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The Ecorobotix ARA spot sprayer detects weeds and crops and sprays only the desired target using nozzles with a small top angle. The design of the Ecorobotix ARA is similar to the shielded bed sprayer, which is listed as a 95% drift reducing technology on the Dutch DRT-list. A condition of the shielded bed sprayer is to use spray nozzles with a medium (M) or coarser spray quality. Drop size measurements using the ISO 25358 reference threshold nozzles show that the (often) used Euspray IC1012 spot spray nozzle has the required droplet size M up to 2.5 bar spray pressure and the Euspray IC1X502 nozzle until 2.0 bar spray pressure. A technical performance comparison has been made between the Ecorobotix ARA and the remaining conditions of the shielded bed sprayer in a full-field spraying scenario. The conditions which are not similar between the machines individually all have a positive effect on the reduction of spray drift. The expectation is therefore that the amount of spray drift reduction of the Ecorobotix ARA sprayer is equal to or higher than the shielded bed sprayer.

Keywords: sprayer, drift, spot spraying.

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Contents

1 Introduction

The Ecorobotix ARA spot sprayer detects weeds and crops with cameras and sprays only the target on the desired location. Artificial lighting is used to optimise target detection. To block sunlight a cover is installed around the cameras and spray boom. The design of the Ecorobotix ARA spot sprayer is similar to the shielded bed sprayer. A technical comparison is made in this report to compare the Ecorobotix ARA spot sprayer with the shielded bed sprayer and assess its impact on spray drift. The comparison is based on a worst-case full field spraying scenario as spot spray itself is currently not classified as a drift reduction technology.

Based on field spray drift measurements with a shielded bed sprayer in comparison with a reference sprayer, the shielded bed sprayer is classified as a 95% drift reduction technology (Porskamp *et al*., 1997; TCT, 2023). The shielded bed sprayer was designed to spray beds with a width of 1.2 meter with flower bulbs. Underneath the cover of the bed sprayer three nozzles were mounted with a height of 35 cm above the crop. In the centre of the cover a TeeJet XR 110-04 was installed and at both sides an TeeJet UB8504 end nozzle.

The shielded bed sprayer is described as follows on the DRT list, see Figure 1.

Driftreducerende spuittechniek	DriftReducerende Techniek-klassen (DRT-klassen)					Druk-registratie-voorziening	Nr. informatie-blad
	75%	90%	95%	97,5%	99%		
Overkapte beddenspuit (tunnelspuit voor beddenteelt) + spuitdoppen ten minste druppelgrootte M + kantdop aan beide kanten van de spuit ten minste druppelgrootte M						Nee	12

Figure 1 *Description of the shielded bed sprayer on the DRT-list (TCT, 2023).*

The following conditions apply for the 95% DRT class of the shielded bed sprayer (TCT, 2018):

- Spray nozzles with medium (M) spray quality or coarser, for which the maximum spray pressure as indicated by the nozzle manufacturer is not exceeded.
- An end nozzle with droplet size medium (M) or coarser, for which the maximum spray pressure as indicated by the nozzle manufacturer is not exceeded.
- The spray nozzles are mounted underneath a cover.
- The top angle of the spray nozzles is 110° or 120°.
- The nozzle spacing is equal to the height of the nozzles above the crop or soil.
- The cover is designed in a way that the sprayed width is almost fully covered.
- Both sides of the cover (parallel to the crop rows) are closed with a minimal distance between cover and ground.
- At the front and back of the cover a provision is installed to reduce the distance as much as possible.
- An end nozzle is installed at both sides of the cover with a spray rate equal to the spray nozzles.

This report consists of drop size measurements to determine the droplet size spectrum of the spot spray nozzles according to ISO 25358 and a technical performance comparison of the remaining conditions.

2 Drop size measurements

The nozzle types Euspray IC1012 and IC1X502 of the Ecorobotix ARA sprayer were measured in the Phase Doppler Particle Analyser (PDPA) setup of Wageningen Plant Research in order to determine their droplet size spectrum classification according to ISO 25358, see Figure 2.

