

# Development of a new tool for orchard sprayer's agro-environmental performances assessment

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## Abstract

Spray quality is a key point to optimize the use of Plant Protection Products (PPPs) from both an agronomic (maintaining effectiveness) and an environmental (reducing drift) point of view. The French national policies encourage the use of high-performance application techniques. This requires the ability to assess sprayers on objectively measured indicators. The Performance Pulvé Arbo project developed a new tool for measuring spray deposits and spray drift in standardized conditions making it possible to compare the performance of orchard sprayers. The method developed is based on the use of a 3 rows of artificial orchard. An artificial wind wall is used when assessing drift. After the design and construction of the equipment, the first series of experiments were used to define the methodology to measure the agronomic performance of sprayer (deposit in the canopy) and to measure the drift, in indoor standardized conditions. Then, with a second series of trials, the developed protocols were tested on different spraying scenarios (different types and settings of orchard sprayers). A total of 57 trials, representing 10690 samples were analysed by spectrophotometry and these data were used to validate the methodologies. The results highlight the ability of the systems to reproduce the data acquired in the field, while clearly mitigating variability. Compared to the methods existing before the start of the project (ISO 22522 and ISO 22866 standards), the developed methods provide better repeatability of measurements, and are less cumbersome.

**Keywords:** spray quality, drift reduction, test facility, fruit growing, orchard.

## 1. Introduction

In French climatic conditions, protecting orchards from pests remains essential to ensure a profitable harvest. This protection still heavily relies on the use of Plant Protection Products (PPPs). Regardless of the production context—conventional or organic—the challenge is to ensure effective orchard protection while reducing applied doses and spray drift (Codis S. et al., 2015).

Optimizing spraying is a practical, short-term solution to address this issue. Indeed, a key factor in improving protection effectiveness and even reducing the quantity of product used is the equipment's ability to deposit the maximum amount of sprayed product on the target as uniformly as possible. Regarding environmental risks, both equipment design and the practices implemented are critical, as they determine product losses into non-target compartments (air and water).

The French Ecophyto 2+ plan encourages the use of high-performance agricultural equipment, which requires the ability to identify, benchmark, and classify machinery based on objectively measured numerical indicators. To meet these objectives, the French wine sector introduced the Performance Pulvé ([www.performancepulve.fr](http://www.performancepulve.fr)) system in 2021. This system is intended for winegrowers and their advisors to help them choose the right sprayer and associated settings (Codis et al., 2024). The scores awarded to sprayers are used by several French regions, such as Occitanie, Grand Est, and Pays de la Loire, for granting subsidies under the PCAE scheme (Plan for

the Competitiveness and Adaptation of Agricultural Holdings). These scores are based on spray quality tests carried out on the EvaSprayViti test bench, an artificial vine that simulates different vegetation stages and ensures standardized testing (Vergès et al, 2017).

The Performance Pulvé Arbo project aims to adapt and deploy the system used in the wine sector to orchard sprayers. This project builds on the findings from the PulvArbo project (2015-2020), which studied sprayer performance through trials in real orchard conditions. As for viticulture, conducting performance tests on sprayers in real orchards raises many constraints. One of the strongest is to obtain climatic conditions that are conducive to evaluation and allow for comparisons between trials. Indeed, a high variability of results obtained in different orchards was observed (difficulties in comparing data obtained from orchards that differ in terms of shapes or vegetation stage). Based on this experience, the goal is to develop a system to measure both agronomic performance (the equipment's ability to efficiently and evenly deposit product on the vegetation) and environmental performance (the equipment's ability to reduce drift) in standardized conditions (Figure 1).

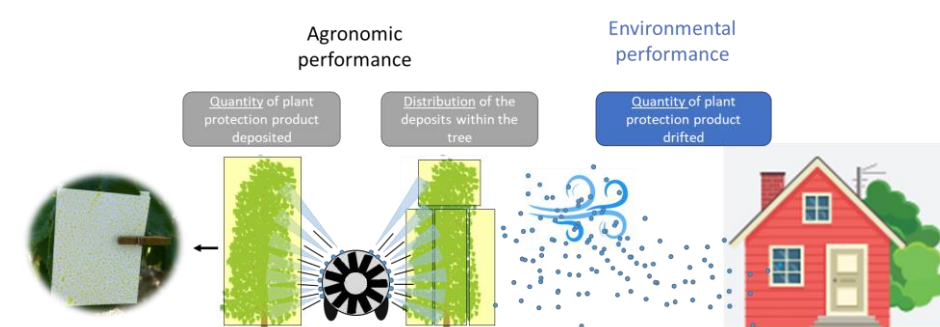


Figure 1: Spraying performance indicators.

