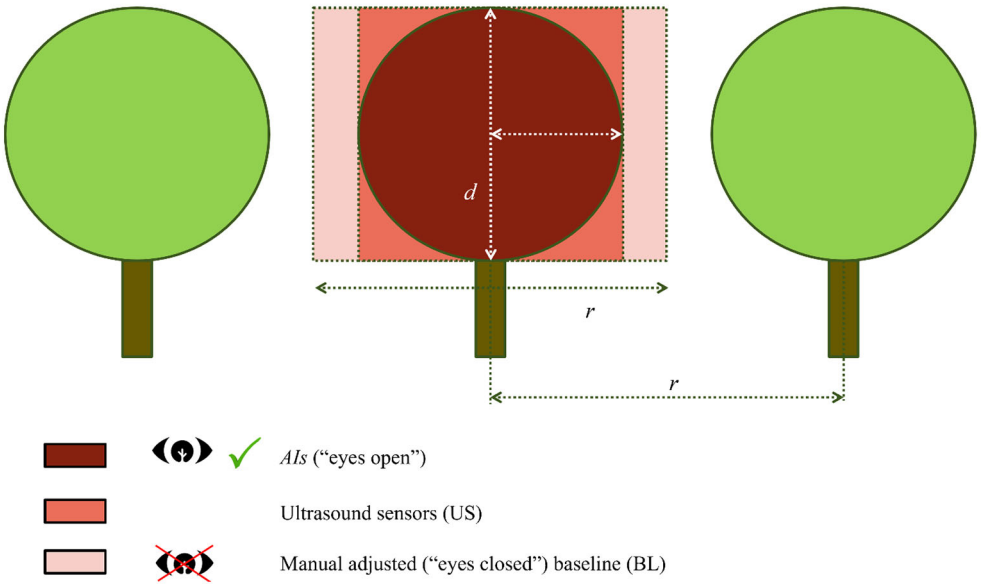

Fig. 8. Simplified 2D representation of the canopy area sprayed when "seen" in side view.

$$= 1 - \frac{d}{r} \qquad \text{(equ. 8)}$$

and,

$$\hat{s}_{AIs} = \frac{(r \cdot d) - \pi \cdot \left(\frac{d}{2}\right)^2}{r \cdot d}$$

$$= 1 - \frac{\pi \cdot d}{4 \cdot r} \qquad \text{(equ. 9)}$$

for the ideal *ultrasound* (US) and ideal *AIs* case, respectively.

Table 1 presents a comparison of the predicted savings upper bounds from equ. 8) and equ. 9) with actual measured savings.

The calculated savings upper bounds, $\hat{s}$, are, in all cases, higher than the actual savings obtained. This is due to real-world imperfections, such as the finite resolution of the *AIs* vision system and, more importantly, the finite granularity with which the spraying nozzle elements operate.

Moreover, especially for the *ultrasound system* (US), the difference between prediction and measurement was approximately 15 and 23 percent, respectively. Hence, it was investigated what could have caused this difference, and it was found that the US system was programmed to trigger nozzle opening slightly earlier and close slightly later than the actual observation, to stay on the safe side, and effectively treat slightly more than the canopy. It was found that the extra opening at the used speed of 3.6 km h^{-1} corresponds to 1.5 m. Adding these 1.5 m to *d* in equ. 8) delivers the modified US results in Table 1, marked as $US'_{(1.5\ m)}$. Accounting for this known margin leads to predicted savings results that are now within 2 percentage points of the measured results (see the last column of Table 1).

Regarding the *AIs* savings in Table 1, it can be seen that mathematical upper bounds are, in most cases, very similar to the actual savings. Only in the case of *AIs* in *Olive - intensive* the mathematical upper bound exceeds the actual measured result by 16 percentage points.