Figure 2 *Nozzle types Euspray IC1012 (left) and IC1X502 (right).*

2.1 Liquid flow rate

For both nozzle types, the flow rates of ten nozzles were measured at 3 bar spray pressure and the three nozzles with a flow rate closest to the median flow rate were selected for further measurements, see Table 1.

Table 1 *Measured flow rates of 10 new nozzles and selection of 3 closest to the median flow rate for the candidate nozzles at 3 bar liquid pressure.*

Nozzle type	**Nozzle number and flow rate [ml/min]**										**Median [ml/min]**	**Selected nozzles**
	1	2	3	4	5	6	7	8	9	10		
IC1012	393	405	390	400	398	390	398	410	395	403	398	4 5 7
IC1X502	230	228	218	235	228	223	210	225	220	220	225	5 6 8

2.2 Drop size distribution

A pre-measurement was done at 2, 2.5 and 3 bar liquid pressure in order to determine whether the nozzles have the potential to be in the ISO25358 spray quality classification medium (M). In order to achieve this, the candidate nozzle pressure combinations should be coarser than the reference threshold nozzle for the Fine/Medium classes and finer than the reference threshold nozzle for the Medium/Coarse classes. The reference threshold nozzles are defined in ISO 25358 with the TeeJet TP11003-SS at 3 bar liquid pressure as reference nozzle for F/M and the TeeJet TP 11006-SS at 2 bar liquid pressure as reference nozzle for M/C (ISO 25358, 2018). For the Euspray IC1012, 2.5 bar liquid pressure was selected and for the Euspray ICIX502, 2 bar was selected. The selected nozzles were measured according to the procedure of ISO 25358, which means for example that the three selected nozzles were measured in three replications. The BCPC F/M (Southcombe *et al*., 1997) reference threshold nozzle was measured as well as internal validation of the measurement setup. The characteristics of the reference threshold nozzles and candidate nozzles are shown in Table 2. More details of individual measurements can be found in Annex 2.

Table 2 *Characteristics of the measured drop size distributions, average droplet velocity and number of drops in each measurement. The reference nozzles are included. Measured using a PDPA.*

Nozzle type	Pressure [bar]	D_{V10} [µm]	D_{V50} [µm]	D_{V90} [µm]	V_{100} [%]	v_{avg} [m/s]	Drop count
BCPC F/M	3.0	119.4	224.6	364.7	5.57	4.04	33000
ISO 25358 F/M	3.0	127.3	247.8	397.0	4.65	4.12	30394
ISO 25358 M/C	2.0	169.2	351.8	570.4	2.01	4.39	22882
IC1012	2.5	129.9	254.6	377.5	4.05	5.86	23618
IC1X502	2.0	149.0	250.2	356.8	2.35	5.91	17008

2.3 Nozzle classification according to ISO 25358

For both candidate nozzles, the average D_{V10} and D_{V50} are larger than the values of the reference nozzle F/M. The average D_{V90} values for the candidates are however smaller than the average of the reference nozzle F/M. ISO 25358 states that in the case that two (D_{V10} and D_{V50}) out of three parameters are larger, the classification can be applied based on these two parameters. This means that both candidate nozzles can be classified as spray quality M according to ISO 25358 at the measured liquid pressures. Before ISO 25358 was introduced, nozzles were classified according to the BCPC classification threshold nozzles. The three parameters (D_{V10}, D_{V50} and D_{V90}) for the BCPC F/M nozzle are lower than those for the ISO F/M nozzle, which implies that the two candidate nozzles would also be classified as M (or coarser) when compared to the former classification nozzle scheme.

3 Technical performance comparison

In this chapter a technical performance evaluation is made by comparing the shielded bed sprayer with the Ecorobotix ARA spot sprayer focussed on drift deposition.

3.1 Cover

The spray nozzles are mounted underneath a cover.
The ARA spot sprayer consists of three sections. Each section has a metal cover under which the cameras and spray lines are mounted. At each side curtains are installed, see Figure 3. The curtains have a dual purpose to block light to the cameras and to prevent spray drift.

