A laboratory test bench to analyse nozzle sprays

Cerruto E., Manetto G., Failla S., Longo D., Caruso L., Schillaci G.
University of Catania. Di3A, Section of Mechanics and Mechanization
Via Santa Sofia, 100 – 95123 Catania, ITALY.
Tel 0039 0957147514, Fax 0039 0957147600, ecerruto@unict.it

Abstract
Aim of this study is to propose a low cost laboratory test bench, suitably designed to analyse nozzle sprays according to the procedure described in ISO 5682-1. It consists of a transportable trolley carrying a tank, a two diaphragms pump driven by an electric motor, and a spray boom carrying one multiple nozzle holder. The spray boom may move, under the control of a DC motor, along two slides placed above the working plane of the trolley. Acceleration and deceleration ramps may be imposed by the speed controller. According to the procedure described in ISO 5682-1, the test liquid is sprayed above Petri dishes placed on the working plane and containing silicon oil: analysing the images of the drops captured inside the oil, it is possible to measure the spray drop diameters and then all the spray features. The image acquisition system is under development.
Moreover, the test bench will be used to correlate spray features to water sensitive paper (WSP) images. Spraying at the same time Petri dishes and WSPs, the image of drops inside Petri dishes will be correlated to images on WSPs, so allowing the calculation of unitary deposits from WSP.
Finally, the tests bench will be used to experimentally validate a model describing the WSP behaviour when sprayed with drops of assigned drop size distribution and volume median diameter. In this paper WSP images were produced by simulation, assuming some simplifying hypotheses: spherical drops and circular stains randomly placed on the images. Three types of spray were simulated (Fine, Medium and Coarse) with two drop size distributions (log-normal and Rosin-Rammler). The simulations showed that the unitary deposit can be derived from the measured percentage of covered surface on the WSP images, but the knowledge of the volume median diameter of the drops is necessary, independently of the probability distribution function of drop size.

Keywords: Pesticide Application, Image Analysis, Drop Pulverisation

Introduction
Spray deposit and superficial coverage are two of the main factors influencing the biological efficacy of a pesticide treatment as well as the environmental hazards. The correct deposit ensures the lethal dose on the target, while the coverage, for non systemic products, increases the probability of contact between pest and pesticide. Both aspects are influenced by many other factors, among which one of the most important is the spray spectrum (Hewitt, 1997; Matthews, 2004; Nuyttens *et al*., 2007). The ideal spectrum maximises spray efficiency as ensures the transfer of the required dose to the target and minimises off-target losses due to drift and run-off (Hewitt *et al*., 1998).

There are many drop size analysers available on the market nowadays, mostly based on optical imaging, laser diffraction, and phase doppler. Each analyser is best suited for specific types of testing; moreover, measurement techniques, type of drop size analyser, optical configuration, sampling methods, data analysis, and reporting techniques, all have a strong influence on the results, so that it is virtually impossible to compare data from different instruments without a clear understanding of the test conditions and methodology (Schick, 2008).

In this paper a low cost laboratory test bench is presented. It allows nozzle spray characterisation according to the procedure described in ISO 5682-1. Moreover, the test bench will be used to correlate the spray features (drop diameter population, coefficient of variation, volume median diameter, arithmetic mean diameter of drops) with data extracted from water sensitive paper images (superficial coverage, particle density). If the correlations will be statistically significant, the WSP image analysis will make it possible both to measure the unitary deposit and to characterise the sprays issuing from nozzles.

Finally, continuing the studies on the simulation of the WSP behaviour at varying spray features and superficial coverage (Cerruto *et al.*, 2013), in this paper further results are presented regarding two drop size distributions (log-normal and Rosin-Rammler) and three types of spray (Fine, Medium and Coarse). The test bench will be used to validate the model and to confirm the results deriving from the simulations.

The laboratory test bench

The test bench under design consists of a transportable trolley with one working plane, carrying a 70 L tank, a two diaphragms pump “Annovi Reverberi AR 30 SP” with maximum flow rate of 36 L min^{-1} at pressure of 40 bar, driven by a 2.2 kW electric motor, and a spray boom carrying one multiple nozzle holder. This type of pump was chosen to be comparable with those installed in agricultural sprayers. Tank, motor and pump are positioned on the base of the trolley, near to the ground. The spray boom is applied to a mobile support that moves along two slides placed above and parallel to the working plane of the trolley, at a distance of about 0.5 m. The movement of the spray boom is realised by using anti-slip toothed belts connected to an axle powered by means of a DC motor with a speed controller. Maximum speed is about 1 m s^{-1}; acceleration and deceleration ramps may be imposed by the speed controller. A schematic view of the device is reported in Figure 1.

