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# New technologies adapted to alternative dose expression concepts

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## Summary

Pesticide application in fruit crops in general, and in vineyard in particular, needs an important revision about the method to determine the application volume rate. Canopy characteristics and spatial distribution of plants on the soil must be aspects to be considered. Recent changes have been proposed to define the dose expression in trees and vineyard crops. Concepts as Tree Row Volume (TRV), Leaf Wall Area (LWA), and leaf surface or canopy height are alternative parameters for a more suitable calculation of spray volume, substituting the traditional method based on land surface. This paper present the results obtained using new technologies as ultrasonic sensors, lidar sensor or the new developed software for volume calculation "Dosaviña" based on the Optimal Coverage Method (OCM), in terms of volume savings and uniformity of distribution among the canopy.

Different field tests were arranged between 2006 and 2010 in a wide range of scenarios in vineyard areas placed in USA (New York) and Spain (Lleida). Variables as crop stage, trellis system, vine variety, type of sprayer and volume rate were tested. In all cases conventional application procedure was compared with the proposed alternative methods based on a modified TRV concept (ultrasonic sensors), or the optimal coverage method (Dosaviña). General results indicate that saving on volume rate (and its equivalent pesticide saving) ranged from 32% in Cabernet Sauvignon using Dosaviña software to 63% in early stages of Merlot using ultrasonic sensors. After those results and by a general analysis of the whole parameters, a general conclusion can be established: whatever the alternative method used in the calculation of volume rate based on canopy characteristics will lead in a improvement of benefits of the crop protection process.

**Key words**: Dose expression, volume rate, TRV, optimal coverage, Dosaviña, vineyard, spray volume

## Introduction

Dose expression and spray volume rate are key questions for spray application in orchard and vineyard plantations. Attempts to improve the dose expression procedures have included recommendations based upon either two (leaf wall area) or three (tree row volume) dimensional factors related to the canopy structure (Walklate *et al*., 2011). However those efforts have led to a "chaotic" situation in which a comparison of label instructions for plant protection products (PPP) authorized in different European countries reveals remarkable differences in dose expression (Koch, 2007). This situation has resulted in a recent proposal by the European agrochemical manufacturing industry to harmonise, across Europe, the efficacy evaluation stage of pesticide registration (Wohlhauser, 2009).

Other than the problem of the "dose expression unit", which expresses the product quantity in relation to the treated area, the achievement of an adequate and optimal volume rate for an intended canopy must be established and determined separately (Koch, 2007). Dose adjustment, which reflects the adaptation of the product quantity to varying canopies, is directly linked to the criteria used to establish the total amount of liquid that is distributed into the canopy. This aspect has been widely discussed previously (Furness, 2003; Walklate *et al*., 2003). In all cases the main goal has been to adapt the total amount of Plant Protection Products (PPP) to the crop characteristics, but difficulties have been encountered in selecting the most suitable crop parameter. The high degree of variability in the crop canopy has increased the difficulty in obtaining general solutions which would be well adapted to all crops and situations.

To solve the difficulties encountered in crop characterization and to accomplish the recent EU aim to reduce the total amount of PPP (European Parliament, 2009), environmentally-safe spraying techniques have been developed to spray only when and where needed with reduced losses to the environment (Doruchowski *et al*., 2009). Crop characteristics are directly related to the total amounts of spray deposit on leaves and values of leaf area and canopy dimensions (mainly height and width) can widely affect the efficiency values, as a relationship between the expected deposit and the actual one. 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 (µg $cm^{-2}$), independently of crop size or canopy density. That system would avoid the problem of over dosage of PPP detected as a frequent problem in the early crop growth stages, especially in orchards and vineyards where in most cases pesticide dose rate is expressed in terms of land surface independently of canopy characteristics.

In addition, other than the use of new technologies to characterise the canopy, different decision support systems (DSS) have been developed to improve the use of PPP (Kuflik *et al*., 2009), the establishment of an adapted volume rate according to the crop structure (Walklate & Cross, 2010), or even for on-line applications to determine the total amount of PPP for any particular crop geometry (Furness, 2003; Siegfried *et al*., 2007; Cross & Walklate, 2008). Those systems, among others, are quite common in agriculture; they have been developed to help growers plan agronomical practices or apply PPP to their crops.

