Precision Viticulture: use of New Technologies to Improve Efficiency in Spray Applications in Vineyard

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ABSTRACT

Two different spray application methods were compared in three vine varieties and different crop stages. A conventional spray application with a constant volume rate per unit ground area (l•ha-1) was compared with a variable rate application method designed to compensate electronically measured variations of canopy dimensions. An air-blast sprayer with individual multi-nozzle spouts was fitted up with three ultrasonic sensors and three electro-valves in one side, to modify the emitted flow rate of the nozzles according to the variability of canopy dimensions in real time. The purpose of this prototype was to precisely apply the required amount of spray liquid and avoid over and under dosing. On average, 58% savings in application volume was achieved with variable rate method, with similar or even better values of leaf deposit. In all cases the variable rate method guarantee a large number of leaves with deposits over the intended theoretical deposit threshold.

Keywords: Ultrasonic sensor, Vineyard, Canopy volume, Variable rate application, Precision Viticulture, Spain.

1. INTRODUCTION

Crop-adapted dosing of agrochemicals has been widely discussed in many publications (Walklate et al., 2003; Furness, 2003; Gil et al., 2005; Godyn et al., 2005; Viret et al., 2005; Pergher and Petris, 2008). In all cases the main goal has been to adapt the total amount of PPP to crop characteristics but difficulties were encountered to select the most suitable crop parameter. The high degree of variability in crop variables has increased the difficulty in obtaining general solutions well adapted to all crops and situations.

The use of orchard canopy volume as a basis for chemical application rate calculation and system design was discussed and tested by Sutton and Unrath (1984 and 1988). The tree row volume concept maintains that chemical rate recommendation and application should be based upon crop canopy volume rather than on land area. Following this methodology other trials have been conducted in order to adapt the spray volume to crop dimensions in vineyard (Pergher and Petris, 2008; Siegfried et al., 2007). In all cases accurate measurements of crop dimensions turns

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into a key factor for the final success. The use of electronic devices to measure crop dimensions is not a new idea. McConnell et al. (1983) proposed the use of a system with a vertical mast with range transducers to measure tree extension, from the trunk outward and towards the row middle. More recently (Giles et al., 1989) using a modified orchard air-blast sprayer equipped with three ultrasonic transducers concluded that saving in pesticide application when using the electronic control system was strongly related to target crop architecture. Same authors concluded that sprayer control based upon target measurement, rather than simple target detection resulted in substantial increases in savings of applied spray liquid.

Both to solve the encountered difficulties for crop characterization and to accomplish the recent EU trends aiming to reduce the total amount of PPP (COM, 2006), environmentally safe spraying techniques have been developed to spray only when and where needed with reduced losses to the environment ((Doruchowski and Holownicki, 2000). Recent advances in computer hardware and software, global navigation satellite systems (GNSS), canopy sensors and remote sensing offer opportunities for fast and inexpensive measurements of tree canopy characteristics for variable rate technologies (VRT) (Zaman and Salyani, 2004). Walklate et al. (2006) using a LIDAR (LIght Detection and Ranging) concluded that area-density and height adjustments were the best crop structure parameters on which a simplified scheme for pome fruit spraying could be based on. Rosell et al. (2009) developed a LIDAR-based measurement system for the estimation of physical and structural characteristics of plants (tree volume, leaf area density and leaf area index). The different shapes, sizes and foliar densities found in tree crops during the same growing season, require a continuous adjustment of the applied dose rate to optimize the spray application efficiency and to reduce environmental contamination (Solanelles et al., 2002).

Target detection has been developed either by using advanced techniques, such a vision systems and laser scanning, or by ultrasonic and spectral systems. Gil et al. (2007) obtained a significant reduction in the total amount of applied volume (57%) using a sprayer prototype with ultrasonic sensors able to measure the crop width variations and to apply a variable dose rate according to the instantaneous measured vine row volume (VRV), in comparison with a conventional and constant application volume rate. However, this reduction did not affect the results in terms of deposit, leaf coverage and penetration where similar normalized values were achieved.

Whitney et al. (2002) investigated the ultrasonic transducer’s response to different parts of a citrus canopy and also examined the effect of the sampling frequency and the transducer spacing on canopy volume determination. More recently (Balsari et al., 2008) using a crop identification system based on ultrasonic sensors confirmed its suitability to detect canopy characteristics in real time, independently of the forward speed, as previous studies already indicated (Zaman and Salyani, 2004).

