Methodology for implementation of satellite-based maps for Variable Rate Application (VRA) of pesticides in vineyards SUDOE

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1.- Introduction

The reduction in the use of plant protection products (PPPs) has become a priority for the European Union in recent years. Therefore, directives and regulations have been issued to address it, setting 50% reductions in PPPs by 2030, according to the Farm to Fork strategy implemented within the Green Deal[1].

One of the most widely used fungicide products is copper, which is applied against the oomycete *Plasmopara viticola* that causes the disease commonly known as downy mildew. This product has also been subject to European regulation, and its use has been reduced in recent years at European level[2] to a maximum of 28 kg·ha^{-1} for a period of 7 years.

Difficulty in controlling pests, poor application management and overuse of application rates have led to copper accumulation in the soil and leaching to ground and surface water. Therefore, it is necessary to implement the use of new technologies in order to reduce the use of copper in vineyards, while maintaining the effectiveness of applications to minimize the effect of the disease on grape production. One of the technologies to be implemented is the use of variable rate application (VRA), based on the existence of areas with different vegetative vigour allowing a rational pesticide dose adjustment based on canopy characteristics.

2.- Objective

The aim of this guide is to present the procedure for the use of Variable Rate Application (VRA) in vineyard plots based on vigour maps generated by satellite imagery, in order to reduce the use of copper in vineyards of the SUDOE region, helping in the accomplishment of the new regulations imposed by the European Union.

3.-Metodology

The methodology used for the implementation of VRA technology is described below and summarized in figure 1, where the entire process is illustrated. As shown in figure 1, the methodology described begins with obtaining a satellite image of the plot which, through a Normalized Difference Vegetation Index (NDVI), generates a vigour map where three differentiated zones are established: high, medium and low vigour.

After a manual characterization of the vegetation (canopy height and canopy width) of these three different vigour zones, the DSS DOSAVIÑA® is used to estimate the

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[1] Communication from the Commission to the European Parliament, the European Council, the European Economic and Social Committee and the Committee of the Regions: European Green Deal COM/2019/640.

[2] Commission Implementing Regulation (EU) 2018/1981 of 13 December 2018 renewing the approval of the active substances copper compounds, as candidates for substitution, in accordance with Regulation (EC) Nº 1107/2009 of the European Parliament and of the Council concerning the placing of plant protection products on the market, and amending the Annex to Commission Implmenting Regulation (EU) Nº 540/2011.

optimum application volume for each of these zones, and to generate the prescription map ($L \cdot ha^{-1}$). This map is uploaded to the software responsible of controlling the sprayer. This software and the hardware implemented in the spraying machine, are capable of reading the position of the tractor, determining the volume rate based on the prescription zone and regulate the flow rate to deliver the prescribed amount of pesticide for every single zone. Finally, the accuracy of the variable application process is observed, due to the similarity between the prescription map and the map actually applied.

