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Garcerá et al.: Effects of drift reducing nozzles on Patricia Chueca

spray distribution and efficacy parameters in citrus

applications against California red scale.

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Comparison between standard and drift reducing nozzles for pesticide application in citrus: Part II. Effects on canopy spray distribution, control efficacy of *Aonidiella aurantii* (Maskell), beneficial parasitoids and pesticide residues on fruit

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15 Abstract

16 Venturi nozzles are often recommended to reduce drift, which is one of the major pollution sources
17 caused by the application of plant protection products on high growing crops. The coarse droplets
18 produced by this type of nozzle could however also affect the spray distribution and therefore the
19 efficacy of pesticide treatments, the population of beneficial parasitoids and levels of residues on
20 fruit. For these reasons, this work aimed at providing scientific evidence of any effect in these
21 parameters when using standard (cone) or drift reducing (Venturi) nozzles for citrus foliar
22 applications against California red scale (CRS) applied with conventional axial fan airblast
23 sprayers. Results showed that Venturi nozzles did not affect efficacy in the conditions of the
24 experiment. Moreover, in general terms, no differences were found in the distribution of the spray
25 deposits over the tree canopy, on levels of residues on fruit or on the effects on the population of
26 parasitoids. All these findings suggest that Venturi nozzles can be regarded as a good alternative to
27 the standard cone nozzles for reducing drift of pesticide applications against CRS in citrus under
28 Mediterranean conditions.

29 **Keywords:** airblast sprayer, California red scale, coverage, chlorpyrifos-methyl, droplet, Venturi
30 nozzle.

31 1. Introduction

32 Pesticide losses are a side effect of chemical crop protection which occurs despite all the efforts
33 of pesticide users and pesticide and sprayer manufacturing industries for improving the
34 applications. Run-off, leaching, evaporation and drift are the source of such losses which may
35 pose risks to the environment and people (sprayer operators, bystanders and residents).
36 Mitigation of these risks is currently a priority for achieving sustainable agriculture (EU,
37 2009a,b).

38 Drift is the portion of the spray that is carried out of the treated area by the action of air currents
39 during the application process (ISO, 2005). It is considered the major pollution source from the
40 application of plant protection products on high growing crops (Morgan, 1981; Raisigl, 1991,
41 Vercruyssen et al., 1999). One solution for reducing drift that is easy to implement by the sprayer
42 operators is the use of Venturi nozzles also known as drift reducing nozzles (DRN). In high
43 growing crops, pesticides are often applied with air-assisted sprayers, usually fitted with
44 standard cone nozzles (STN) that generate a cone of fine droplets. These droplets have a great
45 tendency to drift and evaporate quickly (Fox et al., 1985). In contrast, DRN generate large
46 droplets and limit the production of smaller, drift-prone droplets, and therefore have a lower
47 tendency to drift (Guler et al., 2006). The drift reduction potential of these nozzles has been
48 confirmed in the laboratory, in wind tunnel tests and in fruit trees (Van de Zande et al., 2012;
49 Planas et al., 2013). Moreover, it has been shown that the amount of spray deposited on the

target tree and the pattern of average distribution in the canopy are similar to those of STN, both in citrus (Chueca et al., 2014) and apple trees (Zhu et al., 2006; Derksen et al., 2007; Loquet et al., 2009; Świechowski et al., 2014; Panneton et al., 2015). However, change in droplet size modifies spatial distribution of spray deposition on leaves and fruit, which may affect the level of residues on fruit, which has to be controlled by plant producers to ensure that they do not exceed maximum residue levels established by the European Union (EU, 2004). Furthermore, change of droplet size may also affect the efficacy of plant protection products for controlling targeted pests and diseases. There are various studies dealing with this issue in fruit trees and vines. In almost all of these studies, no differences were found between DRN and STN in the efficacy against a number of pests (European red mite *Panonychus ulmi* Koch, apple rust mite *Aculus schlechtendali* Nalepa, green apple aphid *Aphis pomi* de Geer, grape berry moth *Endopiza vitana* Clemens, mealy bug *Dysaphis plantaginea* Passerini, pear sucker *Eriosoma lanigerum* Hausmann and woolly apple aphid *Cacopsylla pyri* L.) and fungal diseases (apple scab *Venturia inaequalis* Cooke, powdery mildew *Podosphaera leucotricha* Ellis & Everh., downy mildew *Plasmopara viticola* Berk. & Curtis, botrytis *Botrytis cinerea* Pers., apple sooty blotch complex caused by *Peltaster fructicola* Johnson, Sutton & Hodges, *Gaestrumia polystigmatis* Bat., *Leptodontium elatius* Mangelot and other fungi, and summer rots caused by *Colletotrichum* spp. or *Botryosphaeria dothidea*) (Heinkel et al., 2000, 2001; Cross et al., 2002; Knewitz et al., 2002; Frießleben, 2003, 2004; Jaeken et al., 2003; Lešnik et al., 2005; McCartney and Obermiller, 2008; Loquet et al., 2009; Doruchowski et al., 2011, 2016; Bangels et al., 2013; Gil et al., 2014; Panneton et al., 2015). However, some of these authors did find differences between STN and DRN in the control of some pests (apple leaf miner *Leucoptera malifoliella* Zell., green apple aphid, codling moth *Cydia pomonella* Linnaeus, etc) and fungal diseases (apple scab, powdery mildew and flyspeck *Schizothyrium pomi* Mont. and Fr.), for which the STN achieved the highest level of control (Jaeken et al., 2003; Lešnik et al., 2005; McCartney and Obermiller, 2008).

In citrus, Dolera et al. (2012) assessed both the biological efficacy against two-spotted spider mite *Tetranychus urticae* Koch and the sedimenting drift on the ground of a neighbouring orchard. Results showed that DRN decreased drift without detriment to biological efficacy. Discrepancies between studies may be due to differences in pest or disease behaviour and distribution, the droplet spectrum of tested nozzles, air assistance level and direction, weather conditions, mode of action of pesticides, canopy shape and density. As far as authors' knowledge, there are no other studies dealing with this issue in citrus trees, which are characterized by having a globular shape and a very dense canopy. These characteristics may affect drift and the distribution of the spray on the canopy and, therefore, the efficacy of spray applications.