It seems that any approach to adapt the spraying volume rate to crop characteristics will lead with a general principle that foliar application must results in similar deposits independently of crop size or canopy density. That system would avoid over or under-dosage of PPP, a common situation especially in orchards and vineyards where in most cases pesticide dose rate is calculated in a per unit ground area basis ($l \cdot ha^{-1}$).

This paper describes the characteristics of a developed sprayer prototype able to automatically adapt the spray application rate according to the target geometry, using an adapted tree-row-volume (TRV) estimation method (Pergher and Petris, 2008; Rüegg et al., 1999). Results in terms of coverage, deposit and leaf recovery have been compared with these obtained with a conventional method based on a per land surface dosage system. In order to evaluate the influence of the cultivar, research trials have been conducted in three representative vineyards (cv. Merlot, cv. Cabernet Sauvignon and cv. Tempranillo) and at different growth stages.

2. OBJECTIVES

The objectives of this study were as follows:

a) to analyze the ability of ultrasonic sensors in the determination of vineyard structure;
b) to investigate the spray volume savings achieved through the use of a target measurement sprayer control system based on the instantaneous vine volume, iVV (an adapted VRV principle);
c) to evaluate the efficiency of the proposed spraying system, in comparison with the conventional application based on land surface;
d) to determine the relationship between spray volume savings and canopy structure.

3. MATERIAL AND METHODS

2.1 Sprayer design

The development and testing of the target measurement and sprayer control system used in this research have been previously described and discussed (Gil et al., 2007) and will only be briefly outlined in this article. The measurement system and the electronic process unit were mounted on an air-blast orchard sprayer (Hardi LE-600 BK/2 with a centrifugal fan of 400 mm diameter). The sprayer was equipped with six individual and adjustable spouts (three on each side of the machine) in which up to five nozzles could be arranged on each one. A mast was fitted up on its left side to hold three ultrasonic sensors and a solenoid high frequency electro valve was placed before each of the three spouts linked to each ultrasonic sensor. The three sensor and electro valves were connected to the central control unit placed on the rear top of the sprayer on which a purpose developed software based on LabVIEW (National Instruments Corporation, Austin, USA) was used to transform the crop width measured by each sensor into flow rate at every nozzle set (figure 1).

