# Monitoring site-specific spraying in vineyards from a prescription map obtained with a UAV

J. Campos[1], M. Gallart[1], J. Llop[1] and E. Gil[1]
[1]*Universitat Politècnica de Catalunya, Department of Agro Food Engineering and Biotechnology, Esteve Terradas, 8, 08860 Castelldefels, Spain*
javier.campos@upc.edu

## Abstract

This work presents the development of an actual site-specific spraying map of a variable rate sprayer prototype, which works following a prescription map obtained with a UAV. Trials were conducted in Torrelavit (NE Spain) in a representative vineyard of 3 ha of variety Merlot. Prescription map was obtained by merging the canopy data obtained with a multispectral camera mounted on an UAV, and the information provided by the app DOSAVIÑA®. This prescription map was then uploaded into a variable sprayer prototype, obtaining an actual application map, after the spray process.
The actual application map allowed traceability data in all treated areas and calculated pesticide savings versus conventional spray application. Results showed a saving of around 20% of application when compared with conventional spray application.

**Keywords:** variable rate application, UAV, vigour map, actual map.

## Introduction

Considering the specific case of 'specialty crops', the most important factors to ensure an efficient spray application process are canopy characteristics such us canopy dimensions and trellis system (Rosell and Sanz, 2012; Salcedo et al, 2015).
Several studies have been carried out with the aim of adapting the volume application rate to canopy dimensions (Balsari et al. 2008; Gil et al., 2014; Miranda-Fuentes et al., 2016). All of them determined that canopy measurements were the key factor for a successful spray application.
The high degree of variability in the vine canopy characteristics within the field, increases the difficulty to obtain a general solution. When a uniform canopy structure is assumed for the whole vineyard, differences in the total amount of pesticide arriving at the canopy can occur, which reduces the effectiveness of spray application.
Recent advances in hardware and software, global navigation satellite systems, vegetation sensors and remote sensing offer opportunities to obtain canopy measurements to be used for variable application technologies (Zaman and Salyani, 2004). In the case, of variable application technology based on prescription maps, this canopy characterization has to be performed before the application.
Vogel et al. (2005) evaluated a modified conventional boom sprayer for variable application of herbicide based on prescription maps. The system was capable of combating weeds of corn and soybean crops. Michaud et al. (2008) developed a variable application prototype based on maps, obtained from aerial spectral images, to combat weeds in a cranberry crop. Variable rate application technology based on prescription maps is widely used in field crops but is not used in 3D crops. For this reason, the aim

of this research was to develop a variable rate application (VRA) system for vineyard sprayers based on canopy vigour maps obtained with remote sensors.

## Materials and methods

Experimental site

The trials were carried out on a representative vineyard of c.a. 3 ha in Torrelavit, Barcelona, Spain (X:392234, Y:4587843, ETRS89 UTM31). Vineyards of variety Merlot were trained in trellis system *Double Royat* at 1.2 m distance on the row, and 2.2 m between rows. Trials were conducted at growth stage 75-77 at BBCH scale (Meier, 1997) and 31-32 at E-L system (Coombe, 1995).

Data acquisition for canopy characterization

The vineyard was overflown with an unmanned aerial vehicle (UAV) loaded with a multispectral camera (RedEDGE, Micasense, Seattle, USA) equipped with five bands (R, G, B, RedEdge and NIR). Flight was conducted at 95 m above ground level (AGL). Overlapping zones were adjusted at 80% in the sense of flight and 60% in the transverse sense.

Adapted sprayer for variable rate application

The prototype was mounted on a trailed cross flow air sprayer (Saher, Barcelona, Spain) with a 1000 l tank and an axial fan with a diameter of 800 mm. In order to follow a prescription map, the sprayer was equipped with a) One pressure sensor GEMS 1200 series (Gems Sensors & Controls, Plainville, USA) to allow the adjustment of required pressure according to the prescription map, b) Electronic controller (Estel S.L., Barcelona, Spain), including GNSS receiver with a frequency of 1 Hz , a touchscreen and an automatic section controller. The function of the system was to determine the position of the sprayer in the field detected by the GNSS receiver, to calculate the desired volume rate, based on the previously uploaded prescription map, and to modify the working pressure in order to obtain the adjusted nozzle flow rate.