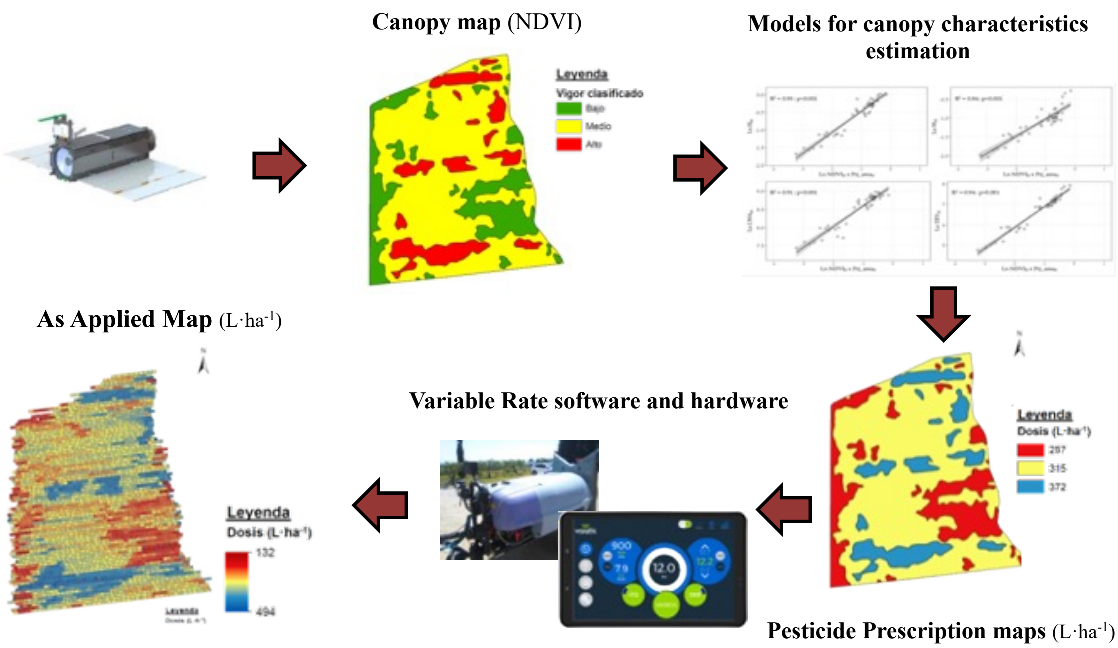

Figure 1.- Diagram of the methodology used for variable rate application (VRA) in vineyards.

3.1.- Image source acquisition and canopy characterization in order to create a vigour map.

Imagery for the production of canopy vigor maps can be obtained from different sources, such as unmanned aerial vehicle (UAV) or satellites. In the COPPEREPLACE project, the use of satellite images has been preferred for plant characterization, due to their ease of collection and low cost compared to drone imagery.

Vigour classes are based on canopy variability maps using high resolution satellite images. Before each copper application, satellite-based images are obtained from PlanetScope (PS)[3], a commercial constellation of nanosatellites consisting of more than 130 triple CubeSat miniature satellites (<5 kg) called as Dove (Planet Labs Inc., San Francisco, CA, USA). Dove satellites are equipped with a line scanner imaging sensor with four spectral bands in the blue (455–515 nm), green (500–590 nm), red (590–670 nm), and NIR (780–860 nm) regions, providing high-resolution imagery (3 m spatial resolution) with an approximately daily revisit time.

[3] https://www.planet.com/

The Normalized Difference Vegetation Index (NDVI) is calculated using bands 3 (red, R) and 4 (NIR):

$$\mathrm{NDVI} = \frac{\mathrm{NIR} - \mathrm{R}}{\mathrm{NIR} + \mathrm{R}}$$

Because of the low spatial resolution (pixel size was larger than the distance between the vineyard rows), segmentation between the canopy and the background elements (weeds, shadows, and soil) is not possible. The raw NDVI images are classified into three vigour levels following the quintile rules (P20, P40, P60 and P80). NDVI values lower than P20 are classify as “low vigour”, NDVI values between P20 and P80 are classify as “medium vigour” and NDVI values higher than P80 are classify as “high vigour” (Campos et al., 2021).