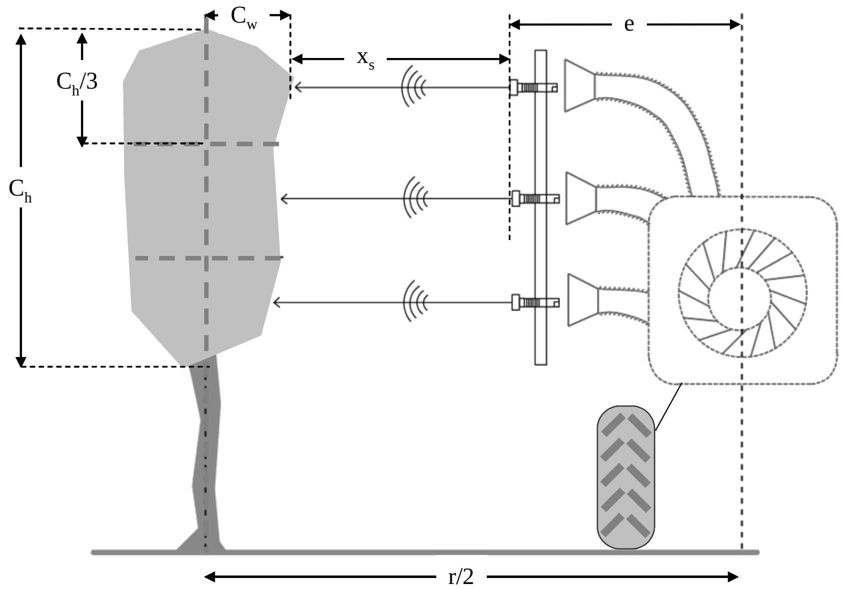


Figure 1. Principle of functioning of the prototype

2.1. Flow chart and system management process

The system starts to run when the control unit is turned on (figure 2) and prompts the introduction of the specific spraying parameters related to crop characteristics (row width, application coefficient, forward speed and maximum crop height). The data acquisition process begins to receive information from ultrasonic sensors (V_{in}) and from the electronic flow meter installed on the system. All data is then managed and processed in the control unit, where signals obtained from each one of the ultrasonic sensors is transformed into canopy volume and to voltage (V_{out}) to send the corresponding electro valve. Previously a laboratory calibration of each ultrasonic sensor and each electro valve was performed in order to accurately determine the relationship between measured crop width (C_w) and electrical signals (V_{in}) from ultrasonic sensors, as well as the relationship between received voltage for each electro valve (V_{out}) and flow rate delivered (q_u).
Once the distance (x_s) has been determined by each ultrasonic sensor, and the range readings converted to crop width (C_w), the system transforms those values into the nozzle flow rate (q_u) according to equation [1], in order to apply a variable amount of liquid proportionally to the vine row variations:

$$q_u = \frac{C_w \times \frac{C_h}{3} \times v \times i \times 1000}{60 \times n} \qquad [1]$$

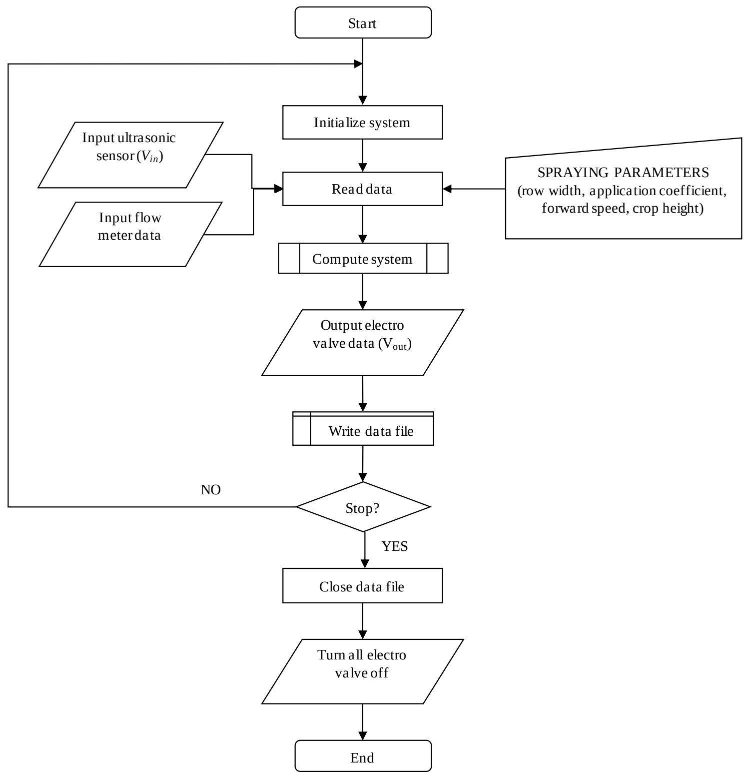


Figure 2.Flow chart of the whole electronic system for variable application

2.3 Experimental plots

Experiments were conducted in three different grape varieties (Merlot, Cabernet Sauvignon and Tempranillo) and in two different growth stages (75 and 85 according to the BBCH-scale (Meier, 2001). In all cases a total length of at least 100 m of five rows were sprayed (1,500 m^2 of experimental plot), and sample leaves for deposit measurements were only taken from the three different blocks randomly established in the center row. On every block, a sample of 1 m length of row was established, on which plants were divided into four different zones according to height (every 0.40 m, ranging from 0.40 m to 1.60 m), and three zones according to depth within the crop (I: external left, II: centre; and III: external right).

2.4. Treatments

A set of tests was arranged on each variety and growth stage in order to compare the efficiency of application of the variable rate system with a conventional spraying procedure based on a constant application volume rate ($l \cdot ha^{-1}$) selected on each situation according to the usual rates in the area and growth stage. For the variable rate system, the application coefficient of i = 0.095 $l \cdot m^{-3}$ vegetation was maintained in all cases. This application rate was selected according to previous research (Gil, 2001) where interest and benefits of this value in terms of efficacy and efficiency of applications were demonstrated.

