VARIABLE RATE APPLICATION TO IMPROVE CRO PROTECTION IN ORCHARDS AND VINEYARDS. PRESCRIPTION MAPS AND SATELLITES TO ACOMPLISH EU FARM TO FORK STRATEGY

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Abstract.

Accurate canopy characterization is crucial for a targeted application of plant protection products following variable rate application (VRA) concept. Remote sensing technologies offer a robust and rapid monitoring tool that allows determining the characteristics of the vegetation from aerial platforms at different spatial resolutions. Previous works exposed that drone-based imagery can be used to estimate canopy height, width, and canopy volume accurately enough to allow a full automation of VRA prescription maps in vineyards using Dosaviña® DSS. The next step is to evaluate the use of satellite images for VRA sprayers, which are simpler and more cost-effective to obtain, while maintaining reasonable accuracy. The potential of this method has been explored through several research projects in Spain. Previous research compared the quality of vigor maps generated by drone and satellite imagery. Results indicated that the VRA sprayers could effectively use satellite-generated prescription maps, similar to those produced by drones, with promising similarities between the vegetation maps from both sources. This technology can be implemented among farmers, allowing them to reduce the use of phytosanitary products. Field experiments in the Barcelona region (Spain) during several season to treat vineyards, showed that the prototype provided the same biological efficacy as conventional treatments while reducing water and copper usage during vineyard applications. Participation with European projects demonstrated successful applications using maps from satellite images too. Preliminary results confirmed the effectiveness of this VRA spray mode, with a significant reduction in copper usage while maintaining biological efficacy. All these efforts align with the spirit of European directives aimed at achieving more sustainable agriculture.

Keywords. *Prescription map, Variable Rate Application, Satellite Imagery, Orchards, Vineyards*

Introduction

Plant Protection Products (PPPs) remain the primary choice for farmers to protect their crops. In agriculture, farmers aim to bring their products to market without reducing production levels or organoleptic quality. The vast majority of them consider pesticide application the most reliable method available (Ortega et al., 2023). Evidence of this is that global pesticide use has nearly doubled in the last 30 years (FAO, 2020). Consumption varies depending on the region and crop. For example, in the key European sector of viticulture, this represents values of 12-14 kg/ha. Vineyards are among the European crops that consume the most PPPs to combat weeds competing for the same resources as the vines, insect pests, and especially fungal diseases (Chen et al., 2022).

However, pesticide applications can significantly impact on environmental contamination, operator safety, and the economic balance of crop production. Traditional plant protection treatments can be more efficient reaching their targets, without the surrounding area. Reducing off-target losses while maintaining pest and disease control in fruit trees and vineyards is a key challenge in European agriculture. Regardless the latest European political decisions, the spirit of the Green Deal's "From Farm to Fork" Strategy (EC, 2019 and 2020) emphasizes the importance of addressing these issues, justifying ongoing research, taking into account that farmers always will be benefited if they can reduce product losses by maintaining biological control over pests and diseases.

There is a complex mechanism involving numerous parameters influencing on the efficiency of the sprayer during a treatment in vineyards and fruit trees, also called ‘3D crops’ (Grella et al., 2017). They can be divided into two main groups. The first pertains to spraying technology, such as droplet spectrum (Campos et al., 2023), application rate (Gil and Escolà, 2009), fan currents (Salcedo et al., 2019), and pesticide formulation properties (Salcedo et al., 2024). The second involves the vegetal structure, which affects spray deposits distribution. Indeed, canopy characteristics critically determine the optimal volume rate and spray quality. Traditionally, canopies are considered homogeneous, leading to uniform PPP application. But there is a variability, in terms of size and density, requiring an adjustment of PPP doses. The larger the canopy and/or the foliar mass, the greater the chances of droplet retention, although on the other hand the sprayed particles have more difficulty penetrating into the vegetation. Current techniques, like Leaf Wall Area (LWA) or Tree Row Volume (Gil et al., 2020), are typically used for constant-rate applications, without including the geometric variations within rows or spaces between vines.