California red scale (CRS), *Aonidiella aurantii* Maskell (Hemiptera: Diaspididae), is a major pest for the global citrus production and is one of the most damaging in Spain (Tena and García-Marí, 2011). It has several features that make it particularly difficult to manage. An important feature is that this insect develops an outer that completely covers its body, protecting it against physical and chemical attacks from the environment. The formation of this shield is progressive and increases its protective capacity as it develops. This implies that individuals have different sensitivity to pesticides depending on their development stage, decreasing sensitivity as development advances (Busvine, 1971). Pesticide applications targeted to early stages (N1 and N2) are the most effective (Rodrigo and García-Marí, 1992; Asplanato and García-Marí, 2001). Moreover, the pest infests all areas of the tree including wood, leaves and fruit, so pesticide applications have to reach all these substrates (Ebeling, 1959). Another feature that makes CRS difficult to control is its preference for areas which initially are difficult to reach with pesticide treatments, such as bud axils and irregularities and cracks in the surface of wood and fruit (Beardsley and Gonzalez, 1975). Furthermore, according to some authors, the need for a good distribution of the product on leaves is critical to controlling this pest, even more than others (Salama and Amin, 1983; Georgala, 1984). It has also to be kept in mind that in Mediterranean conditions, CRS usually develops from late May to September-October when adverse weather conditions for spraying often occur (high temperature and/or low relative humidity). On the other hand, general principles of Integrated Pest Management are compulsory for all European growers since 2014 (EU, 2009b). According to these principles, pesticide application techniques have to be as respectful with natural enemies as possible, so it is important to evaluate the effect of the different techniques on their populations. Regarding natural enemies of armoured scale insects, the main ones are Hymenopteran parasitoids belonging to the Aphelinidae family, particularly the ectoparasitoids of the genus *Aphytis* (Rosen, 1994) and the endoparasitoids of the genus *Encarsia* (Viggiani, 1990). For these reasons, this work aimed at investigating the effect of applying pesticides with DRN on (1) canopy spray distribution, (2) control of CRS, (3) effects on the population of beneficial parasitoids, and (4) fruit residues, under Mediterranean citrus field conditions, in comparison with that obtained with STN, both fitted to airblast axial fan sprayers.

2. Materials and methods

2.1. Experimental orchards

Three trials were conducted during 2014-2015 season on commercial orchards with previous CRS problems. These orchards were located on the most important Mediterranean citrus-growing areas of Spain, Tarragona (Trial 1) and Valencia (Trial 2 and Trial 3). The main characteristics of each orchard are shown in Table 1.

There were big differences in the foliar density between the orchards mainly due to the different cultivars and different pruning practices. Trees in Trial 1 had uniform vegetation within the tree canopy, with a lot of interior small branches and very dense vegetation, similar to the trees in Trial 2; both of these orchards grew clementine varieties. In contrast, orange trees in Trial 3 presented the majority of the foliar mass on the external part of the canopy, with uneven vegetation and lack of leaves in the interior.

Table 1. Characteristics of experimental orchards.

Trial	Location		Plant material	Row direction ¹	Area (ha)	Row distance x Tree spacing (m)	Canopy dimensions (m) (Height x Diameter along row x Diameter across row)	Tree row volume (m ³ TRV ha ⁻¹)	Apparent canopy volume ² (m ³ tree ⁻¹)
	Town	Geographic coordinates							
1	Tortosa (Tarragona)	40° 45' 1.65" N 0° 29' 47.55" E	Clementine cv. Clemenules	East-West (deviated 9° CCW)	1.68	5.7 x 4.0	2.7 x 3.7 x 3.3	15632	16.8
2	Lliria (Valencia)	39° 43' 58" N 0° 35' 32" W	Clementine cv. Clemenules	East-West (deviated 22° CCW)	3.00	6.5 x 3.5	2.7 x 3.7 x 4.7	19523	25.2
3	Ribarroja del Turia (Valencia)	39° 27' 6" N 0° 33' 27" W	Orange cv. Lane Late	North-South (deviated 5° CW)	1.80	6.0 x 4.0	3.1 x 3.8 x 4.1	21183	25.7

¹ CCW= Counterclockwise; CW= Clockwise

² Considering citrus canopy as an ellipsoid

2.2. Treatment and application descriptions

Experiments were conducted to study, under field conditions, the effect of DRN on coverage, efficacy against CRS, effects on the population of beneficial parasitoids and pesticide residue level on fruit. Three treatments were compared: (1) Standard treatment (Treatment applied with standard nozzles) (STN), (2) Drift reducing treatment (Treatment applied with drift reducing nozzles) (DRN) and (3) Control treatment (untreated control). In each trial, four replications were performed.

In Trial 1, a completely randomized design was used, and the assignment of treatments to the plots (experimental units) was performed in a random way, since it was not possible to conduct an estimation of the infestation in the previous season. In Trials 2 and 3, randomized complete block design was used, and treatments were assigned to four replicated plots based on CRS initial density, so that there were no statistically significant differences in the initial infestation between treatments. The initial density of CRS corresponded to densities of CRS at harvest time in the previous season (2013) and was estimated by counting CRS individuals in six fruits per tree on one tree out of every six in each row of the orchard.

The plot size for each trial was adjusted to the size and shape of the corresponding orchard but in all trials it was formed by a certain number of contiguous trees in a number of contiguous

rows. Resulting plot designs for each trial are shown in Figure 1. Eight trees in the centre of each plot were considered as the sample trees (Sample area in each experimental unit) and the outer trees were used as a buffer between different treatments. Buffer trees in plots corresponding to the Control treatment were treated manually, applying the same tank mix of the other plots (Table 3) with spray guns.

Figure 1. Plot size and sample area designs.

Treatments were carried out with the spraying equipment used by the farm. The characteristics of the equipment used in each trial are shown in Table 2.

Table 2. Tractors and sprayers used in each trial.

	Trial 1	Trial 2	Trial 3
Tractor	Same, Frutteto, 90 HP (Treviglio, Italy)	Massey Ferguson, 3655 F, 100 HP (AGCO Iberia S.A., Pozuelo de Alarcón, Spain)	New Holland, TN95NA, 90 HP (Turin, Italy)
Sprayer	Atasa, Abord Special 2000 (Alcantarilla, Spain)	Fede Pulverizadores, Futur 3000 (Cheste, Spain)	Fede Pulverizadores, Futur 1500 (Cheste, Spain)
Nozzle manifold design	14 nozzle outputs (7 on each side)	26 nozzle outputs (13 on each side, divided into two semi-manifolds)	26 nozzle outputs (13 on each side, divided into two semi-manifolds)

Applications to control first and second generations of CRS were carried out in Trials 1, 2 and 3. One more application was needed to control the third CRS generation in Trial 2. The pesticides and the concentrations used in each application are shown in Table 3.