Figure 3 *Ecorobotix ARA (Ecorobotix, 2023).*

The cover is designed in a way that the sprayed width is almost fully covered.
In Figure 4 a top view of the three spray lines with dimensions is shown. The curtains are installed around the three spray lines. The positions of the nozzles closest to the lateral and rear cover are shown in Figure 5.

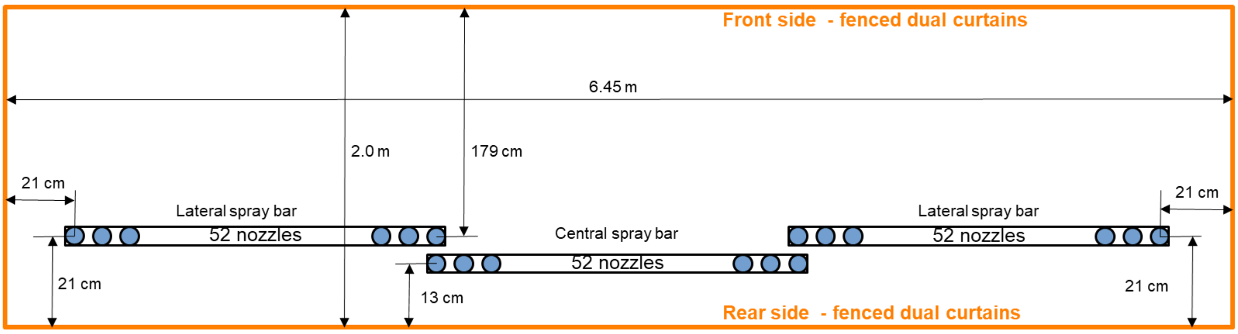

Figure 4 *Top view of the three spray booms.*

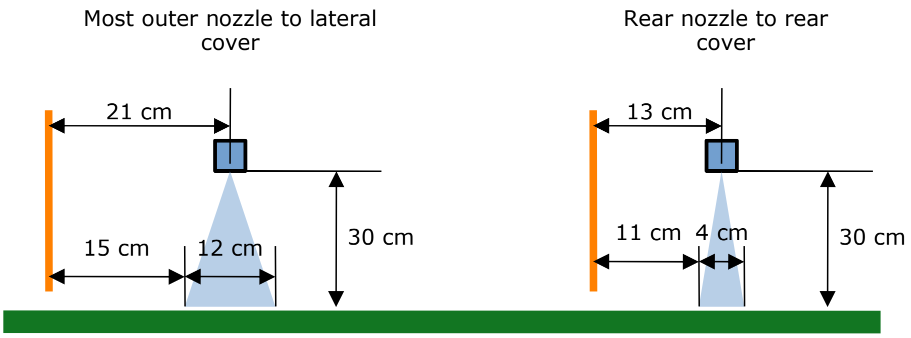

Figure 5 *Position of the most outer nozzle to the lateral cover with indication of the sprayed width of the spot spray nozzle (left). Position of the rear nozzles of the central nozzle bar to the rear cover with indication of the sprayed length in the driving direction (right).*

The spray cones of these nozzles do not interfere with the covers, so the sprayed width is fully covered similar to the shielded bed sprayer.

Both sides of the cover (parallel to the crop rows) are closed with a minimal distance between cover and ground.
At both sides a curtain is installed which closes the distance between the metal cover and the ground, see Figure 6. The flexible curtains, made in one continuous piece, allow flexibility in the varying distance to the ground in case of for example potato ridges or plants.

Figure 6 *Side curtains*

At the front and back of the cover a provision is installed to reduce the distance as much as possible.
At the front a dual curtain design closes the distance between metal cover and the ground, see Figure 7 and Figure 8. The two lines of overlapping curtains are cut every 10 cm with a vertical distance of 15 cm.