The specific objectives of this research were:

- To design and build the test benches for standardized assessment of sprayers.
- To develop methodologies for using the test benches: a protocol to measure the agronomic performance and a protocol to measure the drift reduction performance of sprayers.
- To validate the methodologies by studying the ability of the benches to discriminate the performance of several spray application configurations.

## 2. Materials and Methods

In general, standardizing evaluations is meant to reduce the variability of in-situ experiments, which are heavily influenced by the vegetation stage, orchard shape, and climatic conditions. For the specific case of drift, field measurements are challenging due to the difficulty of managing wind direction, which should be perpendicular ( $\pm 30^\circ$ ) to the sprayer's path relative to the row orientation. As a result, only 48% of trials conducted in orchards between 2015-2020 and just 10% between 2021-2022 were in strict conformance with the weather criteria of ISO 22866.. Another disadvantage is the need for sufficient downwind clearance to place the samplers. The fruit hedge model, specifically for pome fruit orchards like apples and pears, was selected for standardization because of their high pesticide usage (IFT of 36 for apples), significant production area in France, and considering that the rate of renewal of spraying equipment in this cropping sector is high.

### 2.1 Design and construction of the test benches

Designing and constructing the test benches took a year and a half. Four main factors were considered: i) the dimensions (height and depth) of the canopy for different vegetation stages; ii) the composition of artificial leaves to accurately mimic an apple tree leaf's behavior; iii) the type of

netting to simulate the porosity of a fruit hedge; and iv) for drift assessment, the dimensions and positioning of the artificial wind wall. The dimensions of the artificial orchard were based on LiDAR characterization of over 200 apple orchards in various French production areas. Screening tests led to the selection of materials for the artificial apple leaves and canopy nets. The components were chosen to replicate real vegetation conditions as closely as possible. An aerodynamic study, testing different fan configurations, was conducted to design the wind wall. An engineering firm and equipment manufacturer were subcontracted for the construction.

The final test bench consists of an artificial orchard with three rows (10-meters long)—two border rows and one central row. Its height and width are adjustable to simulate early and full vegetation stages. The number and height of net layers can be adjusted to simulate different porosities. The two border rows simulate the surrounding environment during spraying. A collection system for spray deposits on artificial leaves is placed in the middle of the central row. The total leaf area index (LAI) can be adjusted by adding layers of artificial leaves.



Figure 2: Artificial orchard (a) containing the collect spray deposits system: the branches (b), each with 14 artificial leaves.

For drift reduction assessment, only the two net rows are used and are combined with a wind wall composed of 24 fans. A collection system for sedimentary and aerial drift is installed after the net rows to capture droplets leaving the treated area.






Figure 3: Artificial orchard and wind wall for drift reduction performance assessment.

## 2.2 Development and validation of a method for measuring agronomic performance on the artificial orchard







The measurement of spray deposition to assess sprayer's agronomic performance is typically done following the principles of ISO 22522:2007. This standard describes how to measure the quantity and distribution of spray deposits in a tree. Although these principles remain the same, it was necessary to define specific parameters for standardized indoor conditions on the artificial orchard. Eleven pilot tests were conducted from September 2022 to February 2023 using an axial airblast sprayer (the reference) and a pneumatic sprayer. These tests, which involved analyzing 3,400 samples by spectrophotometry, supported the evaluation process design in order to define the unit of analysis (e.g., entire leaf vs. leaf face), the spatial distribution of leaves for different vegetation stages, the tractor and sprayer passage pattern, and the sampling plan.

The developed method involves 1) Positioning artificial branches in the collection area according to the vegetation stage (Table 1), 2) Spraying a solution of water and tartrazine (E102) using the equipment at desired settings, following a predefined tractor route, 3) Collecting the artificial branches and extracting the tracer into an aqueous solution, 4) Analyzing the samples with a spectrophotometer, 5) Converting the absorbance data into a standardized unit of deposits in ng/dm<sup>2</sup> of leaf surface area per 1g of tracer applied per hectare. Each branch is analyzed individually.