Table 3. Pesticide and concentration used in each application.

Application	Pesticide	Concentration (mL L ⁻¹)
1 st generation	Reldan® E ¹ + Juvinal® 10 EC ²	4.0 + 0.5
2 nd generation	Reldan® E ¹	4.0
3 rd generation	Agroil ³	15.0

¹ active ingredient: 224 g chlorpyrifos-methyl L⁻¹. Dow AgroSciences Ibérica, Madrid, Spain

² active ingredient: 100 g pyriproxyfen L⁻¹. Kenogard S.A., Barcelona, Spain

³ active ingredient: 830 g nC21-oil L⁻¹. Sipcam Inagra, S.A., Valencia, Spain

In Trial 3 a mistaken application, not planned in the experimental design, was done by the farmer against the first generation of CRS with Piritec® (active ingredient: 480 g chlorpyrifos-ethyl L⁻¹. Tradecorp España, Madrid, Spain), at 2 mL L⁻¹, mixed with Orizone® (essential vegetal oils + Zn 2.3% + Mn 1.1%. Nufarm España, S.A., Barcelona, Spain), at 3 mL L⁻¹. This treatment was applied with a volume rate of 3000 L ha⁻¹, with standard nozzles (unidentified), to all the plots including those of the control. This application affected the magnitude of the

infestation in the same way for the three treatments but did not affect the comparison between treatments; therefore it is possible to study the effect of the treatments as it is shown in the results section where pesticide treatments were significantly different to the control treatment.

An application volume rate of about 2500 L ha⁻¹ was used for all treatments. The amount of product to be applied for three dimension crops such as citrus in Spain is usually expressed as a concentration i.e. kg a.i. hL⁻¹. For the review of the Spanish authorization of the product to be used in the tests (Reldan® E) under uniform principles, the pesticide manufacturer did set up 2500 L ha⁻¹ as the maximum acceptable water volume. This was made in order to not overpass the maximum g a.i. ha⁻¹ and, therefore, to accomplish the supported “Good Agricultural Practice” (GAP). For the present study, before the applications, the volume application rates were calculated taking into account the characteristics of the canopy and they should have been 2500 L ha⁻¹ for orchard of Trial 1, 3600 L ha⁻¹ for orchard of Trial 2 and 3400 L ha⁻¹ for orchard of Trial 3 (Chueca et al., 2013). Since all of them were equal or above the maximum supported by the pesticide manufacturer for authorization purposes (2500 L ha⁻¹), this was the application volume selected for all the trials. In Table 4 the volume rate is also expressed in relation to tree row volume (L m⁻³ TRV) to show the influence of orchard parameters.

Before testing, a calibration of the sprayers was conducted to distribute the volume rate in each orchard in the optimal way, taking into account tree spacing and volume, shape and leaf density of the canopies.

The characteristics of the nozzles tested in each orchard, the final volume rate and the operating conditions are shown in Table 4. In each application in each trial, all nozzle holders were fitted with the same nozzle. After calibration, the manifolds of the sprayers were set as shown in Table 5.

Table 4. Characteristics of the STN and DRN used for each treatment in the trials, final application volume and operating conditions.

Trial	Nozzle	Cone	Operating nozzles	Output angle (°)	Working pressure (MPa)	Application volume		Air flow (m ³ h ⁻¹)	Average air outlet speed (m s ⁻¹)	Forward speed (km h ⁻¹)
						(L ha ⁻¹)	(L m ⁻³ TRV)			
1	STN	Albuz ¹ ATR Grey	Hollow	12	80	1	2509	0.16	13667	18.43
	DRN	Albuz ¹ TVI 80 03 Blue	Hollow	12	80	1	2495	0.16		
2	STN	TeeJet ² D6- DC23 Green	Hollow	26	100	1	2483	0.13	67000	29.09
	DRN	Albuz ¹ TVI 80 02	Hollow	26	80	1.1	2532	0.13		

Yellow										
TeeJet ²										
STN	D2-DC56	Full	22	18	1	2506	0.12	69000	29.40	1.58
Black										
Albuz ¹										
DRN	TVI 80 025 Lilac	Hollow	22	80	1	2548	0.12			

¹Saint-Gobain Solcera (Évreux, France)
²Spraying Systems Co. (Wheaton, Illinois)

Table 5. Operating nozzles (Y= Yes/N= No) and angle to the horizontal (°) of each nozzle holder in each trial.

Nozzle	Trial 1		Trial 2		Trial 3	
	STN	DRN	STN	DRN	STN	DRN
1	N	N	Y, 40	Y, 40	Y, 40	Y, 55
2	Y, 40	Y, 40	Y, 40	Y, 40	Y, 25	Y, 35
3	Y, 30	Y, 30	Y, 20	Y, 20	Y, 20	Y, 30
4	Y, 25	Y, 25	Y, 10	Y, 10	Y, 5	Y, 10
5	Y, 25	Y, 25	Y, -10	Y, -10	Y, 0	Y, -10
6	Y, 10	Y, 10	Y, -15	Y, -15	Y, -10	Y, -10
7	Y, 5	Y, 5	Y, 40	Y, 40	N	N
8	-	-	Y, 35	Y, 35	Y, 40	Y, 45
9	-	-	Y, 30	Y, 30	Y, 30	Y, 40
10	-	-	Y, 10	Y, 10	Y, 20	Y, 20
11	-	-	Y, -10	Y, -10	Y, 10	Y, 5
12	-	-	Y, -5	Y, -5	Y, 5	Y, -5
13	-	-	Y, 5	Y, 5	N	N

2.3. Application timing decision

All treatments were applied when the percentage of sensitive stages (N1+N2) reached its maximum in each generation. Weekly samplings of leaves and twigs were performed to identify it. Moreover, the orchard of Trial 1 was part of the network of orchards monitored by the official pesticide application warning system of Catalonia (Plant Health Protection Services - Generalitat de Catalunya). For the first generation, the spray was planned for when sensitive stages (N1+N2) achieved around 60-70% of the total live individuals in the sample. In the second and third generations, it was established when the maximum of sensitive stages represented around 50-60% of the sample, because the distribution of stages is less homogeneous in these generations, due to the fact that life cycle of individuals is less synchronised (Vanaclocha et al., 2009).