Variable-rate applications (VRA) can diminish these problems (Wei et al., 2020). This kind of sprayer is equipped with an intelligent control system to recognize the canopy features, and processing the adequate spray volume in real time, keeping the biological efficacy such as a conventional treatment with less amount of water and PPP. In viticulture, these spray technologies start from the prior identification of the crop characteristics. Droplets are directed in an adequate dose to the target vine. The liquid profile is adjusted more effectively to the structure and density of the vine, avoiding using more product than necessary and reducing off-target spray losses.

VRA spray modes can be implemented based on on-line sensors or prescription maps. On one hand, sensors such as laser or ultrasound detectors are used to detect the presence of the canopy and estimate the parameters associated to it. On the other hand, images can be obtained from remote sensing sensors, such as cameras mounted on drones or satellites (García-Ruiz et al., 2023a). This methodology has proven to be reliable, precise, and cost-effective, allowing for mapping large areas with high spatial resolution, which are then used to create maps.

The sprayers based on maps usually utilizes drones equipped with sensors to gather aerial images of the crop. These images are analyzed to obtain the Normalized Differential Vegetation Index (NDVI) and filter out pixels corresponding to the crop of interest. Subsequently, a new vegetation vigor map is generated. Then, with the help of manual measurements and Decision Support Systems, such as Dosaviña® (Gil et al., 2019), the application rate in each zone is calculated. This information is used to calculate a prescription map with the precise amount of pesticide needed in each area. It is uploaded to the sprayer's computer, controlling the correct application rates during treatment (Gil et al., 2023). Numerous studies have shown the effectiveness of these spray systems, minimizing spray wastage while preserving the equivalent level of effectiveness as traditional PPP applications (García-Ruiz et al., 2023b).

It is also worth highlighting the potential of satellites for VRA sprayers. Satellites can cover much larger areas in a single pass at a lower cost than drones, making them highly efficient for mapping extensive areas, such as large vineyards. They can also provide consistent data over time, which is valuable for monitoring changes and trends throughout the growing season. Besides this, satellite data can be less affected by local wind currents compared to drones. In this regard, the Agricultural Machinery Unit of the Polytechnic University of Catalonia (UMA-UPC; Barcelona, Spain) has focused part of its research in recent years on the use of satellites for VRA sprayers in viticulture. It has been proven that satellites offer reasonable precision for creating prescription maps at a much lower cost and with greater simplicity compared to drones.

The aim of this article is to review the efforts made by the UMA-UPC in VRA sprayers based on satellite maps, and compare the first results obtained with other VRA systems with on board sensors such as ultrasounds.

First experiences: comparison between drone and satellite data

Between 2018 and 2019, Campos et al. (2021) compared the manual characterization of vine canopies with the information obtained by remote sensing platforms (drones and satellites) in several commercial trellis vineyards in the Penedès wine region (Barcelona, Spain) (Figure 1). To achieve this, 1400 vines were measured both manually and remotely. To study a representative sample of canopies, a systematic uniform random (SUR) sampling design was followed. Each vine selected was labelled and the projection to the ground was delimited, as Figure 1 exposes.

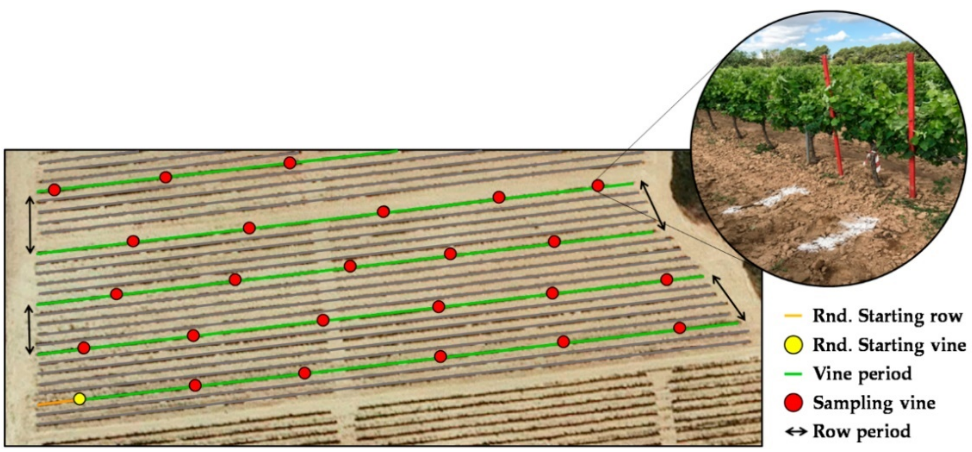

Figure 1. An example of the sampling design followed, including the area delimited on the ground (Campos et al., 2021).

