Document downloaded from:

[\[http://redivia.gva.es/handle/20.500.11939/6107\]](http://redivia.gva.es/handle/20.500.11939/6107)

This paper must be cited as:

[Torrent, X., Garcera, C., Molto, E., Chueca, P., Abad, R., Grafulla, C., Roman, C., Planas, S. (2017). Comparison between standard and drift reducing nozzles for pesticide application in citrus: Part I. effects on wind tunnel and field spray drift. Crop Protection, 96, 130-143.]

ivia
Institut Valencià
d'Investigacions Agràries

The final publication is available at

[\[https://doi.org/10.1016/j.cropro.2017.02.001\]](https://doi.org/10.1016/j.cropro.2017.02.001)

Copyright [Elsevier]

Torrent *et al.*: Comparison between standard and drift reducing nozzles on pesticide application in citrus: Part I. Effects on wind tunnel and field spray drift.

Santiago Planas

Universitat de Lleida–Agrotecnio Center.
RG in AgroICT & Precision Agriculture.

Avenida Rovira Roure, 191. 25198 Lleida
(Spain).

Tel: +34 973702859

Fax: +34 973702673

E-mail: splanas@eagrof.udl.cat

Comparison between standard and drift reducing nozzles on pesticide application in citrus:
Part I. Effects on wind tunnel and field spray drift

Xavier Torrent^a, Cruz Garcerá^c, Enrique Moltó^c, Patricia Chueca^c, Raquel Abad^b, Carmen Grafulla^b, Carla Román^a, Santiago Planas^a

^a Universitat de Lleida–Agrotecnio Center. RG in AgroICT & Precision Agriculture. Avenida Rovira Roure, 191. 25198 Lleida (Spain).

^b Dow AgroSciences Ibérica S.A. C/ Ribera de Loira 4-6. 28042 Madrid (Spain)

^c Centro de Agroingeniería, Instituto Valenciano de Investigaciones Agrarias (IVIA). Ctra. CV-315, Km 10.7. 46113 Moncada (Valencia, Spain). Tel: +34 963424000 Fax: +34 963424001

Funding information: this research was funded in the framework of “Say no to drift” project by Dow AgroSciences LLC

15   **Abstract**

16   The objective of this study was to evaluate and to compare spray drift potential and field
17   spray drift from pesticide application in citrus orchards carried out mainly comparing standard
18   nozzles with drift reducing nozzles. Two different standard nozzles (hollow cone and full
19   cone) and one Venturi drift reducing nozzle (hollow cone) were tested. Spray drift potential
20   was measured by means of wind tunnel experiments according to the ISO 22856:2008. To
21   estimate field airborne and sedimenting spray drift, two trials with 5 replicates each were
22   carried out according to the ISO 22866:2005 standard at two different commercial orchards of
23   Clementine mandarins. Results showed that Venturi nozzles had a statistically significant
24   reduction effect on drift for the two methodologies. Moreover, the wind tunnel method
25   showed the same trend that the field results. Additionally, the results of spray drift deposition
26   variability were lower for the Venturi nozzles. Therefore, it could be concluded that Venturi
27   nozzles can be recommended to be used in citrus orchards to prevent human and
28   environmental risks and its use could be appropriate for different scenarios where spray drift
29   risk must be mitigated.

30

31   **Keywords:** drift potential reduction, airblast sprayer, Venturi nozzles, airborne drift,
32   sedimenting drift.

33 1. Introduction

34 Spraying pesticides is the most common method to protect crops against pests and
35 diseases. When pesticides are applied, several associated problems can appear, especially if
36 the crop to be protected is a tree crop such as top fruits, citrus or vineyards. This is
37 because, in these cases, there is a longer distance between the sprayer nozzles and the
38 target compared to arable crops and the difficulty for the spray droplets to penetrate the
39 tree canopies is higher. In this situation sprayers usually deliver the spray in a horizontal
40 and/or radial way and they are commonly assisted by turbulent air currents generated by
41 fans on the sprayer. The efficiency of these operations is low because losses to the soil and
42 to the atmosphere (off-target movement via spray drift) are high. Spray drift, defined as
43 “The quantity of plant protection product that is carried out of the sprayed (treated) area by
44 the action of air currents during the application process” (ISO 22866:2005 standard), is
45 considered as the main source of contamination of pesticide applications in tree crops and
46 it involves risks for humans (Butler Ellis *et al.*, 2010) and environment (Ozkan *et al.*,
47 1993; Gil and Sinfort, 2005; Nuyttens *et al.*, 2007b; Cunha *et al.*, 2012). This problem is a
48 concern to the society today. In this context, authorities, operators and agrochemical
49 companies are adopting measures to avoid hazard derived from pesticide applications. In
50 the EU, after the approval of the Directive 2009/128/CE, (EU, 2009a), several
51 complementary regulations and technical standards are being implemented to achieve a
52 sustainable use of pesticides, mainly through spray drift prevention. In the same direction,
53 other countries worldwide are dealing with spray drift prevention measures (EPA, 2015).
54 Spraying pesticides in tree crops encompasses many factors which may affect spray drift.
55 These factors are related to the orchard structure (row and in-row spacing, canopy
56 architecture, leafiness, canopy penetrability, etc.), to the nozzles (mainly droplet size
57 spectrum), to the sprayer (fan characteristics, liquid distribution, etc.), to the operating

conditions (liquid volume rate, air flow rate, forward speed, etc.), to the properties of spray mix (viscosity, surface tension and homogeneity) and to the weather conditions (wind speed and direction, temperature and relative humidity) (Fillat *et al.*, 1993; Solanelles *et al.*, 1997; Planas *et al.*, 1998; EU Health & Consumer Protection DG, 2007; Felsot *et al.*, 2010; Doruchowski *et al.*, 2012; Salyani *et al.*, 2013; Balsari *et al.*, 2014; Lešnik *et al.*, 2015).

The assessment of spray drift is based on the measurement of the real spray drift in field conditions and the evaluation of the spray drift potential (DP) defined as the percentage of the spray volume that can be potentially displaced out of the treated area by the action of air currents during the application process under specific weather conditions.

One method to evaluate nozzles for spray DP refers to the analysis of droplet size spectrum performed by means of laser particle analyzer systems. This method has been used over the last three decades to characterize several flat-fan nozzles, commonly used in field crop pesticide applications (Arnold A., 1987; Hewitt *et al.*, 1998; Herbst A., 2001b; Nuyttens *et al.*, 2007a; Holterman, 2008; Holterman, 2009). Studies regarding the orchard sprayers and the nozzles used in tree crops, which usually are cone nozzles, were initiated later (van de Zande *et al.*, 2008).

Another method to evaluate nozzle spray DP, based on wind tunnel measurements, has been used for flat fan nozzles, based on the comparison of the candidate nozzles with a reference nozzle (Herbst A., 2001a; Taylor *et al.*, 2004; Nuyttens *et al.*, 2009).

Spray drift field evaluation of sprayers started more than two decades ago (Miller, 1993).

The widest work ever made included 50 trials in field crops and 72 in fruit orchards (Ganzelmeier *et al.*, 1995; Rautmann *et al.*, 2001). This study was originally made to

obtain basic spray drift values for spray drift risk assessment within the pesticide

authorization process, but, after that, this data allowed to build a general spray drift model which is the basis of the drift reduction techniques (DRT) classification system.