Looking at the *AIs* savings upper bound in the *intensive* and *extensive* olive cases, it can be seen that the results remain with 72% and 70% within the same range. However, looking at the actually measured values, it is found that *AIs* performs in an *Olive - extensive* situation with a saving of 67%, even better than in the *Olive - intensive* case, with a saving of 56%. To obtain a better understanding of the underlying effects, consider the schematic drawing in Fig. 9, which sketches out what is happening when spraying with *"real-world" AIs* and US systems, where *"real-world"* refers to the fact that actual system implementations have a limited spraying resolution/spraying granularity.

The left-hand side in Fig. 9 could, for example, represent the *Olive-intensive* case with smaller trees, while the right-hand side could represent the *Olive-extensive* case with larger trees.

The granularity of the spraying process is determined by two factors: resolution of the detection system and resolution of the spray pattern. The dark red bands symbolize the spray patterns that can be activated with *AIs*, the medium red rectangle

Table 1. Comparison of predicted and achieved spray volume savings for different field situations.

	r	d	$Q_{equivalent}$	$Q_{applied}$	S	s	$\hat{s}$	$\hat{s} - s$
	[m]	[m]	[L ha^{-1}]	[L ha^{-1}]	[L ha^{-1}]	[–]	[–]	[–]
Citrus								
AIs	3.5	2.5	3125	1796	1329	43%	44%	1%
Almonds								
AIs	6	3.7	1000	515	485	48%	52%	3%
Olives intensive								
US	7	2.5	1180	689	491	42%	64%	23%
US´ $_{(1.5\ m)}$	7	2.5	1180	689	491	42%	43%	1%
AIs	7	2.5	1180	522	658	56%	72%	16%
Olives extensive								
US	11	4.25	1100	595	505	46%	61%	15%
US´ $_{(1.5\ m)}$	11	4.25	1100	595	505	46%	48%	2%
AIs	11	4.25	1100	363	737	67%	70%	3%

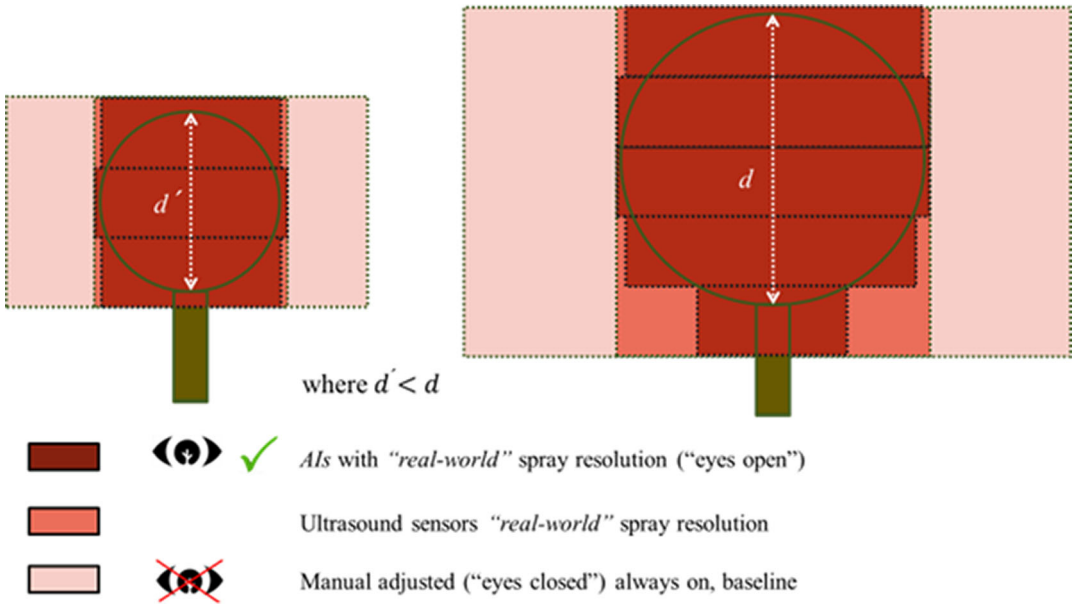

Fig. 9. Impact of non-ideal *AIs* resolution on savings result in small and big tree representation.

