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Smart orchard sprayer to adjust pesticide dose to canopy characteristics

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Summary

Apple scab (Venturia inaequalis) is one of the most endemic diseases that affect apple production worldwide. An accurate management of *Plant Protection Products* (PPP) together with the use of the latest technologies is one of the objectives of the EU Horizon 2020 OPTIMA project, as part of an *integrated pest management* (IPM) system.

Optimal dose adjustment of PPP in orchards requires an accurate identification of canopy characteristics and a precise sprayer adjustment to distribute the adequate amount of active ingredient and liquid proportionally to the canopy variations. Furthermore, the possibility to use available tools and knowledge to consider the potential variability inside the parcel will lead into a reduction of the amount of PPP, which is a shared objective with the EU Farm to Fork strategy.

Within the OPTIMA project a smart orchard sprayer has been developed. The system incorporates 6 ultrasonic sensors (three per side) for canopy characterization. A dedicated program developed using python allows the system to calculate canopy width and canopy density along the row. This information, together with the georeferenced location of the sprayer and the actual forward speed is used to activate the six-solenoid proportional motor-valves controlling the six different spray sections. Information about working pressure and consequently the nozzle flow rate is recorded every 1 s in order to generate the actual application map.

The system is based on the adaptation of the *Tree Row Volume* (TRV) method established by European *and Mediterranean Plant Protection Organization* (EPPO, 2021) with additional information concerning canopy density. The system is linked with development of EDS (*Early Detection System*) and DSS (*Decision Support System*) within the OPTIMA project and the aim at the end of the project will be to link all the three technological developments to achieve a holistic smart sprayer.

Key words: variable rate application, ultrasonic sensors, precision viticulture, motor valves

Introduction

In the last decades, synthetic *Plant Protection Products* (PPP) have been crucial in aiding global farming to control plant diseases. Conventional practices are widely used throughout the territory. These strategies often use a significant amount of PPPs despite the negative impacts on the environment and human health. There exists a general concern to use PPPs under common rules for safer and more efficient applications. Moreover, reducing the negative impact of PPPs was promoted by the European Directive 2009/128/EC, while the issue of plants resistance is becoming a significant problem for the farming community. Spraying technologies have demonstrated improvements in PPP application efficiency by adopting the latest advances in electronics. As a result, new sprayers are capable to adjust dose to canopy structure or to reduce drift.

This study took place within the H2020-project OPTIMA - *Optimised Integrated Pest Management for precise detection and control of plant diseases in perennial crops and open-field vegetables* (http://optima-h2020.eu/es/16219-2/). The objective that drives this study is to adjust sprayer parameters according to an apple crop, one of the three use cases of OPTIMA. To achieve this goal, the spraying parameters must be adapted to the canopy structure. It is implemented with a smart sprayer that is developed in the framework of the project.

The *Tree Row Volume* (TRV) is widely used to adjust the dose rate according to the canopy parameters. This coefficient models the vegetation as a cube and it measures the volume of vegetation per hectare, given a certain crop structure. The sprayer designed in this study use 6 ultrasonic sensors to measure the vegetation and control the flow rate with six motor valves in real time. Therefore, the objective of this research is to design, build and validate an atomizer prototype capable of performing a real-time variable rate application for apple orchards, according to the canopy width. This document is composed by two parts: a) A description of the prototype and its settings; as well as b) preliminary results of the first apple scab applications in a real crop.

Materials and Methods

Test plot

Field assays were conducted in a Malus Domestica (Golden Delicious) apple orchard in Épila (Zaragoza, Spain) (41º33.1’N,1º13.8’). Four applications against apple scab took place. The first two applications were carried out in May 2021 while the next two were performed in June 2021. The target field was composed of eight lines of 120 m length each. The trees were planted 1.5 m apart along the rows and 4.5 m between the rows. The vegetation dimensions remained constants during all applications. The canopy had an average depth of 1.6 m and an average height of 3.1 m, both measured manually.