In the Netherlands, Holterman *et al.* (1997) developed another spray drift-prediction model for field crop sprayers from a set of 48 field trials sprayed in a cross wind. This model was supplemented with new spray drift measurements from orchards, nursery trees and arable fields for the typical Dutch situation (van de Zande *et al.*, 2000). This wide work has provided the basis of the spraying drift risk classification system adopted in the Netherlands and has led to a predicting pesticide spray drift model for pome fruit orchards (Holterman and van de Zande, 2014; Holterman *et al.*, 2016a, 2016b).

In order to improve the protocols of sprayer classification for spray drift, Nuyttens *et al.* (2008) compared the spray drift risk evaluation methodologies (laser droplet size spectrum, wind tunnel and field spray drift experiments) for 10 models of flat fan nozzles. This study was the first one combining these methodologies and concluded that laser and wind tunnel are comparable and allow the prediction of field spray drift data.

Initial models of drift reduction nozzles (DRN) were developed for field crop spraying and after that for tree crop spraying. DRN provide larger droplets than standard nozzles (STN) as it has been demonstrated for flat fan nozzles (Guler *et al.*, 2007; Nuyttens *et al.*, 2007a) and cone nozzles (Derksen *et al.*, 1999; van de Zande *et al.*, 2008).

One of the first field trials spraying fruit orchards with DRN were reported by Balsari *et al.* (2001) and Solanelles *et al.* (2001), demonstrating the beneficial effect of DRN lowering airborne and sedimenting spray drift. In addition, Planas *et al.* (2013) also found beneficial effects for hollow cone DRN in comparison to STN by means of droplet sizing, wind tunnel and spray drift field in an intensive peach orchard. More recently, Douzals and Chalendar (2015) studied, in a wind tunnel, the behavior of horizontally orientated cone

nozzles, finding a relevant relationship between the spray distribution and the droplet size spectrum.

On the other hand, van de Zande *et al.* (2012), proposed a nozzle classification system for spray drift reduction in orchard spraying, including hollow cone DRN, which was validated through field spray drift measurements in apple orchards.

Citrus is one of the most important crops in the world with a yearly production of 131 million tones (FAO, 2012) and citrus groves cover around 8 M ha worldwide (FAO, 2013). Compared to other tree crops, citrus orchards depict a different scenario because of their perennial condition, tree architecture, leafiness and canopy penetrability (Planas *et al.*, 1998); despite this, there are few papers related to spray drift in citrus orchards.

One of these studies was carried out by Meli *et al.* (2003) and found high levels of sedimenting spray drift when spraying citrus with an air assisted sprayer fitted with HC-STN at a distance of 7.5 m from the orchard edge. Garcerá *et al.* (2012) found that sedimenting spray drift, quantified according to the ISO 22866:2005 standard, sprayed with an axial fan airblast sprayer fitted with full cone STN and up to 45 m away from a citrus orchard edge, fit better the general drift model developed in Germany (Ganzelmeier *et al.*, 1995; Rautmann *et al.*, 2001) and fit worse the model from Meli *et al.* (2003). In a different study, Dolera *et al.* (2012) compared the performance of hollow cone DRN and flat fan DRN with full cone STN for the control of the two-spotted spider mite *Tetranychus urticae* (Koch) in citrus and concluded that DRN nozzles decreased the sedimenting spray drift inside the orchard without decreasing the biological efficacy.

Due to the fact that there are very few studies in citrus about the effect of DRN on spray drift, the present work focused on the evaluation of spray DP by means of wind tunnel assessment, and field spray drift for hollow cone STN and full cone STN (currently used

for citrus orchards to control pests and diseases) and hollow cone (Venturi) DRN.

Furthermore, the relationship between both methods has been analyzed.

A second part of this project, devoted to evaluate the effect of DRN versus hollow cone STN and full cone STN in the control efficacy of California red scale (CRS), *Aonidiella aurantii* (Maskell), when applying Reldan® E (Dow AgroSciences Ibérica S.A., Madrid, Spain) is presented in a second manuscript (Garcerá *et al.*, 2017).

2. Materials and methods

For the experiments two models of standard nozzles (STN), Albuz ATR 80 Grey (STN-A) (Solcera; Evreux, France) and TeeJet D3DC35 Brown (STN-T) (Spraying Systems Co. Wheaton, IL, USA), and one model of drift reduction nozzle (DRN), Albuz TVI 8003 Blue (Solcera; Evreux, France) were selected. This DRN is classified as 90% reduction class at 0.7 MPa in the Dutch classification (van de Zande *et al.*, 2008).

2.1. drift potential in wind tunnel

Spray DP of the nozzles was measured in a wind tunnel (2.0 m wide, 1.0 m high and 7.0 m operating length). All the wind tunnel specifications and sensors fulfilled the requirements of the ISO 22856:2008 standard (Fig. 1).

Nozzles were tested at a pressure of 1.0 MPa. A mixture of a water-soluble fluorescent tracer, sulpho flavine brilliant yellow (CI 56205) (BSF) (Biovalley, Marne La Vallée, France), at a concentration of 0.3 g L⁻¹, was sprayed at a temperature of 20±1 °C.

Spray drift deposits were measured by collecting downwind droplets when a laminar air flow was blown at a constant velocity of 2.0±0.1 m s⁻¹ at a temperature of 20±1 °C and a relative humidity of 70-80%. Each nozzle was tested individually, at a static position in the wind tunnel (Fig. 1) and exposed to the air stream for 30 s. Three repetitions for each type

of nozzle were carried out. Each repetition was performed with a different individual nozzle, so three different individual nozzles were tested for each type of nozzle. Because of the their high droplet collection efficiency, 6 nylon lines with 2 mm of diameter were placed as passive sampling collectors in six collecting lines in a horizontal array (2.0, 3.0, 4.0, 5.0, 6.0 and 7.0 m length) and five collecting lines in a vertical array (0.5, 0.4, 0.3, 0.2 and 0.1 m height) to determine the vertical profile of the airborne spray, 2.0 m downwind from the nozzle position (Fig. 1).

Fig. 1. Wind tunnel measuring setup with the temperature and relative humidity sensors, the anemometer, the spray nozzle and the different collecting lines (potential airborne: V1-V5, and potential sedimenting spray drift: H1-H6).

After each application, collectors were left to dry for 5 minutes, and then they were introduced into individual zip bags and kept in a black container to maintain the collectors in fresh and dark conditions. Once in the laboratory, the tracer was extracted with a known volume of deionized water, Mili-Q® quality ("Type II" water according to ISO 3696:1996). Tracer concentration in wash-off water was measured with a fluorimeter (mod. LS-30, Perkin Elmer, Massachusetts), previously calibrated to get the reading BSF concentration curve. The quantification limit for the dye tracer was $2 \mu\text{g L}^{-1}$.

The spray deposit at each distance (H_i) in the ground and at each height (V_i) in the air was deducted from the measurements of the fluorescence of the wash-off water and the average value of the samples extracted from the tank and expressed as the total amount of spray

deposited in each collector (μL). Afterwards, taking into account the projected area of each collector, the deposit per surface unit was calculated ($\mu\text{L cm}^{-2}$) which was finally expressed as percentage of the volume applied in the same area unit.