In addition, a thermal integral was calculated based on the meteorological data to estimate the population development. A development threshold of 11.7 °C and a mean thermal integral (TI) of around 615 degree days (°D) between the peaks of the different stages (Kennett and Hoffmann, 1985) was considered. Thermal integral was calculated by means of the residual method (Snyder, 1985).

Application time in each trial was determined according to monitoring data of twigs and leaves, thermal integral information and news from warning stations (Table 6).

Table 6. Dates and BBCH phenological growth stage at the treatment applications, fruit sampling for residue assessment and harvest for each trial.

Event		Trial 1	Trial 2	Trial 3*
Applications	1 st generation	2014, June 06; BBCH 71-72	2014, May 29-30; BBCH 72	2014, June 05-06; BBCH 72
	2 nd generation	2014, August 27; BBCH 74	2014, August 11-13; BBCH 78	2014, August 05-07; BBCH 75-76
	3 rd generation	-	2014, October 06-07; BBCH 81	-
Fruit sampling		2014, November 10; BBCH 85-89	2014, November 19; BBCH 85-89	2015, February 04; BBCH 85-89
Harvest		2014, November 15; BBCH 89	2014, November 25; BBCH 89	2015, February 09; BBCH 89

*In Trial 3, the out-of-experiment application was done on 2014, June 07.

2.4. Meteorological conditions

During each application, meteorological conditions were recorded at 2 m above the average height of the tree canopy, that is, around 5 m high, and they included wind speed, wind direction, relative humidity and air temperature. To monitor wind speed and direction, a wind speed sensor (model Watson 8681-WSS, W&S, Hockley, Essex, UK) and a wind direction sensor based on ACE-128 (Bourns, Riverside, US) were used in Trial 1, and a 3D ultrasonic anemometer (model WindMaster 1590-PK-020, Gill Instruments Ltd., Hampshire, UK) was used in Trials 2 and 3. To monitor air temperature and relative humidity, a temperature sensor (model MCP9808, Adafruit Industries LLC, New York, US) and a humidity sensor (model HIH 5030/5031, Honeywell, Golden Valley, MN, US) were used in Trial 1, and a thermo-hygrometer (model LOG32, Dostmann electronic GmbH, Wertheim, Germany) was used in Trials 2 and 3. Applications were made targeting temperatures between 5 °C and 35 °C, and wind speeds between 1 and 3 m s⁻¹. Meteorological conditions during the application of each treatment in each trial are shown in Table 7.

Table 7. Meteorological conditions during the applications (mean values).

TrialApplication moment		Meteorological conditions (mean values)			
		Nozzle	T (°C)	RH (%)	Wind speed (m s ⁻¹) Wind direction (°)*
1	1st generation	STN	21.9	87	1.99 305
		DRN	19.0	97	1.34 289
	2nd generation	STN	26.7	50	0.40 135
		DRN	31.6	50	1.10 90
2	1st generation	STN	24.2	35	2.34 168
		DRN	23.9	43	2.65 205
	2nd generation	STN	27.9	44	2.47 349
		DRN	30.2	57	1.81 171

3rd generation	STN	27.1	42	3.03	230
	DRN	25.2	60	1.48	144
1st generation	STN	29.0	38	1.89	81
	DRN	29.8	32	2.01	102
2nd generation	STN	29.3	65	0.99	39
	DRN	27.8	69	0.91	227

*Direction of the wind coming from North= 0°, East= 90°, South= 180°, and West= 270°

2.5. Spray distribution in the canopy

Spray distribution in the canopy was evaluated through the coverage on leaves in Trials 2 and 3. Coverage was estimated in three trees for each nozzle. In each tree, 72 pieces of 7.6 x 2.6 cm water sensitive paper (WSP) (TeeJet, Spraying Systems Co.) were placed in 18 zones of the canopy after dividing it into three heights (Figure 2A) and six locations per height (Figure 2B). On each zone, four WSP were stapled to four randomly selected leaves, two on the upper side of the leaves and two on the underside.

Figure 2. A) Side view of a citrus tree. Distribution of WSP in height. B) Top view of a citrus tree. Distribution of WSP at each height.

The evaluation of spray coverage was done prior to the application of experimental treatments; therefore water was sprayed during these experiments. A previous study showed that similar coverage on WSP is obtained with both Reldan® and water (Garcerá et al., 2014b). Once the trees were sprayed and the WSP had dried, the pieces were collected and stored in dry conditions. In the laboratory, collectors were photographed, and these images were analysed with specific software (Matrox Inspector, v.2.2, Matrox, Dorval, Canada) following the methodology described by Chueca et al. (2010). On each image, the programme calculates the coverage (%) (Percentage of the total surface covered by the impacted droplets).

Once the estimated coverage of each WSP was obtained, the mean coverage of locations 1 to 3 and 4 to 6 were calculated at the three heights, thereby obtaining the value of the coverage at two depths in each height. To study the effect of the nozzle on the coverage, as well as the side of the leaf, at the different levels of height and depth, a two-way analysis of variance (ANOVA) was performed at each combination of height and depth after arcsine square root (x)

transformation of the data. To facilitate understanding of the results, untransformed data is shown in the corresponding graphics. The Fisher's LSD test (Fisher, 1935) was used for mean comparisons.

2.6. Study of the biological efficacy of treatments

The efficacy of each treatment was evaluated by estimating the level of infestation in fruit 45 days after the treatment (DAT) against the first generation, 45 DAT against the second generation and just prior to harvest of 2014 season fruit (Table 6), once the majority of fruit had reached optimum size and colour. In Trial 1, an extra sampling was performed 75 DAT against the first generation, 7 days before the treatment against the second generation, because the infestation level on fruit in the first sampling was very low. In Trial 3, the sampling at 45 DAT against the second generation was not performed because a very low infestation was observed on fruit.

The level of infestation was estimated by counting the number of scales present in 960 fruits per treatment, counting all the stages present in each fruit, without ripping it out from the tree. These fruits were selected from the 8 sample trees of each plot, at a rate of 30 fruits per tree. During the season, the 30 fruits were chosen at random, while at harvest, they were selected from 10 different zones in which the canopies were divided. These zones resulted from dividing the canopy into two heights (Figure 3A) and five locations per height (Figure 3B). Locations 3 and 4 were at 0° spray angle and locations 1 and 2 were at 90° spray angle. Location 5 was the interior of the canopy. The cardinal direction of locations 1 to 4 was different for each orchard depending on the row orientation of the orchard. The evaluation of CRS was carried out in these zones because CRS has different preferences of tree location (Alexandrakis and Michelakis, 1980; Carroll and Luck, 1984) and it is known that the distribution of the spray in the canopy of applications with airblast sprayers is not homogeneous (Derksen et al., 2007; Jamar et al., 2010). Three fruits were randomly selected from top height of each location 1 to 4, and two fruits from the bottom height of each location, respectively. Five fruits were randomly selected from each height of location 5.

