DESIGN OF A DECISION SUPPORT METHOD TO DETERMINE VOLUME RATE FOR VINEYARD SPRAYING

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ABSTRACT. Dose determination in crops such as grapevine, which develops a large canopy within a relatively short period of time, becomes a key factor on the final success of plant protection product (PPP) application. Efficacy of PPP applications depends on many factors. Based on multiple data obtained over several years in real working conditions using different types of sprayers in vineyards, and by adding a complete data base about crop characteristics (structure, crop stage, leaf area, LAI, etc.), the objective of this work has been to develop an easy and useful tool, DOSAVIÑA, able to determine the optimal volume rate in spray applications in vineyards.

DOSAVIÑA, based on a spreadsheet (Microsoft Excel©), allows quantifying all the parameters involved in the application process (sprayer type, crop characteristics, working conditions, weather, etc.), and to determine the efficiency of the application. By selecting and choosing the different options for each parameter (crop, pesticide, working conditions, weather conditions, sprayer, and droplet characteristics) the program calculates the theoretical volume rate (L ha⁻¹) based on two different methods, the Optimal Coverage Method and the Tree-Row-Volume method. Results obtained with DOSAVIÑA allow reducing the recommended volume rate in comparison with traditional application rate selection managed for farmers.

In order to make a complete and useful tool, the program includes the possibility to calculate the final working parameters (pressure, nozzle type, and size) according to the recommendations on volume rate (L ha⁻¹) obtained.

Keywords. Vineyard, Spray application, DOSAVIÑA, Tree-row-volume, Coverage, Volume rate, Dose, Efficiency.

The recently published proposal of Directive of the European Parliament and Council establishing a framework for Community action to achieve a sustainable use of pesticides states: “This Directive establishes a framework for achieving a more sustainable use of pesticides by reducing the risks and impacts of pesticide use on human health and the environment in a way that is consistent with the necessary crop protection” (COM, 2006). Moreover, in article 13, part 1 establishes: “Member States shall take all necessary measures to promote low pesticide-input farming, including integrated pest management (IPM), and to ensure that professional users of pesticides and other Plant Protection Products (PPP) shift towards a more environmentally-friendly use of all available crop protection measures, giving priority to low-risk alternatives when possible, and otherwise to the products with minimum impact on human health and the environment among the ones available for the same pest problem.”

A well-defined method to establish the most suitable working parameters is a key factor to obtain an environmentally friendly application system, reducing drift, improving the sustainability and decreasing the total amount of PPP, directly complying with the main objective of the Directive. The European Plant Protection Organization (EPPO) has widely promoted and encouraged the absolute need to have at one’s disposal a harmonized methodology to determine the optimal volume rate during the spray application process, specially focused in orchards and vine crops, due to its inherent difficulty and influence of crop characteristics on the final success of the operation.

Determination of the amount of liquid to be sprayed is a difficult aspect (a great number of parameters influence the process) with a certain amount of subjectivity. There are many and very variable factors affecting efficacy and efficiency in pesticide applications in vineyard. Most of them can be classified as controllable (depending on sprayer type, working conditions, pesticide characteristics, etc.). Another group of factors is made up of all those that are uncontrollable, on which it is impossible to act but with high influence on the final success of the process such as weather conditions, pest and/or disease requirements, crop development and structure, and others. Taking all those aspects into account or not will turn into important variations in the final selected volume to be sprayed.

The absolute need to improve both quality and profit of PPP applications requires a coordinated action in all the involved aspects of the process: characteristics of pesticide, target (pest, disease or weed), specific crop conditions, and selected application technology for distribution. A good interrelation between all of those aspects will lead to improved control during the PPP application process.
achieving the best and the most suitable benefit of the applied dose.