		Early vegetation stage	Full vegetation stage
			
Total height		3.30 m	3.80 m
Canopy width		0.75/1.45 m	0.75/1.90 m
Collection area: number of branches layers (width)		4	6
Collection area: number of branches level (height)		10	12
Number of total leaves		1680 = 120 branches	3024 = 216 branches
Leaf Area Index		1.19	2.13
Number of sampling leaves for assessment		560 = 40 branches	1008 = 72 branches

*Table 1: Characteristics of the collection area of the artificial orchard*

The second step validated the methodology by evaluating the bench's ability to simulate a real orchard row and provide repeatable measurements. A total of 37 trials with 10 different sprayers were conducted between March and December 2023. The sprayer configurations were chosen based on expert knowledge in order to be diverse and representative of common practices among apple growers. The "Reference practice" was defined as an axial airblast sprayer with hollow cone nozzles (10-12 bars), a speed of 6 km/h, fan gear II, and a volume of 400 L/ha.

Sprayer type	Axial airblast	Cross flow airblast one fan			Cross flow airblast double fan	Pneumatic
						
Number of machine tested	3	1	1	1	1	1
Nozzle type	H*, I**	H*, I**	H*, I**	H*, I**	H*, I**	-
Volume L/ha***	330-400	330-400	330-400	330-400	300-350	250-300
Tractor speed Km/h***	6 - 8	6 - 8	6 - 8	6 - 8	6 - 8	6 - 8
Fan gear***	I-II	I-II	I-II	I-II	I-II	ON

\*H: hollow cone nozzles / \*\*I :Air induction nozzles or anti-drift nozzles / \*\*\* : depending on the vegetation stage

Table 2: Sprayer type and sprayer settings used for the assessment and validation of the methodology for agronomic performance measurement.

### 2.3 Development and validation of a method for measuring environmental performance on the artificial orchard

Reducing spray drift is a major concern for all stakeholders in fruit growing. Before 2015, the method recognized in France for measuring drift was ISO 22866:2005, which describes how to measure sedimentary and airborne drift. The method involves 1) Installing collectors (e.g., Petri dishes, PVC wires) at various distances from the last treated row, 2) Spraying a solution of water and of a tracer (here Sulforhodamine B), 3) Collecting the collectors, 4) Extracting the tracer into an aqueous solution, 5) Analyzing the samples with a spectrofluorometer, 6) Translating the data into a drift index expressed as a percentage of the sprayed volume. The principles of ISO 22866:2005 can be applied under standardized conditions.

The initial challenge was to define the correct configuration of the artificial orchard and the wind wall to approximate the wind conditions required by ISO 22866:2005: Proportion of wind vectors less than 1 m/s greater than 90% and proportion of angles of wind vectors outside the range [- 45°,45°] less than 30%. The hall, which is 35m long by 20m wide, was mapped for artificial airflow under different configurations (Table 3). This mapping was performed using a GILL\_WindMaster ultrasonic anemometer with a temperature probe and hygrometer. Wind measurements were supplemented by drift measurements to ensure consistency. The number of measure points on the vertical and horizontal profiles in the hall varied between tests (iterative method) These wind measurements were supplemented several times by drift measurements to ensure the consistency of the results.