Figure 7 *Dual curtains at the front and rear.*

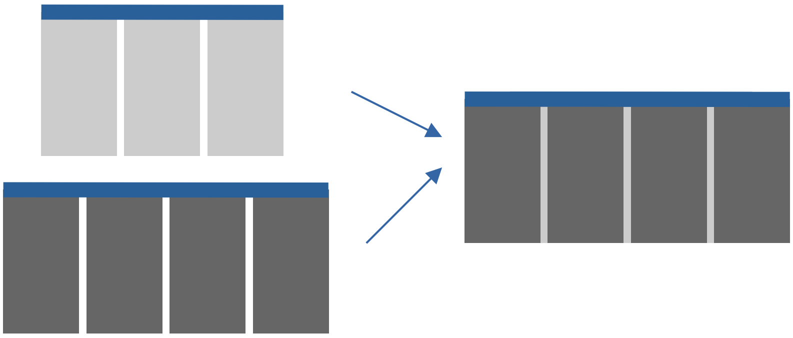

Figure 8 *Sketch of the dual curtain design.*

The curtains allow deformation to keep the cover as closed as possible while preventing plant damage. The curtains have plastic weights at the bottom to avoid lifting of the curtains in case of wind. The distance from the bottom of the curtain to the ground can be adjusted by changing the height of the four wheels (individually adjustable) at the rear and adjusting the height of the three-point hitch of the tractor at the front. The curtains are designed to be in contact with the ground during operation.

3.2 Nozzle mounting

The top angle of the spray nozzles is 110° or 120°.
The top angle of the Ecorobotix ARA spot spray nozzles is 22.5° to allow a more accurate spray deposition pattern at the plant or soil surface. The top angle of this nozzle is smaller than the nozzles used in the shielded bed sprayer design. A smaller top angle has a positive effect on the reduction of spray drift because the average travel distance of the droplets from nozzle to the crop is smaller. Model calculations with a XR 110-03 VS nozzle with the IDEFICS drift model confirm this statement. In these calculations the same drop size spectrum was used as input and only the top angle was changed between 80° and 140°. The amount of spray drift decreased from 6% with a top angle of 140° to 3% with a top angle of 80° (Porskamp & Van de Zande., 2001), see Figure 9.

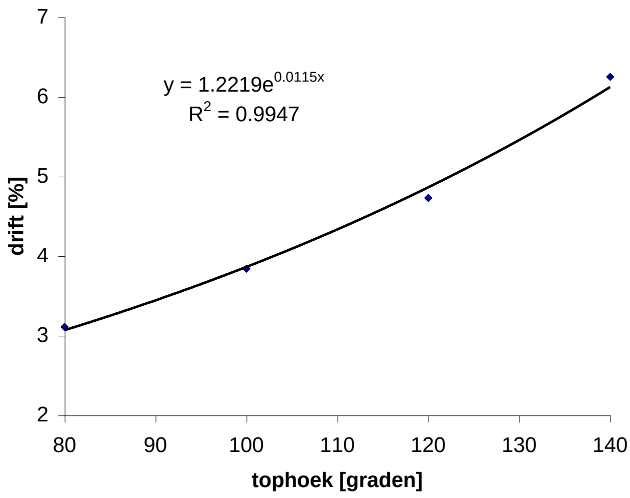

Figure 9 *Impact of the nozzle top angle on the calculated amount of drift using the IDEFICS model, at 2.125 – 3.125 m from the last nozzle, using a TeeJet XR 110-03 VS nozzle (Porskamp & Van de Zande, 2001).*

The nozzle spacing is equal to the height of the nozzles above the crop or soil.
The differences in nozzle spacing, number of nozzles and nozzle height between the ARA spot sprayer and shielded bed sprayer and the effect on spray distribution will be explained in the next paragraphs.

Nozzle spacing
The total number of nozzles of the ARA spot sprayer (156 nozzles for a working width of 6 m) is larger than the number of spraying nozzles of the shielded bed sprayer (3 nozzles for a working width of 1.5 m). The spacing between the nozzles of the Ecorobotix ARA is therefore smaller (4 cm) than of the shielded bed sprayer (60 cm). The effective nozzle spacing of the ARA spot sprayer is 8 cm since only the odd or even spray nozzles are commanded simultaneously. A smaller nozzle spacing itself has a limited, but positive effect on the reduction of spray drift. According to the measurement protocol of drift reducing spraying techniques (TCT, 2017) and the measurement protocol of drift reducing nozzles (TCT, 2021) the drift evaluation zone is located at a fixed distance from the most outer nozzle. Compared to a standard nozzle spacing of 50 cm the flow of the most outer nozzle, and in fact all nozzles, is distributed across multiple nozzles in case of a smaller nozzle spacing. Hence, these additional nozzles are located at an increased distance from the evaluation zone and therefore result in a lower drift deposition (% of applied dose) at the evaluation zone. The nozzle positions for different nozzle spacings are shown in Figure 10.