Figure 3. A) Side view of a citrus tree. Height zones to select fruit. B) Top view of a citrus tree. Zones at each height to select fruit.

The number of CRS individuals in each fruit was counted, with no distinction of stages or conditions (alive, dead, or parasitized). Fruit infestation by Diaspididae is usually evaluated by the percentage of fruit with a certain number of scales, equivalent to the frequently adopted commercial cull threshold. That is the reason why the percentage of fruit with no scales, the percentage of fruit with 1 to 3 scales, the percentage of fruit with 4 to 10 scales and the percentage of fruit with more than 10 scales was also calculated at harvest (according to a restrictive criteria (>3 scales per fruit) (EPPO, 1997; Vacas et al., 2009), an indulgent criteria (>10 scales per fruit) (Costa-Comelles et al., 1999; Grafton-Cardwell et al., 2009), and an intermediate one (4-10 scales per fruit)).

To test the efficacy of the treatments, four different parameters were analyzed.

First, the number of scales per fruit was studied using Dunnett's test (Dunnett, 1955) in order to determine whether pesticide treatments differed significantly from the Control treatment in each orchard and each sampling date. A significant difference would indicate that they could be considered effective.

Next, to study if the progression of this parameter through the season was different between treatments, multifactor ANOVA tests of the infestation level were performed in each orchard using *Treatment* and *Sampling date* as factors. Moreover, to study if there were differences between treatments in each sampling date in each orchard, a simple ANOVA test of the infestation level in each date was performed using *Treatment* as factor.

Next, the percentage of occupied fruit at the different levels (0, 1-3, 4-10, >10 scales per fruit) at harvest was analyzed using ANOVA after arcsine square root (x) transformation of the data and using *Treatment* as factor. To facilitate understanding of the results, untransformed data are shown in Figure 6.

Finally, the distribution of the pest within the tree at harvest was evaluated, and the effect of the nozzle and the location within the tree was studied with multifactor ANOVA tests of the number of scales per fruit at harvest in each orchard with *Treatment*, *Orientation* and *Height* as factors.

In all of the ANOVA tests, the Fisher's LSD test (Fisher, 1935) was used for mean comparisons, the assumption of normal distribution of data was assessed using the Shapiro-Wilk test (Shapiro and Wilk, 1965), and the assumption of homoscedasticity using Levene's test (Levene, 1960).

In all tests, a confidence level of at the 95% was applied.

2.7. Effects on the population of beneficial parasitoids

In order to assess the influence of the pesticide applications with the different nozzles on the population of Aphelinidae parasitoids, a non-scheduled monitoring was performed in Trial 1. The development of the population of adult stages of Aphelinidae parasitoids, mainly *Aphytis*

melinus DeBach (Hymenoptera: Aphelinidae) was monitored every 10 days approximately, between the 30th of May and the 17th of October. Yellow sticky traps (15 cm x 15 cm) were placed on the central tree of each plot, attached to the external South face of the canopy, at a middle height (1.5 m approximately).

From the monitoring data, the ratio of parasitoids trapped per day was calculated. With these data the dynamics of Aphelinidae related to CRS development was studied in the control plots. In addition, a one-way ANOVA analysis was run using *Treatment* as factor. Each sampling date was studied independently. The Tukey's HSD test was used for mean comparison. In all tests, a confidence level of 95% was utilized.

2.8. Chlorpyrifos-methyl and pyriproxyfen residue levels on fruit

The amount of chlorpyrifos-methyl and pyriproxyfen residues on fruit (ppm) were measured around 5 days prior to harvest (Table 6). Each fruit sample should be at least of 1 kg of fruit per replication. Therefore, 2 fruits per tree from six trees were picked in the clementine orchards (12 fruits) (Trials 1 and 2) and 2 fruits per tree from four trees were picked in the orange orchard (8 fruits) (Trial 3). Fruit was selected from the medium height and the outer canopy, which is the area most exposed to applications (worst case scenario).

Fruit was kept refrigerated until their arrival to the laboratory. They were then macerated and kept at -18 °C until extraction (13 days for fruit of Trial 1, and 3 days for fruit of Trials 2 and 3). The extraction and determination of residues were done as described by Cherta et al. (2013). Extracts were kept at -18 °C until determination, which was performed by means of liquid chromatography coupled to mass spectrometry with triple quadrupole type detector (UPLC / Xevo TQ-S) with experiment type Multiple Reaction Monitoring quantification by using pattern with straight white matrix patterns.

The effect of *Treatment* on residue level was studied by an ANOVA analysis and the Tukey's HSD test (Tukey, 1953; Kramer, 1956, 1957) was used for mean comparison. In all tests a confidence level of 95% was applied.

3. Results

3.1. Spray distribution in the canopy

Independent of the nozzle used, coverage was higher in the outer part of the canopy than in the inner part at the three heights in both orchards (Trials 2 and 3) (Figure 4). Moreover, the highest coverage was achieved at the bottom of the tree, while the lowest was achieved at the top.

The effect of the nozzle on coverage was significant only in some locations of the tree in Trial 2 ($P_{\text{Top Inside}} = 0.0099$; $P_{\text{Middle Inside}} = 0.0342$; $P_{\text{Middle Outside}} = 0.0489$; $P_{\text{Bottom Inside}} = 0.0063$; $P_{\text{Bottom Outside}} = 0.0432$) (Figure 4), and in those cases DRN achieved higher coverage. In Trial 3, the nozzle

did not have any significant effect on coverage. There was no significant interaction between nozzle and leaf side in any orchard or any combination of depth x height, which means that the effect of the nozzle did not depend on the side of the leaf in any case.

In Trial 2, there were significant differences between the sides of the leaves at the middle height ($P_{\text{Middle Inside}} = 0.0047$; $P_{\text{Middle Outside}} = 0.0084$), with higher coverage on the front side of the leaves for both nozzles. In Trial 3, differences between leaf sides were found only at the bottom height ($P_{\text{Bottom Inside}} < 0.0001$; $P_{\text{Bottom Outside}} = 0.0008$), with higher coverage on the front side for both nozzles as well.