Sprayer settings

The base sprayer chosen was an air-assisted Fede orchard sprayer (model Fede Inverter Qi 9.0 from Pulverizadores Fede S.L., Cheste, Spain) with a tank capacity of 2000 L. This atomizer sprayer has an air-blast inverter system, which means that the air inlet is in the front of the fan supply area. The sprayer was equipped with eleven nozzles per side, although only ten nozzles were used in response to the crop height requirements. Three sections per side were defined, corresponding to an ultrasonic sensor, a motor valve, a pressure sensor and three or four nozzles. Twenty IDK 90015 nozzles (Lechler GmbH, Metzingen, Germany) were used in the first two applications, while the other two applications made use of ten IDK 90025 nozzles per side. The working pressure was always within the range of 4 to 14 bar. During the trials the atomizer was driving at 5 km h-1, spraying all the rows. The objective application coefficient used was 0.1 L*m^3.

Variable Rate Application (VRA) implementation

In order to implement *variable rate application* (VRA), the sprayer was equipped with six *ultrasonic sensors* (US), three on each side. Llorens *et al.* (2010) and Gil *et al.* (2013) demonstrate a good performance with a similar prototype but for vines. The ultrasonic sensor model used in this project was the UC4000-L2-U-V15 (Pepperl+Fuchs, Germany), this sensor offers an analogue output within the ranfe of 0 to 10 V with a sensing range from 200 to 4000 mm. Three US per side were installed at three different heights (1.2 m, 2.1 m and 3 m) using a vertical metal bar which was placed in front of the sprayer. Therefore, three independent sections per side were defined, corresponding to one ultrasonic sensor, one motor valve and one pressure sensor (Fig. 1). Each section represented a third part of the total vegetation height (H/3). A sampling time of 1 s was defined. During this sampling time all the signals generated by the US were stored in the controller, defining a vegetation slice. The controller averaged the signals stored within this slice and transform them into canopy width, using the US calibration curves. The controller was a Raspberry Pi 4 Model B running an operating system based in Linux. The canopy width was used to obtain the slice vegetation profile, considering a constant height. Once the vegetation was characterized, the controller calculated the flow rate per section, obtaining the forward speed from a *global positioning system* (GPS) module. The GPS model is the L80-39, whose speed accuracy is 0.1 m s^{-1}, with a frequency of 1 Hz and a sensitivity of 165 dBm. To control the real flow rate, one *motor valve* (MV) per section was installed. The motor valve model is the 3280 from Burkert (Bürkert Werke GmbH & Co. KG, Germany). This actuator is driven with a stepper motor and supplied with 24 V DC. Therefore, the controller used the theoretical flow rate and the motor valve calibration curves, to obtain the required voltage to each motor valve. The order to change the flow rate was sent when the MV reach the block previously characterized, considering the MV time response and the forward speed. The controller output pins offer a *pulse width modulation* (PWM) signal with a current up to 16mA per pin. The calibration curves depend on the nozzle type used and the nozzle number. The bottom and top sections had three nozzles while the middle section had four nozzles. Once the motor valve acts on the hydraulic system, the pressure was measured by a *pressure sensor* (PS). The PS used were of type PU5403. The output signal is between 0 and 10 V with a measuring range of 0 to 25 bar. The PS operating voltage could be from 16 to 36 V_{DC}. The pressure data was stored all along the trial to evaluate the spray application in post-processing.

Moreover, the variable rate device was designed to adjust the volume rate according to the canopy density. This was implemented by analysing all the US data samples within a vegetation slice. To obtain a measure of density, a distance threshold (TH) of 0.2 m was applied to classify the samples which exceed this threshold as holes (Fig 2.). The hole percentage was obtained dividing the number of samples classified as holes over the total amount of samples within a slice. These percentages were used to assign a density class to each slice. Each density class had associated a *density factor* (DF). The DF was used to adjust the theoretical flow rate. Table 1 shows the relation proposed between the percentage and the density factor.