2.2. drift at field conditions

Field experiments were carried out from November 6th to December 12th 2013 to estimate spray drift generated by STN and DRN fitted to conventional axial fan airblast sprayers. Experiments were set up according to the ISO 22866:2005 standard and Good Agricultural Practices for citrus crops. Experiments were placed in two commercial Clementine orchards, cv. Clemenules (*Citrus clementina* Hort. ex Tan.): Roquetes (Tarragona, Spain) (40° 47' 00' N, 0° 27' 52'' E, 69 m altitude) (Trial 1-Roquetes) and Montserrat (Valencia, Spain) (39° 22' 00'' N, 0° 35' 17'' W) (Trial 2-Montserrat). Applications were performed as usual for insecticide treatments against CRS in citrus. The characteristics of the orchards and operating equipment are shown in Table 1.

Table 1. Characteristics of the orchards, sprayers and nozzles.

		Trial 1-Roquetes		Trial 2-Montserrat	
Orchard	Area (ha)	6.67		0.27	
	Rows direction	E-W (18° ^a)		N-S (32° ^b)	
	Tree spacing (m x m)	6.00 x 4.00		5.00 x 3.50	
	(between rows x between trees)				
Canopy	Height, h (m)	2.85		2.75	
	Width along row (m)	2.80		2.90	
	Width crossing row (m)	2.50		3.70	
	Volume (ellipsoid) (m ³)	10.40		14.60	
	Volume occupied (%) ^c	15.20		30.30	
Sprayer	Model	Máñez y Lozano Twister 2000		Fede Futur 1500	
	Operating nozzles (number)	20 ^d		16 ^e	
Nozzles	Type	Albuz ATR 80	Albuz TVI 8003 Blue	TeeJet D3DC35	Albuz TVI 8003
		Grey		Brown	Blue
	Cone	Hollow	Hollow	Full	Hollow
	Nominal flow at 10 bar (l min ⁻¹)	2.08	2.19	2.00	2.19
	Output angle	80	80	48	80

^a CCW = Counterclockwise;
^b CW = Clockwise
^c Volume of the canopy (ellipsoid) related to the orthogonal volume (tree spacing x tree height)
^d Ten nozzles on each side of the manifold.
^e Eight nozzles operating on each side of the manifold.

The operating conditions on each trial, shown in Table 2, were chosen to deliver a spraying volume rate of 2500 L ha⁻¹ approximately. Before testing, the sprayers were calibrated. The nozzles setting-up was decided in order to fit the spray to the canopies, however for Trial 1-Roquetes the nozzle holders were not adjustable and all the operating nozzles were spraying in radial direction.

Table 2. Operating conditions for the spray applications.

Trial	Nozzle	Work pressure (MPa)	Forward speed (km h ⁻¹)	Liquid volume rate			Fan air flow rate (m ³ h ⁻¹)	Air expansion coefficient, k ⁽¹⁾
				L ha ⁻¹	L tree ⁻¹	L m ⁻³		
1-Roquetes	STN-A	1.5	1.00	2456	5.89	0,57	29700	0.57
	DRN	1.3	1.00	2388	5.73	0.55		
2-Montserrat	STN-T	1.0	1.58	2550	4.46	0.31	69700	0.31
	DRN	1.0	1.58	2713	4.75	0.33		

⁽¹⁾ *k = w · h · s · 10³ · V⁻¹; where w: tree spacing between rows (m); h: trees height (m); s: forward speed (km h⁻¹); V: fan air flow rate (m³ h⁻¹)

Applications consisted of spraying the downwind ending rows and measuring spray drift in the bare downwind area next to the orchard. The ISO 22866:2005 standard state the acceptable wind conditions for testing (the mean wind direction shall be at $90^{\circ} \pm 30^{\circ}$ to the spray track and no more than 30 % of results shall be $> 45^{\circ}$ from the perpendicular of the spray track). At first, a wind direction range around $\pm 30^{\circ}$ was expected. In this way, a sprayed length of 46.20 m was enough, for this reason a sprayed length of 50 m was considered in trials, starting at the edge row and continuing by spraying the adjacent rows. In total, four rows were sprayed in order to reach a minimum width of 20 m of sprayed area and fulfill the requirements of the ISO 22866:2005 standard (paragraph 3.2). There were five replicates for each evaluated nozzle.

Each measurement included airborne and sedimenting deposition spray drift. Measurements were carried out as shown in Fig. 2. Distances were measured from the directly sprayed area, considering as such the center of the outer swath of application to the center of any collector surface.

Airborne spray drift was measured by means of the same nylon string collectors used for the wind tunnel tests (6.0 m long). These collectors were placed in pairs in two poles placed at 5 and 10 m distance from the directly sprayed area, respectively. At each distance, 2 parallel collectors were placed 2 m apart. After the application, the strings were cut into sections of 1.0 m length

Sedimenting spray drift was measured by means of 51.5 x 6.5 cm horizontal blotting paper collectors (73 g m⁻² filters. ANOIA S.A., Barcelona, Spain) located at ground level as indicated in Fig. 2.

Fig. 2. Trial sketch: Location of collectors, sprayer path.

BSF tracer at 1 g L^{-1} was added to the water tank to measure spray deposition. To know the actual concentration of the tank liquid for each application, two samples were taken from a nozzle of the sprayer. The amount of tracer deposited on the collectors was measured following a similar methodology described in wind tunnel tests and calculated as is indicated in ISO 22866:2005 standard (Annex C).

Weather conditions were recorded during each application at a frequency of 1 Hz, air temperature at 2 m and 4 m above the average height of the tree canopies, that is, 5 and 7 m high, and relative humidity, wind speed and wind direction at 7 m high. Wind direction was set to 0° when the wind came perpendicular to the rows, towards the spray drift measurement zone (Fig. 2).

3. Data analysis

2.3. 2

2.3.1. 1. Spray drift statistical analysis

The effect of the nozzle on the airborne and sedimenting deposits for each distance or height in wind tunnel and field trials were studied by means of one way analysis of variance (ANOVA) with Fisher's Least Significant Difference LSD test (Fisher, 1935).

Previously, the normality and homogeneity of variance of the studied variables were verified by the Shapiro-Wilk test (Shapiro and Wilk, 1965) and Levene's test (Levene, 1960), respectively. In all tests a confidence level of 95% was considered. Statistical analyses were done using JMP® Pro 11 (SAS Institute Inc., Cary, NC, 1989-2007 for Windows).