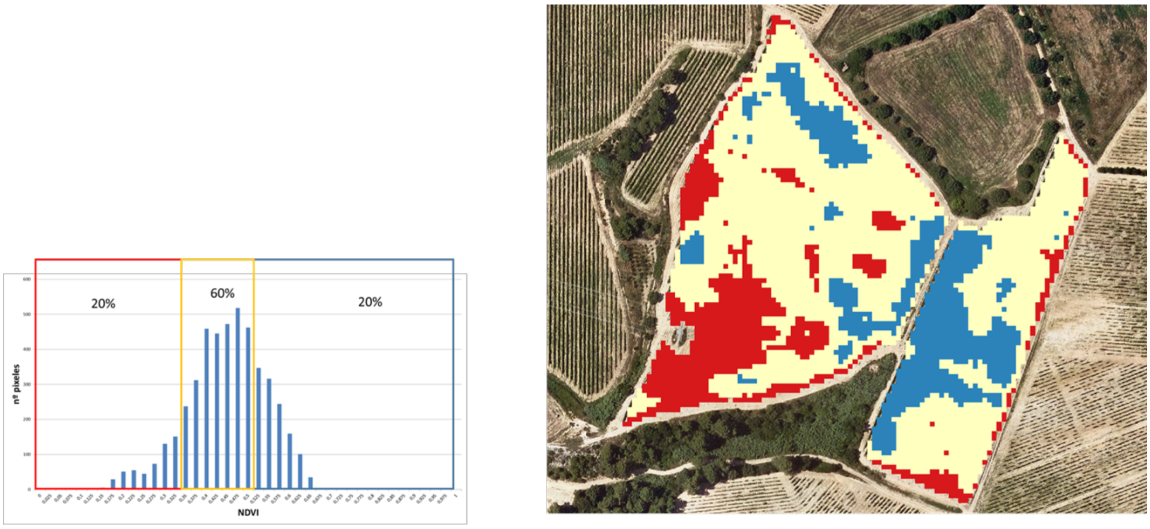

Figure 2.- Histogram with NVDI values and selected quintiles, with different colours, and vigour map obtained from de same plot.

From this information, a vigor map is obtained (Figure 3) in which each color describes a differentiated vigor zone. The process was executed using the QGIS software (QGIS Development Team, 2016. QGIS Geographic Information System. Open-Source Geospatial Foundation. URL http://qgis.osgeo .org).

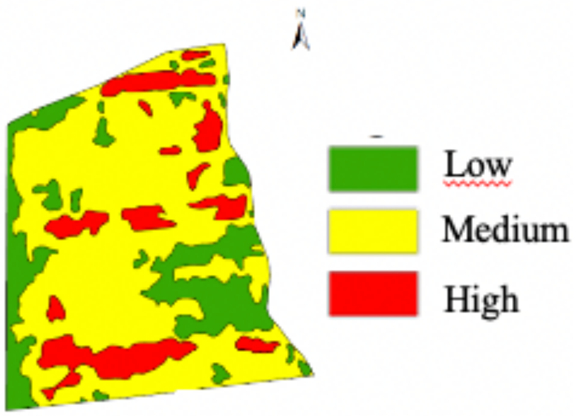

Figure 3.- Vigour map from a vineyard plot obtained from NDVI quintiles.

3.2.- Determination of pesticide dose and volume rate

Subsequently, the vegetation in each of the previously defined vigor zones is characterized. Canopy characterization for each of the sampling vines (10 vines in each vigor zone) consists of measuring the most representative parameters (canopy height and width) (Figure 4a). Manual measurements are conducted using a regular measuring tape following the EPPO standard (EPPO, 2021), which included 95% of the canopy, excluding protruding branches (Figure 4b). The final value is calculated form the average of the corresponding ten measurements per vigour zone.

