An innovative pneumatic electrostatic sprayer useful for *tendone* vineyards

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Abstract

The aim of this note is to analyse the features of the ESS *150 RB14* electrostatic sprayer, an innovative model compared to the standard air-assisted sprayers traditionally used by Apulian growers (Southern Italy) in *tendone* vineyards. The experimental tests showed that the activation of the electrostatic system produced a significant increase in the mean deposit, but it was located only on the foliar layer of the canopy closer to the sprayer. However this result should also imply an increase in the deposits on the bunches when the electrostatic system is activated, even if further tests are necessary to verify this expectation. If this will be substantiated, the electrostatic sprayer ESS *150 RB14* would be suitable for the targeted applications usually performed in *tendone* table grape vineyards.

Introduction

An overhead canopy supported by a trellis system, so-called *tendone*, characterises the most common vine training system for table grapes in Apulia (Southern Italy), the Italy's leading region for table grape production, accounting for 61% of the total Italian production (ISTAT, 2012). The trellis consists of a high stake at each vine with two orthogonal steel wires attached 1.7-1.8 m above ground level, and a grid of steel wires supporting the shoots.

In this typology of vineyards the most employed sprayers for plant protection product (PPP) applications are conventional air-assisted sprayers fitted with arc-shaped spray boom and axial-flow fan, or pneumatic sprayers equipped with air shear nozzles and centrifugal fan producing airflow through fixed or adjustable diffusers (Cerruto *et al.*, 2008; Pascuzzi, 2013).

The monitoring of the physiological processes, linked to the gradual adoption of seedless cultivars, the distribution of bio stimulants of plant growth, the use of microbial antagonists, the sustainable use of synthetic pesticides, the reduction of doses and volumes per hectare, and so on, promotes improvements and innovations in sprayer use and design, also according to the impulses arising from the European Directive 2009/128/EC (European Commission, 2009).

These requirements may be partly satisfied by using air-assisted electrostatic sprayers, which produce a stream of electrostatically charged fine droplets having trajectories guided and governed by electrostatic force fields, though not automatically in the desired manner (Maski and Durairaj, 2010). Electrostatic forces may be used both to atomise a liquid surface, so producing a highly charged stream of fine droplets, or to produce a finer and more uniform spray when a liquid is atomised mechanically (Vieri, 2002; Esehaghbeygi *et al*., 2010). Electrostatic atomisation and electrostatically assisted atomisation are both used in many different industrial processes, but the requirements of the agricultural electrostatic sprayers are different from those of industry mainly due to the different conductive characteristics of the aqueous mixtures of pesticides to charge and to the three-dimensional target to cover inside and outside. Nevertheless, according to tests concerning pest controls carried out indoor and outdoor, the use of agricultural electrostatic sprayers improves the overall deposition and distribution of PPPs on the foliage and reduces spray drift (Machowski and Balachandran, 1997). Other studies substantiate that electrostatic charging of spray droplets may allow a better deposition on the undersides of leaves (Western *et al*., 1994; Wolf *et al*., 1996).

The aim of this note is to analyse the technical and operative characteristics of an innovative sprayer model compared to the standard air-assisted sprayers traditionally used by Apulian growers: the electrostatic sprayer ESS *150 RB14* (2003; Electrostatic Spraying Systems Inc., Watkinsville, GA, USA), available on the market among the commercial models equipped with devices for electrostatic charging of the droplets.

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Key words: Electrostatic sprayer; *tendone*-trained vineyard; crop protection.

Acknowledgements: the authors wish to thank C. Gidiuli, V. Marzano and D. Sfregola of DiSAAT for their helpfulness and commitment in conducting the experimental tests. Furthermore, the Authors wish to thank Mr. Tony Romanazzi, owner of the Romanazzi farm for his willingness to use the tendone vineyard and the tested sprayer.

Contributions: the authors contributed equally.

Received for publication: 26 February 2015.
Accepted for publication: 19 April 2015.

Journal of Agricultural Engineering 2015; XLVI:458
doi:10.4081/jae.2015.458

Materials and methods

The sprayer

The 3-point hitch mounted ESS *150 RB14* sprayer (Figure 1A) is designed to operate at low volumes of mixtures and to produce droplets in the range 30-50 μm that may be electrostatically charged by induction using an electrode inside each nozzle. The atomisation of the mixture is accomplished by a pneumatic system thanks to the high velocity created by the expansion of compressed air, in a substantially different way from the conventional sprayers employed in *tendone* vineyards (Pascuzzi and Cerruto, 2015).