251

2.3.2. 2. Spray drift potential and spray drift potential reduction

For the wind tunnel, DP was calculated as a global collecting recovery according to ISO 22856:2008 standard (Annex E) by the following expressions:

$$DP_V = \sum_{i=1}^5 V_{T(i)} \quad (\text{Eq. 1})$$

$$DP_H = \sum_{j=1}^6 H_{T(j)} \quad (\text{Eq. 2})$$

Where DP_V represents the total airborne DP; DP_H , the total sedimenting DP; $V_{T(i)}$, the airborne DP at the vertical collector line i (%) and $H_{T(j)}$ the sedimenting DP at the collector line j (%), according to the following expressions:

$$v_{(i/j)} = \frac{v_D \cdot F}{C_n \cdot 10^6} \quad (\text{Eq. 3})$$

$$V_{T(i)} \text{ or } H_{T(j)} = \left(\frac{v_{(i/j)} \cdot \frac{d_c}{D_c}}{q_N \cdot (t_s/60)} \right) \cdot 100 \quad (\text{Eq. 4})$$

Where v_D is the sample dilution volume (L); F , collector fluorimeter lecture ($\mu\text{g BSF L}^{-1}$); C_D , BSF concentration (g BSF L^{-1}); $v_{(i/j)}$, deposit volume to the collector line i or j (L); d_c , distance between collectors (0.1 m for vertical collectors and 1.0 m for horizontal collectors); D_c , collector diameter (0.002 m); q_N , nozzle flow rate (L min^{-1}); t_s , spraying time (s);

For the field, only the replicates fulfilling ISO 22866:2005 standard (paragraph 5) for wind conditions have been considered for DP and drift potential reduction (DPR) calculation. Spray drift deposition and percentage were calculated accordingly the ISO 22866:2005 standard (Annex C) and the collecting recovery (CR) according to the following expressions:

$$CR_V = \sum_{i=1}^6 V_{F(i)} \quad (\text{Eq. 5})$$

$$CR_H = \sum_{j=1}^{13} H_{F(j)} \quad (\text{Eq. 6})$$

Where CR_V represents the total airborne drift recovery; CR_H , the total sedimenting drift recovery; $V_{F(i)}$, the airborne drift at the vertical section of the collector line i (%) according to the following expressions:

$$V_{F(i)} = \left(\frac{v_{(i)}/D_c}{(S_V \cdot A)/L_R} \right) \cdot 100 \quad (\text{Eq. 7})$$

Where $v_{(i)}$, represents spray drift deposit to the section of the collector line i (L); D_c , collector diameter (m); S_V , sprayed volume rate (L ha^{-1}); A , sprayed area (ha); L_R , sprayed row length (m).

281 In Eq. 6, $H_{F(j)}$ represents the sedimenting drift at the collector placed at the downwind
282 distance j (%) according to the following expression:

$$H_{F(j)} = \left(\frac{v_{(j)} \cdot \left(\frac{d_{C(j)}}{W_c \cdot L_c} \right)}{(S_v \cdot A) / L_R} \right) \cdot 100 \quad (\text{Eq. 8})$$

284 Where $v_{(j)}$, represents spray drift deposit to the collector j (L); $d_{C(j)}$, distance representing
285 each collector (1.0, 1.75, 2.50, 2.50, 2.50, 2.50, 2.50, 2.50, 3.75, 5.00, 5.00, 5.00 and 5.00
286 m); W_c , collector width (m); L_c , collector length (m); S_v , sprayed volume rate (L ha⁻¹); A ,
287 sprayed area (ha); L_R , sprayed row length (m).

288 The DPR (%) was calculated by the following expressions:

289 For the tunnel,

$$DPR_V = \left(1 - (DP_{V(DRN)} / DP_{V(STN)}) \right) \cdot 100 \quad (\text{Eq. 9})$$

$$DPR_H = \left(1 - (DP_{H(DRN)} / DP_{H(STN)}) \right) \cdot 100 \quad (\text{Eq. 10})$$

292 Where DPR_V is the airborne DPR; $DP_{V(DRN)}$ and $DP_{V(STN)}$ are DP_V measured for DRN and
293 STN, respectively; DPR_H , the sedimenting DPR; $DP_{H(DRN)}$ and $DP_{H(STN)}$ are DP_H measured
294 for DRN and STN, respectively.

295 For the field,

$$DPR_V = \left(1 - (CR_{V(DRN)} / CR_{V(STN)}) \right) \cdot 100 \quad (\text{Eq. 11})$$

$$DPR_H = \left(1 - (CR_{H(DRN)} / CR_{H(STN)}) \right) \cdot 100 \quad (\text{Eq. 12})$$

298 Where $CR_{V(DRN)}$ and $CR_{V(STN)}$ are CR_V measured for DRN and STN, respectively; $CR_{H(DRN)}$
299 and $CR_{H(STN)}$ are CR_H measured for DRN and STN, respectively.

300

2.3.3. 3. Sedimenting regression functions

Only the replicates fulfilling ISO 22866:2005 standard (paragraph 5) for wind conditions have been considered for this purpose. A double exponential regression of the sedimenting values was calculated for field trials for the 50th percentile of each nozzle at each distance following the methodology of Holterman *et al.* (2016b). All equations are represented in log scale for horizontal axis, allowing easy comparisons between them.

3. Results and discussion

3.1. drift potential in wind tunnel

The global recovery fractions in relation to the sprayed volume were 2.50% for STN-A airborne deposits, 1.24% for STN-T airborne deposits, 0.57% for DRN airborne deposits, 16.53% for STN-A sedimenting deposits, 9.39% for STN-T sedimenting deposits, 6.87% for DRN sedimenting deposits.

For all the tested nozzles, the highest collecting position received the lowest airborne deposits (Fig. 3) at 2 m distance from the nozzle. Significant differences were obtained at all heights between STN-A and DRN. STN-A and STN-T differences will be examined through DP values.

Moreover, the lower variability of DRN airborne deposits in comparison to the STN nozzles is remarkable. Largest droplets from DRN seemed to behave in a more reproducible way, because they tend to follow a ballistic trajectory and are less affected by air currents than small droplets from STN that are prone to have a random behavior.

Fig. 3. Comparison of the airborne deposit (% of spray volume) (mean±SE) for the three tested nozzles at 2 m from the nozzle in a wind tunnel. Different letters indicate significant differences between each STN and DRN at each height (LSD test, $P < 0.05$).

For the sedimenting deposits (Fig. 4), values decreased with the distance from the nozzle.

Significant differences were found between STN-A and STN-T in relation to DRN at all

distances (2.0-7.0 m) except to 5 m.

Fig. 4. Comparison of the sedimenting deposit (% of spray volume) (mean±SE) for the three tested nozzles at 2 m from the nozzle in a wind tunnel. Different letters indicate significant differences between each STN and DRN at each distance (LSD test, P < 0.05).

3.2. drift at field conditions

Weather parameters recorded during trials are shown in Appendix A. The replicates fulfilling ISO 22866:2005 standard (paragraph 5) for wind conditions were for Trial 1-Roquetes, STN-A 1,2,3,4,5 and DRN 2,3,4,5 and for Trial 2-Montserrat STN-T 2,5 and DRN 1,3,5. Results of each individual replicate for airborne and sedimenting spray deposits are represented in Appendix B and means for each test in Figs. 5-8.

The total collecting recoveries on the vertical array of collectors in Trial 1-Roquetes were: 24.12% for the STN-A and 8.73% for the DRN at 5 m, 15.78% for the STN-A and 4.60% for the DRN at 10 m. In Trial 2-Montserrat these were 12.61% for the STN-T and 6.41% for the DRN at 5 m, 8.02% for the STN-T and 3.14% for the DRN at 10 m. On the horizontal collectors the total collecting recoveries were 12.66% for the STN-A and 7.63%

for the DRN in Trial 1-Roquetes and 8.04% for the STN-T and 5.18% for the DRN in Trial 2-Montserrat.