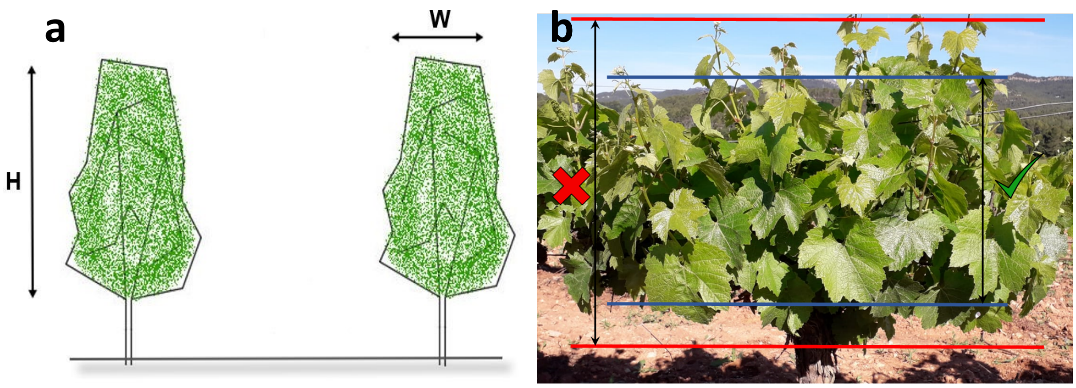

Figure 4.- Measurements of the height (H) and width (W) of the canopy of the vineyard to characterize the vegetation (4a). Correct determination of the vegetation height and width (just 95th percentile of vegetation) (4b).

A decision support system (DSS), DOSAVIÑA ® (Gil et al., 2011) is used to determine the optimal volume rate based on the canopy characteristics of each vigour zone (Figure 5).

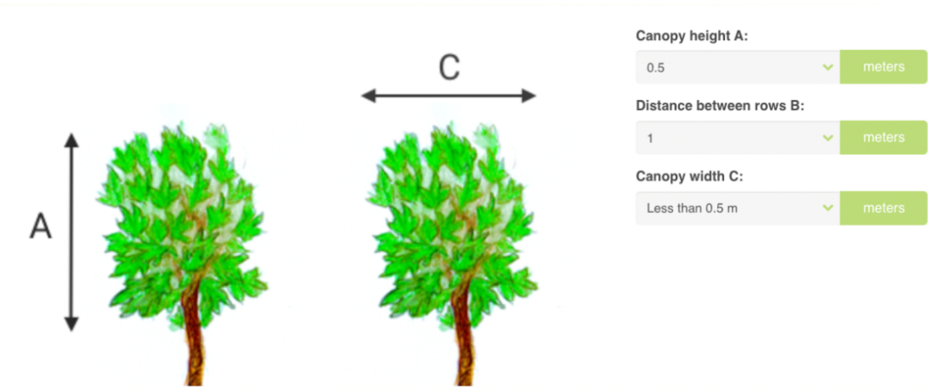

Figure 5: Image captured of the DOSAVIÑA® decision support system for determining the optimum application volume according to the height and width of the canopy.

Vegetation density is determined according to the number of visible holes in the vegetation wall according to different categories (Figure 6): Very low dense (6a, vegetation is scarce, there are many holes in the wall), Low dense (6b, vegetation does not completely cover the entire space, there are some holes in the vegetation wall), Dense (6c, vegetation covers almost all the space, there are a few holes in the vegetation wall), Very dense (6d, the vegetation is very dense and there are no holes in the vegetation wall). Other information about the plot is also determined, as number of rows per plot, vine training system, row spacing, spacing within the row, plant row diameter.

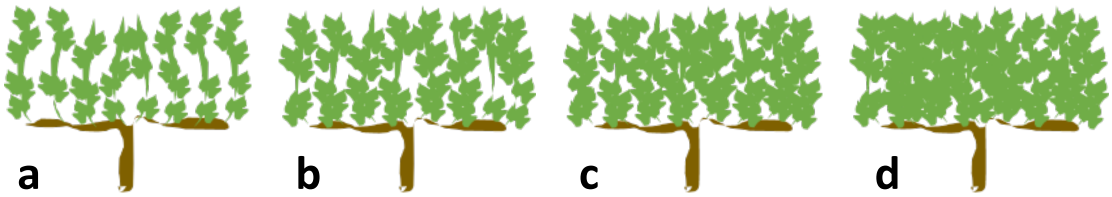

Figure 6: Vegetation density. Very low dense (a), Low dense (b), Dense (c), Very dense (d).