The machine is equipped with a gearbox multiplier (gear ratio 1:7) whose input must be connected to the tractor power take-off (PTO) by a gimbal, whereas its output is connected to a Roots blower and a centrifugal pump.

The Roots blower has two lobe impellers mounted on parallel shafts and rotating in opposite directions to suck air through a filter from the environment, propelling it into a pressured reservoir, whose output is connected to the nozzles. The manufacturer's instructions state that in order to work correctly, the machine requires a relative air pressure of 100 kPa to produce an airflow rate of 195 m^3 h^{-1}. At the beginning of the treatment, the operator must adjust the engine rotation speed until the air pressure reaches the required value.

The centrifugal pump moves the spray mixture available in the tank. The liquid flow rate can be adjusted in the range 1.68-2.80 L min^{-1} by using different flow disks fitted with calibrated holes and/or by modifying the liquid pressure in the range 150-300 kPa by means of a valve that restricts the return flow of liquid to the tank. Outside this range of liquid flow rate, nozzle charging is poor and spray deposition is low. Setting the liquid flow rate in the range 1.68-2.24 L min^{-1} attains the optimum performance.

The key components of this machine are the patented MaxCharge™ (Electrostatic Spraying Systems Inc.) nozzles (Cooper and Law, 1998), so-called embedded-electrode electrostatic-induction nozzles, in which the liquid is atomised by the impact with a high-speed air stream and the droplets are electrostatically charged by induction (Pascuzzi and Cerruto, 2015) (Figure 1B). The compressed air and the liquid enter the nozzle separately (Figure 1B); inside the nozzle, the liquid, in the form of a thin cylindrical shell, exits from a central tube and is shattered into droplets by the viscous and turbulent energy transferred by the surrounding near-sonic speed air stream emerging through an annulus from the converging section of the nozzle. During their formation inside the nozzle, the droplets are charged by electrostatic induction. This type of nozzle is the improved version of the original one pointed out by Law (1977, 1978), being more consistent and reliable in the severe agricultural environment (Zhao *et al*., 2005).

The operating instructions of the sprayer state that the nozzles need to be positioned approximately 0.5 m from the crop, so that the air stream is able to push the charged spray into the canopy and to provide adequate overlap of the spray cloud from each nozzle. The spray arms may be adjusted by modifying the height of the tractor's 3-point hitch, the orientation of each boom and/or its width and extension.

Flow rate measurement

In order to assess the sprayer performance, the flow rate was evaluated at the highest (300 kPa) and the lowest (150 kPa) allowed pressure; in both cases the same 0.051 inch (1.295 mm) flow disks were used. Measurements were replicated five times (ISO, 1997) by collecting the liquid sprayed by each nozzle during a working time of 60 s. For this purpose, the nozzles were subdivided between the left- and right-hand sides of the sprayer and numbered from 1 to 7 starting from the topmost nozzle (Figure 1A).

Flow rate values were statistically analysed to point out significant differences between left- and right-hand side of the sprayer and between nozzles within each side.