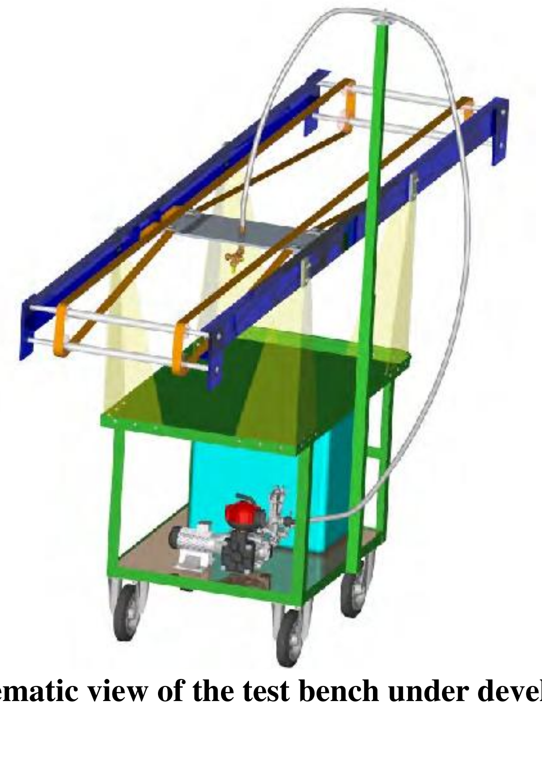

Figure 1. Schematic view of the test bench under development.

Following the procedure described in ISO 5682-1, the test liquid, a mixture with coloured dye tracer, will be sprayed above Petri dishes containing silicon oil of suitable viscosity placed on the working plane. The images of the drops captured inside the silicon oil will be acquired by means of a video system, at present under development, and will be analysed by means of an image processing software. The drop analysis will make it possible to measure all the spray features (probability distribution function of drop size PDF, volume median diameter VMD, arithmetic mean diameter AMD, coefficient of variation CV), as well as the calculation of the unitary deposit d_n (L cm^{-2}). All data will be correlated with nozzle type and working parameters.

Placing water sensitive papers beside the Petri dishes, the data deriving from the analysis of their images will be correlated with those deriving from the analysis of the drops inside the Petri dishes: if the correlations will be statistically significant, the WSP image analysis will make it possible both to measure the unitary deposit and to characterise the sprays issuing from nozzles. Spraying in the same manner natural targets (fruits or leaves), it will be possible to correlate the unitary deposit on their surface, evaluated following well known procedures (Pascuzzi and Cerruto, 2015), to spray features and images of WSPs.

Finally, comparing effective and simulated water sensitive paper images, the test bench will allow the validation of the model (or will suggest appropriate corrections) and the assessment of the results obtained from the simulations.

Water sensitive paper simulation

WSP images were simulated using two drop diameter probability distribution functions, log-normal and Rosin-Rammler, widely used for describing drop pulverisation (Babinsky and Sojka, 2002; Schick, 2008). The PDF of the number of drops are:

Log-normal: $$f_0(D)=\frac{1}{\sqrt{2\pi}\,\sigma D}e^{-\frac{(\ln D-\ln\ )^2}{2\sigma^2}}; \qquad (1)$$

Rosin-Rammler: $$f_0(D)=\frac{k\,D^{k-4}}{\lambda^{k-3}\Gamma\left(1-\frac{3}{k}\right)}e^{-\left(\frac{D}{\lambda}\right)^k}, \qquad (2)$$

being D the drop diameter and $\Gamma(x)$ the gamma function. The scale (σ and λ) and location (and k) parameters are analytically correlated to CV, AMD and VMD of the drop diameters.

For each PDF three spray types were simulated, classified as Fine, Medium and Coarse (Hewitt *et al.*, 1998). They were obtained by changing the scale and location parameters of the two PDFs. The values chosen for the simulations are reported in Table 1.