DOSAVIÑA® enables determination of the most accurate volume rated based on a modified version of the leaf wall area (LWA) method. The results of the characterization of the vegetation, as well as the pesticide recommendations written down on the label (percentage of concentration and recommended dose ($L \cdot ha^{-1}$)) are introduced in the application. Once this is done, the tank capacity (L) must be chosen and the application gave us the results of a recommended spray application volume ($L \cdot ha^{-1}$), pesticide dose ($L \cdot ha^{-1}$) and the amount of pesticide to add to the tank (L or Kg) (Figure 7).

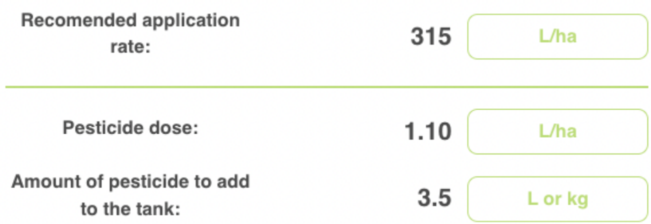

Figure 7: Image captured of the DOSAVIÑA® decision support system with the result of the optimum application volume for a given vegetation characterization.

DOSAVIÑA® offers a useful tool for nozzle selection based on the forward speed ($Km \cdot h^{-1}$), the recommended spray application volume ($L \cdot ha^{-1}$) previously determined, as well as the number and distance between rows. Finally, DOSAVIÑA® allow to choose between different nozzles types, the flow rate and the working pressure, and therefore the drop size.

3.3.- Generation of prescription maps.

Once the three different volume rates are calculated, the corresponding values are introduced into the georeferenced canopy vigour map using the specific software QGIS (QGIS Development Team, 2016. QGIS Geographic Information System. Open-Source Geospatial Foundation. URL http://qgis.osgeo.org) in order to generate the georeferenced prescription map (Figure 8).

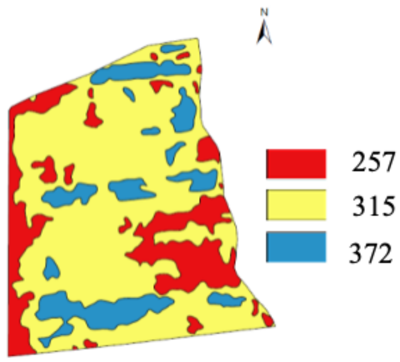

Figure 8.- Prescription map (L·ha^{-1}) according to recommended application rate by DOSAVIÑA®, generated by QGIS.

The generated map is uploaded to the VRA controller in the spraying machine (via USB or via internet). Specific data concerning dedicated working parameters for each vigour zone must also be entered into the software: volume (L·ha^{-1}), nozzle type, number of nozzles, pressure (bar) and forward speed (Km·h^{-1}).

It is advisable to maintain constant forward speed and number and nozzle type. In order to adapt the requested application rate, only the working pressure is automatically modified, always maintaining the values inside the recommended range provided by nozzle manufacturer.

Finally, figure 9 shows the final result of the variable application on a plot. The different colours indicate the actual dose applied to each area of the plot, which fits perfectly with the prescribed map (Figure 8).

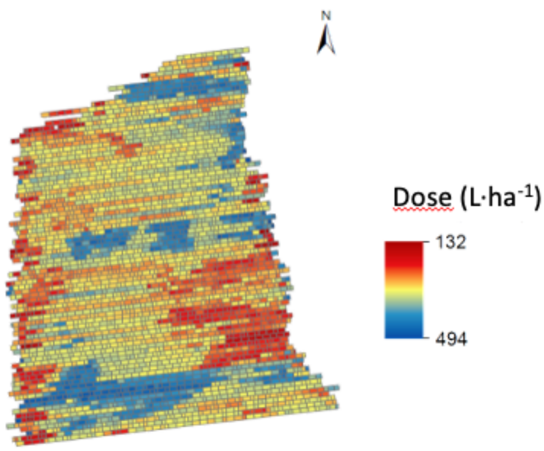

Figure 9.- Applied map (L·ha^{-1}) generated by the electronic controller.