NOTATION

AF Leaf area per lineal meter of canopy (m² m⁻¹)
D₁ Optimal droplet density per unit area (droplets cm⁻²)
E₁ Efficiency factor for optimal coverage method (%)  
E₂ Efficiency factor for TRV method (%)  
h Crop height (m)  
i Recommended amount of liquid per cubic meter of canopy (L m⁻³)  
K Correction factor for droplet diameter  
LAI Leaf area index, or ratio of leaf area per unit ground area (m² m⁻²)  
M Relative value of Rᵢ  
Q Total flow rate (L min⁻¹)  
Rᵢ Recovery value for i factor  
Rᵢ,j Recovery value for i factor, j sub-factor  
r Row spacing (m)  
T Maximum value for Rᵢ,j  
TRV Tree row volume, or ratio of canopy volume per unit ground area (m³ ha⁻¹)  
V₀ Real application volume after efficiency factor (L ha⁻¹)  
v Forward speed (km h⁻¹)  
VMD Volume median diameter (µm)  
VMDref Volume median diameter of a reference spray application (µm)  
w Crop width (m)

LITERATURE REVIEW

Concern for human safety and environmental contamination due to the inefficient use of PPP in orchard spraying has resulted in a range of practical models aimed at minimizing the orchard-to-orchard variation of deposit through suitable adjustments of the label-recommended dose rate to different crop structure parameters (Walklate et al., 2006). In this sense, environmentally safe spraying techniques have been developed to reduce the use of PPP and apply them only when and where needed with reduced losses to the environment (Doruchowski and Holownicki, 2000).

Adequate knowledge of the relationship among operative parameters (working pressure, forward speed, spraying pattern, etc.) and crop characteristics (morphology, structure, development, etc.) will lead to quality improvement of the spraying process. One of the aspects on which these parameters have more influence is on the establishment of the adequate spraying volume rate for each treatment. Trends in dose recommendations have been widely discussed. Parameters such as row width, tree height, canopy volume, leaf area index (LAI), and leaf area density (LAD) have been proposed to characterize the canopies and their relationship with deposition values obtained in field trials (Walklate et al., 2000; Friesleßen and Koch, 2005; Gil et al., 2005; Siegfried et al., 2007).

Efforts invested in developing new technologies to adjust the dosage to the characteristics of the vegetation are very well known. Measurements obtained using LIDAR (Light Detection And Ranging) technology conclude that area-density and height adjustments are the best crop structure parameters on which a simplified scheme for pome fruit spraying could be based (Walklate et al., 2006). According to Balsari (2001), when applying the same amount of liquid with the same pesticide concentration the deposit on leaves decreases when increasing leaf area, whichever sprayer was employed. The same author concludes that differences of deposition due to an increase of foliar area are much more evident in the inner area of the canopy than in the outer. Salyani and Whitney (1990) showed that vegetation density and the placement inside the canopy have a direct effect on deposition variability.

The vegetation thickness is directly related to crop volume. Macarrone and Scienza (1998) showed the relation between vegetation volume and the amount of deposit per unit leaf area, and demonstrated the inverse relation between both parameters. According to Balsari (2001) it is out of question to obtain similar results, in terms of pest control, spraying similar doses, and water volume, on vines of 22 000 m² ha⁻¹ or of 15 000 m² ha⁻¹ of leaves. When applying 600 l ha⁻¹, the theoretical amount of product on a leaf square centimeter would be, respectively, 27.6 and 57.1 mL.

Walklate et al. (2003) using a LIDAR to adjust the pesticide application rate in order to keep the average deposit in apple trees constant, demonstrated the relative potential for varying the pesticide application rate according to different crop structural parameters. Moreover, Gil et al. (2005) established a correlation between deposition and leaf area index, as well as a direct relationship between deposition and TRV.

Interest of adoption of TRV-based method has been widely demonstrated. Jones et al (2000) indicated that volume rates used in Australia for thinning applications have been reduced from 4000 L ha⁻¹ on large trees to 200 L ha⁻¹. Dose rates of active ingredients have also been reduced by 25% without reducing efficacy.

Spray applications in vineyard following TRV variations using ultrasonic sensors (Gil et al., 2007) allow to increase the efficiency of applications from 0.15 to 0.31 compared with conventional applications based on ground area dosage.

Following the structural crop criteria as a way to determine the optimal volume rate, Furness (2007) proposed the UCR method, based on a unit canopy size and length of row, which appears simpler and easier to understand than other previous methods (Furness et al., 1998).

But not only morphological and structural crop characteristics influence the final success of PPP use. Pergher and Gubiani (1995) and Pergher et al. (1997) found differences ranging from 35% to 92% in deposition on leaves directly exposed to the spray jets and on leaves more or less covered or totally hidden, when using an air-assisted sprayer with vertical deflectors, due to the perpendicular nozzle orientation. Pezzi and Rondelli (2000), in trials in vineyard with a conventional air-assisted sprayer showed that deposition uniformity decreases as the distance from the plant to the machine increase.