Figure 4. Coverage (%) on WSP achieved with each nozzle at each height, depth and leaf side (mean ± SE) in Trials 2 and 3. In each orchard, means within each combination height x depth with different letters are significantly different; asterisk tags the side of the leaf with significantly higher coverage (LSD test, $P < 0.05$).

3.2. Biological efficacy of treatments

3.2.1. Infestation level and development of the pest through the season

In all the trials, there was a significant reduction in the infestation level in the treatments with pesticide applications compared to the Control, independent of the level of infestation, and independent of the application technique used.

In Trial 1 (Figure 5A), there were significant differences between the pesticide application treatments (DRN and STN) and the Control (Dunnnett test, $P < 0.0001$) on the second ($P = 0.0626$) and the fourth sampling dates ($P = 0.0508$). They did not differ from the Control on the first and third sampling dates. No statistical differences between DRN and STN treatments were shown at any sampling date.

In Trial 2, the number of scales per fruit for the treatments with pesticide applications differed significantly from the Control on the second and third sampling (Dunnnett test, $P < 0.05$) (Figure 5B). The development of the number of scales per fruit through the samplings in Trial 2 significantly differed between treatments ($P < 0.0001$) (Figure 5B). Differences between treatments with pesticide application and the Control treatment increased with time, showing a very fast CRS infestation over the untreated fruit. At the time of the first sampling, fruit was very small ($\varnothing \approx 1\text{-}2\text{ cm}$), so migration of scales from twigs and leaves to fruit had not taken place yet. In fact, all the treatments showed very low values. In the second and third samplings, no statistical differences between treatments with pesticide application were found, but they differed from the Control ($P_{\text{Second sampling}} = 0.0001$; $P_{\text{Third sampling}} = 0.0003$).

In Trial 3 (Figure 5C), the trend was similar to Trial 2, which means that the development of the number of scales per fruit through the samplings significantly differed between treatments ($P = 0.0130$), in such a way that infestation on control trees grew much faster than for treated trees, but with a much lower number of scales per fruit at harvest than in Trial 2. It should be kept in mind that in Trial 3 an extra application against the first generation of CRS was performed with chlorpyrifos-ethyl in all plots including control plots. This may have decreased the CRS population from the beginning. Even so, it was observed that differences between trial treatments with pesticide application and the Control persisted.

Figure 5. Development of the number of scales per fruit (mean±SE) through the samplings for each treatment in A) Trial 1, B) Trial 2, and C) Trial 3. In each orchard, means within each sampling date with different lower case letters are significantly different (Capital letters indicate the treatments: C= Control, L= DRN, S= STN).

Regarding the percentage of occupied fruit at harvest (Figure 6), in Trial 1, there was not a significant difference between the treatments in the percentage of fruit infested with 1-3 scales ($P_{1-3 \text{ scales}} = 0.6137$). In the rest of the studied classes (0 scales, 4-10 scales and >10 scales), there were no differences between nozzles, but there were with the Control treatment ($P_{0 \text{ scales}} = 0.0773$; $P_{4-10 \text{ scales}} = 0.0151$; $P_{>10 \text{ scales}} = 0.0923$). Both pesticide treatments showed significantly higher percentage of fruit with no scales and lower percentage of fruit with 4 or more scales than the Control treatment.

In Trial 2, there were no significant differences between nozzles, and they differed significantly from the Control for all studied classes ($P_{0 \text{ scales}} = 0.0003$; $P_{1-3 \text{ scales}} = 0.0020$; $P_{4-10 \text{ scales}} = 0.3417$; $P_{>10 \text{ scales}} < 0.0001$). Pesticide treatments showed a higher percentage of fruit with no scales and with 1-3 scales than the Control treatment. However, the percentage of fruit with 4-10 scales and with more than 10 scales for the Control treatment was higher than for the pesticide treatments.

In Trial 3, there were no significant differences between treatments in the percentage of fruit with no scales and with 1-3 scales at harvest time ($P_{0 \text{ scales}} = 0.5703$; $P_{1-3 \text{ scales}} = 0.5734$), but it is worth noting that pesticide treatments showed a higher average percentage. Regarding the percentage of fruit with 4-10 scales and with more than 10 scales, significant differences were found between pesticide treatments and the Control treatment, and no differences were found between nozzles ($P_{4-10 \text{ scales}} = 0.0750$; $P_{>10 \text{ scales}} = 0.0176$).

Figure 6. Percentage of fruit with no scales (□), infested with 1-3 scales (▤), infested with 4-10 scales (▥), and infested with more than 10 scales (■) (mean±SE) for the Control, DRN and STN treatments in Trial 1, Trial 2, and Trial 3 at harvest.

3.2.2. Distribution of the pest in the canopy at harvest

In Trial 1, the interaction between 'Treatment' and 'Orientation' was significant ($P_{\text{Treatment} \times \text{Orientation}} = 0.0229$). The distribution of the pest within the canopy at harvest of STN and DRN treatments was similar but they differed from the Control treatment (Figure 7A).

The south facing side of all treated trees had significantly more infestation than the north facing side and the tree interior showed lower numbers of scales per fruit than the external zones (Figure 7A). Regarding the distribution in height, the top area showed the highest levels of CRS for all the treatments ($P_{\text{Height}} = 0.0006$).

In Trial 2 the distribution was similar for pesticide treatments but they differed significantly from the Control treatment ($P_{\text{Treatment} \times \text{Orientation}} = 0.0003$) (Figure 7B). Comparing CRS distribution at differing heights, it was observed that at the bottom of the canopy, infestation

was the lowest, for every treatment, even though differences between heights were not significant. The Control treatment showed the highest infestation in the southern face of the trees, both at the top and the bottom of the canopy. The sides between trees within the row, that is, 90° spray angle sides (East and West) showed the second highest infestation, very similar to that found in the interior of the canopy. The northern face showed the lowest infestation. In contrast, scale infestations of treatments with STN and DRN did not significantly differ in the different locations.

In Trial 3, even significant differences were found between treatments ($P_{\text{Treatment}} < 0.0001$), with the Control trees showing higher levels of infestation than the pesticide treatments in all the areas, the distribution of the infestation within the tree was not significantly different between them, since the interactions '*Treatment x Height*' and '*Treatment x Orientation*' were not significant. Moreover, there were no significant differences between the different locations, regardless of the treatment, since the simple effects '*Height*' and '*Orientation*' were not significant as well, maybe due to the low infestation by CRS (Figure 7C).