The objectives of this research were: a) to analyse the ability of two different methods to calculate the optimal applied spray volume (Wine Row Volume and Optimal Coverage Method); b) to determine the adaptation of new technologies to implement those alternative methods; and c) to quantify the benefits in comparison with the traditional method to calculate the application rate based on land surface.

## Methodology

Two different methods (Fig. 1) to calculate the spray volume rate to be applied were tested. The first one is the Wine Row Volume and consists on an adaptation of the Tree Row Volume concept (Byers *et al*., 1971) for vineyard applications with a variable application rate procedure. A set of ultrasonic sensors placed on a conventional orchard sprayer for vineyard applications was used to measure "on the go" the canopy characteristics in order to adapt the nozzle flow rate according the crop volume variations. The second one has been defined as the Optimal Coverage Method (Gil & Escolà, 2009) and calculates the spray volume rate according to the value of leaf area. A wide data base including leaf area variation according growth stage, weather conditions, and operational parameters during the spray process and efficiency of different sprayers is used in the software to calculate the optimal volume rate according any particular circumstances.

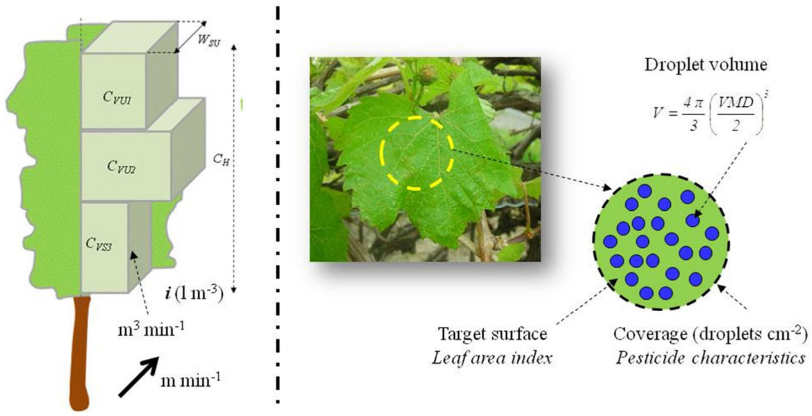


Fig. 1. Principle of action of the two proposed methods. Wine Row Volume (left) and Optimal Coverage Method (right).

*The Wine Row Volume concept (WRV)*

The Wine Row Volume concept (Gil *et al*., 2007; Llorens *et al*., 2010) was developed from the TRV concept. This method consists on the determination of the applied volume (L $ha^{-1}$) according to the canopy characteristics ($m^3$ $ha^{-1}$) and the intended application rate (L $m^{-3}$). In this research the canopy volume to be sprayed by unit time ($m^3$ $min^{-1}$) was automatically estimated after the canopy measurements obtained with three ultra sonic sensors placed on a mounted air blast orchard sprayer Hardi LE-600 BK/2 (Llorens *et al*., 2010). Variability of canopy width along the row was recorded and further used in the automatically process of calculation of the variable flow rate to be delivered by every individual nozzle manifold in order to apply a constant amount of liquid "i" per canopy unit (L $m^{-3}$). In this case the intended value was fixed at 0.095 L $m^{-3}$ in accordance with results obtained in previous research (Byers *et al*., 1971; Gil, 2001). Fig. 2 shows the principle of functioning and the whole mathematical process can be explained according equation [1]:

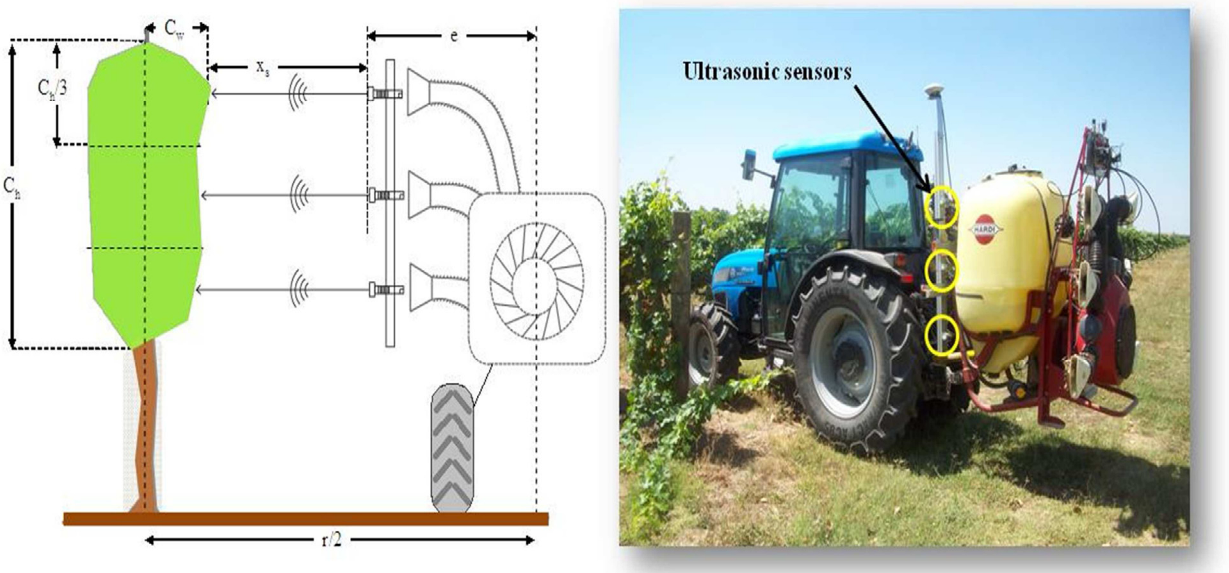


Fig. 2. Automatic procedures for determination of canopy characteristics applied in the Wine Row Volume method (left). Conventional sprayer equipped with ultrasonic sensors used for this purpose (right).

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

Where $q_u$ is the variable nozzle flow rate (L min$^{-1}$), $C_w$ the half crop width (m), $C_h$ crop height (m), $v$ is forward speed (km h$^{-1}$), $i$ the application coefficient per unit vegetation volume (L m$^{-3}$) and n the number of nozzles per manifold (equal to 2).

*The Optimal Coverage Method (OCM)*

This second method was proposed to determine the spray volume rate in vineyard plantations (Gil, 2003) and is based in the estimation of the value of leaf area. The concept includes in its calculation (Gil & Escolà, 2009) aspects related with canopy characteristics, working parameters during the application process, pesticide typology and weather conditions. The main concept of this method is the procedure applied to convert the optimal coverage value (droplet impacts cm$^{-2}$) into volume per surface unit (L ha$^{-1}$). For this purpose, the averaged value of theoretical VMD of applied droplets shall be included in the calculation according Equation [2]:

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

where $V_T$ is the intended application rate (L ha$^{-1}$), LAI is the estimated value of leaf area index (m$^2$ m$^{-2}$), $D_i$ the calculated coverage value (impacts cm$^{-2}$), *VMD* is the volume median diameter of the generated droplets, and *K* the a-dimensional factor to correct the big effect of cubic exponent of VMD.

During the period 2006−2010 both methods were tested in different field tests where aspects as growth stage, canopy characteristics, variety and type of sprayer were introduced. In order to have a wide range of scenarios, the field experiences were conducted in different vineyard in the Finger Lake region of New York (USA) and Castell del Remei in Lleida (Spain). Table 1 indicates the total field tests carried out with those two methods and the main variables included. Spray application quality was evaluated by the determination of normalised spray deposit (dn), the amount of liquid deposited by leaf area unit (µg cm$^{-2}$). For this purpose different metal chelates were used as a tracer at different concentrations (Gil *et al*., 2007; Llorens *et al*., 2011).

## Results

The obtained results were analysed in terms of its potential saving on pesticide and/or applied volume, deposition on leaves and distribution quality among the whole canopy.

*Potential saving on pesticides*

Savings in general can be evaluated from two perspectives: a) in terms of the total active ingredient applied in an established period; or b) in terms of the reduction of the applied volume per surface unit, which is directly related to time, fuel consumption, and the applied dose. The average amount of savings in terms of applied spray volume using Dosaviña was 43.0% (Table 2). The recommended volume rate (L ha$^{-1}$) using the proposed software was always lower than that applied in the traditional conditions. For the variable rate application method using ultrasonic sensors (WRV method), saving values were greater than 40% with the highest value for cv. Tempranillo (77%) in the last growth stage (BBCH-scale 85; Meier, 2001). In this particular situation some pruning 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 ha$^{-1}$) compared to previous applications, whereas the conventional application volume rate was increased according to the normal procedure in the area. In general, the average savings obtained were approximately 58%, being in accordance with previous research (Koch & Weisser, 2000).