OBJECTIVES

The objective is to design software to help farmers in the process of deciding the volume rate to be applied in their vineyards. Determination of the optimal application volume rate in vineyard crops is an important aspect in order to obtain
the best results during the spraying process. The software application has to be an easy to use and practical tool, able to determine the optimal volume rate required in vineyards, based on different calibration procedures. The use of software to highlight good spraying practices will enable growers to optimize their pesticide use. Improving the output from an air blast sprayer will lead to a more accurate application of PPP, increasing efficiency and efficacy; less drift problems, avoiding environmental problems; and an improvement of timeliness, avoiding the need of extra out of date applications due to poor efficacy.

**FUNDAMENTOS DE DOSAVIÑA**

**DOSAVIÑA** has been developed allowing the data input process to be as easy as possible. From the structural point of view, the flow chart (fig. 1) shows three different screen types: data input, results, and information. The intercommunication between these screens allows the user to modify any particular parameter anytime just working over the three first screens. The procedure of data input, based on a multi-option boxes, makes it very intuitive even for a non-expert.

In order to achieve these objectives, two different methods are described and mathematically implemented into the software: the Optimal Coverage Method (OCM) and the Tree-Row-Volume method (TRV) described by Byers (1987). In both cases (fig. 2), after determining the theoretical volume rate to apply, DOSAVIÑA allows, as a new and innovative characteristic, estimating the efficiency of the application process, including the calculation of all external factors affecting the process (weather, crop characteristics, working parameters, and sprayer type).

The proposed methodology is based on achieving a level of coverage (impacts per unit leaf area) according to the pest/disease characteristics and the type and way of action of the applied pesticide (table 1). From the combination of the optimum value of coverage (impact density – droplets cm⁻²) with the calculated droplet volume (assuming a spherical
shape) and knowing or estimating the leaf area. Equation 1 is used to calculate the theoretical optimum volume to spray:

$$V_T = 2 \cdot LAI \cdot D_i \cdot \frac{4}{3} \pi \cdot \left( \frac{VMD}{2} \right)^3 \cdot 10^{-7} \cdot K$$

(1)

where $V_T$ is the theoretical volume (L ha$^{-1}$); $LAI$ the leaf area index; $D_i$ the optimal droplet density per unit area (droplets cm$^{-2}$); $VMD$ is the volume median diameter of applied droplets (μm), and $K$ the correction factor for droplet diameter.

In order to reduce the high influence that droplet size has in equation 1 ($VMD$ value acts as cubic ratio) factor $K$ is included. Small differences in the selected VMD give big differences in the final recommended volume. The purpose of $K$ is to relate the droplet diameter of any selected nozzle with a reference droplet diameter (200 μm). Equation 2 shows the calculation procedure for $K$ values (see table 2):

$$K = \frac{VMD_{ref}}{VMD}$$

(2)

where $VMD_{ref}$ is the droplet size of a reference application (200 μm) and $VMD$ the selected droplet size (μm).

In the selection procedure of droplet size, amongst the different values used for the characterization of a given droplet population, $VMD$ is the most representative and hence adopted for the quantification of the spraying process. Droplet size classification (table 2) is included in the DOSAVIÑA database and used in the internal calculations.

Regarding the procedure for leaf surface quantification (Leaf Area Index), DOSAVIÑA includes two options: a) the adoption of the real value, if it is known, or b) to estimate the

![Figure 2. Proposed methods in DOSAVIÑA to determine of the optimal volume rate.]

![Figure 3. Principle of the “Optimal Coverage Method” proposed in DOSAVIÑA.]