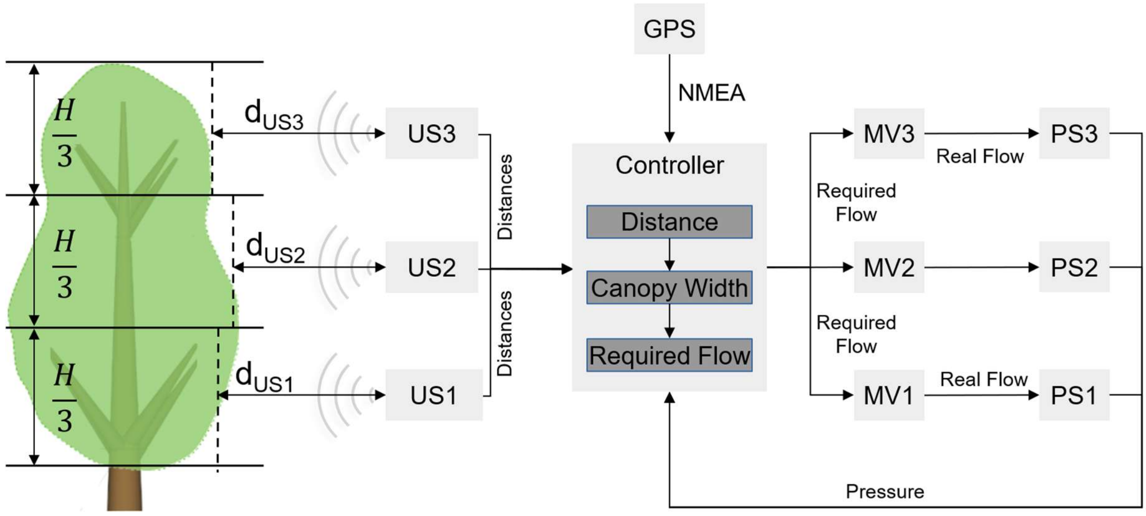

Figure 1. Layout of the data path representing three sections of the sprayer. A multiprocessing code runs in the controller and reads the *ultrasonic sensors* (US) data to send the required flow to the *motor valves* (MV). The *pressure sensor* (PS) and the GPS data were constantly updated.

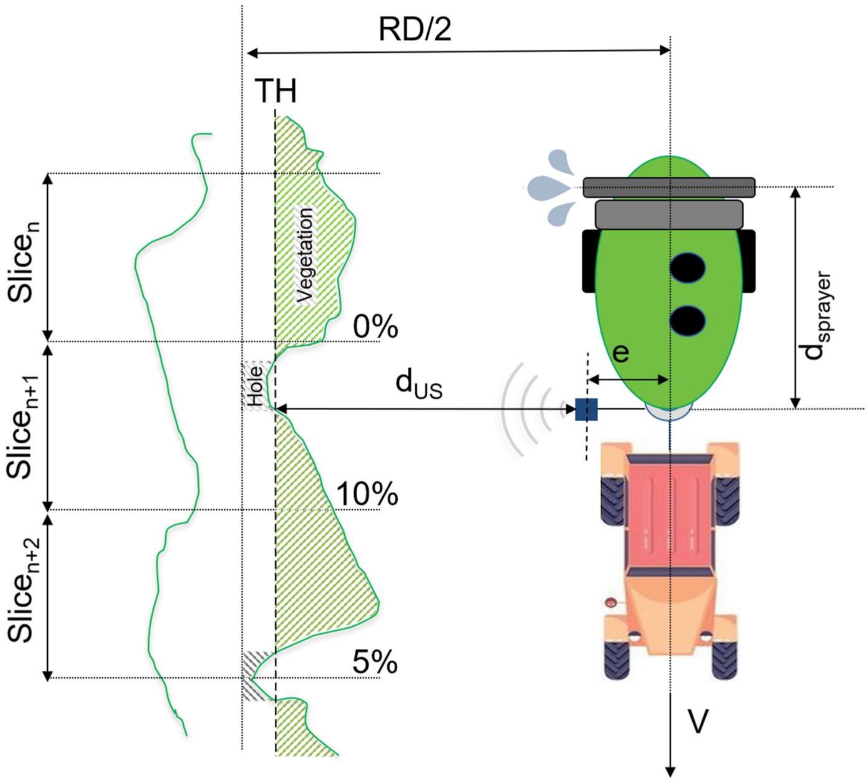

Figure 2. Hole classification process. A distance threshold was applied to all samples within each slice. The percentage obtained express the number of samples classified as holes, over the total number of samples within the slice.