Decision Support System to determine optimal volume rate

A decision support system (DSS) was used to determine the optimal volume rate based on the canopy characteristics. The DSS used was DOSAVIÑA® (UMA-UPC, 2018). DOSAVIÑA® (Gil et al., 2011) allows determination of the most accurate volume rate based on a modified version of the leaf wall area method (LWA) (Walklate and Cross, 2012).

Methodology of the process

The whole process for variable rate application based on vigour maps is shown in Figure 1. A orthophotomap was obtained from spectral images acquired with the UAV. The orthophotomap was radiometrically calibrated using four grayscale standards (22, 32, 44, and 51% grayscale reflectance) placed in the field during the flight, to transform grayscale 12-bit digital numbers to reflectance values. This new data was used to calculate the normalized differential vegetation index (NDVI) (Rouse et al. 1973) (Eq.1).

$$\text{NDVI}=\frac{NIR-RED}{NIR+RED} \tag{1}$$

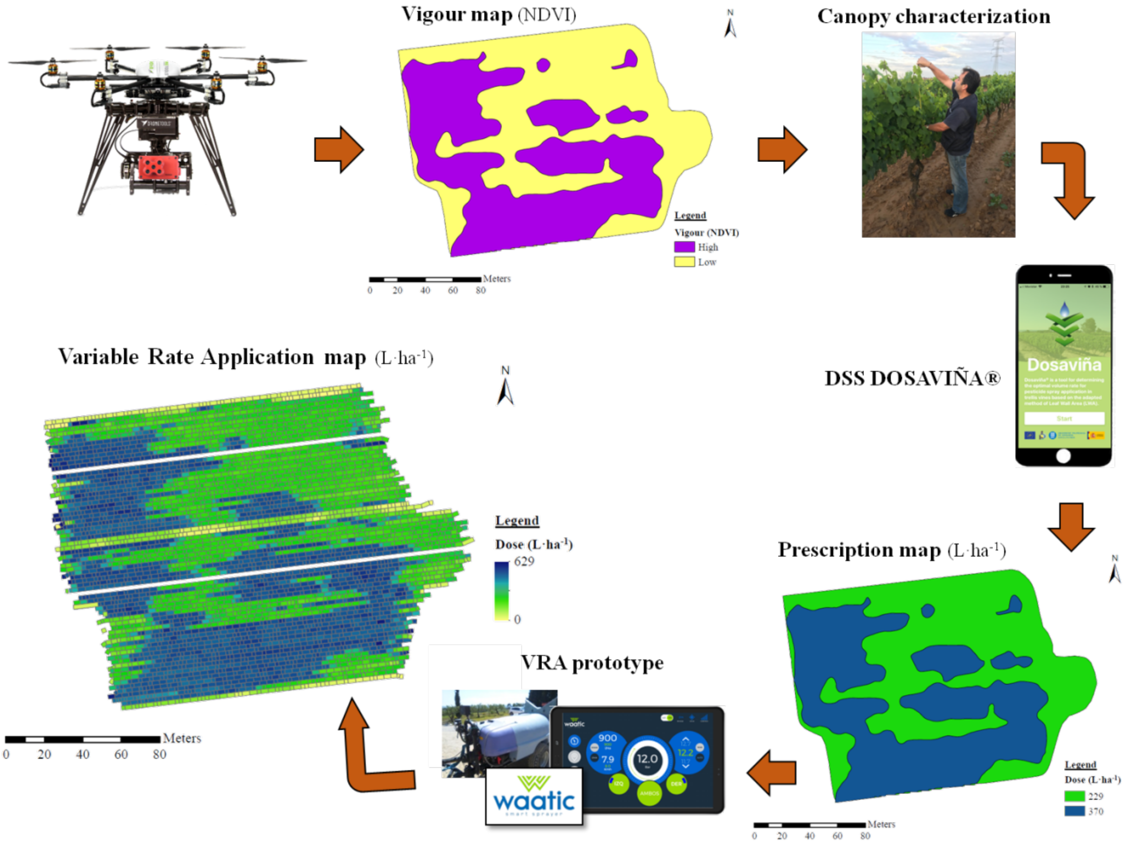


Figure 1: Scheme of the whole process: From UAV vigour map to actual variable rate application map.

Due to the vineyard growth in rows, the image was segmented by an NDVI threshold in order to eliminate weeds, shadows and soil between rows.