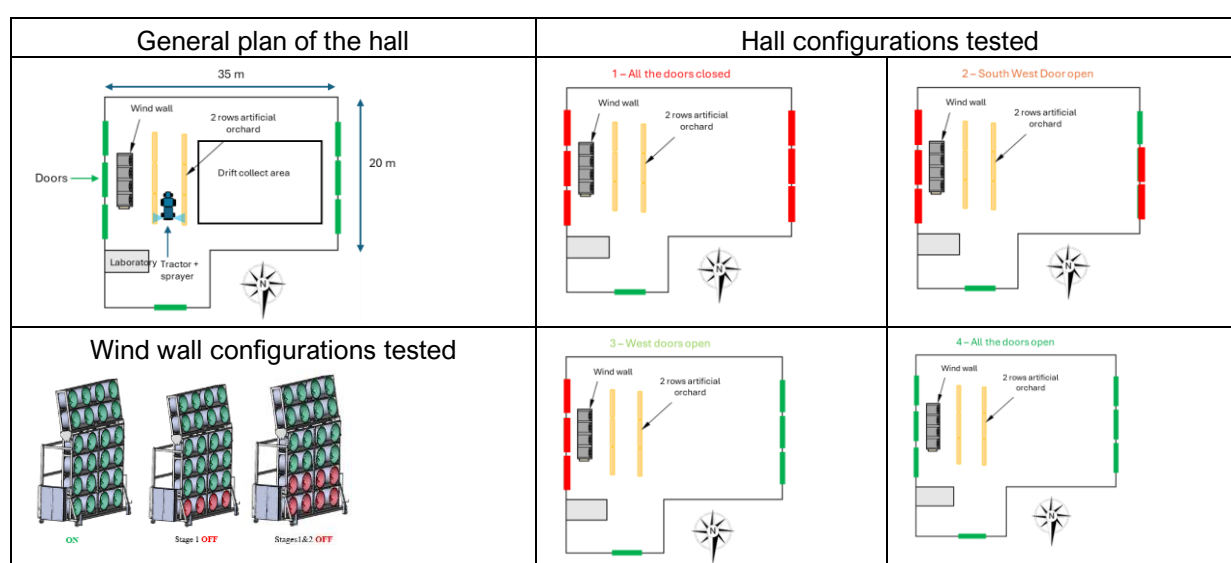


Table 3: Description of the configurations of the hall and wind wall tested, in red doors closed, in green doors opened, in red fans closed, in green fans opened.

The results were presented graphically, with arrows indicating wind direction and color showing speed (Figure 4).

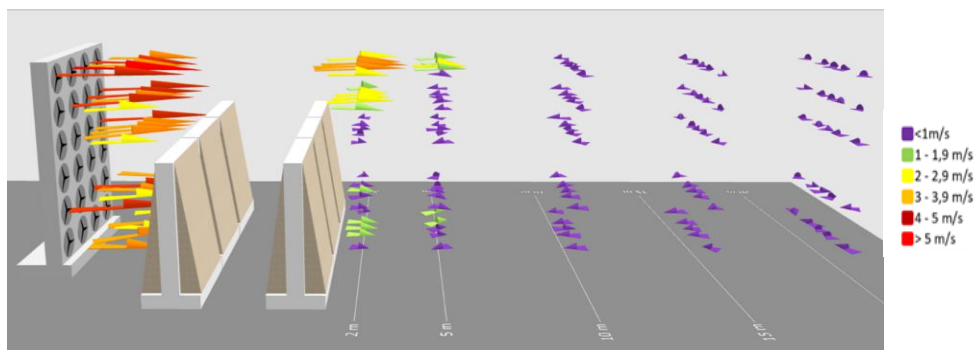


Figure 4: Example of direction and speed of artificial wind measured in the hall with the presence of artificial orchard in the configuration 4 “all doors open”.

Taking into account all these preliminary tests, the final experimental setup is the one described in figure 5.

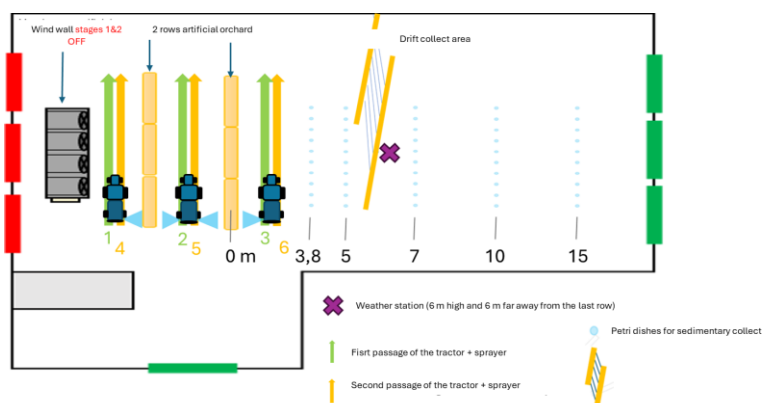





Figure 5: experimental setup for indoor drift trials in artificial conditions of vegetation and wind.

After defining the optimal experimental setup, the method was validated by testing different sprayer types and settings. Nine trials, representing 55 passages and 2,912 samples, were conducted.