Table 1. Density classes, classified by percentage of holes obtained in each slice and the correspondent density factor proposed for each class.

Canopy density class	Holes (%)	Density Factor (DF)
Low density	60-100	0.8
Medium	20 - 60	1.0
High	0 - 20	1.2

Data processing

Initially the signal sent by the US was transformed to the real distance (d_{US}) using the calibration equations from each sensor. One all the samples corresponding to a slice were stored, the average and its DF were computed. The forward speed (V) was taken from the GPS. The i coefficient was introduced as a constant input, as well as the total height (H), the row distance (RD) and the distance between de US and the sprayer axis (e). With this data the flow rate per section was calculated using Eq. 1.

$$Q_{section} = \frac{\frac{(RD - d_{US} - e) * i * V * 1000 * H}{3} * DF}{60} \quad , (1)$$

where $Q_{section}$ is the flow rate per section; RD is the row distance; d_{US} is the distance measured and averaged by the ultrasonic sensor during Δt; e is the distance between the US and the axis of the sprayer; i is the objective application coefficient $m^3\ l^{-1}$; V is the forward speed; H is the total height of the tree; and DF is the density factor. The required nozzle flow rate was determined dividing the total flow rate by the number of nozzles the section had:

$$Q_{Nozzle} = \frac{Q_{Section}}{Nº nozzles} \quad , (2)$$

where Q_{Nozzle} is the flowrate per nozzle; $Q_{Section}$ is the flow rate per section; Nºnozzles is the number of nozzles composing the section, it can take the values 3 or 4. The pressure was limited within the range 4-15 bar, transformig the flow rate to a theoretical pressure considering the nozzle type. In our case IDK 90015 and IDK 90025 were used:

$$P_{IDK-90015} = 8.3358 * Q_{Nozzle}^{2.002}$$
$$P_{IDK-90025} = 2.9949 * Q_{Nozzle}^{2.005} \quad , (4)$$

where $P_{IDK-90015}$ and $P_{IDK-90025}$ are the theoretical pressures for the correspondent nozzle. Once limited, the theoretical pressure rate was used to compute the required voltage, using the calibration motor valve curve. In paralel, the real pressure of the system was measured by the pressure sensors.

Results

Applications with IDK90015

The first applications took place on 12/05/2021 and 27/05/2021. Both had all ten IDK 90015 nozzles. Fig.3 presents every sample recorded during one application for three and four nozzle sections. It faces the half-tree width obtained and the pressure. The red points represent the required or theoretical pressure the sprayer should had when reading each tree width. The blue points represent the real pressure measured by the pressure sensors. More than 95% of required pressure for sections with three nozzles were on the highest possible value, around 14 bar. This indicates that th system was dosing less flow than is required, a larger nozzle would be more adequate for this section. Sections with four nozzles present more values in the variable rate range, even so, most of them were at the maximum pressure limit, which was 13 bars. This differences in pressures between sections were due to the need to obtain almost the same flow rate with one more nozzle. Sections with four nozzles needed less pressure to obtain the same flow rate than sections with three nozzles.