Once the NDVI threshold was applied, an inverse distance weighting interpolation (IDW) was performed to generate a continuous NDVI map. Final processing consisted of a value clustering in 2 NDVI levels, which were later smoothed by performing a neighbor median filtering to produce the final vigor map. The process was executed using the QGIS software (QGIS Development Team, 2016).

Once the vigour map was created with the two different zones, both were located in the field, corresponding to low, and high canopy vigour. In order to obtain the recommended volume rate using DOSAVIÑA® (Gil et al., 2011), 15 manual measurements of canopy height and width were randomly taken in both zones to have a complete canopy characterization (Table 1).

Table 1. Canopy characterization and volume rates following *Dosaviña*®

| Vigour | Canopy height (m) | Canopy width (m) | LWA* ($m^2_{canopy}$ $ha^{-1}$) | Volume (l $ha^{-1}$) |
|---|---|---|---|---|
| Low | 0.79 | 0.43 | 7182 | 230 |
| High | 1.06 | 0.53 | 9636 | 370 |

* LWA calculated for a row distance of 2.2 m

Then, the values obtained were introduced into the georeferenced canopy vigour map using QGIS software (QGIS Development Team, 2016) to obtain the georeferenced prescription map.
The prescription map was transferred via USB to the touch screen previously described and installed into the sprayer. Furthermore, it was uploaded into the system information concerning working parameters for each vigour zone (Table 2). The number and nozzle type were maintained constant in all cases, using hollow cone nozzles Albuz ATR (Albuz Saint-Govain, Evreux, France).

Table 2. Specific working conditions for each vigour zone

| Vigour | Volume ($l\ ha^{-1}$) | Nozzle type | Nº nozzles | Pressure (kPa) | Fwd. speed ($km\ h^{-1}$) |
|---|---|---|---|---|---|
| Low | 230 | ATR Brown + ATR Yellow | 2 + 6 | 5.8 | 6.8 |
| High | 370 | ATR Brown + ATR Yellow | 2 + 6 | 15.6 | 6.8 |

Once the parameters were loaded on the touch screen, the spraying started. From the start, the system recorded information every second concerning the sprayer position in the field, the applied volume rate and the adjusted working pressure. At the end, the system generated an actual application map which was downloaded from the touch screen via USB.

Comparison of prescription vs actual application map

In order to evaluate the precision of the system, the prescription and actual maps were compared using QGIS software (QGIS Development Team, 2016). For the comparison process, a random net of *c.a.* 56,000 points was developed. For every value of expected value "*r*", 11 intervals of tolerance were assigned (each representing an increase of 5% compared with the previous one). The defined intervals ranged from zero to 50% deviation. Each point was compared and quantified for its coincidence between obtained value (actual) "*p*" and expected value "*r*". In addition, a determination was made as to whether the *p* value was inside the calculated range [*r*-i, *r*+i]. Once all the points were compared, the percentage of coincidence was also calculated. Finally, in order to visualize the level of accuracy of the actual spray application map, a specific interpolation process based on the inverse distance weighted (IDW) method was applied.

## Results and discussion

Developed maps

This subsection presents and discusses the maps generated during the process. The sequence of the maps obtained was as follows: (1) NDVI map, (2) canopy vigour map, (3) prescription map, and (4) actual application map (Fig. 2).