Preliminary field tests

Some preliminary field tests were carried out to evaluate the effect

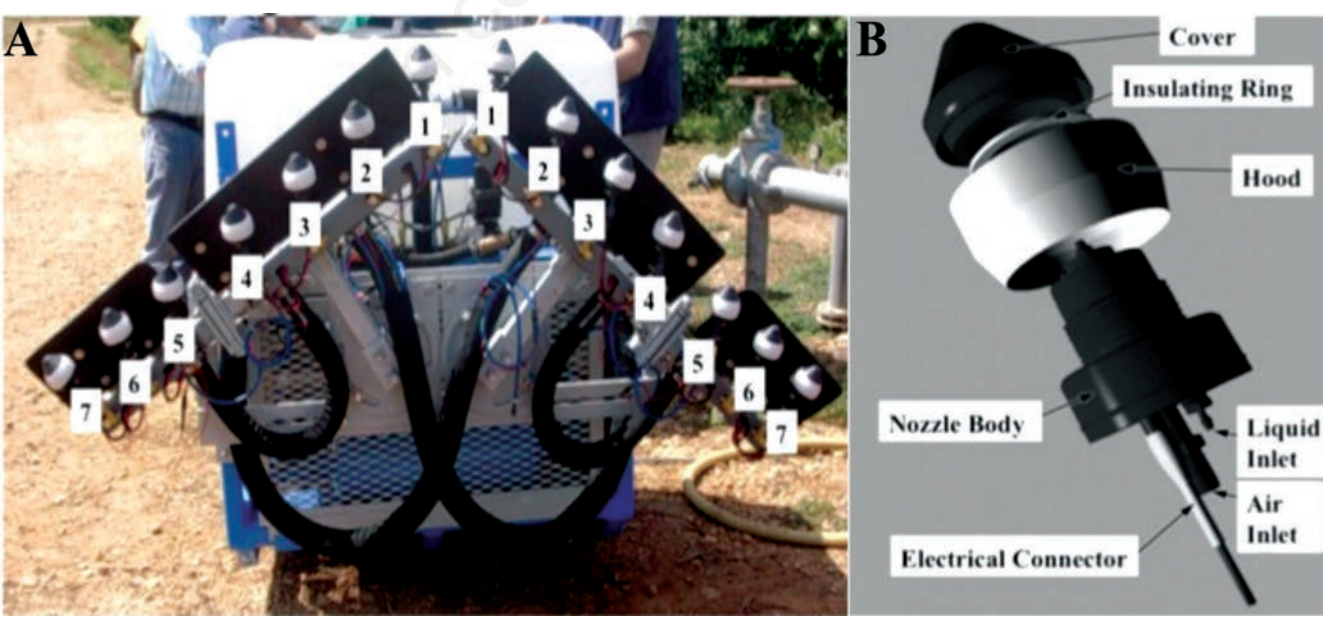

Figure 1. A) The mounted ESS *150 RB14* electrostatic sprayer; B) MaxCharge™ (Electrostatic Spraying Systems Inc.) nozzle.

of the electrostatic charge on foliar spray deposition, varying the tractor speed (1.11, 1.39 and 1.67 m s^{-1}). The sprayer was tested in a double-grid *tendone* vineyard (*Pizzutello* seedless variety) with a plant layout of 2.5×2.5 m, located on a farm in the territory of Castellaneta (province of Taranto, Apulia). The trials were carried out during a phenological stage with high leaf density (code 85 of the BBCH scale, *Softening of berries*), to evaluate the performance of the machine under particularly challenging operative conditions (average leaf area index of 5.09, ranging from 4.56 up to 5.78).

The tractor operated at 41.8 rad s^{-1} of the PTO, so ensuring the correct relative air pressure (100 kPa) and air flow rate (195 m^3 h^{-1}) required by the machine. The liquid pressure was set equal to 170 kPa, so producing an average liquid flow rate of 156 mL min^{-1} from each nozzle and an overall flow rate of 2.18 L min^{-1}. The corresponding volume rates were 131, 105 and 87 L ha^{-1}, at 1.11, 1.39 and 1.67 m s^{-1}, respectively.

Using as reference the wires of the grids, the canopy was divided into two layers (lower layer and upper layer) and four sectors (S_1, S_{2a}, S_{2b}, and S_3), so defining eight areas, useful for foliar sampling and foliar spray deposition assessment (Figure 2). Field tests were carried out spraying a mixture containing a food dye tracer (yellow tartrazine; Sigma Chemical, Sigma-Aldrich, St. Louis, MO, USA) and the foliar deposit was measured in the laboratory using a spectrophotometric technique (Pascuzzi and Cerruto, 2015). The experimental design was developed according to a randomised block design with three replicates.

Results and discussion

Flow rate analysis

Table 1 reports the results of the flow rate measurements at both pressures. It shows differences both between the two sides of the sprayer and the nozzles within each side. On average, the right-hand side flow rate was 15% greater than that of the left-hand side. This difference is attributable to different pressure drops on the two sides of the sprayer, not equally compensated by the pump. The technical standard (ISO, 2015) regarding the inspection of sprayers in use, states that, for symmetrical spraying, the difference between left and right hand side shall be a maximum of 10%. So, in this sprayer the difference between the two sides is greater than that proposed by the ISO regulation and this could affect spray deposits.

The statistical analysis of the data pointed out that the nozzles of each side had significantly different flow rates; moreover, some nozzle had a flow rate deviating by more than 10% from the mean value of the side where it was installed (ISO, 2015). The number of nozzles with flow rates statistically different or deviating by more than 10% from the mean value was higher when the pressure increased. Finally, the coefficient of variation between the flow rates of the nozzles of each side ranged from 6.0 up to 8.8%, with higher values at higher flow rates.

Foliar deposit

The statistical analysis of the data, normalised at 100 L ha^{-1}, revealed that the foliar deposits were affected by the electrostatic system and unaffected by the tractor speed (Figure 3).