Images of water sensitive papers (2 cm × 7 cm) were produced by simulation with a resolution of 1200 dpi, randomly allocating the stains, circular shaped. Given the drop diameter D (µm), the corresponding stain diameter D_s (µm) was calculated by using the Equation 3 (QInstruments):

$$D_s=0.938\cdot D^{1.143} \qquad (3)$$

These simulated WSP images were treated as effective WSP images and then they were analysed by means of an image processing software, the *ImageJ* (Abramoff *et al.*, 2004). All data provided by the *ImageJ* were correlated with the reference ones used to produce the images so to analyse their trend at varying spray and image features. In this study the possibility of assessing the unitary spray deposition (L cm^{-2}) at varying superficial coverage on WSP images and spray features was exploited.

All simulations, statistical analyses and graphical representations were carried out by using the R software (R Development Core Team, 2012).

Table 1. Parameters used for the simulations of the sprays

			Rosin-Rammler			Log-normal		
Spray type	VMD (m)	CV (%)	AMD (m)	*k*	λ (m)	AMD (m)	(m)	σ
	141	70	70	3.874	155	52	43	0.631
Fine	160	80	70	3.702	177	46	36	0.703
	181	90	70	3.576	201	41	31	0.770
	261	70	130	3.874	287	96	79	0.631
Medium	296	80	130	3.702	327	86	67	0.703
	334	90	130	3.576	370	76	56	0.770
	362	70	180	3.874	398	134	109	0.631
Coarse	410	80	180	3.702	453	119	93	0.703
	466	90	180	3.576	516	106	79	0.770

Results and discussion

The reference percentage of covered surface S^* (%), fixed without considering overlaps between stains, and that S_m (%) provided by *ImageJ*, measured with overlaps, were related as reported in Figure 2.

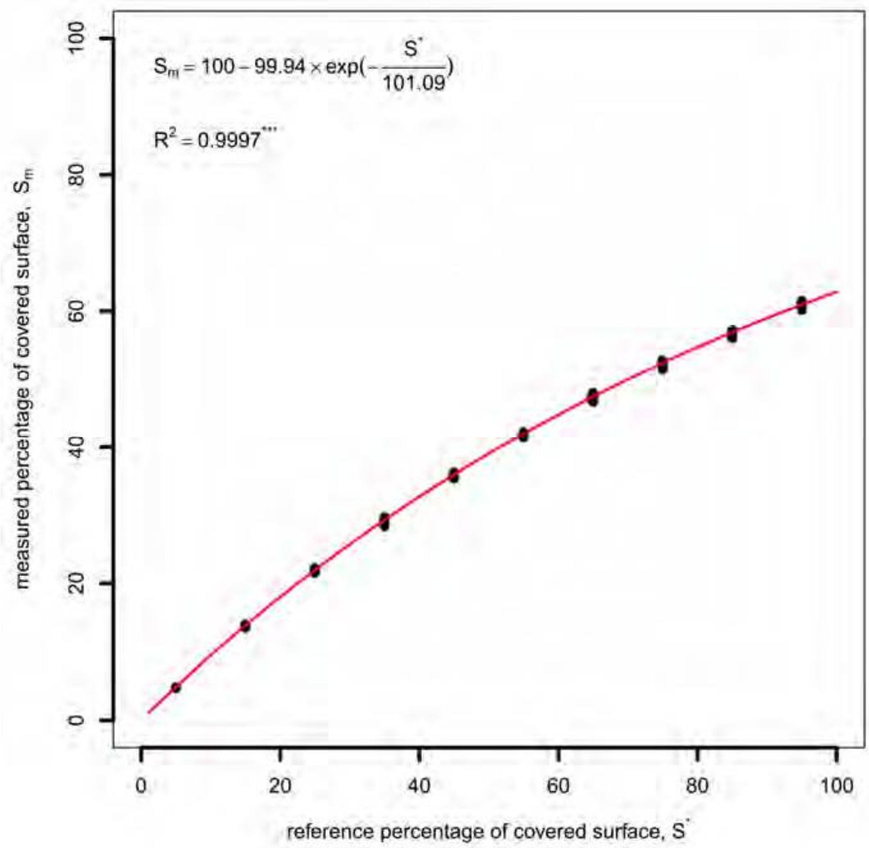

Figure 2. Correlation between reference S^* and measured S_m percentage of covered surface.