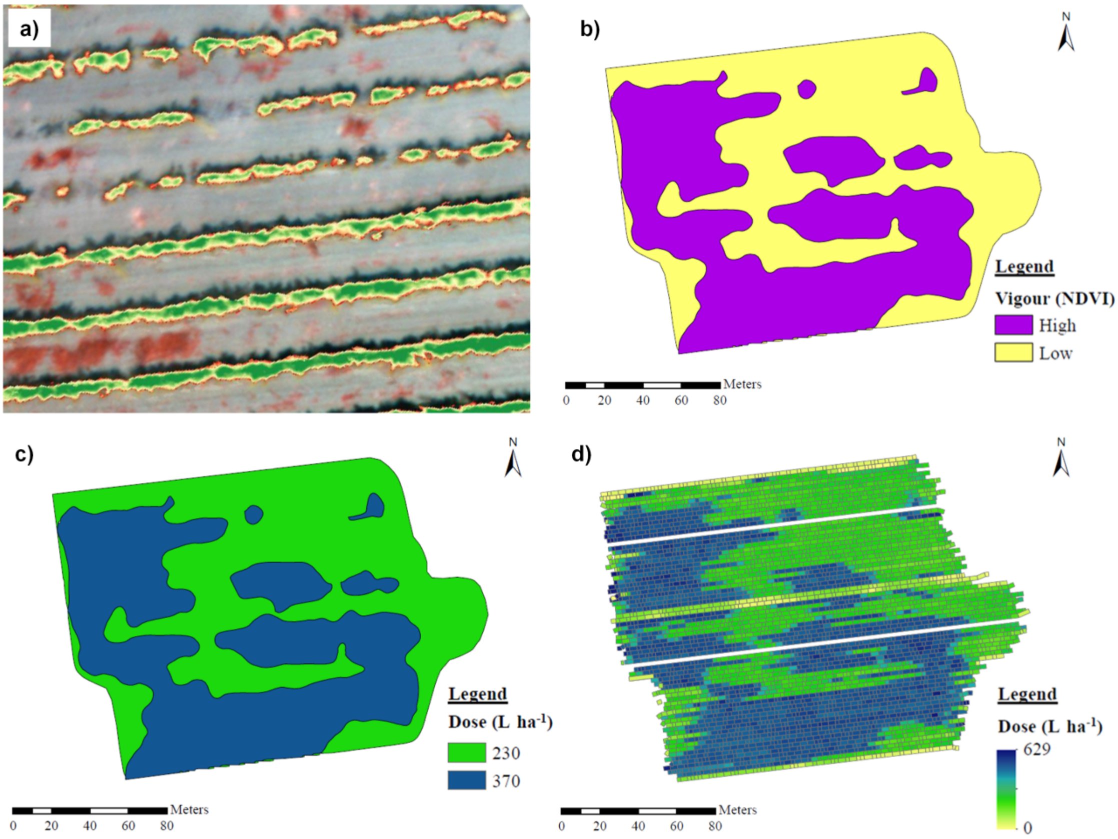


Figure 2: a) Raw NDVI map; b) Canopy vigour map; c) Prescription map; d) Actual variable application map.

<u>NDVI map</u>

The spectral images obtained from the multispectral camera mounted on the UAV was used to generate the NDVI map (Fig. 2a). This map shows the condition of the vegetation.

<u>Canopy vigour map</u>

Once the NDVI map was developed, it was treated in order to obtain two different zones in the vineyard. The zones were plotted on the map (Fig. 2b). According to the values obtained, the total area of the field (2.8 ha) was distributed as follows: 50.9% (1.42 ha) for low canopy vigour and 49.1% (1.37 ha) for high canopy vigour.

<u>Prescription map</u>

Taking the canopy vigour map as the starting point, 15 complete manual characterizations of the canopy were made in each zone. Table 1 shows the results obtained per zone. These measures were used to determine the optimal volume rate using the DSS DOSAVIÑA® (UMA-UPC, 2018). In this case, the corresponding values were 230 l $ha^{-1}$ for low canopy vigour, and 370 l $ha^{-1}$ for high canopy vigour. From that, the intended prescription map was generated (Fig. 2c).

<u>Actual variable application map</u>

Once the prescription map was loaded into the touch screen installed on the sprayer, the spray application process started. During the process, the system recorded information concerning the sprayer position in the field, the applied volume rate, and the adjusted working pressure, at a frequency of 1 Hz. Following further processing of the saved data, the actual application map was generated (Fig. 2d). A detailed analysis of this map facilitates explanation of certain characteristics. The white lines observed in the actual application map (Fig. 2d) correspond to two row lines that were not sprayed due to driver failures.

Quantification of the accuracy of the system

In order to quantify the correspondence between prescription and actual map, a range of eleven different thresholds was established, from 0% to 50% tolerance. The most restrictive threshold (0%) measured the percentage of points (56,000) where there was no difference between the intended and actual application rate. In this case, only 3.5% of points were classified as successful points. At the opposite extreme, the highest tolerance (50%) quantified the percentage of points where variations of ±50% of applied volume was detected. In this case, 92.1% of points were classified as successful points. Assuming that from a practical point of view a tolerance of ±10% could be allowed, the system was able to classify 75% of the points as successful points. Figure 3 shows the accuracy distributed around the field, classified according to the established threshold level. The dark zones on the maps indicate the areas where the accuracy of the system exceeded the established thresholds. The main percentage of dark zones corresponds to transition zones, where the sprayer was ordered to modify the working pressure. As the results show, in terms of the comparison between the current and the prescription map, the variable rate application method obtained good accuracy.