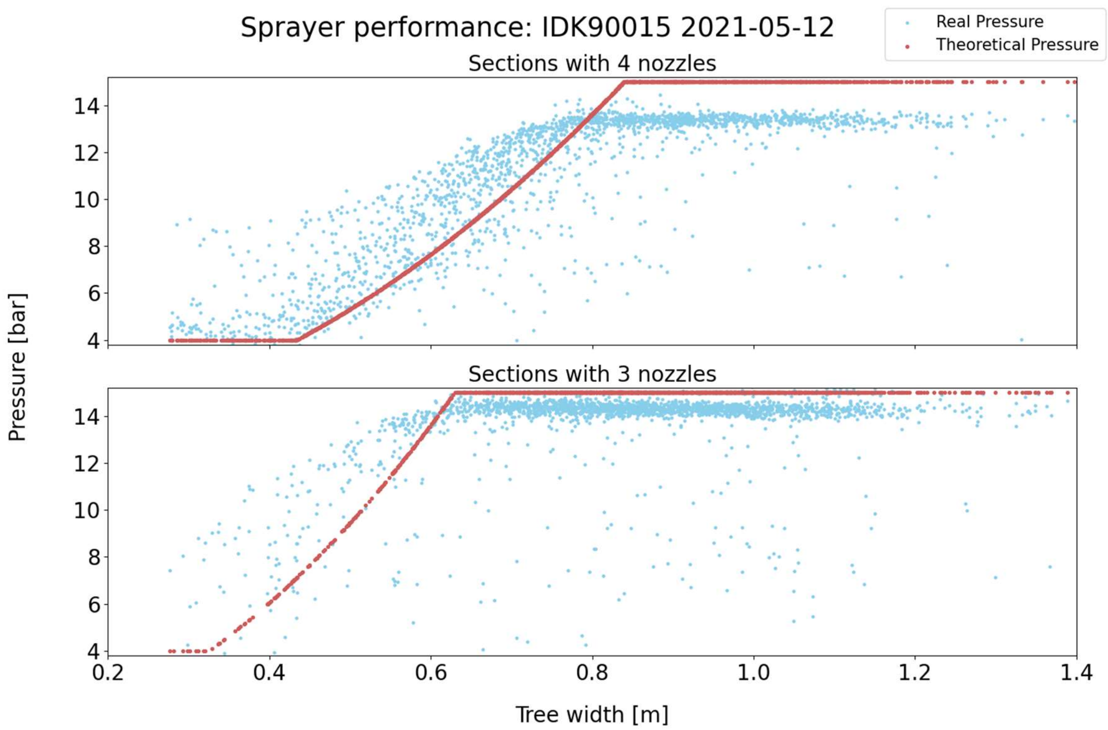

Figure 3 Sprayer performance during the application carried out on 12/05/2021. Half-Tree width measured by the ultrasonic sensors gave a theoretical pressure (red). This theoretical pressure generates the real pressure response of the system (blue).

The differences of the maximum pressure reached between both sections is due to the motor valve capacity. The higher the number of nozzles the higher where the pressure loses. Fig. 4 presents the frequency for each pressure along the application. It confirms that the pressure values in sections with three nozzles were almost all, at the maximum pressure. The pressure obtained in sections with four nozzles were more distributed along the pressure range. To obtain pressure values in the whole range, a larger nozzle like IDK 9002 or IDK 90025 would be used.