The correlation between S^* (%) and S_m (%) was described by Equation (4), independently of spray features:

$$S_m = 100 - 99.94 \cdot e^{-\frac{S^*}{101.09}} \quad (4)$$

This result confirms those of previous researches (Cerruto and Aglieco, 2013; Cerruto *et al.*, 2013), obtained considering sprays with log-normal PDF only. Probably it is independent of spray features, but could be affected by other factors (circularity of the stains, for example) that will be investigated in further researches. According to the Equation (4), the measured percentage of covered surface increases exponentially towards 100% when the reference one tends to infinity. This means that high values of percentage of covered surface are obtained with very high overlaps between stains.

The unitary spray deposit was related to the superficial coverage as reported in Figure 3 at varying spray type, PDF and CV of drop diameters. The graph shows that the spray deposit is primarily affected by spray type, then by CV and finally by PDF.

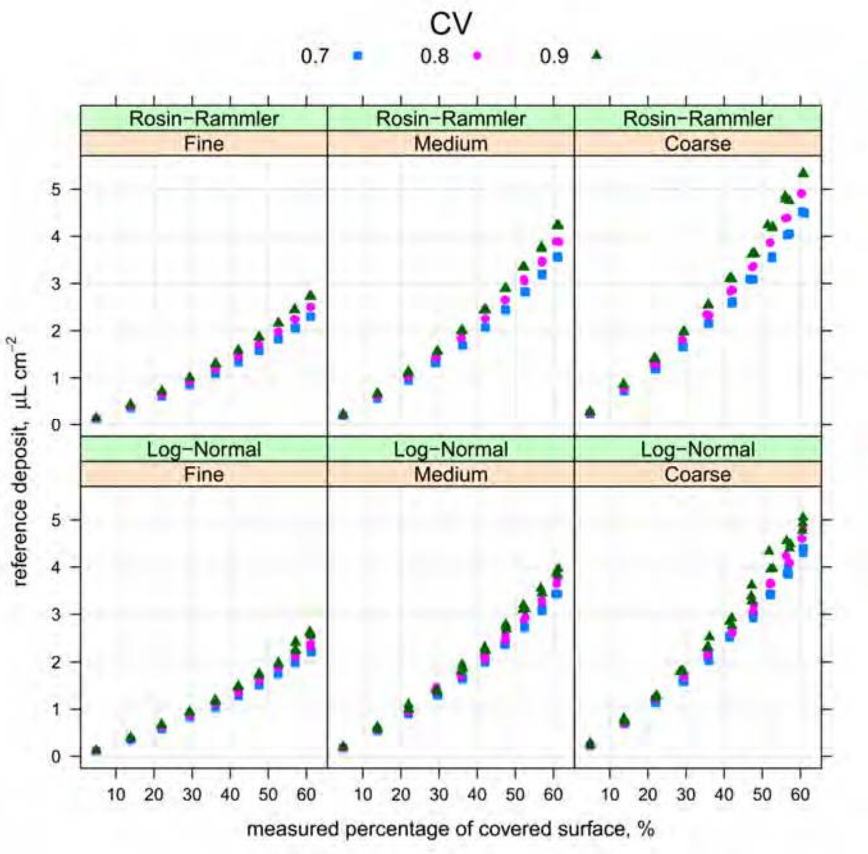

Figure 3. Correlation between unitary spray deposit and measured percentage of covered surface at varying spray type, CV and PDF.

Fixing spray type, CV and PDF, the trends of unitary deposit vs. superficial coverage were well explained by quadratic relations, with coefficients of determination ranging from 0.9949 up to 0.9996, highly significant. This result confirms the possibility of calculating the unitary spray deposit by known spray features and percentage of covered surface on WSP images.

Making explicit the effect of spray type in terms of volume median diameter VMD, the graph of Figure 4 was obtained. As expected, it shows a strong effect of VMD and a negligible effect of PDF.