Table 1. *Working parameters during field tests*

| Variety | Year | BBCH[1] | LAI | Conv. application Fwd speed (km h$^{-1}$) | Conv. application Pressure (bar) | Adapted application Fwd speed (km h$^{-1}$) | Adapted application Pressure (bar) |
|---|---|---|---|---|---|---|---|
| *Wine Row Volume method (Prototype for Variable application rate)* | | | | | | | |
| Merlot[2] | 2008 | Me-85 | 1.32 | 4.5 | 7.0 | 4.5 | Min 3.0 Max 7.0 |
| Cabernet Sauvignon[2] | 2008 | Cs-75 | 1.08 | 4.5 | 7.0 | 4.5 | |
| | | Cs-85 | 0.99 | 4.5 | 11.0 | 4.5 | |
| Tempranillo[2] | 2008 | Te-75 | 1.24 | 4.5 | 7.0 | 4.5 | |
| | | Te-85 | 1.50 | 4.5 | 11.0 | 4.5 | |
| *Optimal Coverage method (DOSAVIÑA)* | | | | | | | |
| Merlot[2] | 2009 | Me-75 | 1.21 | 4.8 | 1.2 | 5.6 | 0.8 |
| | 2010 | Me-85 | 1.45 | 4.8 | 2.3 | 5.6 | 4.2 |
| Cabernet Sauvignon[2] | 2009 | Cs-75 | 0.61 | 4.8 | 1.2 | 5.6 | 0.8 |
| | 2010 | Cs-85 | 0.89 | 4.8 | 2.3 | 5.6 | 4.2 |
| Baco[3] | 2006 | Ba-65 | 0.65 | 5.6 | 17.0 | 5.6 | 5.0 |
| | | Ba-75 | 1.35 | 5.6 | 17.0 | 5.6 | 14 |
| | | Ba-85 | 1.90 | 5.6 | 34.0 | 5.6 | 28 |
| Riesling[3] | 2006 | Ri-65 | 0.33 | 5.5 | 12.0 | 5.5 | 9.5 |
| | | Ri-75 | 1.23 | 5.5 | 10.0 | 5.5 | 4.0 |
| | | Ri-85 | 1.07 | 5.5 | 14.0 | 5.5 | 5.5 |
| Vignoles[3] | 2006 | Vi-65 | 0.10 | 7.7 | 12.0 | 7.7 | 17 |
| | | Vi-75 | 0.52 | 7.7 | 12.0 | 7.7 | 5.0 |
| | | Vi-85 | 0.50 | 7.7 | 15.0 | 7.7 | 15 |

[1]Vine variety and growth stage classification according (Meier, 2001); [2]Tests in Spain; [3]Tests in USA.

*Spray deposition on leaf surface*

The spray application process can be evaluated through the analysis of the amount of pesticide (tracer) deposited on the leaves according the intended application rate, and also by the uniformity of distribution among the canopy. The proportion of spray retained (% Dl) was determined following the criteria established previously (Pergher & Gubiani, 1995; Cross *et al*., 2001; Llorens *et al*., 2010), and those values were related with the uniformity of distribution among the canopy measured by calculation of coefficient of variation of all the deposition values in the different sections of the tree per individual leaf or number of drops per leaf. Table 2 shows the obtained values of proportional recovery. Both methods presented similar averages close to 40%, without differences with conventional application. Fig. 3 shows the general tendency in a slow but homogeneous movement to the right of the graph, which means an increase in normalised on leaf spray recovery with better uniformity, obtained in all cases with the lower volume rates. The diameter of each individual circle represents the average normalised deposit ($d_n$) on the leaves.

An interesting relationship between savings on applied volume and canopy characteristics was observed when values of leaf area index and tree row volume were compared with saving values obtained using Dosaviña (LAI) and the proportional application prototype (TRV). Good relations were obtained (Fig. 4) in both methods. In the case of Dosaviña, the lower the value of LAI the higher is the saving, in accordance with the principle of functioning of the software. Fig. 4 (right) shows also the influence of TRV value on spray saving using the WRV concept. In this case the lower the TRV is the higher the benefits, demonstrating clearly the interest of any of the proposed methods especially in case of low canopy densities.