In both trials, when spraying with DRN, airborne spray drift values were significantly lower than STN values at 5 m (Figs. 5-6) from the sprayed area and at every measured height. In Trial 1-Roquetes mean airborne deposit at 10 m of STN were almost five times higher than mean drift values of DRN, but they were not significantly different at any height when a confidence level of 95% was considered, maybe due to the high variability of the results (Fig. 5). This variability could be explained for changes in wind angle which can cause that the spray drift comes from further away distances. Nevertheless, there are significant differences if the confidence level is decreased (80%). Whereas in Trial 2-Montserrat airborne deposits at 10 m were significantly different at every measured height (Fig. 6).

In both trials, the variability of STN was higher than the DRN at both distances, probably because the smaller spray droplets of STN have a random behavior and are highly affected by wind (Figs. 5-6). This was also observed in the wind tunnel test (Fig. 3).

On the other hand, for both STN and DRN, airborne spray drift from Trial 1-Roquetes decreased with height, mainly at the 5 m distance pole (directed spray flow rate dominated over airborne drift) (Fig. 5) but not for Trial 2-Montserrat (Fig. 6). This fact could be explained because of the lower volume occupied by canopies and the higher air expansion coefficient in Trial 1- Roquetes (Table 1). Whereas, for Trial 2-Montserrat it seems that more airborne spray drift was running on top of the trees because of the canopies shade effect and the lower air expansion coefficient.

Fig. 5 Airborne deposit (% of sprayed volume) (mean±SE) at 5 m and 10 m for the Trial 1-Roquetes STN-A and DRN nozzles. Different letters indicate significant differences between nozzles at each height (LSD test, P < 0.05).

Fig. 6. Airborne deposit (% of sprayed volume) (mean±SE) at 5 m and 10 m for the Trial 2-Montserrat STN-T and DRN nozzles. Different letters indicate significant differences between nozzles at each height (LSD test, P < 0.05).

380 As expected, in both trials, sedimenting spray drift decreased with the distance from the
381 orchard edge. This reduction started at the shortest evaluated distance and the effect was
382 stronger for the DRN. From 20.0 m from the orchard edge to the last collecting distance,
383 the sedimentation remained quite constant for the DRN in both trials. In the case of STN,
384 this happened at 30 m from the orchard edge (Figs. 7-8).

385 Moreover, in both trials, at the initial measurement distance (1.5 m), sedimenting spray
386 drift values were higher for DRN at a non-significant level. At the initial distances the
387 sedimenting deposits could be due to the direct spraying and not only to drift dragged by
388 the wind. This effect could be more important for DRN as coarse drops have a ballistic
389 behaviour (Heijne *et al.*, 2002).

390 Beyond this initial point, at each distance, spray drift values were higher for STN. Spray
391 drift reduction effect of DRN was significant from 7.5 to 20.0 in Trial 1-Roquetes (Fig. 7)
392 and from 10.0 m to 20.0 m in Trial 2-Montserrat (Fig. 8).

393 Finally, at the end of the section (25.0-40.0 m) sedimentation spray drift differences
394 between DRN and both STN were not significant with the exception of the last point of
395 measurement (40.0 m) in Trial 2-Montserrat when the absolute spray drift values were
396 close to zero (Fig. 8). These figures could be considered to discriminate STN from DRN
397 for buffer zone dimensioning. So, if the width of the buffer zones is defined as the distance
398 to come a 5% spray drift deposition level, in this case it would be at 25 m for both STN,
399 17.5 m for DRN in Trial 1-Roquetes and 20.0 for DRN in Trial 2-Montserrat. However,
400 there are other factors that have to be into account such as product toxicity.

Fig. 7. Sedimenting deposit (% of sprayed volume) (mean±SE) for the Trial 1-Roquetes STN-A and DRN nozzles. Different letters indicate significant differences between nozzles at each distance (LSD test, P<0.05).

Fig. 8. Sedimenting deposit (% of sprayed volume) (mean±SE) for the Trial 2-Montserrat STN-T and DRN nozzles. Different letters indicate significant differences between nozzles at each distance (LSD test, P<0.05).

3.3. DP

DP values for STN were always higher than for DRN in wind tunnel assessment method (Table 3) at a significant level for airborne deposits and sedimenting deposits. This rule can be consistently translated to the field trials, because STN obtained also higher CR values in both trials, but not at significance level (Table 3). Nevertheless, there are significant differences if the confidence level is decreased (80%). This fact was due to the differences on depositions between replications because of the wind disturbances. This is an important constraint for the implementation of the ISO 22866:2005 standard, where trials are developed on not controlled conditions. In spite of this, results from the wind tunnel and the field trials follow the same trend.

For the tunnel, differences between DP_V and DP_H can be justified by the droplet trajectories when approaching to the collecting strings (straight initial trajectory, contouring strings for vertical and parabolic for horizontal). For the field, differences between CR_V and CR_H can be justified by the droplet evaporation, more evident for the smaller spectrum of STN.

Table 3. Spray drift risk assessment. DP mean values (%) for the wind tunnel and CR (%) for the field trials. Different letters indicate significant differences between STN and their respective DRN in each scenario (LSD test, $P < 0.05$).

Nozzle	Wind tunnel		Field trials			
	DP_V	DP_H	Trial	CR_V at 5m	CR_V at 10m	CR_H
STN-A	2.50 (a)	16.53 (a)	1	24.12 (a)	15.78 (a)	12.66 (a)
STN-T	1.24 (a)	9.39 (a)	2	12.61 (a)	8.02 (a)	8.04 (a)
DRN	0.57 (b)	6.87 (b)	1	8.73 (a)	4.60 (a)	7.63 (a)
			2	6.41 (a)	3.14 (a)	5.18 (a)

3.4. DPR

DPR values from wind tunnel tests and from field trials were in accordance (Table 4). Again, results from field tests follow a similar trend to the wind tunnel results as Nuytens *et al.* (2008) stated for several flat-fan nozzles. In all cases, DPR was higher when DRN

was compared to STN-A rather than to STN-T; this is a direct consequence of the higher DP values shown by STN-A in wind tunnel and field trials.

Table 4. DPR mean values (%) of the DRN in relation to STN-A and STN-T for the two different spray drift risk assessment methods.

Nozzle	Wind tunnel		Field trials		
	DPR _V	DPR _H	DPR _V at 5m	DPR _V at 10m	DPR _H
DRN _{STN-A}	77.06	58.46	63.82	70.84	39.75
DRN _{STN-T}	53.91	26.90	49.15	60.91	35.59

For both drift assessment methods, DRN was more able to reduce airborne spray drift than sedimenting spray drift (Table 4). This consideration could be interesting when determining buffer zones if prevention of human risk is the main objective.

A general comparison between trials should not be carried out because, as mentioned, several factors may affect spray drift, such as the fan air flow rate, sprayer design, orchard structure, canopies architecture, penetrability and sprayer forward speed.

3.5. Sedimenting regression functions

The double exponential function (50th percentile) of the sedimenting spray drift of Trial 1-Roquetes and Trial 2-Montserrat are shown in Fig. 9. The parameters of the different double exponential regression equations with their corresponding standard errors are indicated in Table 5.