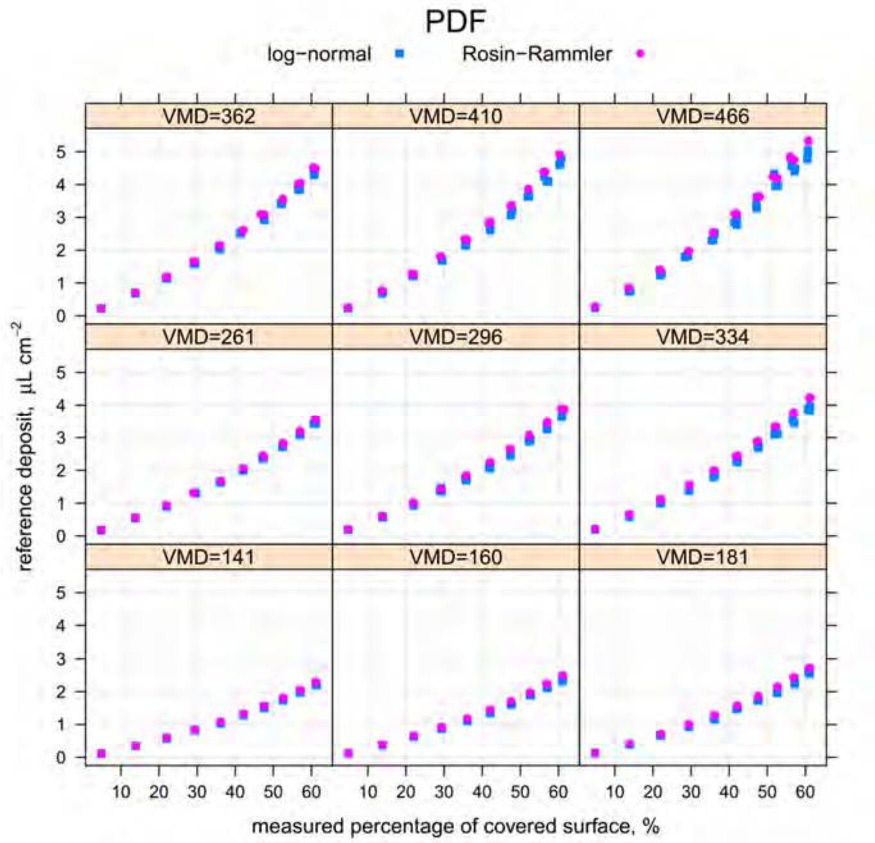

Figure 4. Correlation between unitary spray deposit and measured percentage of covered surface at varying volume median diameter VMD and PDF.

Taking into account only the volume median diameter VMD (m) and using a multiple regression approach, the unitary deposit $\hat{d}_n$ (L cm^{-2}) can be calculated according to the Equation 5:

$$\hat{d}_n = 10^{-6}[12770 + 8169 \cdot S_m + 124.7 \cdot S_m^2 + \mathrm{VMD} \cdot (189.7 + 72.26 \cdot S_m + 1.242 \cdot S_m^2)] \qquad (5)$$

The regression equation had determination coefficient R^2 equal to 0.9952, highly significant. The relative error between reference d_n^* and computed $\hat{d}_n$ unitary deposit, calculated according to Equation 6:

$$e = \frac{d_n^* - \hat{d}_n}{d_n^*}, \qquad (6)$$

ranged from -23% up to 8%. The highest relative errors were detected estimating low unitary deposits (less than 0.05 L cm^{-2}), whereas in other cases the error was less than 10% (Figure 5). A better estimation can be obtained by including in Equation 5 the effect of PDF.