symbolizes an entire side switched either on or off based on ultrasound sensor commands, and the light red rectangle symbolizes the area of the continuously on *baseline.* From the right-hand side in Fig. 9, it can be seen that the *AIs* spray bands largely follow the tree crown circumference, and there is a clear differentiation towards the medium red area sprayed by the US-based sprayer.[2] However, when shifting to the smaller tree on the left (while not increasing the *resolution* of the sprayer), it can be seen that following the circumference of the crown is now much less accurate. Furthermore, the difference between *AIs* operation in bands and spray operation based on a single US diminishes. This effect of decreasing returns of *AIs* over the *US* for smaller trees is reflected by the savings advantage decreasing from 21 percentage points for *Olives-extensive* to only 14 percentage points in *Olives-intensive.*

While *AIs* works well in all investigated situations, with savings results ranging from 42% to 67% in comparison to a high-end constant-rate sprayer, it should be noted that the effectively achievable savings depend on the variability of the canopy and the exploitability of gaps and their relationship to the sprayer resolution. In very heterogeneous canopies with little gaps/spacing between trees, less savings will be achievable, whereas in highly variable canopies with considerable tree gaps/spacing, or even missing trees, savings can be very significant. Moreover, if the spatial resolution of an *AIs* enabled sprayer stays constant, then higher saving percentages are expected in trees with larger crowns than in trees with smaller crowns because of *AIs´* increased ability to follow the crown circumference in bigger trees. Moreover, it should be noted that the derived analytic saving upper bounds assume round tree crowns with spacing between trees. For other growing systems such as hedge-type orchards or vineyards, these predictions are not equally applicable and must be adjusted.

Overall, the presented results indicate that the latest advances in computer vision enabled specialty crop sprayer developments allow growers to significantly reduce their production costs due to PPP savings in line with EU objectives and in tune with the environment along the motto:

"Life-AIs: See & Save!"

Ethics and consent

This study did not involve human participants, human data, identifiable personal information, animals, or biological samples requiring oversight. An ethical self-assessment was performed. Ethical approval and consent were not required.

Data Availability

The datasets supporting the findings of this study are openly available in the Zenodo repository under the title *"Accompanying data to 'Upper Bounds on real-time Spot Spraying of Tree and Bush Crops".*[19] The dataset displays the comprising raw measurements relevant to the evaluation of real-time spot spraying performance in tree and bush crops.

DOI: **https://doi.org/10.5281/zenodo.18845206.**[19]

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All files in the dataset are made available under a Creative Commons Attribution 4.0 allowing re-distribution and re-use of a licensed work on the condition that the creator is appropriately credited.

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[2]While several ultrasound sensors could be mounted at different heights to increase the sensing resolution and therewith control different nozzle sections,[20] here a single ultrasound sensor is used to control an entire side. Hence, the usage of US is not necessarily worse than *AIs* and it is the specific setup here that leads to inferior performance.