Quantification of savings

The variable application process based on maps was compared with a conventional spay application process based on a constant volume of 350 l $ha^{-1}$ ha, the normal volume used by farmers in the area. For those two cases, the amount of water, the total application time assuming 45 minutes for the filling of the machine and the hypothetical amount of active material, assuming a copper concentration of 0.4% (400 g $hl^{-1}$) were calculated (Table 3). The results show a positive effect of the use of the variable rate application. Despite not obtaining a saving in the time used, the amount of liquid consumed and the amount of active ingredient were reduced by 17.9% using the variable rate application.

Table 3. Quantification of potential savings of the site-specific sprayer for conventional application and variable rate application (VRA)

| | Volume (l $ha^{-1}$) | Total volume (l) | Volume savings (%) | Nº of filling tanks | Time (h) | Time savings (%) | a.i. (kg) | a.i. savings (%) |
|---|---|---|---|---|---|---|---|---|
| Conv. | 350 | 950 | 0.0 | 1 | 2.8 | 0.0 | 3.8 | 0.0 |
| VRA | 230/370 | 780 | 17.9 | 1 | 2.8 | 0.0 | 3.12 | 17.9 |

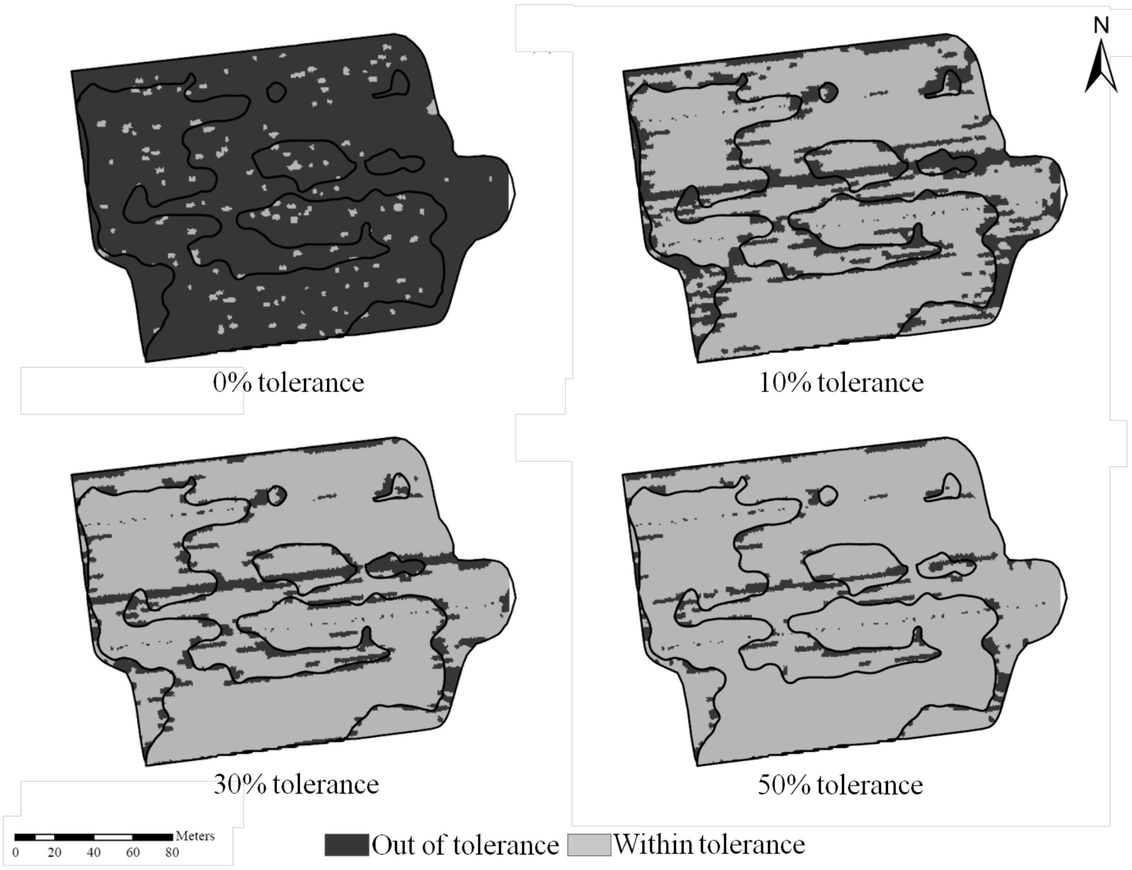


Fig. 3: Spatial distribution of accuracy (intended vs. actual application).