On average, when the electrostatic system was activated, the mean foliar deposit increased by +44% (significant at 5% p-level), from 0.061 up to 0.088 μL cm^{-2}, so confirming the efficacy of electrostatic spraying in improving total deposition (Matthews, 1989; Law, 2001; Zhao *et al*., 2008; Singh *et al*., 2013). However, the increase, from 0.106 up to 0.159 μL cm^2 (+50%, significant at 5% p-level), was located on the lower layer only. On the contrary, foliar deposit in the upper layer was unaffected by the electrostatic system: it increased only by +12.5% (from 0.016 up to 0.018 μL cm^{-2}), not significant at 5% p-level. Therefore, the electric charge increased the foliar spray deposition only on the foliar layer closer to the sprayer. This behaviour should imply an increase in the deposit also on the bunches, but further tests are necessary to verify this expectation. If this were proven, this sprayer model would be useful for targeted treatments commonly carried out in table grape vineyards, for example the application of bio stimulants of bunches growth.

The mean deposits at the three tractor speeds ranged from 0.067 μL cm^{-2} at 1.11 m s^{-1} up to 0.080 μL cm^{-2} at 1.39 m s^{-1}, not statistically different (Figure 3). Similar results are common in literature when testing the effects of forward speed (Cross *et al*., 2001; Pergher and Lacovig, 2005; Cerruto, 2007).

The uniformity of deposits on the canopy was quite unsatisfactory: significant differences were found both between the four sectors and between the two foliar layers (Figure 3). The mean foliar deposit in sectors S_1 and S_3 (0.086 μL cm^{-2}) was significantly higher than that in

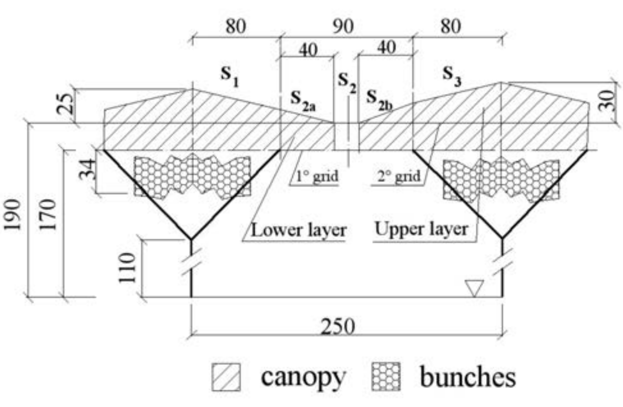

Figure 2. Canopy structure and sampling zones (sizes in cm).

Table 1. Average flow rate discharged by each nozzle (mL min^{-1}).

Pressure bar	Side	Nozzle 1	2	3	4	5	6	7	Mean	CV %
1.5	Left	121[b]	134[a]	133[a]	130[a]	114[c]	131[a]	122[b]	126	6.0
	Right	148[b]	134[d]	139[cd]	151[b]	139[c]	142[c]	*170*[a]	146	8.3
3.0	Left	171[c]	177[b]	*185*[a]	171[c]	*142*[f]	163[d]	153[e]	166	8.8
	Right	201[b]	177[d]	192[c]	202[b]	*170*[e]	177[d]	*216*[a]	190	8.7

CV, coefficient of variation. [a-d]Comparisons between nozzles within each side. Mean separation at 5% p-level. Values in italics deviate by more than 10% from the mean value.

sectors S_{2a} and S_{2b}, (0.063 μL cm^{-2}). This result is due to the arrangement of the two spray booms and the orientation of the nozzles towards the lateral zones, with higher leaf density. But the greatest difference was that observed between the two foliar layers: 0.133 μL cm^{-2} on the lower layer and 0.017 μL cm^{-2} on the upper layer (7.8:1 ratio). When the electrostatic system was switched off, the ratio lower layer/upper layer was 6.5:1 and increased up to 9.0:1 when it was switched on. This difference is very difficult to reduce in *tendone* vineyards because only the lower side of the canopy is sprayed (Cerruto *et al*., 2008; Pascuzzi, 2013).