References

1. World Health Organization (WHO): **Promoting fruit and vegetable consumption around the world. Information sheet.** 2019.
Reference Source
2. Food and Agriculture Organization (FAO): **How to feed the world. Expert report.** 2009.
Reference Source
3. Grethe H, Dembele A, Duman N: *How to feed the world's growing billions.* Heinrich Böll Foundation & WWF Deutschland; 2011.
Reference Source
4. Food and Agriculture Organization (FAO): **Preventing, anticipating and responding to high-impact animal and plant diseases and pests. Web press release.** 2020.
Reference Source
5. European Commission: **Special Eurobarometer 354: food-related risks.** 2010.
Reference Source
6. European Food Safety Authority: **The 2019 European Union report on pesticide residues in food.** *EFSA J.* 2021; **19**(4): e06491.
7. **Directive 2009/128/EC of the European Parliament and of the Council of 21 October 2009 establishing a framework for Community action to achieve the sustainable use of pesticides.** *Off. J. Eur. Union.* 2009 Nov 24; **L 309**: 71–86.
8. **Regulation (EU) 2016/2031 of the European Parliament and of the Council of 26 October 2016 on protective measures against pests of plants.** *Off. J. Eur. Union.* 2016 Nov 23; **L 317**: 4–104.
9. Moltó E, Rosell JR, Gil E, *et al.*: **Integrated strategies for a safe and efficient use of phytosanitary products.** *Vida Rural.* 2012; 353.
Reference Source
10. Coscollà C, Hart E, Pastor A, *et al.*: **LC–MS characterization of contemporary pesticides in PM10 of Valencia Region, Spain.** *Atmos. Environ.* 2013; **77**: 394–403.
Publisher Full Text
11. Blaschke U, Felkers E, Hewitt NJ, *et al.*: **Proposals for new spray drift exposure values in orchards and vineyards for residents and bystanders.** *Asp. Appl. Biol.* 2024; **148**.
12. European Climate, Infrastructure and Environment Executive Agency (CINEA): **Life Farm, Fresh Fruit. LIFE Public Database.**; 2022.
Reference Source | Reference Source
13. Berger LT, Gil E, Ortega P: **Smartomizer – proactivity and traceability in orchard spray.** *Suprofruit: 15th Workshop on Spray Application and Precision Technology in Fruit Growing.* East Malling, UK: 2019 Jul 16–18; **2019**.
14. Berger LT, Ukhandeeva E, Andreu F, *et al.*: **Life Farm, Fresh Fruit – effects of operator training and sprayer adjustments on agronomic inputs.** *Asp. Appl. Biol.* 2022; **147**: 19–26.
15. Gil E, Goñi JM, Mackay N, *et al.*: **Implications of Precision Application Technology for Refinement of Environmental Risk Assessment Default Representations: A Case Study.** *Presented at: 15th European Conference on Precision Agriculture (ECPA 2025).* Barcelona, Spain: 29 June–3 July 2025.
16. European Climate, Infrastructure and Environment Executive Agency (CINEA): *Life AIs – See & Save.* LIFE Public Database; 2024.
Reference Source
17. Świechowski W, Godyń A, Hołownicki R, *et al.*: **Calibration of orchard sprayers – parameters and methods.** *SPISE 4.* Lana, Italy: Julius Kühn-Archiv; 2012.
18. Government of Western Australia (GOVWAU): **SnapCard spray app.** 2023.
Reference Source | Reference Source
19. Berger LT, Perales P, Esteve E, *et al.*: **Accompanying data to "Upper Bounds on real-time Spot Spraying of Tree and Bush Crops".** *Zenodo.* 2024.
20. Salas B, Ortega P, Berger LT, *et al.*: **Smart orchard sprayer to adjust pesticide dose to canopy characteristics.** *Asp. Appl. Biol.* 2022; **147**: 157–164.
Reference Source
21. Berger LT, Alarcon J, Perales P, *et al.*: **3D computer vision for real-time sprayer adjustments.** *Suprofruit: 16th Workshop on Spray Application and Precision Technology in Fruit Growing.* Montpellier, France: Agropolis International; 2023; p. 15–16.
Publisher Full Text | Reference Source
22. Berger LT, Perales P, Alarcon J: **Real-time variable rate spraying based on 3D visual inputs.** *Asp. Appl. Biol.* 2024; **148**: 81–88.