Sprayer type	Axial airblast	Cross flow airblast double fan	Pneumatic
			
Number of machine tested	1	1	1
Nozzle type	H*, I**	H*	-
Volume L/ha	400	400	250
Tractor speed Km/h	6	6	6
Fan gear***	II	II	ON

\*H: hollow cone nozzles / \*\*I :Air induction nozzles or anti-drift nozzles

Table 4: Sprayer type and sprayer settings used for the assessment and validation of the methodology for drift measurement.

### 3. Results and Discussion

#### 3.1 Main results on the agronomic performance measurement

The first key finding is that the spray deposits measured on the artificial orchard are consistent with

values obtained in a real orchard during the previous PulvArbo project (Figure 6). The cross and value represent the general average of mean deposits obtained in each condition of assessment: red for early vegetation stage, black for full vegetation stage.

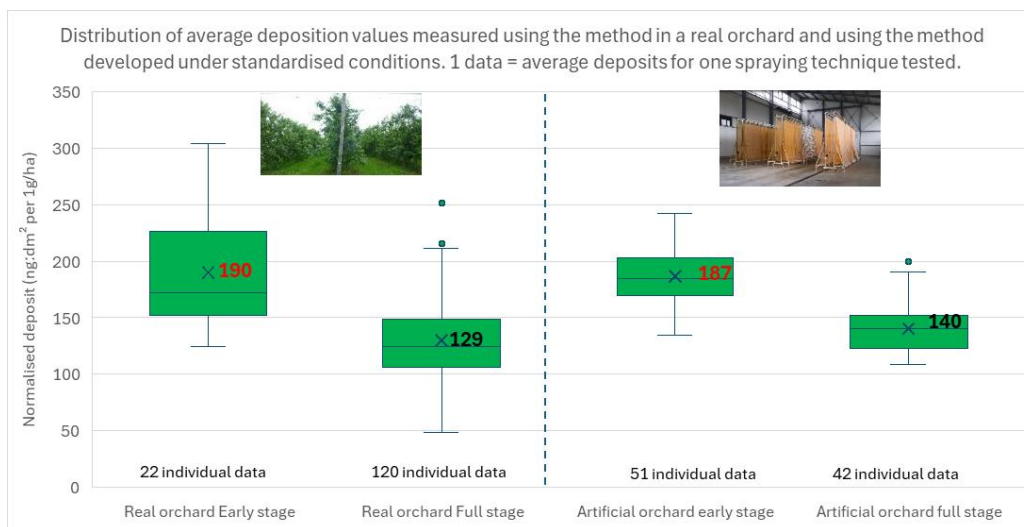


Figure 6: Box plot of the mean deposits measured in real orchard and artificial orchard.

This validates the technical design choices, including the materials for artificial leaves and the LAI for each stage. For both vegetation stages, deviations from the average are less than 10%, and the And the deviations from the mean are smaller.in the artificial orchard, demonstrating the benefits of standardization in reducing variability.

Figure 7 highlights the bench's repeatability. For the same axial airblast sprayer and settings (400 L/ha, 6 km/h, hollow cone nozzles, 11 bars, fan gear II), the average variability (coefficient of variation) on deposits within a single repetition was 15.7%, while the variability between repetitions was less than 1%. These results were also confirmed with pneumatic spraying technology. The study on reproducibility showed that the results were also reproducible regardless of temperature or humidity variation in the hall.

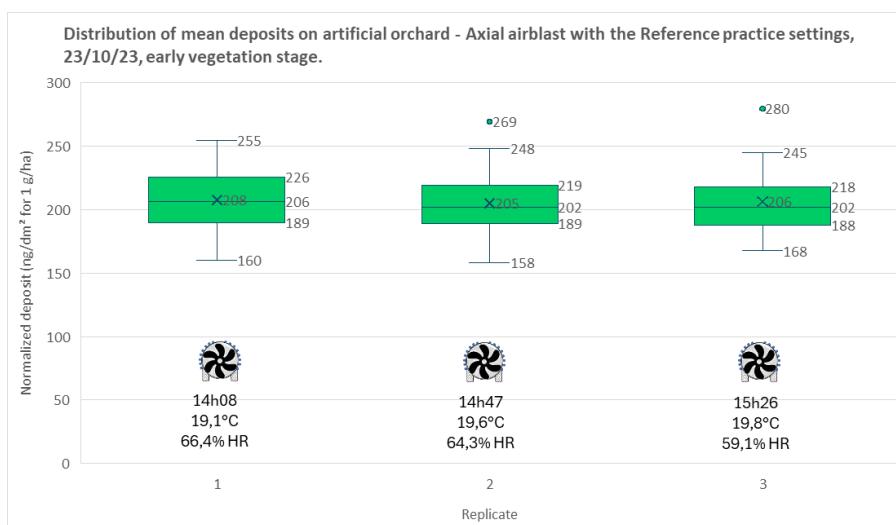


Figure 7: Box plot of the deposits measured on artificial orchard: same machine, same setting, same day, same climatic conditions in the hall.