Table 2. *Results in saving application rate and proportional leaf recovery for the two analysed methods*

| Variety | BBCH[1] | Application rate (L ha$^{-1}$) Conv. | Adapted | % Saving of adapted | Proportional leaf recovery (% Dl) Conv. [A] | Adapted [B] | B/A (+) | B/A (-) |
|---|---|---|---|---|---|---|---|---|
| *Wine Row Volume method (Prototype for Variable application rate)* | | | | | | | | |
| Merlot | Me-85 | 266 | 141 | 47.0 | 76.6 | 52.5 | | 0.69 |
| Cabernet Sauvignon | Cs-75 | 299 | 179 | 40.1 | 48.3 | 56.1 | 1.16 | |
| | Cs-85 | 373 | 111 | 70.2 | 65.1 | 56.4 | | 0.87 |
| Tempranillo | Te-75 | 299 | 127 | 57.5 | 38.4 | 54.9 | 1.43 | |
| | Te-85 | 373 | 86 | 76.9 | 21.9 | 15.1 | | 0.69 |
| Average | 322 | 129 | 58.4 | 50.1 | 47.0 | | | |
| *Optimal Coverage method (DOSAVIÑA)* | | | | | | | | |
| Merlot | Me-75 | 162 | 79 | 51.2 | 22.1 | 8.5 | | 0.38 |
| | Me-85 | 235 | 136 | 42.1 | 22.0 | 19.5 | | 0.88 |
| Cabernet Sauvignon | Cs-75 | 145 | 71 | 51.0 | 31.4 | 38.3 | 1.22 | |
| | Cs-85 | 210 | 122 | 41.9 | 24.5 | 28.8 | 1.17 | |
| Baco | Ba-65 | 468 | 150 | 67.9 | 24.5 | 31.8 | 1.29 | |
| | Ba-75 | 468 | 460 | 1.7 | 15.9 | 19.4 | 1.21 | |
| | Ba-85 | 936 | 700 | 25.2 | 10.3 | 16.1 | 1.55 | |
| Riesling | Ri-65 | 233 | 135 | 42.1 | 18.1 | 9.2 | | 0.51 |
| | Ri-75 | 400 | 200 | 50.0 | 60.8 | 47.1 | | 0.77 |
| | Ri-85 | 500 | 310 | 38.0 | 35.5 | 60.9 | 1.72 | |
| Vignoles | Vi-65 | 350 | 130 | 62.9 | 37.5 | 51.5 | 1.37 | |
| | Vi-75 | 350 | 130 | 62.9 | 37.4 | 86.0 | 2.30 | |
| | Vi-85 | 355 | 270 | 23.9 | 43.3 | 42.2 | | 0.97 |
| Average | 370 | 223 | 43.1 | 29.5 | 35.3 | | | |

## Discussion

The success in pesticide application in vineyards depends directly on the selected method to determine to most suitable application rate, and for this purpose some measurements (direct or indirect) of the canopy characteristics are needed. Results obtained in this research indicate that the use of those proposed alternative methods (Wine Row Volume and Optimal Coverage Method) seems interesting procedures for that purpose.

The two proposed methods to determine the application rate have lead into important savings in terms of applied volume and, as a consequence, in the total amount of plant protection products, maintaining or even increasing the quality of the spray process. Those results are right linked with the established guidelines on the recently published European Directive for a Sustainable use of Pesticides (EC/2009/128).

However, those values could also be linked to those proposed by Ebert & Downer (2006) who stated that for agricultural applications, dose has little to do with efficacy because there is already sufficient pesticide to kill all the pests in the field many times over. And this conclusion demonstrated, once again, the high importance that all the calibration procedure represents, with great benefits when it is developed prior the application task.