Open Peer Review

Current Peer Review Status: ? ✗

Version 1

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✗

Seweryn Lipiński
University of Warmia and Mazury in Olsztyn, Olsztyn, Poland

The manuscript presents a commercially implemented precision spraying system. It was evaluated in citrus, almond, and olive orchards in Spain. The authors report reductions in applied spray volume of 43% in citrus, 48% in almond, 56% in intensive olive, and 67% in extensive olive orchards compared with a constant-rate baseline. In addition, simplified analytical expressions are proposed to estimate theoretical upper bounds on spray-volume savings as a function of canopy geometry and tree spacing.
The topic is relevant and timely. Real-time adaptation of orchard spraying to canopy structure may contribute to reduced pesticide use, lower production costs, and improved environmental performance.
However, in its form, the manuscript is closer to a technical demonstration or commercial case study than to a journal paper. The authors show that the system reduces the applied volume of spray liquid. They do not, however, provide sufficient evidence that the reduced-volume treatment is equivalent to the baseline treatment in terms of spray deposition, canopy penetration, retention, biological efficacy, or crop protection performance.
Moreover, the experimental design is insufficiently described, replication and statistical analysis are absent, the AI and computer-vision components are not documented in sufficient detail, and the literature review and Discussion do not adequately position the work in relation to the current state of the art.
Therefore, in my opinion, the manuscript requires major revision.

My remarks:
1. The manuscript repeatedly suggests that the system reduces pesticide use without compromising canopy coverage or treatment quality. This conclusion is not supported.
Treatment equivalence was assessed using water-sensitive papers, visual inspection, and the SnapCard application, with the statement that minimum coverage exceeded 10%.
This evidence is insufficient to demonstrate equivalent treatment performance.

- Measurements of deposition by water-sensitive papers must be given numerically, processed statistically, shown in visual examples (including scanned WSPs), and the deposition with and without the system should be compared directly. Giving the results in

this way could basically mean that, for example, with the system the coverage is 11% and without the system it is 90%, both values are above 10%...
- The 10% coverage threshold is not justified in any way.

2. The manuscript does not provide enough information to assess the validity of the experiments or allow replication.
For each crop and orchard, the authors should report:
- field area,
- number of rows,
- number of trees,
- cultivar,
- tree age,
- phenological stage,
- tree height and width distributions,
- descriptor of foliage structure,
- inter-row and inter-tree spacing,
- number of repetitions,
- aggregate speed,
- nozzle manufacturer, model, size, and spray angle,
- operating pressure,
- fan speed and airflow settings,
- working fluid used,
- number and position of water-sensitive papers in relation to the direction of travel, position in the field, height, etc.
- weather conditions,
- and the procedure used to ensure comparable conditions between the baseline and spot-spraying treatments.

Without this information, the study cannot be critically evaluated or reproduced.
3. The manuscript uses expressions such as “significantly reduced,” but no statistical analysis is presented.
Also, for water-sensitive-paper measurements, the full distribution of results should be presented, not only the minimum coverage. Ideally, results should be reported separately by canopy position.
4. The baseline appears to have been configured according to the maximum tree dimensions and then operated at a constant rate. This can generate substantial apparent savings in orchards with large gaps, missing trees, or variable canopy dimensions.
The authors should separate the contribution of different mechanisms to the total reported savings:
- detection of tree presence or absence,
- avoidance of spraying between trees,
- adjustment to canopy height,
- adaptation to the external canopy contour,
- response to canopy density,
- and response to internal canopy gaps.