If comparing each STN curve to the respective DRN curve, the spray drift reduction effect was more evident in Trial 1-Roquetes as was for the DPR results. According to the CR_H results, curves for STN-A (Trial 1-Roquetes) and STN-T (Trial 2-Montserrat) were clearly distinct, being nearly parallel at distances between 1.5-10.0 m, but close to 10.0 m these

curves start to converge. Therefore, this model could be appropriate for different scenarios where spray drift risk must be mitigated.

Fig. 9. Double exponential function by means of 50th percentile sedimenting drift values.

Table 5. Parameters of the double exponential function equation for 50th percentile values for the nozzles tested. The general function equation is: $y = a \cdot \exp(-b \cdot x^c)$ (SE).

Trial	a	b	c
1-Roquetes STN-A	28.094 (0.924)	-0.111 (0.018)	0.981 (0.053)
1-Roquetes DRN	63.884 (10.931)	-0.594 (0.143)	0.675 (0.082)
2-Montserrat STN-T	44.234 (22.132)	-0.788 (0.444)	0.425 (0.136)
2-Montserrat DRN	37.253 (8.641)	-0.599 (0.194)	0.632 (0.105)

4. Conclusions

The results achieved by the two methodologies (wind tunnel test and field trials) were in agreement and confirmed the spray drift reduction ability of the DRN in relation to the STN-A and STN-T for both airborne and sedimenting spray drift up to 20.0 m from the

citrus orchard edge. Consequently, this type of DRN can be recommended as a DRT for chemical treatments with axial fan sprayers, normally used in citrus crops.

Specifically, spray drift reduction for DRN was higher when considering airborne than when considering sedimenting spray drift. Moreover, airborne spray drift variability for both methodologies was reduced when DRN were used, confirming its greater spray robustness. These facts are relevant if human and environmental risks are mainly considered.

Nevertheless, beyond nozzle type, other factors determining spray drift, such as orchard architecture and sprayer characteristics and settings, should also be taken into consideration in order to minimize spray drift and fulfill the requirements of the Directive 2009/128/CE, Good Agricultural Practices rules. For this objective a drift reduction classification system is needed to buffer zone determination.

In this regard a remarkable effect of the canopies density and structure is realized on the airborne spray drift for height distribution. Gaps between the canopies and the ground led to increase the spray drift at the low heights. Additionally, the sprayer setting (nozzle holder orientation) can strongly influence sedimenting drift at short distances, allowing greater values for DRN than for STN because the ballistic effect on the larger droplets.

Regarding the field trial methodology, the hard required resources and the difficulty in having the appropriate weather conditions, recommend establishing a more simplified testing procedure. Additionally, when testing nozzles used in tree orchards, the tunnel methodology should be adapted, i.e. placing the nozzle spraying with the orientation and sense of the air stream as suggested Douzals and Chalendard (2015). These conclusions lead to propose the revision of both drift assessment standards, ISO 22866:2005 and ISO 22856:2008.

A second part of this project, evaluating the control efficacy of California red scale (CRS), *Aonidiella aurantii* (Maskell), when applying Reldan® E (Dow AgroSciences Ibérica S.A., Madrid, Spain) is presented in a second manuscript (Garcerá *et al.*, 2017).

Acknowledgements

Authors would like to thank to Cítrics Terres de l'Ebre, S.A.T. and Manantiales Entrepinos, S.L. for allowing the use of their fields and sprayers. Also, Agrícola la Realense Coop.V. for allowing the use of their fields and Pulverizadores Fede S.A. for the use of equipments. Besides, Universitat de Lleida is also thanked for Mr. X. Torrent's pre-doctoral fellowship.

References

- Arnold, A., 1987. The drop size of the spray from agricultural fan spray atomizers as determined by a Malvern and the particle measuring system (pms). Atomization & Spray Technol. 3, 155-167.
- Balsari, P., Oggero, G., Tamagnone, M., 2001. Assessment of the efficiency of anti-drift nozzles on orchard sprayers: first results. Parasitica 57, 75-85.
- Balsari, P., Marucco, P., Oggero, G., 2014. La prevenzione dell'inquinamento, in particolare delle acque, da agrofarmaci: le buone pratiche e gli strumenti operativi individuati dai progetti TOPPS. Turin: Edizioni DiSAFA – Università degli Studi di Torino, Grugliasco (Italy).
- Butler Ellis, M.C., Lane, A.G., O'Sullivan, C.M., Miller, P.C.H., Glass, C.R., 2010. Bystander exposure to pesticide spray drift: new data for model development and validation. Biosystems Engineering 107, 162-168.

- 515 Cunha, J.P., Chueca, P., Garcerá, C., Moltó, E., 2012. Risk assessment of pesticide spray
516 drift from citrus application with air-blast sprayers in Spain. Crop Prot. 42, 116-123.
- 517 Derksen, R.C., Ozkan, H.E., Foz, R.D., Brazee, R.D., 1999. Droplet spectrum and wind
518 tunnel evaluation of Venturi and pre-orifice nozzles. T. ASAE 42 (6), 1573-1580.
- 519 Dolera, L., Vercher, R., Garcerá, C., Soler, J.M., Val, L., 2012. Spraying citrus orchards
520 with antidrift nozzles. Poster presented in the International Conference of Agricultural
521 Engineering CIGRAgEng 2012.Valencia (Spain) Julio 8-12, 2012.
- 522 Doruchowski, G., Roettele, M., Herbst, A., Balsari, P., 2012. Drift Risk Diagnosis (DRD) -
523 a decision support tool to help diagnose and mitigate spray drift for field applications in
524 practice. Structures and Environmental Technologies. International Conference of
525 Agricultural Engineering - CIGR-AgEng 2012: agriculture and engineering for a
526 healthier life, Valencia, Spain, 8-12 July 2012 pp. C-1527
- 527 Douzals, J.P., Chalendard M.P. 2015. Vertical and horizontal spray distribution of hollow
528 cone nozzles in a wind tunnel. A preliminary study to mitigate spray drift in orchards
529 applications. Suprofruit 2015. Lindau.
- 530 EPA - United States Environmental Protection Agency. Reducing Pesticide Drift.
531 <http://www.epa.gov/reducing-pesticide-drift> (Accessed 22/12/2015).
- 532 EU Health & Consumer Protection DG, 2007. Landscape and mitigation factors in aquatic
533 ecological risk assessment. Vol. 2. Detailed Technical Reviews. 436 pp.
534 [http://esdac.jrc.ec.europa.eu/public_path/projects_data/focus/lm/docs/FOCUS%](http://esdac.jrc.ec.europa.eu/public_path/projects_data/focus/lm/docs/FOCUS%20LM%20volume%20%20v2_0.pdf)
535 [20LM%20volume%20%20v2_0.pdf](http://esdac.jrc.ec.europa.eu/public_path/projects_data/focus/lm/docs/FOCUS%20LM%20volume%20%20v2_0.pdf).
- 536 EU (European Parliament and Council of the European Union) (2009a). Directive
537 2009/128/EC of 21 October of 2009 establishing a framework for Community action to
538 achieve the sustainable use of pesticides. Official Journal of the EU, L309, 71-86.