The manual characterizations were conducted at three growth stages: BBCH 59, 75, and 81, respectively according to Meier (1997). Each manual characterization involved measuring the height and width of the vine canopy. On the other hand, two remote sensors were used. One was a hexacopter equipped with a multispectral camera to capture images of vineyards. The obtained images were processed to produce orthophoto maps, calibrated with reflectance plates, and georeferenced using ground control points and a real-time kinematic (RTK) satellite navigation system. The flights were conducted during three growth stages. Additionally, satellite images were used to characterize the vineyard canopy, allowing for efficient mapping of large areas with high spatial resolution at a lower cost than drones. Finally, all these data were compared together.

An image analysis based on the methodology proposed by Campos et al. (2019) was used. An outline of the process is summarized in the Figure 2. For the drone images, the selected vines were identified. Given that the camera resolution was 6.5 cm per pixel and the general canopy boundaries were recognizable thanks to prior ground marking (Figure 1), the number of pixels corresponding to each specific canopy was determined. The NDVI of each pixel was calculated, and finally, a mean NDVI was assigned to each canopy. A similar process was applied for satellite data. On the other side, the procedure for satellites was simpler. The image resolution was 3x3 meters, so the NDVI of this sampling point was estimated directly. In both situations, it was possible to obtain the vegetative vigor map.

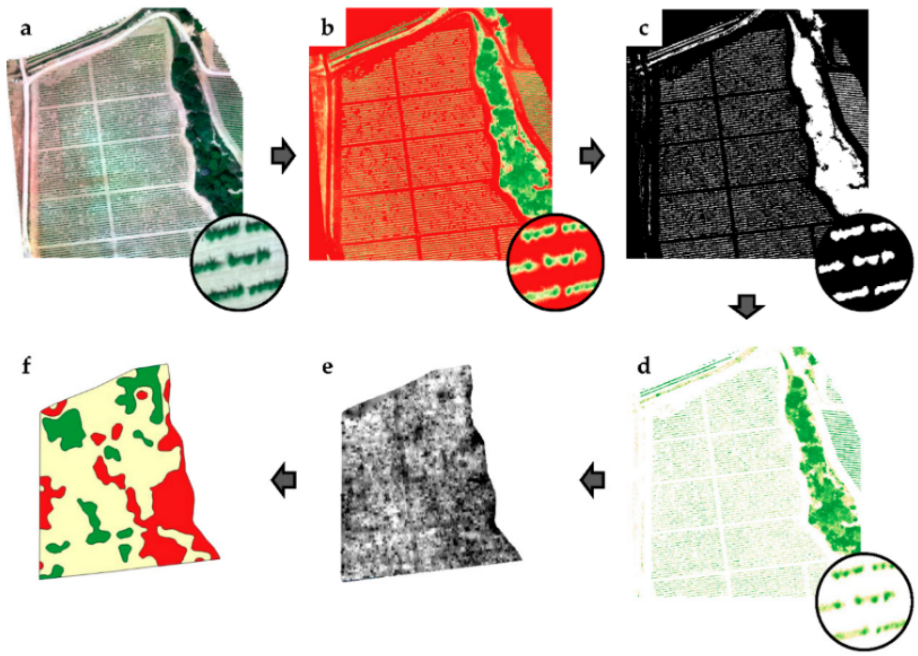

Figure 2. Methodology proposed by Campos et al. (2019): (a) radiometrically adjusted multi-spectral image, (b) NDVI image, (c) binary filter of vineyard-specific pixels, (d) NDVI vineyard-only pixels, (e) NDVI map, (f) clustered vigor map by level colors.