At present, all of these effects are combined into a single percentage.
This distinction is particularly important for the extensive olive orchard, where much of the reported 67% reduction may result from large inter-tree gaps rather than from detailed AI-based canopy characterization.
The authors should also explain why the selected constant-rate baseline represents the most appropriate comparison and whether it reflects recommended best practice.
5. The comparison with a single ultrasonic sensor controlling an entire sprayer side is not sufficient to establish superiority over existing precision-spraying technologies.
The manuscript should discuss or, where possible, compare the proposed system with other state-of-the-art methods (like e.g. multi-level ultrasonic sensing, multiple ultrasonic sensors positioned at different heights, other vision systems, etc.).
The authors should clarify whether the observed advantage results from the stereo-vision method itself, the number of individually controlled nozzles, the control algorithm, or the relatively low resolution of the ultrasound benchmark.
6. The current reference list is not sufficient for a paper in a well-established research area.
The manuscript contains only 22 references, including six self-citations. A substantial proportion of the references consists of institutional documents, European regulations, conference publications, etc. with only a very limited number of independent peer-reviewed journal articles used to establish the scientific context.
The authors should include a considerably broader and more current review of peer-reviewed research.
The Introduction should clearly identify what has already been achieved, what limitation remains unresolved, how the present system differs from existing technologies, and what the specific scientific novelty of this study is.
At present, the manuscript demonstrates commercial integration, but does not establish the novelty of the sensing, control, or application method.
7. The current Discussion mainly restates the reported savings, develops a simplified geometric model, and compares the system with a low-resolution ultrasound configuration.
It does not critically compare the findings with independent scientific literature.
The authors should also discuss both the strengths and the limitations of the proposed approach.
8. The system is repeatedly described as “AI-enabled,” but the manuscript provides almost no information about the AI or computer-vision algorithm.
Without this information, the study cannot be independently evaluated, and the use of the term “AI” remains insufficiently substantiated.
If parts of the system are proprietary, the authors should still provide enough information to allow scientific assessment of its function and performance.
9. The nozzle-control and hydraulic response must be documented
The system relies on individual nozzle switching while maintaining approximately constant pressure. This is central to the study, but the hydraulic response is not quantified.
The authors should report e.g. pressure stability during nozzle opening and closing nozzle response time, switching frequency, and whether opening one nozzle affects the flow through neighboring nozzles.
10. The proposed analytical model is based on a two-dimensional circular representation of the canopy and simple area ratios. It is useful as an illustrative concept, but its predictive value is limited.
The model does not account for three-dimensional canopy geometry, canopy depth, foliage density, internal canopy gaps, irregular crown shape, overlapping crowns, etc. These assumptions and limitations must be explicitly stated.

The title should also be reconsidered because the term “upper bounds” suggests broader theoretical generality than is supported by the four field cases and the idealized geometry.
11. The authors add 1.5 m to the canopy dimension to account for early nozzle activation and delayed deactivation in the ultrasound system. This adjustment brings the predicted and observed values into close agreement. However, it is unclear whether this value was defined before model fitting, derived from system specifications, or selected after observing the discrepancy.
The authors should explain how the 1.5 m value was obtained and whether it was validated under different speeds and orchard conditions.
If it was introduced after inspection of the results, it should be described as a calibration parameter…
13. Claims concerning drift reduction must be removed or qualified, as no drift measurements are presented.
Although lower spray volume may reduce total off-target emission, drift also depends on droplet size, nozzle type, canopy interception, air assistance, weather conditions, etc.
14. The commercial and scientific components should be more clearly separated
All authors are employees or collaborators of the company manufacturing and selling the system. The conflict of interest is appropriately disclosed, which is positive. Nevertheless, the manuscript contains promotional expressions and product-oriented descriptions, including phrases such as “eyes open” and “eyes closed,” “growers’ eyes on the ground,” and “Life-AIs: See & Save!” The detailed presentation of the company’s digital platform, cloud environment, and commercial ecosystem is only partly relevant to the scientific evaluation.
The authors should use neutral scientific language and clearly separate product description, research methodology, experimental results, and commercial interpretation.

Responses to the questions:
Is the work clearly and accurately presented and does it cite the current literature?
Partly.
The overall concept is understandable, but essential methodological and technical details are missing. The reference base is inadequate and does not reflect the breadth of current peer-reviewed research in precision orchard spraying. The Introduction and Discussion must be substantially expanded using independent, recent literature.
Is the study design appropriate and does the work have academic merit?
Partly.
The study addresses an important problem, and the practical implementation has academic and technological value. However, the design is incomplete because replication, quantitative deposition assessment, biological efficacy evaluation, and statistical analysis are missing or insufficiently documented.
Are sufficient details of methods and analysis provided to allow replication by others?
No.
As given above, the manuscript does not provide enough information about the field trials, sprayer settings, canopy characteristics, water-sensitive-paper placement, replication, AI algorithm, image processing, control rules, or statistical analysis, so replication is currently not possible.
If applicable, is the statistical analysis and its interpretation appropriate?
No.
No statistical analysis is presented despite the use of terms suggesting statistical significance. The manuscript lacks sample sizes, replication, uncertainty measures, confidence intervals, and hypothesis tests.