3.4.- Technical requirements for the implementation of the variable rate application

In order to make feasible the implementation of VRA in vineyards, an adaptation of a conventional sprayer is required. The following sensors and controllers are necessary (Figure 10):

- One pressure sensor, with the purpose of adjusting the required pressure according to the prescription map.

- A flowmeter to register in real time the liquid that is being applied by the entire machine.

- Two ultrasonic sensors to detect presence/absence of vegetation along the canopy lines.
- The needed number of electrovalves to control the machine (e.g. two if two sides want to be controlled independently). The function of the electro valves is to shut-off the nozzle flow rate from a section when the signal received from the ultrasonic sensors indicated no vegetation.
- Electronic controller, including a GPS receiver with a touchscreen and an automatic section controller.

The whole system is in charge to determine the exact sprayer position and to adjust the solenoid valves to modify the working pressure, emitting a flow rate at the nozzles to match the application volume determined for each position in the plot.

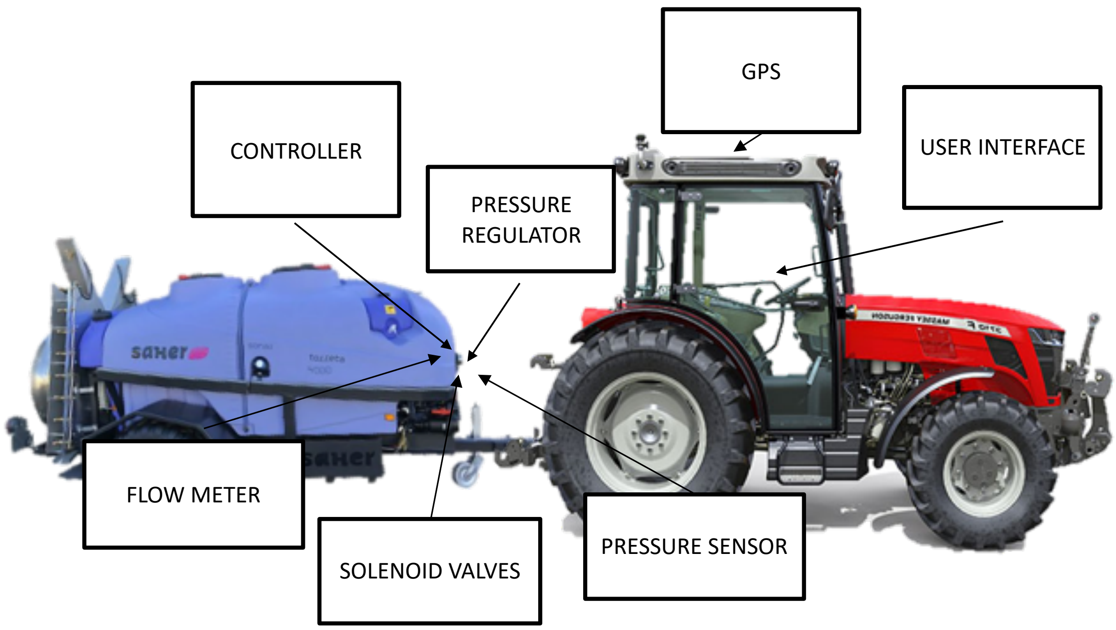

Figure 10.- Equipment necessary to use to modify a conventional sprayer for the implementation of variable rate application in vineyards.

The modified sprayer is able to operate according to the following two different scenarios: i) According to the position in the parcel detected by the GPS receiver, the system identifies the canopy characteristics and, from that, the recommended volume from the prescription map. At this point the embedded controller calculates the required flowrate based on the nozzle type and number and adjusts the working pressure sending the order to the pressure controller to deliver the desired flowrate, and ii) if at a certain point in the parcel, the ultrasonic sensors detect absence of vegetation (end of the canopy row), the corresponding signal is transformed into a shut-off order to the electro valves, which turn off the entire flow rate of the vertical booms.

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