Drone and satellite data was used to determine the correlations between the drone data and the height, width, TRV, and LWA of the canopies obtained from the manual measurements. Remote sensing was able to detect variations in canopy characteristics associated with growth stages. The combination of the NDVI and the projected area extracted from drone images correlated with the TRV when raw point data were done. This relationship improved and extended to canopy height, width, leaf wall area, and TRV when the data were clustered. Similarly, satellite-based NDVI yielded moderate coefficients of determination for canopy width with raw point data, and for canopy width, height, and TRV when the vines were clustered according to vigor (Figure 3).

Drones and satellites for variable-rate application in olive and vineyard plantations (ADOPTA project)

The ADOPTA project (PDC2022-133395) is a Proof of Concept, funded by the Spanish Ministry of Science, born as a result of another project called PIVOS (PID2019-104289RB), in which a VRA sprayer based on maps was developed for vineyard crops (Gil et al., 2023). In this case, the sprayer included a computer (Figure 4) that interpreted the prescription maps generated from drone images and sent corresponding instructions to PWM (Pulse Width Modulation) valves that regulated the final flow from the nozzles. Additionally, this control unit was in constant contact with a geo positioning sensor to interpret its location within the plot at the time of treatment and make the corresponding application rate adjustment. Additionally, for field operations, the computer features a touchscreen interface, offering the possibility to make adjustments with the equipment in static or dynamic positions. For field tasks, the computer allows for adjusting the row width and pre-selecting the plot to be treated. It also displays working pressure, flow rate, and geodetic coordinates of the machine during treatment.

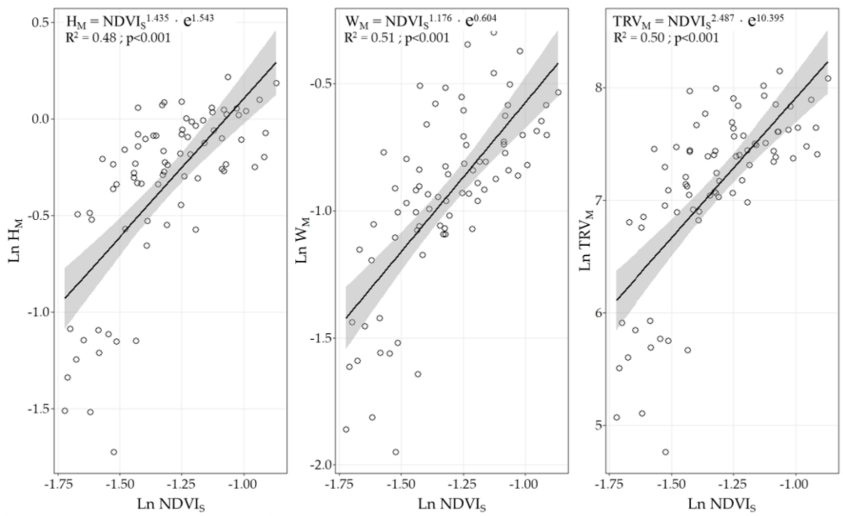

Figure 3. Regression curves evaluating the NDVI obtained from satellite imagery (X-axis) and the manually measured canopy structural parameters (height-H, width-W, TRV) (Y-axis).

Figure 4. General image of the smart multi-row sprayer for vineyards during an application (left) and detail of the computer for map interpretation and spray control.

Preliminary field fungicidal applications in Penedès (Barcelona, Spain) in 2022 and 2023 in trellised vineyards showed that the prototype offered the same biological efficacy as conventional treatment. Additionally, water and PPP consumption were lower compared to conventional applications in the area, with an average reduction of approximately 19%. Previous results in drift trials, in collaboration with INRAE in Montpellier (France), show an average reduction in losses compared to conventional application of approximately 40%.

The relationship between the PIVOS project and ADOPTA is based on the latter project's aim to implement this technology among the involved farmers. This implies that potential users can reduce the amount of PPP through the implementation of these VRA sprayers. To facilitate this task, since 2024, the option of working with maps from satellite images has been introduced. Local farmers have agreed to manage this prototype for two complete campaigns (2023 and 2024), using drone-provided images in the first campaign and satellite-obtained images in the second (project outline shown in Figure 5). Initial results have shown that the prototype is perfectly capable of working with these prescription maps as if they were from a drone, with many similarities found between the vigor maps obtained through drones and satellites.