A

B

C

Figure 7. Distribution of the pest (mean number of scales per fruit $\pm$ SE) at two canopy heights (Top and Bottom) and five orientations (N: North, S: South, E: East, W: West, I: Inner) for the Control (□), DRN (■) and STN (▨) treatments in A) Trial 1, B) Trial 2 and C) Trial 3 at harvest time.

3.3. Effects on the population of beneficial parasitoids

The number of trapped adult individuals per day was lower in the treated plots than in the Control, with no significant differences between DRN and STN treatments for almost all the dates (Figure 8). Unexpectedly, just after the first application, parasitoid population dynamics showed significantly higher values in treated plots (STN and DRN) than in untreated control plots ($P = 0.0002$). This is most likely because the chromatic traps were removed just after the application to count trapped individuals. At that moment, the number of flying individuals was

high, probably because parasitoids were flying away from pesticide treatments and because of sprayer fan turbulence, and so the number of trapped individuals increased. In the second application, the procedure was changed and all traps were collected just before the application. This must be why Aphelinidae population was higher in the pesticide treated plots than in the control plots just from 25 days after the first application onwards. After that date, the trend was the opposite.

Figure 8. Parasitoids dynamics during 2014 season: Aphelinidae per trap and day (mean ± SE). In each sampling date, different letters indicate significant differences (Tukey's HSD test, P < 0.05).

It has to be taken into account that instead of the percentage of parasitism, the number of adult Aphelinidae individuals was assessed. Therefore, Aphelinidae population decrease observed on pesticide treatments was not only due to the side effects of pesticides on Aphelinidae themselves but also to the reduction of the hosts.

3.4. Chlorpyrifos-methyl and pyriproxyfen residue level on fruit

In all trials, independently of the nozzle used, fruit residues were under the maximum residue level (MRL) established by the European Commission (Table 8b); it also has to be considered that the analyzed fruit was that from the worst-case scenario positions, expected to have the highest residue levels in the tree.

Both clementine trials (Trials 1 and 2) had a similar trend on residue levels, without significant differences between DRN and STN (Table 8a). In contrast, Trial 3 had higher chlorpyrifos-methyl residues in DRN treatment than in STN one.

Table 8. a) Residue levels (ppm) of chlorpyrifos-methyl and pyriproxyfen at harvest for each treatment in each trial (mean ± SE). In each trial, means within each active ingredient column with different letters are significantly different (Tukey's HSD test, P < 0.05); b) Current Maximum Residue Level (MRL) (ppm) of chlorpyrifos-methyl and pyriproxyfen in oranges and mandarins established by the European Commission.

Parameter	Plant material	Trial	Treatment	Chlorpyrifos-methyl (ppm)	Pyriproxyfen (ppm)
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Residues	Mandarin	1	Control	0.0010 ± 0.0000 b*	0.0001 ± 0.0000 b
			DRN	0.1801 ± 0.0120 a	0.0101 ± 0.0010 a
			STN	0.1637 ± 0.0100 a	0.0108 ± 0.0020 a
		2	Control	0.0232 ± 0.0120 b	0.0002 ± 0.0000 b
			DRN	0.2225 ± 0.0180 a	0.0274 ± 0.0030 a
			STN	0.2846 ± 0.0200 a	0.0310 ± 0.0070 a
	Orange	3	Control	0.0045 ± 0.0010 c	0.00001 ± 0.0000 b
			DRN	0.1716 ± 0.0220 a	0.0024 ± 0.0007 a
			STN	0.0869 ± 0.0160 b	0.0017 ± 0.0009 a
MRL	Mandarins	-	-	1.0**	0.6***
	Oranges	-	-	0.5**	0.6***

*Under quantification detection limit

**Established by Regulation (EC) No 839/2008 (01/09/2008)

*** Established by Regulation (EU) No 737/2014 (30/07/2014)

4. Discussion and conclusions

This study emphasizes the advantage of the use of the tested DRN instead of STN during pesticide applications with axial fan airblast sprayers in citrus orchards, since drift was reduced (Torrent et al., 2016) and CRS control efficacy was not compromised under the conditions of the experiments. Regarding the distribution of the spray in the canopy, in general, it was observed that the use of DRN increased mean coverage in the canopy, which is in accordance with the findings of other authors (Heinkel et al., 2002; Knewitz et al., 2002; Jaeken et al., 2003; McArtney and Obermiller, 2008; Doruchowski et al., 2011; Panneton et al., 2015). DRN achieved the same or higher coverage in the canopy than STN in all trials, although differences were only statistically significant in certain cases and at different locations inside the canopy, which could be caused by differences in foliar density, canopy size and pruning (Stover et al., 2002). In general, DRN achieved higher coverage in the clementine orchard (Trial 2). In the orange orchard (Trial 3), nozzles had no effect on coverage. This could be because bigger droplets coming out from DRN penetrated more easily the high foliar density mandarin trees than smaller droplets from STN. On the contrary, orange trees showed lower foliar density and both nozzles penetrated in a similar way. This could be because bigger drops have higher inertia and will not follow airflow contouring around obstacles to the extent smaller droplets will do (Jaeken et al., 2003). The distribution pattern of the spray in the canopy showed a similar trend for both nozzles in both trials, which means that the sprayer-induced differences in the tree zones were more important than the ones induced by the nozzles, as Jaeken et al. (2003) also found. Moreover, the distribution pattern corresponded with that usually achieved with axial fan airblast sprayers, reducing coverage with increasing height and depth (Derksen et al., 2007; Jamar et al., 2010).