The results show that analyzing only average deposits is insufficient to discriminate between machines. For identical settings and vegetation stages, the average deposits were very similar across different sprayer designs (Figure 8).

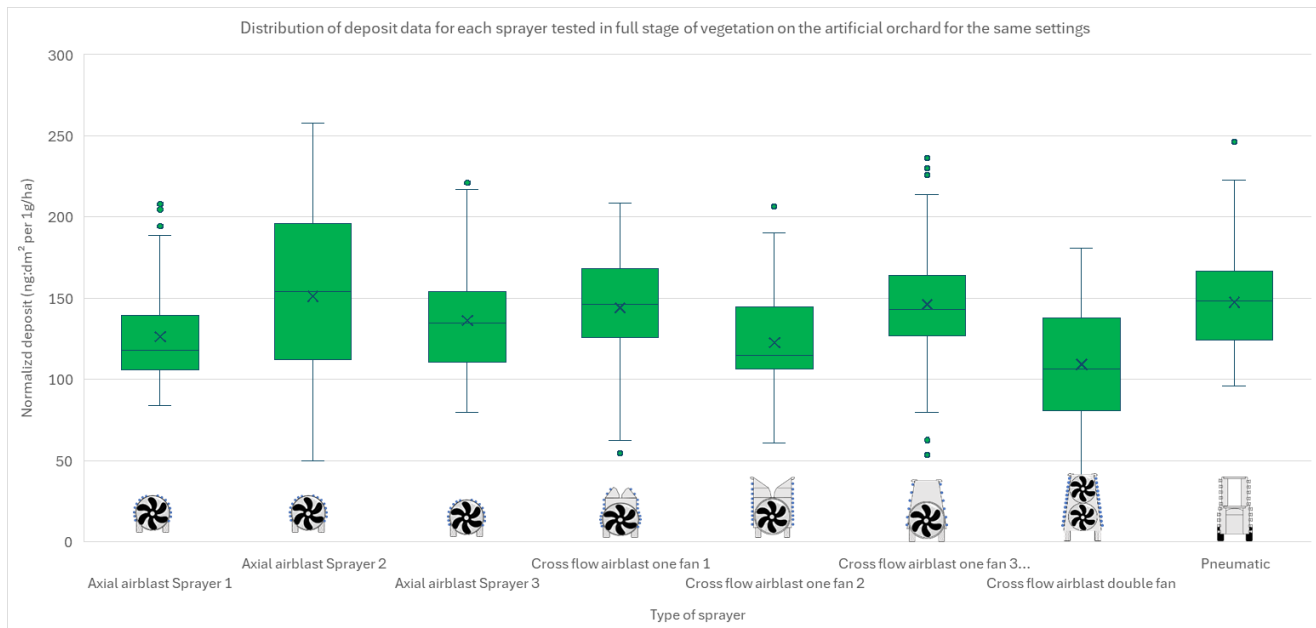


Figure 8: Box plots of the deposits measured in the artificial orchard at full vegetation stage for the four spraying techniques considered: axial airblast, cross flow airblast one fan, cross flow airblast double fan and pneumatic.

A more detailed analysis of the deposit distribution throughout the vegetation is necessary. The goal of effective spraying is to achieve an even distribution of a minimum effective quantity of product throughout the tree. Figure 9 graphically compares the deposit distribution profiles for four sprayers with similar average deposits (respectively 141, 144, 146 and 148 ng/dm<sup>2</sup> for 1 g of product applied per ha) but different distribution profiles. Some sprayers covered the lower part better, others the upper part, while some were more homogeneous. The greener the compartment, the higher the deposit; the redder, the lower.