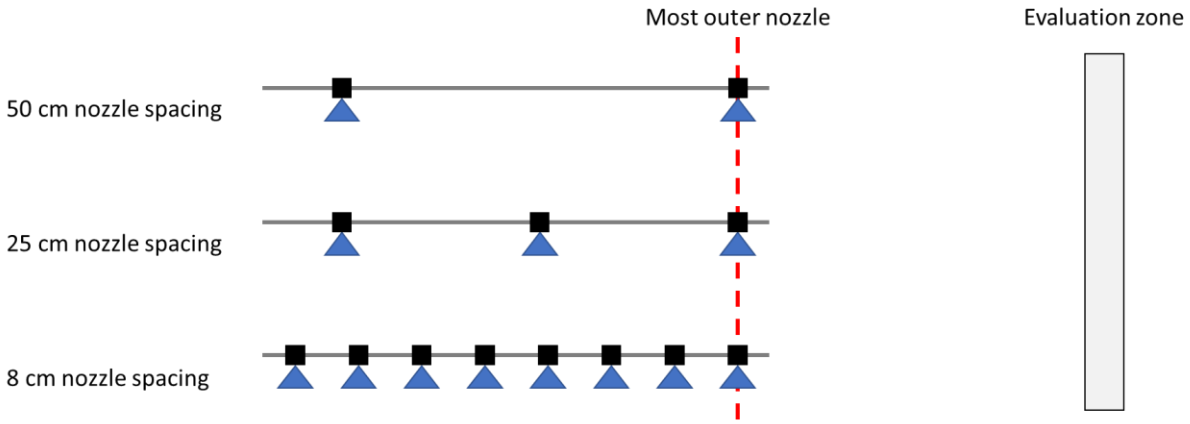

Figure 10 *Nozzle positions in case of 50, 25 and 8 cm nozzle spacing. The most outer nozzle is located at the same distance from the evaluation zone in all cases (distance between most outer nozzle and evaluation zone not to scale). The additional nozzles compared to 50 cm nozzle spacing are located at an increased distance from the evaluation zone.*

An example of this effect is presented in the results of the drift reducing nozzle classification measurements of the Albuz CVI 80-04 and Albuz CVI 80-05 nozzles. The drift reduction percentage of the CVI 80-04 nozzle increased from 83% to 84% and of the CVI 80-05 nozzle from 81% to 82% when the nozzle spacing was decreased from 50 to 25 cm nozzle spacing. These reduction percentages were calculated with the IDEFICS drift model with the same distance between most outer nozzle and the evaluation zone, nozzle height and other remaining parameters (Holterman *et al*., 2022).

Number of nozzles

The amount of spray drift is expressed as a percentage of applied dose, which means that a change in the absolute spray rate (l/ha) of the total tank mix due to more nozzles or an increased nozzle size has no effect on the amount of spray drift. The concentration of the tank mix should always be adapted to not exceed the maximum allowed dose, which is indicated on the label, of the specific plant protection product.

Nozzle height

The nozzle height during the field drift measurements with the shielded bed sprayer was 35 cm (Porskamp *et al*., 1997). The height of the spray nozzles of the Ecorobotix ARA is 30 cm above the crop or soil and the nozzle spacing is 4 cm. A decrease in nozzle height decreases spray drift. A field drift measurement with a boom sprayer with the reference nozzle TeeJet XR110-04 showed a decrease in spray drift of 54% when the boom height was lowered from 70 to 50 cm above the crop. When the boom was lowered from 50 to 30 cm height, spray drift decreases by 56% (De Jong *et al*., 2000). Field measurements with a band sprayer with a nozzle height of just 7 to 10 cm above the crop resulted in 90% drift reduction compared to a reference sprayer. The nozzle used in these experiments had a droplet size Fine or Medium (Stallinga *et al.*, 1999; Van de Zande *et al.*, 2000). The expectation is therefore that the reduced nozzle height of the Ecorobotix ARA compared to the shielded bed sprayer results in an equal to lower amount of spray drift.