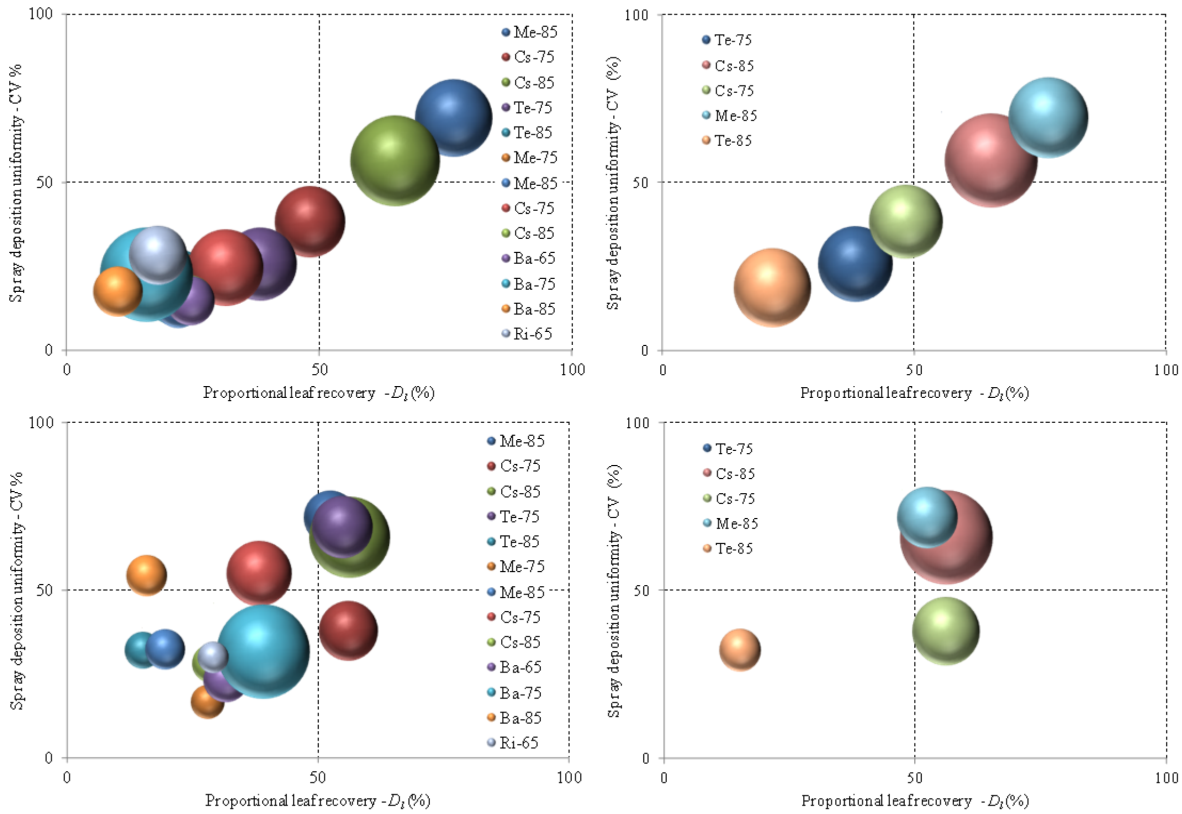


Fig. 3. Relation between proportional recovery and uniformity of spray deposition in the whole canopy. Upper graphics correspond to conventional application in the Dosaviña comparison (left) and WRV comparison (right). The lower graphics represent the results obtained with Dosaviña (left) and WRV method (right).

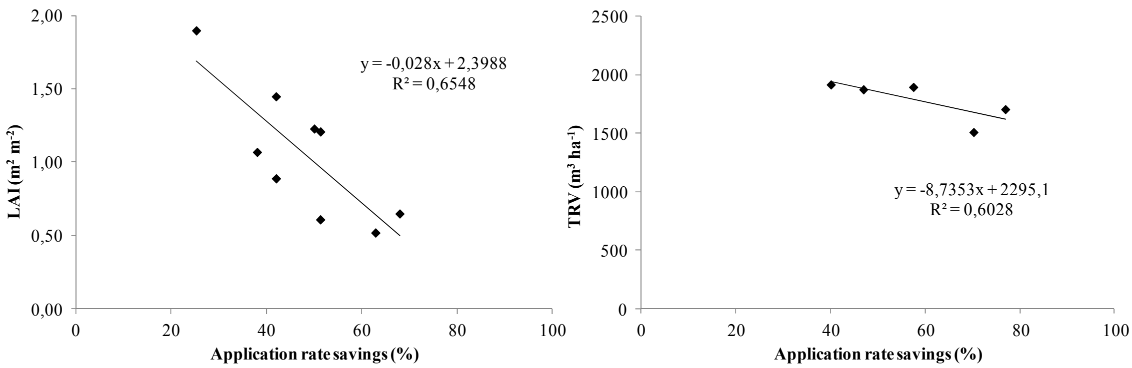


Fig. 4. Influence of canopy characteristics on application rate saving. On the left results using Dosaviña. On the right the influence of WRV method using electronic sensors on saving.

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