4. RESULTS

4.1 Savings

According to the application rate adjusted for every individual test, table 1 shows the individual and average saving of liquid for all varieties and crop stages. In all cases saving values are greater than 40%, with the highest value for cv. Tempranillo (77%) in the last growth stage (BBCH-scale 85). In this particular situation, some prune action before the test probably affected the measurements obtained by the sensors, increasing the distance to the crop and reducing substantially the applied volume (86 $l \cdot ha^{-1}$) compared to previous applications, whereas conventional application volume rate was increased according to the normal procedure in the area.

Table 1. Percentage of savings (VRT/conventional) for different cultivars and crop stages

Variety and crop stage*		Application rate ($l \cdot ha^{-1}$)		Total saving (%)
		Conventional	VRT	
Merlot	85	266	141	47.0
Cabernet Sauvignon	75	299	179	40.1
	85	373	111	70.2
Tempranillo	75	299	127	57.5
	85	373	86	76.9

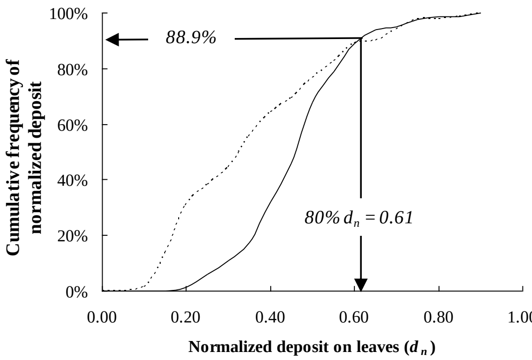
* According to BBCH classification

Those values give an important possibility to reduce the total amount of PPP and its interest is even higher if this analysis is made together with the obtained results in terms of deposit on leaves (table 2), where statistically differences can be observed in all cases in favour of the variable rate application method, except for cv. Merlot.

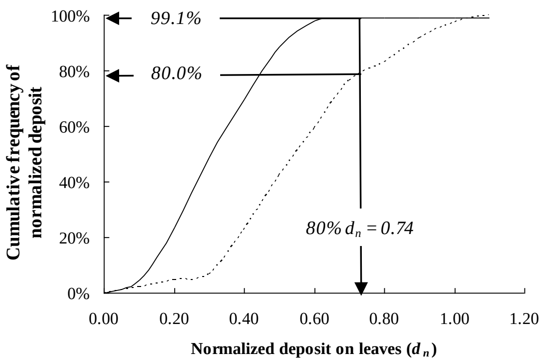
Table 2. Normalized deposit average values, proportional leaf recovery and coefficient of variation for all varieties and crop stages analyzed

Variety and crop stage		Normalized deposit d_n ($\mu g \cdot cm^{-2}$)		Proportional leaf recovery D_l (%)		Deposit uniformity (CV %)	
		Conventional	VRT	Conventional	VRT	Conventional	VRT
Merlot	85	0.46 **a**	0.35 **b**	60.85 **a**	47.14 **b**	28.00	54.00
Cabernet Sauvignon	75	0.33 **b**	0.56 **a**	35.51 **b**	60.94 **a**	50.44	38.73
	85	0.37 **b**	0.52 **a**	37.51 **b**	51.46 **a**	32.27	34.94
Tempranillo	75	0.30 **b**	0.69 **a**	37.45 **b**	86.85 **a**	51.12	43.15
	85	0.28 **a**	0.28 **a**	43.38 **a**	42.23 **a**	45.46	49.76

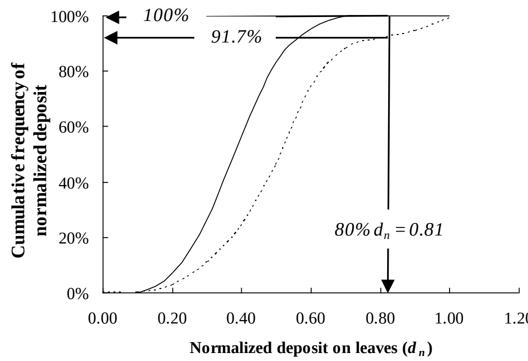
Values followed by the same letter in rows do not differ statistically (Student-Neuman-Keuls test, $p<0.05$)