**Crop characteristics**

- Sprayer type
- Working conditions
- Weather
- Pesticide

**Optimal Coverage Method (OCM)**

- Determination of the optimal volume rate ($V_{T1}$) based on leaf area and droplet characteristics

**Tree-Row-Volume method (TRV)**

- Determination of the optimal volume rate ($V_{T2}$) based on crop structure and “i” value ($l \cdot m^{-3}$)

$VE_1 (l \cdot ha^{-1})$

$VE_2 (l \cdot ha^{-1})$

$VT_1$

$VT_2$

$En_1$

$En_2$

Volume index “i” ($l \cdot m^{-3}$)

$Droplet volume$

$$V = \frac{4 \pi}{3} \left( \frac{VMD}{2} \right)^3$$

$Coverage (droplets cm^{-2})$

$Pesticide characteristics$

$Target surface$

$Leaf area index$
Figure 4. Principle of the Tree-Row-Volume method proposed in D獠牛igaM’a.

leaf area index value from the included database (Gil, 2003). Four different and representative crop stages have been defined and its leaf area index characterized. For those four selected crop stages, representing the most intense and difficult in terms of spray application, the mean value of leaf area per linear meter of vegetation is calculated (table 3). Once this parameter is determined, transformation to leaf area per linear meter of vegetation is calculated (table 3). For those four selected crop stages, representing the most intense and difficult in terms of spray application, the mean value of leaf area per linear meter of vegetation is calculated (table 3).

OPTIMAL VOLUME RATE ACCORDING TO THE CANOPY VOLUME (TRV) METHOD

The most common procedure used for sprayer calibration is based on the adequate combination of three parameters: forward speed, row spacing, and flow rate, according to equation 4:

\[
TRV = \frac{h(w(m) \cdot 10,000(m^2\cdot ha^{-1}))}{r(m)}
\]  (5)

where \( TRV \) represents volume of canopy per unit area \((m^3 ha^{-1}); h \) is crop height \((m); w \) is crop width \((m); and \ r \) row spacing \((m)\).

Table 3. Values of optimal impact density per unit area according to pesticide and pesticide characteristics used in D獠牛igaM’a calculations.[a]

| Pesticide Type | Action | Optimal Density (droplets cm\(^{-2}\)) |
|----------------|--------|--------------------------------------|
| Fungicide      | Systemic | 80                                    |
|                | Contact | 90                                    |
| Insecticide    | Systemic | 100                                   |
|                | Contact | 120                                   |

[a] Gil, 2001.

Table 2. Droplet size categories according BCPC classification and values of K factor for each droplet size.

| Spraying Quality | VMD Extreme Value (μm) | VMD Medium Value (μm) | Values of “K” factor |
|------------------|------------------------|-----------------------|----------------------|
| Very fine (VF)   | <130                   | 100                   | 4.000                |
| Fine (F)         | 130-190                | 160                   | 1.563                |
| Medium (M)       | 190-230                | 210                   | 0.907                |
| Coarse (C)       | 230-350                | 240                   | 0.694                |
| Very coarse (VC) | >350                   | 350                   | 0.327                |

where \( V_T = TRV \cdot i \) (6)

Efficiency Quantification and Losses Balance

Once the optimal volume rate have been calculated following any of the two described methods, the program quantifies the efficiency of the application through the value of recovery factor \( R \) according to the selected parameters related to working conditions, sprayer type, crop structure and weather conditions (Gil, 2001). The polynomial expression used for the determination of that parameter is established from different monomials (table 4), each one with a different specific influence, with the aim to quantify the effect of the different factors in the final quality of the application. Each one of these factors is established in turn by a combination of one or several sub-factors and the final
Table 4. List of factors, sub-factors, and its mathematical relationship established to calculate the average values for efficiency (R).