Spray distribution

The right combination of nozzle spacing, nozzle height and nozzle characteristics is important to get a good lateral distribution. A lateral distribution measurement with the Ecorobotix ARA with Euspray OC1X502 nozzles, a spray pressure of 3 bar and a spray height of 22 cm resulted in a coefficient of variation of 5.9% (Anken, n.d.). Lateral distribution measurements were also part of the 'JKI-Anerkennung' procedure performed by the Julius Kühn Institute in Germany. The coefficient of variation, measured with the Euspray OC1X502 nozzles, a spray pressure of 3 bar and a spray height of 20 cm passed the requirement of a maximum coefficient of variation of 7% (JKI, 2013; Zwerger, 2023). These measurements show that a proper lateral distribution is possible with the mentioned settings, which is required for a 'good agricultural practice' using this machine.

An end nozzle is installed at both sides of the cover with a spray rate equal to the spray nozzles.

The Ecorobotix ARA is equipped with nozzles with a small top angle of 22.5°, but is not equipped with off-centre or end nozzles at both sides. An end nozzle reduces overspray next to the crop by limiting the spray angle at the side of the field edge compared to a nozzle with equal spray angle to both sides. For example, in case of a standard nozzle with 120° which sprays 60° to both sides relative to the vertical axis, an 80° end nozzle sprays 60° towards the field and 20° towards the field edge (Stallinga *et al*., 2013). The Ecorobotix ARA nozzles spray 11.25° to both sides, which is a smaller top angle than an end nozzle in this case, see Figure 11. The distance of the last nozzle is 21 cm from the side of the machine, see Figure 5.

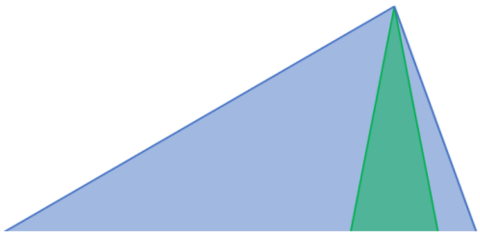

Figure 11 *Comparison of the spray angle of an 80° end nozzle (blue) and the 22.5° Ecorobotix ARA spot spray nozzles (green).*

The combination of top angle and distance from the side of the machine result in a deposition pattern which is smaller than when using conventional end nozzles. The expectation is therefore that the contribution to spray drift at the evaluation zone of 2 till 3 meter form the most outer nozzle of the last Ecorobotix ARA nozzle is lower than when using an end nozzle in this location as used in the shielded bed sprayer.

4 Conclusion

Drop size measurements according to ISO 25358 show that the drop size of the two spot spray nozzles is equal to medium drop size quality with a maximum pressure of 2.5 bar for the IC1012 nozzle and a maximum pressure of 2.0 bar for the IC1X502 nozzle. The cover of the Ecorobotix ARA spot sprayer is installed according to the conditions in the information leaflet of the shielded bed sprayer. The spot spray nozzles do have a smaller top angle, nozzle spacing and nozzle height than described in the information leaflet of the shielded bed sprayer, but these items all individually result in a lower deposition of spray drift. The expectation is therefore that the spray drift reduction of the Ecorobotix ARA spot sprayer is equal to or higher than the shielded bed sprayer in a full-field spray application. The shielded bed sprayer is listed as a 95% drift reducing technology on the DRT list (TCT, 2023).