For both remote sensors, the procedure is always the same: First, the drone or satellite acquires aerial images of the target plot. Then, they are analyzed to calculate the NDVI, filtering out pixels corresponding to vineyards to eliminate distortions. Subsequently, the image is interpolated and isolated pixels are discarded to form a new map of vegetation vigor. Parallelly, manual measurements of diameter and canopy height are conducted to estimate leaf density and determine the corresponding application volume for each vigor zone using the Dosaviña(R) tool, generating the final prescription map. The information is transferred to the sprayer's computer to adjust the application rate within the different vigor zones of the plot, controlling the nozzles through PWM valves.

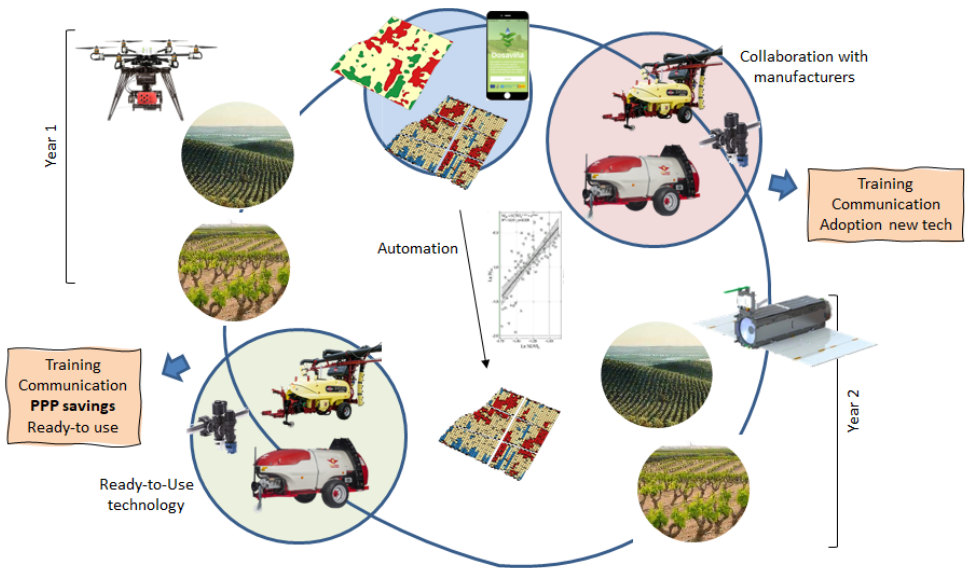

Figure 5. Scheme of the ADOPTA project. Field results from applications with prescription maps will be obtained with satellite date and compared with drone.

VRA based on satellites

Our recent involvement in the INTERREG SUDOE COPPERREPLACE project has demonstrated that control of diseases in vineyard is possible even though a reduction of the volume rate used when the amount of pesticide is adapted to canopy characteristics. During the season 2022, satellite-based vigor maps were used to determine management zones in which manual sampling of vines were conducted to determine canopy characteristics and subsequent volume rate using Dosaviña. Reduction of 30% of copper used was achieved in the whole campaign, and the assessment of biological efficacy showed no differences with plots treated using conventional methods.

A step forward in this working methodology was achieved during the participation of the UMA-UPC research group as a partner in NOVATERRA EU project. Among other objectives, the project was focused in the design and development of a prescription map generation algorithm utilizing satellite images in vineyards that could undertake the challenge of automatic generation of prescription maps. For this, a sensing device was designed, implemented and validated in the field to make possible the massive acquisition of data in the vineyard using ultrasound sensors. The sensing device was mounted in the tractor and acquired georeferenced canopy height and canopy width data every second (Figure 6). This data was combined with NDVI information and models for automatic canopy characteristic estimation based on satellite remote sensing data were obtained. These models were tested in commercial vineyards in Spain and Portugal to assess the performance of the prescription maps in the field (García-Ruiz et al., 2023c). During the season 2023, a complete campaign of spray applications was conducted in Spain using the variable rate prescription maps generated using the models developed in NOVATERRA. Results showed savings of 33 and 44% of pesticide in each of the two plots used in the trial as compared with the conventional applications performed by the farmer. Most important, no differences were found in the biological control of the fungus under VRA and conventional methods of application of pesticides. Similarly, in Portugal, after a whole campaign of VRA treatments in mountain viticulture, reductions of 20-30% compared to conventional application methods were achieved, with no significative differences in pest and disease control.