- 539 FAO - Food and Agriculture Organization of the United Nations, 2012. Agricultural
540 commodities production. Available in [http://faostat3.fao.org/faostat-](http://faostat3.fao.org/faostat-gateway/go/to/browse/Q/*/E)
541 [gateway/go/to/browse/Q/*/E](http://faostat3.fao.org/faostat-gateway/go/to/browse/Q/*/E).
- 542 FAO Food and Agriculture Organization of the United Nations, 2013. Agricultural
543 commodities production. <http://faostat3.fao.org>. (Accessed 15/06/2015).
- 544 Felsot, A.S., Unsworth, J.B., Linders, J.B.H.J., Roberts, G., Rautman, D., Harris, C.,
545 Carazo, E., 2010. Agrochemical spray drift; assessment and mitigation – a review. J.
546 Environ. Sci. Health, Part B, 45, 889-911. DOI: 10.1080/03601234.2010.515161.
- 547 Fillat, A., Planas, S., Bosch, M., Pons, L., Solanelles, F., 1993. Measuring contamination
548 (losses to the soil & drift) of pesticide application on fruit orchards. Proceeding of the
549 IV International Symposium on Fruit, Nut and Vegetable Production Engineering 1,
550 195-203. València.
- 551 Fisher, R.A., 1935. The Design of Experiments. Edinburgh and London: Oliver and Boyd.
- 552 Ganzelmeier, H., Rautmann, D., Spangenberg, R., Streloke, M., Herrmann, M.,
553 Wenzelburger, H.J., Walter, H.F., 1995. Studies on the spray drift of plant protection
554 products: results of a test program carried out throughout the Federal Republic of
555 Germany, Mitteilungen aus der Biologischen Bundesanstalt für Land- und
556 Forstwirtschaft, Berlin-Dahlem. Heft 305.
- 557 Garcerá, C., Cunha, J.P., Moltó, E., Chueca, P., 2012. Measured and predicted drift in
558 pesticide applications of citrus in Spain. Power and Machinery. International
559 Conference of Agricultural Engineering CIGRAgEng 2012: agriculture and engineering
560 for healthier life, Valencia (Spain), 8-12 July 2012 pp. C-1991.
- 561 Garcerá, C., Román, C., Moltó, E., Abad, R., Insa, J.A., Torrent, X., Planas, S., Chueca, P.,
562 2017, Comparison between standard and drift reducing nozzles for pesticide application
563 in citrus: Part II. Effects on canopy spray distribution, control efficacy of Aonidiella

- 564   aurantii (Maskell), beneficial parasitoids and pesticide residues on fruit. Crop Prot. 94,
565   83-96.
- 566   Gil, Y., Sinfort, C., 2005. Emission of pesticides to the air during sprayer application: A
567   bibliographic review. Atmos. Environ. 39, 5183-93.
- 568   Guler, H., Zhu, H., Ozkan, H.E., Derksen, R.C., Yu, Y., Krause, C.R., 2007. Spray
569   characteristics and drift potential reduction with Venturi and conventional flat-fan
570   nozzles. T. ASABE 50 (3), 745-754.
- 571   Heijne, B., Wenneker, M., van de Zande, J.C., 2002. Air inclusion nozzles don't reduce
572   pollution of surface water during orchard spraying in the Netherlands. International
573   advances in pesticide application. Aspects of Applied Biology 66, 2002. 193-200.
- 574   Herbst, A., 2001a. A method to determine spray drift potential from nozzles and its links to
575   buffer zone restrictions. ASAE Annual International Meeting. Sacramento. USA.
- 576   Herbst, A., 2001b. Droplet sizing on agricultural sprays-A comparison of measuring
577   systems using a standard droplet size classification scheme. Proceedings Ilass Europe
578   2001, Zurich, Switzerland.
- 579   Hewitt, A.J., Valcore, D.L., Teske, M.E., Schick, R.J., 1998. Droplet size classification for
580   agricultural sprays. Proceedings Ilass 11th Annual Conference on Liquid Atomization
581   and Spray Systems, Sacramento, CA, 55-59.
- 582   Holterman, H.J., van de Zande, J.C., Porskamp, H.A.J., Huijsmans, J.F.M., 1997.
583   Modelling spray drift from boom sprayers. Comput. Electron. Agr. 19, 1-22.
- 584   Holterman, H.J., 2008. Effects of PDA sampling techniques on spectruml characteristics of
585   agricultural sprays. WUR Plant Research International. P.O. Box 16, 6700 AA.
586   Wageningen.

- 587 Holterman, H.J., 2009. Comparison of 1D PDA sampling methods to obtain drop size and
588 velocity distributions inside a spray cone of agricultural nozzles. WUR-Plant Research
589 International. P.O. Box 616, 6700 AP. Wageningen.
- 590 Holterman, H.J., van de Zande, J.C., 2014. Developing a generic model for spray drift in
591 fruit crop spraying. International Advances in Pesticide Application, Aspects of Applied
592 Biology 122, 2014. p. 255-262.
- 593 Holterman, H.J., van de Zande, J.C., Huijsmans, J.F.M., Wenneker, M., 2016a.
594 Development of a spray drift model for pesticide applications in fruit orchards.
595 International Advances in Pesticide Application, Aspects of Applied Biology 132, 2016.
596 p. 377-384.
- 597 Holterman, H.J., van de Zande, J.C., Huijsmans, J.F.M., Wenneker, M., 2016b. An
598 empirical model based on phenological growth stage for predicting pesticide spray drift
599 in pome fruit orchards. Biosyst. Eng. (2016).
600 <http://dx.doi.org/10.1016/j.biosystemseng.2016.08.016>.
- 601 ISO 3696:1996. Water for analytical laboratory use – Specification and test methods.
602 UNE-EN ISO 3696, 1996. International Organization for Standardization, Geneva.
- 603 ISO 22856:2008. Equipment for Crop Protection - Methods for the Laboratory
604 Measurement of Spray Drift - Wind Tunnels. International Organization for
605 Standardization, Geneva.
- 606 ISO 22866:2005. Equipment for Crop Protection - Methods for Field Measurement of
607 Spray Drift. International Organization for Standardization, Geneva.
- 608 Lešnik, M., Stajniko, D., Vajs, S., 2015. Interactions between spray drift and sprayer travel
609 speed in two different apple orchard training systems. International Journal of
610 Environmental Science and Technology 12, 3017-3028.

- 611 Levene, H., 1960. Robust Tests for Equality of Variances, in: Olkin, I., Ghurye, S.G.,
612 Hoeffding, W., Madow, W.G., Mann, H.B. (Eds.), *Contributions to Probability and*
613 *Statistics: Essays in Honor of Harold Hotelling*. Stanford University Press, Palo Alto,
614 CA, 278-292.
- 615 Meli, S.M., Renda, A., Nicelli, M., Capri, E., 2003. Studies on pesticide spray drift in a
616 Mediterranean citrus area. *Agronomie* 23, 667-672.
- 617 Miller, P.C.H., 1993. Spray drift and its measurement in *Application Technology for Crop*
618 *Protection*, Eds: G.A. Matthews i E.C. Hislop. CAB International. UK.
- 619 Nuyttens D., Baetens K., De Schamphelre M., Sonck B., 2007a. Effect of nozzle type,
620 size and pressure on spray droplet characteristics. *Biosystems Engineering* 97 (3), 333-
621 354.
- 622 Nuyttens, D., Dekeyser, D., De Schamphelre, M., Baetens, K., Sonck, B., 2007b. The
623 effect of air support on droplet characteristics and spray drift. *Comm. Agric. Appl. Biol.*
624 *Sci* 72(2): 71-80.
- 625 Nuyttens D., Taylor W.A., De Schamphelre M., Verboven P., Dekeyser D., 2009.
626 Influence of nozzle type and size on drift potential by means of different wind tunnel
627 evaluation methods. *Biosystems Engineering* 103, 271-280.
- 628 Ozkan, H.E., Reichard, D.L., Zhu, H., Ackerman, K.D., 1993. Effect of drift retardant
629 chemicals on spray drift, droplet size and spray pattern. *Pesticide formulations and*
630 *application systems* 13, 173-190.
- 631 Planas, S., Solanelles, F., Fillat, A., Walklate, P., Miralles, A., Ade, G., Pezzi, F., Val, L.,
632 Andersen, P.G., 1998. Advances on air-assisted spraying on the Mediterranean orchards
633 (fruit, vine and citrus). *EurAgEng Paper* N° 98-A-019. Oslo.