Are all the source data underlying the results available to ensure full reproducibility?
Partly.
A public Zenodo dataset is provided, which is a strength. However, the Data Availability section should list precisely what is available and what is not.
Are the conclusions drawn adequately supported by the results?
Partly.
The results support the conclusion that the system reduced applied spray volume under the tested field conditions.
They do not adequately support claims of unchanged spray quality, equivalent treatment performance, preserved biological efficacy, proportional pesticide reduction, drift reduction. These claims must either be supported by additional experimental evidence or substantially moderated.

Other comments:

1. A separate Conclusions section should be added.
2. The equations defining savings and the theoretical model should be moved to the Materials and Methods section.
3. Interpretation should be placed in the Discussion, not in the Results.
4. The description of the cloud platform should be shortened unless it directly affects the experimental methodology.
5. The Introduction should focus more directly on the scientific and engineering problem. General statements about global fruit consumption and population growth are only indirectly related to the study.

Is the work clearly and accurately presented and does it cite the current literature?
Partly

Is the study design appropriate and does the work have academic merit?
Partly

Are sufficient details of methods and analysis provided to allow replication by others?
No

If applicable, is the statistical analysis and its interpretation appropriate?
No

Are all the source data underlying the results available to ensure full reproducibility?
Partly

Are the conclusions drawn adequately supported by the results?
Partly

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Image Analysis, AI, Agricultural Engineering, Mechanical Engineering

I confirm that I have read this submission and believe that I have an appropriate level of

expertise to state that I do not consider it to be of an acceptable scientific standard, for reasons outlined above.

Reviewer Report 17 June 2026

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Upper Bounds on real-time Spot Spraying of Tree and Bush Crops
General Summary
There is a need for sustainable crop production. To support this need, agriculture should decrease the volume of plant protection products while maintaining high yields. This can be done by integrating AI coupled with computer vision sensors on crop sprayers. This study presents the potential savings in plant protection products that the use of AI enabled crop sprayers can achieve. According to the authors, the savings may exceed 60% based on the crop type and plantation compared to uniform application. Their study indicates that smart crop sprayers enabled with AI can significantly decrease the use of plant protection products and consequently help crop growers meet the EU target of 50% savings.
Introduction
The authors should include relevant studies in which AI tools and edge systems are used to decrease application volume of plant protection products. They could refer to AI algorithms and types of sensors.
Materials and Methods
The authors should support their statements (e.g., “AIs also presents significant technical challenges…”) by introducing relevant scientific papers. These statements could be moved to the introduction section.
The authors could provide more details on the field trials (area in ha, type of product applied, age of crops, crop stage, weather conditions, etc.).
The authors should refer to the metrics that they used for assessing the performance of their experiment (e.g., application volume, number of nozzle openings, etc.).
Results
The equations could be moved to materials and methods, so the authors should directly present the results.
Discussion
The US methodology could be moved to the Materials and Methods, while the relevant results could be presented in the Results section. The authors could state that they simulated a US sprayer based on previous studies for comparing their results.
This section should discuss the results of the study based on relevant scientific literature.
Additional Comment

A section referring to conclusions from the study is missing.
The authors could have subsections to have readability in their manuscript

General Comment
I recommend this manuscript be revised. The authors present the impact of AI enabled smart crop sprayers on the use of plant protection products compared to other types of applications. Their study is very useful due to the need to decrease the use of plant protection products by 50%. However, the authors should revise the structure of the manuscript and better justify their results by comparing them with other studies.

Is the work clearly and accurately presented and does it cite the current literature?
Partly

Is the study design appropriate and does the work have academic merit?
Partly

Are sufficient details of methods and analysis provided to allow replication by others?
Partly

If applicable, is the statistical analysis and its interpretation appropriate?
Partly

Are all the source data underlying the results available to ensure full reproducibility?
Partly

Are the conclusions drawn adequately supported by the results?
Partly

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Farm Machinery, Smart farming, Precision Agriculture

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however I have significant reservations, as outlined above.