Conclusions

The key component of the electrostatic sprayer ESS *150 RB14* is the MaxCharge™ (Electrostatic Spraying Systems Inc.) nozzle, able to atomise (30-50 μm) and induce negative charges on the droplets surface when a positive voltage is applied to it. The results of the flow rate measurements highlighted statistically significant differences between the two sides of the sprayer and also among the nozzles placed within each side, referable to dissimilar pressure drops, not equally compen-

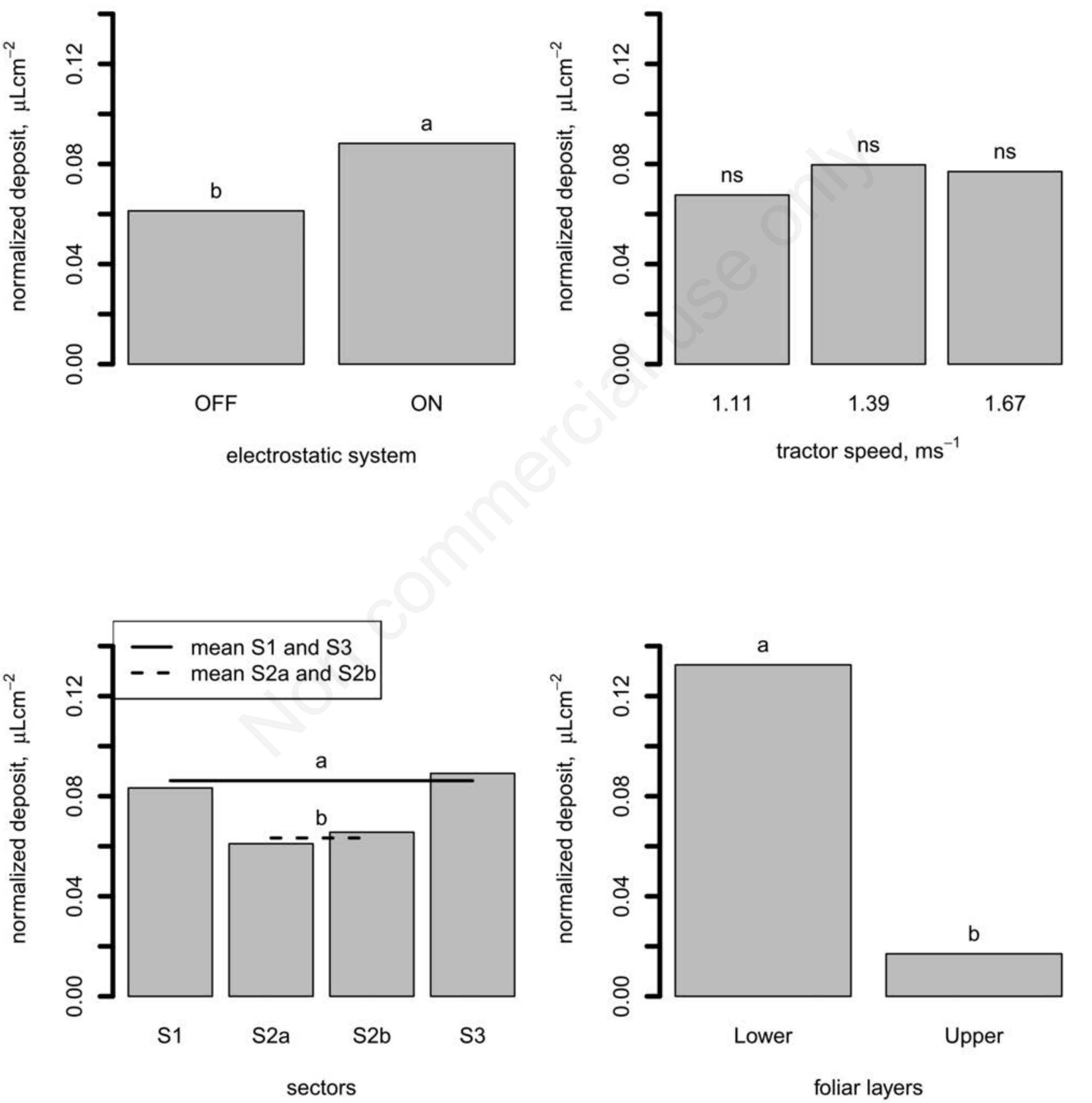

Figure 3. Mean foliar spray deposition as affected by electrostatic system, tractor speed, sectors and foliar layers (mean separation by Tukey's HSD test: in each graph, means with the same letter are not significantly different at 5% level; ns: not significant).

sated by the pump. The results of field tests showed a remarkable increase in the mean foliar spray deposition when the electrostatic system was activated, even if only on the lower layer of the canopy (+50%), whereas it had no significant effect on the upper layer (+12.5%). The raise of foliar deposits on the lower layer of the canopy should involve also an increase in the deposits on the bunches when the electrostatic system is activated, even if further tests are necessary in order to verify this aspiration. If this were substantiated, the electrostatic sprayer ESS *150 RB14* would be suitable for targeted treatments, such as the application of bio stimulants of bunches growth, usually performed in *tendone* table grape vineyards with seedless cultivars.

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