The distribution of the pest in the canopy in untreated Control trees corresponded to the preferred location of the pest. CRS shows negative geotropism, which means that larvae tend to move against gravity and that they preferably locate on the top of the tree (Flanders, 1952; McLaren, 1971;

Orphanides, 1984). Moreover, CRS larvae also show positive phototropism and influence of insolation, which means a directional response to thermal gradients and a preference to go towards the light, to the exterior of the tree (Bodenheimer, 1951; Tashiro, 1966; Alexandrakis and Michelakis, 1980; Carroll and Luck, 1984). This reason can also explain the preference of CRS to specific orientations of the canopy depending on the weather conditions within the season. Since outer coverage was higher than inner one for both DRN and STN, the effect of the treatments changed the distribution of the pest by decreasing the differences of infestation between the exterior and the interior of the canopy. Differences of coverage between top and bottom were lower than differences in depth. Therefore, pesticide applications could not compensate for the natural distribution in height. Moreover, the general absence of differences in coverage between nozzles, with higher values for DRN, could explain the absence of differences in efficacy against CRS between treatments with STN and DRN in all three trials, differentiating them from the Control treatment. This happened with the different parameters used to assess the biological efficacy (number of scales per fruit, development of the number of scales per fruit through the season, percentage of fruit with the different number of scales and distribution of the pest in the tree at harvest). It is important to highlight that the lack of efficacy differences between nozzle treatments may also indicate that the lowest level of spray deposition and/or coverage achieved with any treatment was enough to control the pest, and that no higher spray deposition values were necessary, which is in accordance with the findings of Garcerá et al. (2011).

Differences between trials in the different parameters could be due to different factors such as weather conditions, crop features, operative characteristics, sprayer set-up and CRS initial infestation level in the orchard. Garcerá et al. (2014a) found that CRS pressure in an orchard directly influenced the level of infestation of treated trees. In the present study, Trial 2, with the highest infestation on the control trees, also showed the highest infestation on treated trees, but also the highest absolute differences of infestation between the pesticide applications and the Control. Moreover, Frießleben (2004) found that the greatest fluctuations on efficacy of DRN with respect to STN, both positive and negative, could be found in the cases where less than 80% of absolute efficacy was achieved. This fact is also observed in this work, where the Trial 2, with the highest efficacies, showed the lowest differences in efficacy between DRN and STN when comparing all the trials. In the case of Trial 3, all the parameters were influenced by the chlorpyrifos-ethyl application on the first generation, which decreased the total pest pressure in the whole orchard.

It is important to highlight that a level of coverage on WSP of around 40-50% is considered enough to control the most sensitive stages of CRS when applying Reldan® E alone (Garcerá et al., 2011, 2014a). This level was mostly achieved on the outside of the canopy with both nozzles, although in the inside of the canopy this level was only obtained at the bottom. However, it should be taken into account that the chlorpyrifos-methyl-based product was applied together with a pyriproxyfen-

based product against the first generation, so the minimum necessary coverage could be lower than when applying the chlorpyrifos-methyl-based product alone.

As stated before, other authors also found no effect of DRN on efficacy against some pests and diseases on other crops apart from citrus (mainly apples and vineyards) (Heinkel et al., 2000, 2001; Cross et al., 2002; Knewitz et al., 2002; Frießleben, 2003, 2004; Jaeken et al., 2003; Lešnik et al., 2005; McArtney and Obermiller, 2008; Loquet et al., 2009; Bangels et al., 2013; Gil et al., 2014; Panneton et al., 2015; Doruchowski et al., 2016), and also in citrus (Dolera et al., 2012). However, some of them did find nozzle effects in various cases. McArtney and Obermiller (2008) found differences between nozzles in the control of a fungal disease, flyspeck, after a long season fungicide program, with higher incidence of the disease where DRN had been used. First, these authors found that there was an interaction between across-row wind speed and nozzle on coverage, but no information on wind speed is provided during the applications of the spray program performed for the biological efficacy assessment, so no information on coverage achieved during these applications is provided. Lešnik et al. (2005) found better results with STN for some apple pests (codling moth, apple leaf miner). They give no information on the distribution of the products in the tree, moreover they used the same volume for the whole season, when apples are deciduous trees and canopy characteristics change. On the other hand, the authors only highlight that most of the sprays were performed in appropriate meteorological conditions (wind speed less than 3 m s^{-1} and relative humidity between 60-70%), with no information on when these conditions were or were not attained. Finally, authors affirm that orchards suffered high temperatures and low relative humidity, which could have had great impact on pesticide efficacy and the duration of action of the mixtures. Jaeken et al. (2003) only found worst results with DRN in comparison to STN against one fungal disease, powdery mildew, in one of the two years of experimentation, when applying a mesostemic fungicide. The authors focused on the high infection of shoots in the top of the canopy and the lowest spray deposition achieved on that area, which made that the infection spread to the whole tree. As it can be seen, main differences between nozzles are found when applying fungicides. So these results could not be extrapolated to pesticide applications because fungicides have different modes of action in comparison to pesticides, fungal diseases behave differently to insects and moreover, as far as the authors are aware, there is no scientific literature on the requirements of spray deposition or coverage of fungicides, compared to those of pesticides. On the other hand, fungicide applications use to be performed following a whole season program, and many factors could affect their performance, mainly changes in foliar density and meteorological conditions during each application, which could affect DRN and STN differently.

Additionally, in the present study, no effect of nozzles on residue levels of chlorpyrifos-methyl and pyriproxyfen on fruit at harvest was found in clementine trials, as Doruchowski et al. (2011) and Poulsen et al. (2012) found with fungicides applied to apple trees. In the orange trial (Trial 3), DRN showed significantly higher residue level of chlorpyrifos-methyl than STN. This could be

because orange fruit has larger size than mandarins, and small droplets have a bigger relative surface and thereby they are more susceptible for degradation due to sunlight or evaporation (Poulsen et al., 2012). More studies would be necessary to evaluate if this would happen systematically as for example did not happen for pyriproxyfen. Nevertheless, in all the trials residue levels were well below the MRLs even though fruit samples for residue determination was taken from the middle height of the 0° spray angle face of the trees that is the most exposed to pesticide in the tree canopy (= worst case scenario).

Moreover, in the present study, interestingly, no differences on beneficial Aphelinidae populations were observed between STN and DRN treatments, but they differed from the untreated control. A similar trend was observed in the study carried out in apples by Panneton et al. (2015) where no differences on Stigmaeidae and Phytoseiidae populations were found between nozzles.

In conclusion DRN have been found to be a viable solution to reduce drift (Torrent et al., 2016) without compromising efficacy of pesticide applications against CRS in citrus under Mediterranean conditions, achieving similar number of scales per fruit, development of the number of scales per fruit through the season, distribution of the pest in the canopy and percentage of un-infested fruit or infested fruit with more than 3 scales or more than 10 scales at harvest. Furthermore the use of DRN did not affect the residue levels nor the population of Aphelinidae natural enemies. All these reasons together with its ease for farmer implementation make DRN a technology to be recommended in citrus orchards for pesticide application to achieve a more sustainable pesticide use in this crop.

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