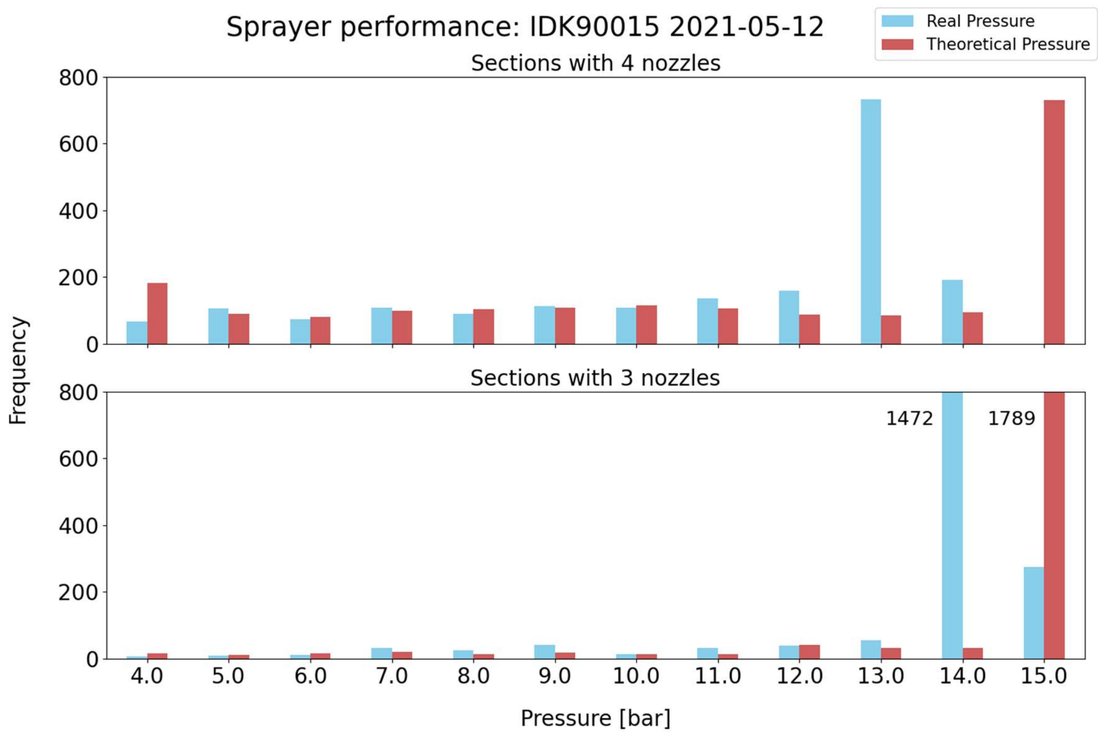

Figure 4. Sprayer performance during the application carried out on 12/05/2021. Pressure frequencies of each section values along the assay. Theoretical pressure (red) is presented as well as the real pressure (blue).

Applications with IDK90025

This second application took place on 09/06/2021 and 22/06/2021. Considering the results from the previous tests IDK 90025 nozzles were used for all sections. Fig. 5 presents the theoretical pressure faced with the half-tree width, for one section with 4 nozzles and one with 3 nozzles, from this last two applications.

In this case a limit on tree width was considered, the vegetation measured bigger than 1 m per side was set to 1 m. This limit in tree width, induced a pressure threshold in sections with four nozzles. These sections did not need more than 11 bars to spray the required flow. On the other hand, sections with three nozzles presented most of pressure values on the upper limit, which is 12 bar. Fig. 6 confirms that the pressure was more distributed along variable rate range than the previous applications. For sections with three nozzles, the upper limit pressure was 12 bar while for the last applications pressures were 14 bar, this is due to the motor valve loses. The larger the nozzles size the lower were the maximum pressures reachable.