Figure 6. Developed device provided with ultrasonic sensors for in-field canopy measurements (right); results obtained after in-field measurements compared with satellite images in order to determine the optimal relationship (left).

Development of an easy to use platform for prescription map generation

Increasing the adoption of VRA technology for pesticide application needs easy and rapid generation of prescription maps. For this reason, UMA-UPC has recently started the development of a user-friendly platform to connect maps service providers and VRA hardware providers on a single interface that helps generating, in few clicks, a prescription map with the automatic calculation of the volume rate for every area of the field. This platform gathers satellite based maps from platforms in the market, applies the models for volume rate calculation developed during more than 20 years in the group, and sends the maps to the he hardware in the sprayer machines capable of implementing the VRA. This platform is still in its initial steps, but it will be tested in the future seasons.Comparison with VRA sprayers with on-board sensors

VRA spraying systems based on satellite prescription maps and proximal sensors represent two different approaches to optimizing pesticide application in agriculture. Map-based VRA systems offer a more economical and technically less complex solution, as they use data collected from satellite images to generate prescription maps. Proximal sensor-based VRA systems have been proved to be very effective, such as the airblast sprayer developed by UMA-UPC within the European Horizon OPTIMA project (Grant Agreement Nº 881777) (Xun et al., 2023; Salas et al., 2024). But they require additional electronic devices to collect real-time data on crop characteristics, and the price is higher. Considering these differences, map-based VRA systems have demonstrated reasonable precision in pesticide dosing and comparable biological efficacy to proximal sensor-based VRA systems during our latest field applications. Furthermore, map-based VRA systems have shown a reduction in pesticide consumption without compromising treatment effectiveness, making them an attractive option for farmers in terms of efficiency and profitability.

Summary

Several projects, performed by UMA-UPC these latest years, have been exploring the potential of VRA technology in 3D crops, particularly focusing on map-based approaches. These projects aim to optimize PPP application by using data from satellite images to generate prescription maps for VRA sprayers. First studies demonstrated comparable efficacy from drone to satellite maps. It is being successful the implementations in sprayers for vineyards, showcasing the feasibility and effectiveness of this approach. The automate canopy characterization using high-resolution satellite images, offering a cost-effective and scalable solution for precision agriculture is possible. And these VRA sprayers are displaying their potential to reduce copper application in vineyards while maintaining biological efficacy.

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References

Campos, J., Llop, J., Gallart, M., García-Ruiz, F., Gras, A., Salcedo, R., Gil, E. (2019). Development of canopy vigour maps using UAV for site-specific management during vineyard spraying process. Precision Agriculture, 20(6), 1136-1156.

Campos, J., García-Ruíz, F., Gil, E. (2021). Assessment of vineyard canopy characteristics from vigour maps obtained using UAV and satellite imagery. Sensors, 21(7), 2363.

Campos, J., Zhu, H., Jeon, H., Salcedo, R., Ozkan, E., Roman, C., Gil, E. (2023). Air-pinch PWM valve to regulate flow rate of hollow-cone nozzles for variable-rate sprayers. Journal of the ASABE. 66(5): 1317-1329.

Chen, Y., Herrera, R. A., Benitez, E., Hoffmann, C., Möth, S., Paredes, D., Schwarz, N. (2022). Winegrowers' decision-making: A pan-European perspective on pesticide use and inter-row management. Journal of Rural Studies, 94, 37-53.

EC, European Commission. (2019). The European Green Deal, Communication from the Commission to the European Parliament, the Council, the European Economic and Social, Committee and the Committee of the Regions, 2019.

EC, European Commission. (2020). A Farm to Fork Strategy-For a fair, healthy and environmentally-friendly food system, Communication from the Commission to the European Parliament, the Council, the European Economic and Social, Committee and the Committee of the Regions, 2020.

Food and Agriculture Organization. (2020). Pesticide indicators. Food and Agriculture Organization Corporate Statistical Database: Rome, Italy.