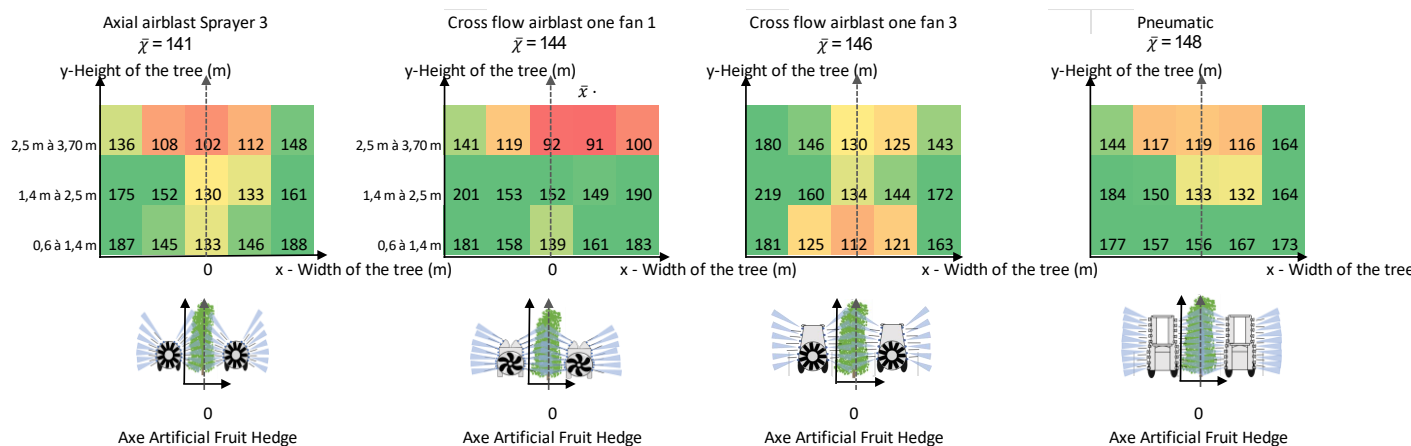


Figure 9: Spray deposits profiles in the (x, y) plan for the 4 different types of sprayers as measured at the artificial orchard at the full vegetation stage with a passage in each row (left and right sides of the fruit hedge treated).

One of the main findings is that spray quality is highly impacted by sprayer settings. The bench is sensitive enough to differentiate between settings like nozzle type, driving speed, and airflow. The most impactful factor is the type of air ducting, which affects both the quantity and distribution of deposits. Figure 10 shows the difference in deposit profiles for the same cross-flow sprayer before and after air adjustments. The adjustments optimized the effective treatment height from 2.5m to 3.7m, significantly improving deposit distribution in the upper part of the trees, with a 3.5-fold increase in deposits there.

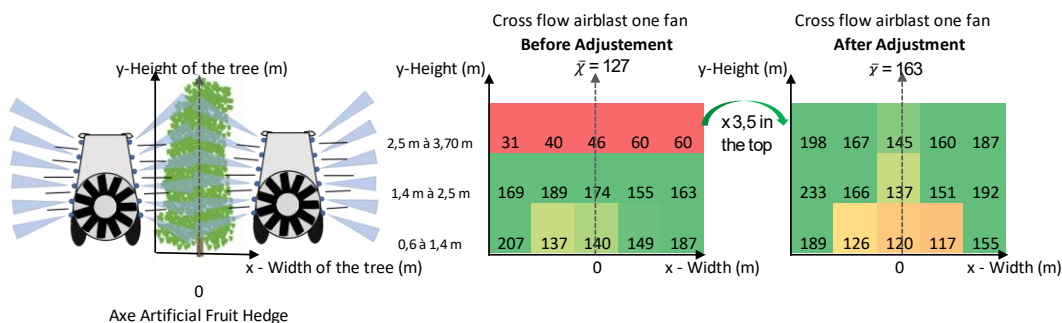


Figure 10: Spray deposits profiles in the (x, y) plan for the same sprayer before et after air adjustment as measured at the artificial orchard at the full vegetation stage with a passage in each row (left and right sides of the fruit hedge treated).