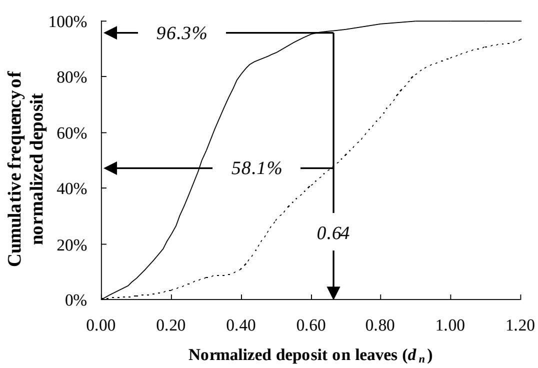
Var. *Merlot*; Crop stage: *85*; LAI: *1.20*



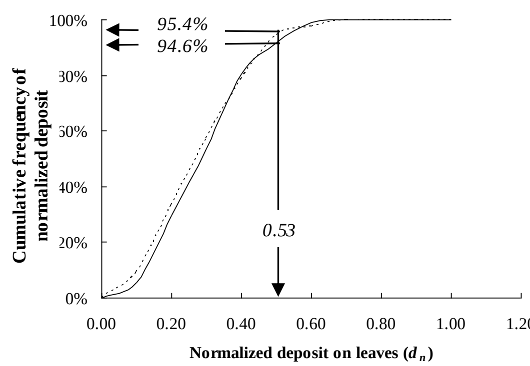
Var. *Cabernet Sauvignon*; Crop stage: *75*; LAI: *1.08*



Var. *Cabernet Sauvignon*; Crop stage: *85*; LAI: *0.99*



Var. *Tempranillo*; Crop stage: *75*; LAI: *1.24*



Var. *Tempranillo*; Crop stage: *85*; LAI: *1.5*

Figure 3. Cumulative frequency of normalized deposit on total leaf samples and cumulative number of samples below 80% of theoretical normalized deposit. Results for conventional application (—) and proportional according sensors measurements (------)

4.2 Efficiency

Efficiency of applications has been estimated by relating the individual leaf deposit obtained on each sample, d_n (according equation [2]) with the theoretical expected deposit for each individual test, d_{tn} (obtained with equations [3] and [4]):

$$d_n\,(i,j) = \frac{d\,(i,j) \times 10^5}{V \times T_{cs}} \qquad [2]$$

Where $d(i,j)$ is tracer deposit per unit leaf area for leaf i in location j, μg·cm^{-2}; V spraying application volume rate, l·ha^{-1}; and T_{cs} tracer concentration of spray mixture in tank, mg·l^{-1}

$$d_t\,(i,j) = \frac{V \times T_{cs}}{LAI \times 10^5} \qquad [3]$$

$$d_{tn}\,(i,j) = \frac{d_t\,(i,j) \times 10^5}{V \times T_{cs}} \qquad [4]$$

In order to simulate the real circumstances during the spray application process, 80% of this value (0.8 x d_{tn}) has been adopted as an objective threshold and for any individual test. According to that, a detailed analysis of the distribution of sample frequencies was conducted in order to quantify the relative amount of leaf samples that achieved that threshold value. Figure 3 shows the cumulative frequency of leaf samples for all individual varieties and crop stages. It is interesting to remark that in all cases variable rate applications gave higher cumulative frequencies of leaf samples with deposition over the threshold value. Remarkable results have been obtained at the earlier crop stage (BBCH-75) in cv. Cabernet Sauvignon and cv. Tempranillo, with the greatest amount of leaf samples (41.9%) achieving the intended threshold.

5. CONCLUSIONS

Even in uniform vineyards, important differences can be observed in crop width and thus in canopy volume along the line. The use of electronic systems capable to determine these differences in real time and the ability to adjust the working parameters according to these variations is an interesting way to achieve savings in the total amount of sprayed pesticides.
The use of ultrasonic sensors together with variable rate electro-valves and the corresponding software for automation, made possible a real time modification of the sprayed flow rate according to the canopy volume. This allowed a significant reduction in sprayed volume while maintaining coverage and penetration rates similar or even better to conventional methods.
Ultrasonic sensors and its measurements of crop canopy allow achieving tracer deposits according to leaf distribution in the crop profile. This fact is extremely important in order to obtain leaf deposits values close to the intended threshold.
The electronic prototype must be improved in order to avoid the negative effect of tractor deviation from the center of the row and to increase the regulating range.

Results obtained in all crop conditions and varieties encourage to continue this research, maintaining as the main goal increasing pesticide savings and improving liquid distribution according to the crop characteristics.

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