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Annex 1 PDPA drop size measurements

The droplet size spectrum of spray nozzles was determined with a Phase Doppler Particle Analyzer (PDPA, TSI). The spray liquid was tap water with a temperature of 20°C. The climate chamber was set to a temperature of 20°C and a relative humidity of 70%. During the measurement, the nozzle position described a trajectory of 11 parallel paths (Figure 12). The length of the paths and the distance between paths were set in such a way that the paths covered the total spray pattern well. The moving speed of the nozzle along the paths was adjusted in such a way that at least 10,000 drops were measured per measurement. The nozzle height was 0.30 m above the measuring plane. The measurement height above the floor was 0.70 m.

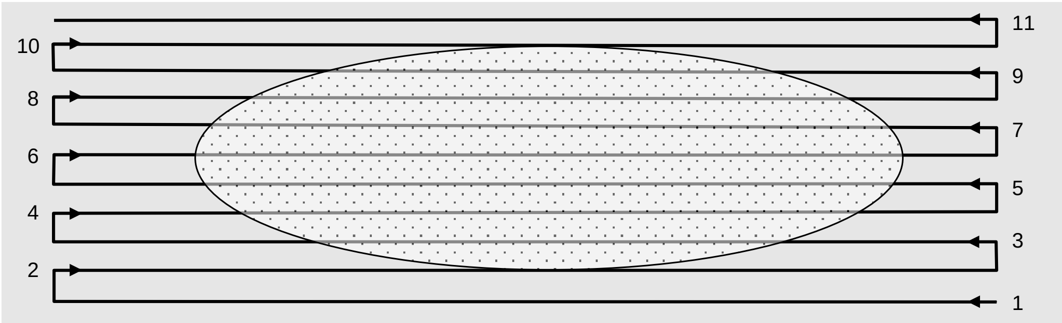

Figure 12 *Pattern of paths along which the tested nozzle was moved to obtain the drop size distribution averaged over the cross-sectional area of the spray cone in a horizontal plane 0.30 m below the nozzle. Length of the paths and distance between parallel paths were adjusted to fit the cross-section of the spray. Path no. 6 crosses the centre of the spray.*

The PDPA settings were:

- Laser power at measuring point	25 mW
- Focus front lens of transmitter	1000 mm
- Focus front lens of detector	1000 mm
- Expander/contractor	contractor
- Detection angle	40°
- Detector voltage	540 V
- Signal threshold	50 mV
- Measuring range	5 - 1250 µm
- Diameter resolution	2,4 µm
- Probe Volume Correction	yes

The laser power was checked at the start of each measurement and adjusted if necessary. The proper coupling of the laser beams into the glass fibres of the so-called 'fibre drive' was also checked before each measurement, since this fibre connection is sensitive to temperature changes and vibrations. In all cases the laser power in the measurement point was the major quantity to keep constant: this power was kept constant at the stated value of 25 mW.

The results of the drop sizing measurements are presented as D_{V10}, D_{V50}, D_{V90} and V_{100}. These quantities are defined as follows:

- D_{V10} [µm]: 10% of the spray volume consists of droplets with a diameter less than D_{V10}.
- D_{V50} [µm] = VMD [µm] (Volume Median Diameter): 50% of the spray volume consists of droplets with a diameter less than D_{V50}.
- D_{V90} [µm]: 90% of the spray volume consists of droplets with a diameter less than D_{V90}.
- V_{100} [%]: volume fraction of the spray consisting of droplets with diameter less than 100 µm.

Annex 2 Measurement of drop sizes

In Table 3, Table 4 and Table 5 the results of the drop size measurements are shown for the reference nozzles BCPC F/M, ISO 25358 F/M and ISO 25358 M/C. The ISO 25358 reference nozzles were used to classify the Ecorobotix ARA nozzles types Euspray IC1012 and IC1X502 of which the results are shown in Table 6 and Table 7.