### 3.1 Main results on environmental performance measurement

The tests validated the indoor drift measurement methodology under artificial vegetation and wind conditions. The results for sedimentary drift deposit values were consistent between field and indoor conditions for all sprayer types (axial airblast, crossflow, pneumatic). However, the quantity of airborne drift collected was greater indoors similarly to what happens in a wind tunnel compared to outdoors, and even if the height and width of the indoor testing platform are much higher than in a wind tunnel. Figure 11 compares the aggregate drift curves for the reference practice (axial airblast) from 16 field trials and 19 indoor trials. Indoor conditions significantly reduced field variability. The coefficient of variation between trials for airborne drift was 82% in open fields (highly dependent on wind speed) but only 27% indoors.

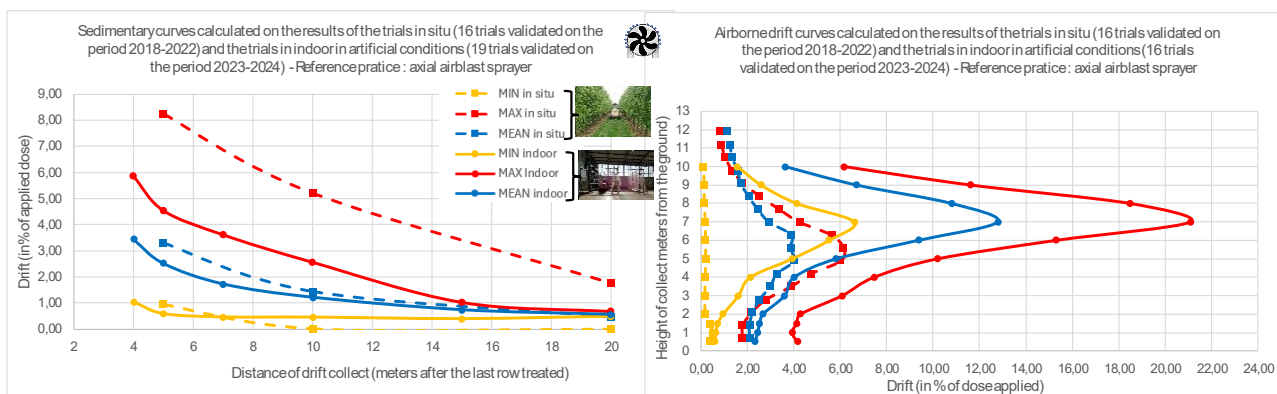


Figure 11: Comparison of drift Reference curves (axial airblast sprayer 1) measured in the field (natural conditions) and in indoor (artificial conditions) with a sedimentary collect (left) and a aerial collect (right).

Indoor conditions also greatly improve repeatability when tests are done under the same climatic conditions. Wet conditions increase sedimentary deposits, while dry conditions increase droplet evaporation. Therefore, it will be necessary to integrate the reference practice into each trial, avoid

periods of high evaporation, and perform three replicates. Finally, the impact of drift reduction measures, such as air-injection nozzles and cross-flow sprayers, was consistent with findings from the past ten years of field trials.

#### 4. Conclusions

During the three-year project Performance Pulvé Arbo was successfully developed and validated a comprehensive evaluation system for measuring the agronomic and environmental performance of orchard sprayers. For agronomic performance evaluation, the artificial orchard yields spray deposition values that are consistent with reference values measured in real orchards. The system also provides repeatable results from one trial to another for the same equipment, both in terms of deposit quantities and distribution profiles. The device can effectively discriminate between different settings for a single sprayer, such as nozzle type, airflow, and forward speed. A key finding is that classifying orchard sprayers based solely on their technological design criteria (e.g., axial, cross-flow) is not relevant. Instead, the sprayer's settings are crucial, as a single sprayer can generate very different deposit profiles depending on how it's configured. Further work is needed to define relevant agronomic performance indicators that account for the importance of airflow settings.

For environmental performance (drift reduction), the project validated a methodology for quantifying both sedimentary and aerial spray drift under artificial conditions. The results are qualitatively and quantitatively consistent with profiles measured in real orchards over the last decade. A major benefit is the use of artificial wind, which offers controlled speed and direction, stabilizing measurement conditions. This allowed 95% of the tests to comply with standard climatic requirements, compared to less than 50% in the open field.

Overall, this indoor facility significantly facilitates the work of researchers and drastically increases the number of tests that can be conducted. The tool is open to manufacturers. In the longer term, the aim will be to promote the comprehensive assessment scheme as a tool to assist in the renewal of the spray equipment fleet among the various players in the sector and the various political decision-makers responsible for allocating purchase subsidies.

#### Acknowledgements

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