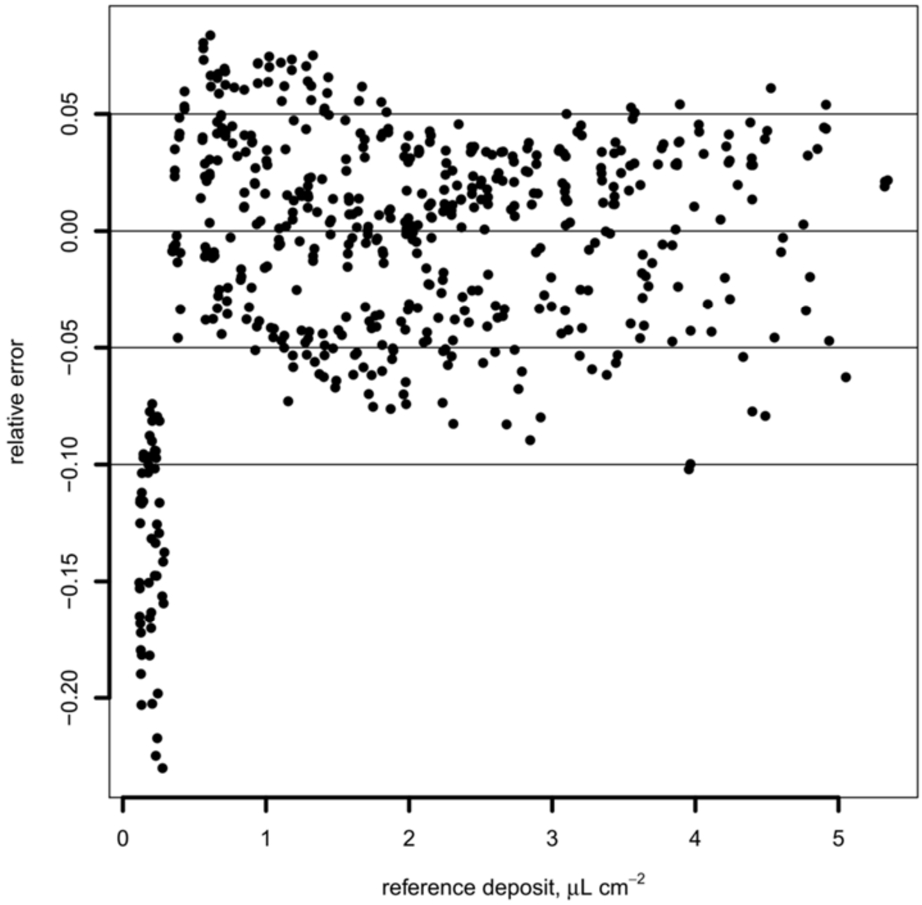

Figure 5. Relative error on unitary spray deposit when computed by using Equation (5).

Conclusions

The results of this research provided some important hints for further developments of the study. In particular:

- Reference and measured percentage of covered surface on water sensitive paper images were related by a simple relation (Equation 4), independently of the spray features. This allows a quick estimate of the overlap between stains by measuring the percentage of covered surface, the easiest parameter to measure during the analysis of WSPs.
- The spray unitary deposit can be estimated from the percentage of covered surface, but the knowledge of the spray features is necessary (spray type and CV of drop diameters). As a first approach, the unitary deposit was estimated, with a relative error in most cases less than 10%, knowing the volume median diameter only (Equation 5).
- The test bench under development should be suitable to validate (or suggest corrections to) the model used to simulate the behaviour of water sensitive papers. When it will be completed and available for experimental activities, it will be possible to correlate the data extracted from the WSP analysis (superficial coverage) to spray features and unitary deposit on natural targets, parameters strictly correlated to the efficacy of a pesticide application.

References

Abramoff M.D., Magelhaes P.J., Ram S.J. 2004. Image processing with ImageJ. Biophotonics International, vol. 11, 7, 36–42.

Babinsky E., Sojka P.E. 2002. Modeling drop size distribution. Progr. Ener. Combustion Sci., 28, 303–329.

Cerruto E., Aglieco C. 2013. Water sensitive papers simulation to assess deposits on targets. Journal of Agricultural Engineering 2013, vol. 44(s1), e80, 397–401.

Cerruto E., Aglieco C., Failla S., Manetto G. 2013. Parameters influencing deposit Estimation when using water sensitive papers. Journal of Agricultural Engineering, vol. 44, 2, 62–70.

Hewitt A.J. 1997. The importance of droplet size in agricultural spraying. Atomization Spray 7, 235–244.

Hewitt A.J., Valcore D.L., Teske M.E., Schick R.J. 1998. Droplet size classification for agricultural sprays. Proc. Ilass 11th Annual Conf. Liquid Atomization and Spray Systems, Sacramento, CA, USA, 55–59.

ISO 5682-1. 1996. Equipment for crop protection - Spraying equipment - Part 1: Test methods for sprayer nozzles.

Matthews G.A. 2004. How was the pesticide applied? Crop Prot. 23:651–653.

Nuyttens D., Baetens K., De Schampheleire M., Sonck B. 2007. Effect of nozzle type, size and pressure on spray droplet characteristics. Biosyst. Eng. 97, 333–345.

Pascuzzi S., Cerruto E. 2015. Spray deposition in "tendone" vineyards when using a pneumatic electrostatic sprayer. Crop Protection 68 (2015), 1–11.

QInstruments. Water sensitive papers. Available from: http://www.qinstruments.com/en/service/downloads/downloads-wsp.html. Accessed: July 2013.

R Development Core Team. 2012. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, URL http://www.R-project.org.

Schick R.J. 2008. Spray technology reference guide: understanding drop size. Bulletin no. 459C, ©Spraying Systems Co.