- 634 Planas, S., Solanelles, S., Torrent, X., Camp, F., Gregorio, E., Rosell, J.R., 2013.
635 Comparing standardized methods of potential drift assessment. Suprofruit 2013.
636 Valencia.
- 637 Rautman, D., Streloke, M., Winkler, R., 2001. New basic drift values in the authorisation
638 procedure for plant protection products. Workshop on risk assessment and risk
639 mitigation measures in the context of the authorisation of plant protection products. Eds:
640 R. Foster i M. Streloke. BBA. Heft 383.
- 641 Salyani, M., Miller, D.R., Farooq, M., Sweeb, R.D., 2013. Effects of sprayer operating
642 parameters on airborne drift from citrus air-carrier sprayers. *Agric Eng Int: CIGR*
643 *Journal* 15 (1), 27-36. www.cigrjournal.org.
- 644 Shapiro, S.S., Wilk, M.B., 1965. An analysis of variance test for normality (complete
645 samples). *Biometrika*, 52, 591-611.
- 646 Solanelles, F., Planas, S., Fillat, A., Pifarré, C., 1997. Effect of the volumetric air flow rate
647 and sprayer speed on the reduction of spray drift losses in an apple orchard. Abstracts of
648 the 5th Workshop on Spraying Technique in Fruit Growing. Skierniewice. Polònia.
- 649 Solanelles, F., Fillat, A., Escolà, A., Planas, S., 2001. Effect of air injector nozzles on the
650 spray distribution of a pear orchard. *Parasitica* 57, 61-68.
- 651 Taylor, W.A., Womac, A.R., Miller, P.H.C., Taylor, B.P., 2004. An attempt to relate drop
652 size to drift risk. Proceedings of the International conferenc. Pesticide Application for
653 Drift Management. Washington State university.
- 654 Van de Zande, J.C., van de Porskamp, H.A.J., Michielsen, J.M.G.P., Holterman, H.J.,
655 Huijsmans, J.F.M., 2000. Classification of spray applications for driftability, to protect
656 surface water. *Aspects of Applied Biology* 57, 57-65.
- 657 Van de Zande, J.C., Holterman, H.J., Wenneker, M., 2008. Nozzle classification for drift
658 reduction in orchard spraying: Identification of drift reduction class threshold nozzles.

659   Agricultural Engineering International: the CIGR Ejournal. Manuscript ALNARP 08
660   0013. Vol. X.
661   Van de Zande, J.C., Wenneker, M., Michielsen, J.M.G.P., Stallinga, H., van Velde, P.,
662   Joosten, N., 2012. Nozzle classification for drift reduction in orchard spraying. Aspects
663   of Applied Biology 114, 253-260.
664

POSTPRINT

Appendix A – Meteorological conditions during trials

Table A.1. Meteorological conditions on the spraying time at 7 m height. Mean values (SE). Replicates and values fulfilling ISO 22866:2005 standard (paragraph 5) are indicated in bold typeface.

Trial and nozzle	Replicate	T direction (°C) measurements	RH	Wind speed (%)	Wind direction (m s ⁻¹)	Wind (°)* (%)
1 – Roquetes STN-A	1	10.62 (0.09)	58.58 (0.07)	1.90 (0.03)	-25.54 (0.71)	1.08
	2	10.43 (0.05)	56.24 (0.03)	1.00 (0.01)	-28.25 (0.45)	0.00
	3	7.31 (0.03)	64.35 (0.05)	1.77 (0.02)	-21.33 (0.78)	7.03
	4	9.21 (0.04)	63.22 (0.04)	3.50 (0.05)	-10.07 (0.81)	0.61
	5	7.84 (0.03)	64.26 (0.05)	2.69 (0.04)	-18.96 (0.64)	0.96
1 – Roquetes DRN	1	10.87 (0.05)	58.34 (0.06)	1.68 (0.02)	-31.95 (0.76)	21.88
	2	8.40 (0.11)	60.56 (0.09)	1.75 (0.03)	-23.94 (1.09)	3.21
	3	8.75 (0.01)	61.22 (0.07)	1.07 (0.01)	-26.91 (0.52)	0.00
	4	9.12 (0.03)	63.04 (0.04)	2.44 (0.03)	-9.90 (0.69)	0.58
	5	9.74 (0.04)	62.94 (0.04)	2.63 (0.04)	-9.29 (0.92)	1.32
2- Montserrat STN-T	1	27.62 (0.02)	39.91 (0.04)	3.68 (0.05)	52.25 (1.60)	70.15
	2	18.44 (0.03)	52.73 (0.13)	1.56 (0.01)	8.77 (1.89)	2.90
	3	15.90 (0.01)	28.88 (0.03)	2.88 (0.04)	-40.87 (2.70)	45.49
	4	10.56 (0.02)	44.09 (0.04)	3.25 (0.04)	36.03 (1.70)	22.16
	5	18.03 (0.01)	34.20 (0.03)	2.25 (0.02)	16.15 (1.95)	4.77
2- Montserrat DRN	1	19.19 (0.00)	47.54 (0.03)	1.80 (0.02)	-2.90 (2.07)	2.47
	2	21.50 (0.02)	39.13 (0.06)	2.60 (0.05)	-37.60 (3.91)	28.01
	3	12.73 (0.01)	37.58 (0.05)	3.14 (0.04)	18.63 (1.87)	4.04
	4	16.00 (0.02)	30.89 (0.03)	2.05 (0.03)	35.95 (1.85)	29.90
	5	15.62 (0.02)	39.30 (0.04)	2.28 (0.05)	28.00 (2.88)	19.35

Appendix B - Airborne and sedimenting field deposits

Fig. B.1. Airborne deposit of the 5 repetitions in Trial 1-Roquetes STN-A and DRN nozzles at 5 m (A) and 10 m (B).

Fig. B2. Airborne deposit of the 5 repetitions in Trial 2-Montserrat STN-A and DRN nozzles at 5 m (A) and 10 m (B).

Fig. B.3. Sedimenting deposit (% of sprayed volume) in Trial 1-Roquetes for STN-A and DRN nozzles.

Fig. B.4. Sedimenting deposit (% of sprayed volume) in Trial 2-Montserrat for STN-T and DRN nozzles.