| Factor         | Sub-factor            | Values       | Equation                                                                 | M (%) | T (max. value of ΣRij) |
|----------------|-----------------------|--------------|--------------------------------------------------------------------------|-------|------------------------|
| Crop, Rc       | Crop stage (Rc1)      | 5; 4; 2; 1   | \( R_c = 100 - \left[ R_{c1} + R_{c2} + R_{c3} + R_{c4} + R_{c5} \right] \cdot 20/25 \) | 20    | 20                     |
|                | Crop structure (Rc2)  | 5; 3         |                                                                                     |       |                        |
|                | Canopy width (Rc3)    | 5; 2         |                                                                                     |       |                        |
|                | Row distance (Rc4)    | 5; 3; 1      |                                                                                     |       |                        |
|                | Crop height (Rc5)     | 5; 3; 2      |                                                                                     |       |                        |
| Adjuvants, Rp  | Adjuvant (Rp1)        | 5; 0         | \( R_p = 100 - \left[ Rp_{p1} \right] \cdot 5/5 \)                              | 15    | 5                      |
| Sprayer, Re    | Sprayer type (Re1)    | 5; 2; 1      | \( R_e = 100 - \left[ R_{e1} + R_{e2} + R_{e3} + R_{e4} \right] \cdot 30/20 \) | 30    | 30                     |
|                | Deflectors (Re2)      | 5; 2         |                                                                                     |       |                        |
|                | Nozzle type (Re3)     | 5; 1         |                                                                                     |       |                        |
|                | Droplet size (Re4)    | 5; 3; 1      |                                                                                     |       |                        |
| Working conditions, Rt | Fwd. speed (Rt1) | 5; 3; 1 | \( R_t = 100 - \left[ R_{t1} + R_{t2} + R_{t3} \right] \cdot 30/15 \) | 30    | 30                     |
|                | Pressure (Rt2)        | 5; 2; 1      |                                                                                     |       |                        |
|                | Air flow rate (Rt3)   | 5; 3; 1      |                                                                                     |       |                        |
| Weather, Rm    | Temperature (Rm1)     | 5; 3; 1      | \( R_m = 100 - \left[ R_{m1} + R_{m2} + R_{m3} \right] \cdot 20/15 \) | 20    | 20                     |
|                | Rel. humidity (Rm2)   | 5; 3; 1      |                                                                                     |       |                        |
|                | Wind speed (Rm3)      | 5; 3; 1      |                                                                                     |       |                        |

result is the pondering of all the individual values, according equation 7:

\[
R_i = 100 - \left[ \sum_{j=1}^{n} R_{ij} \right] \cdot \frac{M}{T}
\]

(7)

where \( R_i \) is the efficiency for any selected factor; \( X_i \) is the individual influence of each monomial; \( M \) is the relative value (%) for \( R_i \); and \( T \) is the maximum theoretical value of \( \sum R_{ij} \).

Once the final value of each monomial has been estimated, the total value of recovery factor (R) corresponding to each one of the proposed methods is calculated through the equations 8 and 9:

\[
E_1 = (R_c \times R_p \times R_e \times R_t \times R_m) \times 10^{-10}
\]

(8)

\[
E_2 = (R_p \times R_e \times R_t \times R_m) \times 10^{-8}
\]

(9)

In the former expressions, \( E_1 \) and \( E_2 \) are, respectively, the values of the efficiency obtained for the two proposed methods (optimal coverage and TRV methods). DOSAVIÑA uses these values to modify and recalculate the real volume to apply (eq. 10). The existing difference in the calculation of R factor between the two different methods lies in the fact of not using the “crop factor” (\( R_c \)) in the case of the TRV method. This omission can be justified as the parameters used in quantifying \( R_c \) are the same as used to determine the canopy volume and so, the crop characteristics, have been taken into account before.

The calculated value of efficiency factor (\( E_i \)) is then used to modify the theoretical values of optimal volume rate obtained with the two proposed methods (eqs. 1 and 2), determining the real volume to be applied according to equation 10.

\[
V_R = \frac{V_T}{E_i}
\]

(10)

where \( V_R \) is the real volume rate (L ha\(^{-1}\)); \( V_T \) is the theoretical volume rate (L ha\(^{-1}\)); and \( E_i \) is the efficiency factor (%).

**CONCLUSIONS**

Determination of the optimal application volume in vineyard crops is an important aspect in order to obtain the best results during the spraying process. DOSAVIÑA offers growers a straightforward method of inputting data into an easy to use software application at their office computer. Changes in various operating parameters, i.e. canopy growth stage, can be made and a print-out of the recommended application rate, correct nozzles, forward speed, etc. is given.

DOSAVIÑA draws the grower’s attention to the many points involved in the application process, becoming an interesting tool to improve the user’s knowledge.

In general, the use of DOSAVIÑA will result in a reduction of the total amount of applied pesticides. In all previous simulations carried out using real data of the most representative vineyard varieties, the proposed applied volume have always been reduced compared to that applied by growers (c.a. 30%). This fact seems a great benefit in terms of economy and sustainability, and lies completely with the major tendency in the use reduction of plant protection products, according the oncoming new regulations at EU level.

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