## Conclusions

In this research, a prototype of a variable rate application sprayer based on prescription maps was tested. According to the results, the major findings were:

- The system is able to read a prescription map and modify the working parameters (working pressure) depending on the position of the sprayer in the field. However, it is necessary to mention that the modification of working pressure could affect physical properties of delivered spray and therefore drift risk and spray coverage.
- Good accuracy was obtained with the system (demonstrated by comparing the intended and actual application maps), with assumed tolerances of around 10% deviation.
- The combination of vigour maps with Dosaviña® (DSS) to determine the optimal volume rate can reduce by around 20% the amount of water wasted in a spray application process and the amount of pesticide, as long as the concentration of the product is maintained.

## References


Balsari, P., Doruchowski, G., Marucco, P., Tamagnone, M., Van de Zande, J., and Wenneker, M. 2008. A system for adjusting the spray application to the target characteristics. Agricultural Engineering International: CIGR Journal 10 1-11

Coombe, B.G. 1995. Growth stages of the grapevine: Adoption of a system for identifying grapevine growth stages. Australian Journal of Grape and Wine Research 1, 104–110

Gil, E., Gallart, M., Llorens, J., Llop, J., Bayer, T. and Carvalho, C. 2014. Spray adjustments based on LWA concept in vineyard. Relationship between canopy and coverage for different application settings. International Advances in Pesticide Applications. Aspects of Applied Biology 122 25-32

Gil, E., Llorens, J., Landers, A., Llop, J. and Giralt, L. 2011. Field validation of DOSAVIÑA, a decision support system to determine the optimal volume rate for pesticide application in vineyards. European Journal of Agronomy, 35 (1), 33-46; doi:10.1016/j.eja.2011.03.005

Meier, U. 1997. BBCH-Monograph. Growth stages of plants - Entwicklungsstadien von Pflanzen - Estadios de las plantas - Développement des Plantes. Berlin and Wien, Germany and Austria: Blackwell Wissenschaftsverlag. 622 p

Michaud, M., Watts, K.C., Percival, D.C., and Wilkie, K.I. 2008. Precision pesticide delivery based on aerial spectral imaging. Canadian Journal of Biosystems Engineering. 50: 2.9-2.15

Miranda-Fuentes, A., Llorens, J., Rodriguez-Lizana, A., Cuenca, A., Gil, E., Blanco-Roldán, G.L., et al. 2016. Assessing the optimal liquid volume to be sprayed on isolated olive trees according to their canopy volumes. Science of the Total Environment, 568 (2016), 269-305

QGIS Development Team, 2016. QGIS Geographic Information System. Open Source Geospatial Foundation. URL http://qgis.osgeo.org

Rosell, J. R., and Sanz, R. 2012. A review of methods and applications of the geometric characterization of tree crops in agricultural activities. Computers and Electronics in Agriculture, 81, 124-141

Rouse, J. W., Haas, R. H., Schell, J. A. and Deering, D. W. 1973. Monitoring vegetation systems in the Great Plains with ERTS, Third ERTS Symposium, NASA SP-351 I, 309-317

Salcedo, R., Garcerá, C., Granell, R., Moltó, E. and Chueca, P. 2015. Description of the airflow produced by an air-assisted sprayer during pesticide applications to citrus. Spanish Journal of Agricultural Research, 13 (2), 2-8

UMA-UPC. 2018. DOSAVIÑA®. Decision Support System for determining the optimal volume rate in vineyard. URL: https://dosavina.upc.edu (last accessed August 2018)

Vogel, J.W., Wolf, R.E. and Dille, A. 2005. Evaluation of a Variable Rate Application System for Site-Specific Weed Management. Paper No. 051120, St Joseph, MI, USA: ASAE

Walklate, P. and Cross, J. 2012. An examination of Leaf-Wall-Area dose expression. Crop Protection, 35, 132-134

Zaman, Q.U. and Salyani, M. 2004. Effects of foliage density and ground speed on ultrasonic measurement of citrus tree volume. Applied Engineering in Agriculture. 20: 173-178