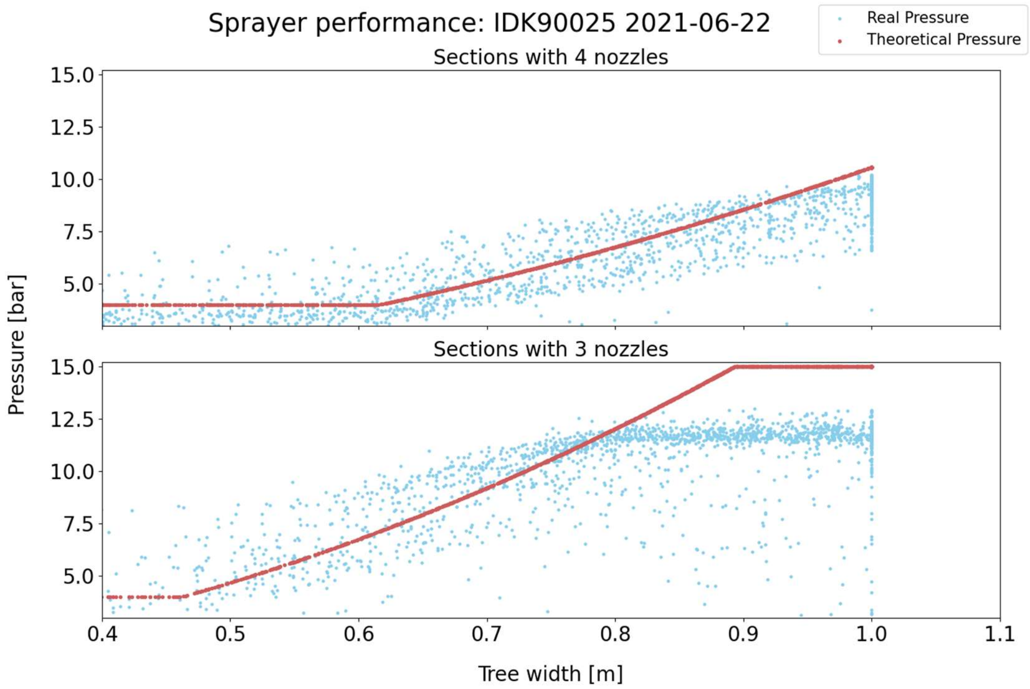

Figure 5 Sprayer performance during the application carried out on 09/06/2021 and 22/06/2021. Half-Tree width measured by the ultrasonic sensors gave a theoretical pressure (red). This theoretical pressure generates the real pressure response of the system (blue).

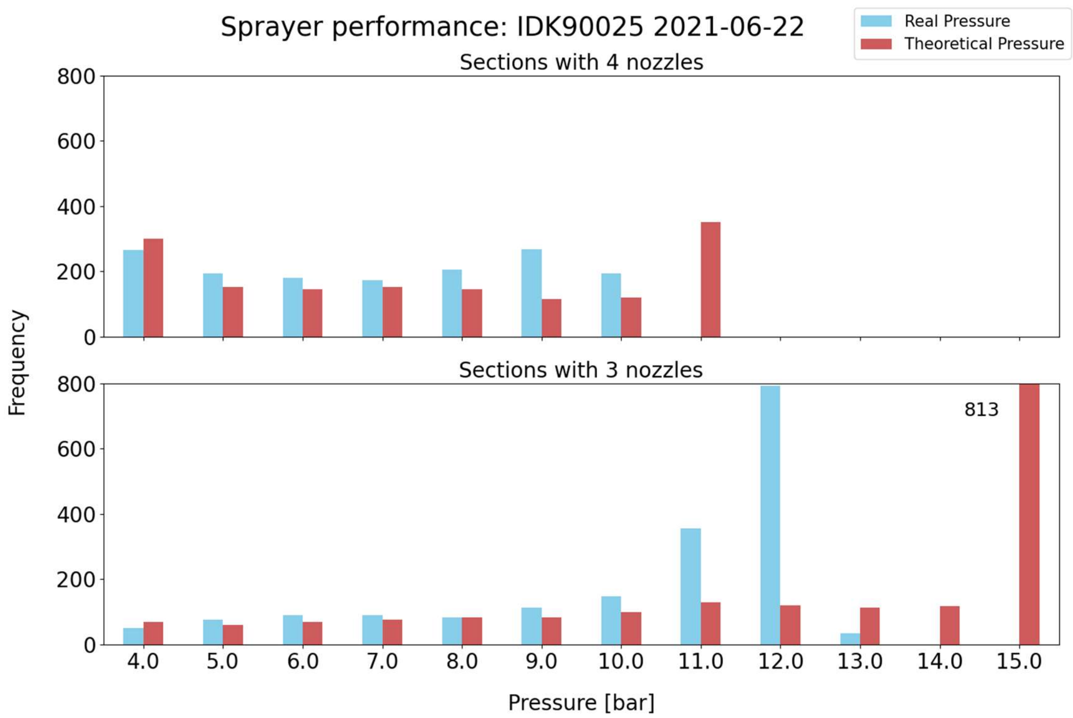

Figure 6 Sprayer performance during the application carried out on 09/06/2021 and 22/06/2021. Pressure frequencies of each section values along the assay. Theoretical pressure (red) is presented as well as the real pressure (blue).

Conclusions

The prototype developed in this project allows a real time dose adjustment, according to the canopy width. The sensors and actuators used in this project present enough accuracy and reliability to detect minor changes in tree width, and control or record the flow rate. The measurements made could be used to adjust the flow rate according to the crop volume. Even so, some difficulties were encountered during the applications because of motor valve performance. These could be avoided replacing motor valves with similar actuators with more robustness.

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