Table 3 *Overview of the drop size characteristics for the BCPC-F/M reference nozzle at 3 bar liquid pressure. Measured using a PDPA at the same date on which the candidate nozzles were measured.*

Run	Date	D_{V10} [µm]	D_{V50} [µm]	D_{V90} [µm]	V_{100} [%]	v_{avg} [m/s]	Droplet count
1	28-9-2023	120.6	225.4	366.2	5.39	4.01	32930
2		118.4	224.3	364.3	5.72	4.00	33344
3		119.3	224.2	363.7	5.59	4.10	32726
	average	**119.4**	**224.6**	**364.7**	**5.57**	**4.04**	**33000**

Table 4 *Overview of the drop size characteristics for the ISO 25358-F/M reference nozzle at 3 bar liquid pressure. Measured using a PDPA. With maximum deviation (max dev.) for D_{V10} and D_{V50} between replicates.*

Run	Date	D_{V10} [µm]	D_{V50} [µm]	D_{V90} [µm]	V_{100} [%]	v_{avg} [m/s]	Droplet count
1	28-9-2023	126.5	247.5	393.6	4.65	4.13	30059
2		124.7	245.8	397.4	5.01	4.09	31321
3		130.6	250.2	399.9	4.30	4.14	29803
	average	**127.3**	**247.8**	**397.0**	**4.65**	**4.12**	**30394**
	max dev.	**4.7%**	**1.8%**				

Table 5 *Overview of the drop size characteristics for the ISO 25358-M/C reference nozzle at 2 bar liquid pressure. Measured using a PDPA. With maximum deviation (max dev.) for D_{V10} and D_{V50} between replicates.*

Run	Date	D_{V10} [µm]	D_{V50} [µm]	D_{V90} [µm]	V_{100} [%]	v_{avg} [m/s]	Droplet count
1	3-10-2023	171.2	355.7	573.4	1.86	4.42	22146
2		170.4	347.3	559.8	1.99	4.43	21955
3		165.9	352.5	578.1	2.17	4.32	24546
	average	**169.2**	**351.8**	**570.4**	**2.01**	**4.39**	**22882**
	max dev.	**3.2%**	**2.4%**				

Table 6 *Overview of the drop size characteristics for the Euspray IC1012 nozzles at 2.5 bar liquid pressure. Measured using a PDPA. With maximum deviation (max dev.) for D_{V10} and D_{V50} between replicates of the same nozzle number.*

Run	Nozzle index	Date	D_{V10} [µm]	D_{V50} [µm]	D_{V90} [µm]	V_{100} [%]	v_{avg} [m/s]	Droplet count
1	4	28-9-2023	126.5	251.0	364.2	4.39	5.75	23711
2	5		128.8	254.1	376.2	4.17	5.95	23694
3	7		127.8	254.0	383.1	4.26	5.69	23830
4	7		128.9	253.8	376.5	4.16	5.80	23879
5	5		132.0	254.3	371.6	3.94	5.98	23087
6	4		132.1	256.6	382.2	3.78	5.94	23486
7	4		131.4	256.0	380.2	3.77	5.85	23437
8	5		133.2	255.9	385.3	3.72	5.98	23347
9	7		128.1	255.4	377.9	4.25	5.77	24090
		average	**129.9**	**254.6**	**377.5**	**4.05**	**5.86**	**23618**
		max dev.	**4.4%**	**2.2%**				

Table 7 *Overview of the drop size characteristics for the Euspray IC1X502 nozzles at 2 bar liquid pressure. With maximum deviation (max dev.) for D_{V10} and D_{V50} between replicates of the same nozzle number.*

Run	Nozzle index	Date	D_{V10} [µm]	D_{V50} [µm]	D_{V90} [µm]	V_{100} [%]	v_{avg} [m/s]	Droplet count
1	5	28-9-2023	157.8	253.2	363.8	1.82	6.27	16458
2	6		147.6	250.6	360.5	2.64	5.74	17605
3	8		146.1	250.4	357.4	2.45	5.79	17196
4	8		146.3	251.0	353.2	2.47	5.82	17453
5	6		139.8	241.4	342.6	3.14	5.51	19995
6	5		152.2	251.7	352.0	2.22	6.08	16318
7	5		152.6	249.5	362.3	1.99	6.13	15001
8	6		150.5	252.8	363.0	2.13	5.98	15804
9	8		148.5	251.5	355.9	2.26	5.91	17242
		average	**149.0**	**250.2**	**356.8**	**2.35**	**5.91**	**17008**
		max dev.	**7.7%**	**4.7%**				

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