García-Ruiz, F., Salcedo, R., Campos, J. Gil, E. (2023a). Preliminary analysis of satellite base canopy characterization in the vineyard for prescription map generation. In: Targeted Application, Spray Technology and Authorization Workshop – AAB. Wageningen (The Netherlands). May (2023).

García-Ruiz, F., Campos, J., Llop-Casamada, J., Gil, E. (2023b). Assessment of map based variable rate strategies for copper reduction in hedge vineyards. Computers and Electronics in Agriculture, 207, 107753.

García-Ruiz, F., Graça, A., Correia, S., Fontes, N., Manso, J., Ferreira, A. R., Salcedo, R., Gil, E.

(2023c). Variable Rate Application in mountain viticulture based on canopy maps generated by satellite remote sensing. In: 16th Workshop on Spray Application Techniques in Fruit Growing (Montpellier, France). September (2023).

Gil, E., Escolà, A. (2009). Design of a decision support method to determine volume rate for vineyard spraying. Applied engineering in agriculture, 25(2), 145-151.

Gil, E., Campos, J., Ortega, P., Llop, P., Gras, A., Armengol, A., Salcedo, R., Gallart, M. (2019) DOSAVIÑA, new Decision Support System (App and website) for a more sustainable and efficient use of Plant Protection Products in vineyard. Computers and Electronics in Agriculture, 160, 117-130.

Gil, E., Salcedo, R., Soler, A., Ortega, P., Llop, J., Campos, J., Oliva, J. (2021). Relative efficiencies of experimental and conventional foliar sprayers and assessment of optimal LWA spray volumes in trellised wine grapes. Pest management science, 77(5), 2462-2476.

Gil, E., Salcedo, R., García-Ruiz, F., Biscamps, J., Xun, L., García-Ramos, F. J., Vidal, M., Vigo, A., Blanco-Roldán, G. L, Rodríguez-Lizana, A., Mariscal, J. M., Rovira-Más, F., Cuenca, A., Saiz-Rubio, V., Ortiz, C., Ortí, E., Pérez, M. (2023). Diseño y aplicación de un sistema inteligente de pulverización variable para tratamientos fitosanitarios en viña y olivo – PIVOS y ADOPTA. In: XII Congreso Ibérico de Agroingeniería. Sevilla (Spain). September (2023).

Grella, M., Gallart, M., Marucco, P., Balsari, P., Gil, E. (2017). Ground deposition and airborne spray drift assessment in vineyard and orchard: The influence of environmental variables and sprayer settings. Sustainability, 9(5), 728.

Meier, U. (1997). BBCH-Monograph. Growth stages of plants - Entwicklungsstadien von Pflanzen – Estadios de las plantas - Développement des Plantes. Blackwell Wissenschaftsverlag, Berlin und Wien. 622 p.

Ortega, P., Salcedo, R., Sánchez, E., Gil, E. (2023). Biopesticides as alternatives to reduce the use of copper in Spanish and Portuguese viticulture: Main trends in adoption. European Journal of Agronomy, 151, 126996.

Salas, B., Salcedo, R., Garcia-Ruiz, F., Gil, E. (2024). Design, implementation and validation of a sensor-based precise airblast sprayer to improve pesticide applications in orchards. Precision Agriculture, 25(2), 865-888.

Salcedo, R., Pons, P., Llop, J., Zaragoza, T., Campos, J., Ortega, P., Gallart, M., Gil, E. (2019). Dynamic evaluation of airflow stream generated by a reverse system of an axial fan sprayer using 3D-ultrasonic anemometers. Effect of canopy structure. Computers and electronics in agriculture, 163, 104851.

Salcedo, R., Maristany, G., Biscamps, J., Collantes, R., García-Ruiz, F., Gil, E., (2024). Influence on drift reduction by combining nozzle profile, droplet size and surfactant concentration. In: Aspects of Applied Biology 148. International Advances in Pesticide Application. Brighton (United Kingdom). January (2024).

Wei, Z., Xue, X., Salcedo, R., Zhang, Z., Gil, E., Sun, Y., Li, Q., Shen, J., He, Q., Dou, Q., Zhang, Y. (2023). Key Technologies for an Orchard Variable-Rate Sprayer: Current Status and Future Prospects. Agronomy, 13(1), 59.

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. Precision Agriculture, 24(4), 1526-1546.