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This study was carried out by the Wageningen Research Foundation (WR) and was commissioned and financed by RIVM within the Research project Onderzoek Bestrijdingsmiddelen Omwonenden
(project number 3710434304; OBO-Deliverable 032).

WR is part of Wageningen University & Research, the collaboration of Wageningen University and Wageningen Research Foundation.

Wageningen, December 2022

Report WPR-838

Stallinga, H., P. van Velde, J.M.G.P. Michielsen & J.C. van de Zande, 2022. *Effect of edge of field shields on spray drift of a boom sprayer.* Wageningen Research, Report WPR-838. 40 pp.; 13 fig.; 8 tab.; 10 ref.

This report can be downloaded for free at https://doi.org/10.18174/581994

Spray drift experiments were performed under practical circumstances to quantify the effect of a field edge barrier on airborne spray drift and spray drift ground deposit in front and behind the barrier. A bare soil surface was sprayed using a conventional boom sprayer operating at 0.50 m spray boom height, and standard flat fan nozzles (XR11004). Screens covered with 30% wind-closed windbreak shield was used to model a hedgerow and screens covered with anti-root growth cloth as a closed fence. The use of screens at the field edge reduces spray drift ground deposit as well as airborne spray drift behind the screens. Spray drift reduction was 73%-78% for ground deposition at 4-5 m distance behind the screens. Airborne spray drift at 5 m distance behind the screens over 0-3 m height was 68%-83% when measured with passive collectors. Using active sampling techniques measuring airborne spray drift almost no spray drift reduction or small increases in airborne spray drift were measured at the same distance. Spray drift deposition at the wall of the (green)house at 15 m distance from the last nozzle was on average 0.25%. When screens are positioned at 5 m distance from the last nozzle spray deposit at the wall was similar for the closed screen and 57% lower using a 30% wind-closed windbreak screen.

Key words: spray drift, resident, bystander, spray drift reduction, shield, windbreak screen, field edge barrier, wind speed profile

Report WPR-838

Photo cover: Jan van de Zande (JvdZ-SprayDriftShield_IMG_0275.JPG)

Contents

Preface

The research presented in this paper was performed within the Research on exposure of residents to pesticides (OBO-project; Deliverable 032) and financed by the Dutch ministries of Infrastructure and the Environment and of Economic Affairs. The research is carried out in a research consortium, consisting of: Institute for Risk Assessment Sciences (IRAS) of Utrecht University, TNO, University Medical Centre Groningen (UMCG), Radboud University Medical Centre Nijmegen, Wageningen University and Research, Centre for Agricultural Environment (CLM), Schuttelaar & Partners and is coordinated by the National Institute for Health and the Environment (RIVM). The spray drift measurements relating the edge of field shields and the exposure of gardens and residents' homes were performed at the fields and around a (green) house of WageningenUR Unifarm in Wageningen and in cooperation with WageningenUR Unifarm.

Wageningen, July 2018

Summary

The research project "Onderzoek Bestrijdingsmiddelen Omwonenden" (OBO) was set up to assess the exposure of residents to pesticides next to flower bulb fields. Important exposure routes from the field to the residents' houses are spray drift and vapour drift during application and volatilization from a treated crop after application. The initial plan was to measure spray drift deposit in resident's gardens with and without artificial or natural barriers at the field edge to quantify the exposure of persons in the garden and on the wall of the house. Because the measurements could not be made in a practical flower bulb situation, measurements were performed using shields to mimic fences and hedgerows and a plastic greenhouse tunnel as house. The effect of a field edge barrier on airborne spray drift and spray drift ground deposit in front and behind the barrier was measured; spraying a bare soil surface using a conventional boom sprayer operating at 0.50 m spray boom height, and standard flat fan nozzles (XR11004). Screens covered with 30% wind-closed windbreak shield was used to model a hedgerow and screens covered with anti-root growth cloth as a closed fence. Spray drift experiments were performed under practical circumstances, representative for applications in a flower crop, however using a fluorescent tracer instead of a Plant Protection Product.

The use of screens at the field edge reduces spray drift ground deposit as well as airborne spray drift behind the screens. At 4-5 m behind a 30% wind-closed windbreak screen spray drift reduction was 78% when spraying a bare soil surface using standard flat fan nozzles (XR11004) at 0.50 m boom height. Using a closed screen spray drift reduction at this distance was 73%.

Airborne spray drift at 5 m distance behind the screens over 0-3 m height was for the 30% wind-closed windbreak screen 83% when measured with passive collectors. Airborne spray drift reduction for the closed screen was for this situation 68%.

Using active sampling techniques measuring airborne spray drift almost no spray drift reduction (17%) because of usage of screens at the field edge was over 0-3 m height measured at 5 m behind the screen for the 30% wind-closed windbreak screen. Using the closed screen at the field edge resulted in an increase in airborne spray drift measured at 5 m behind the screen with active sampling techniques of 12%.

Spray drift deposition at 0-3 m height collectors positioned at the wall of the (green)house at 15 m distance from the last nozzle was on average 0.25%. When screens are positioned at 5 m distance from the last nozzle; spray deposit at the wall 10 m behind the screens was similar for the closed screen and 57% lower using a 30% wind-closed windbreak screen.

Samenvatting

In het Onderzoeksproject “Onderzoek Bestrijdingsmiddelen Omwonenden” wordt de potentiële blootstelling van omwonenden gemeten. Belangrijke routes voor de blootstelling zijn spuitdrift tijdens de toediening van de middelen en verdamping vanaf het gewas na de toediening van de middelen. Het initiële plan was driftmetingen te doen tot in de tuinen van omwonenden met en zonder de aanwezigheid van schuttingen en andere barrières om het effect daarvan op de blootstelling van personen in de tuin en de gevel van de woning vast te leggen. Door omstandigheden konden deze metingen niet uitgevoerd worden en is gekozen voor driftmetingen met en zonder gaasschermen, om schuttingen en hagen na te bootsen, voor een tunnelkas die als huis diende. Het effect van een barrière op de perceelsgrens op de luchtdrift en driftdepositie op de grond en in de lucht voor en achter de barrière en de gevel bij de bespuiting van een kale grond met een veldspuit is vastgelegd. Om een schutting en een windhaag na te bootsen is een dicht scherm van anti-worteldoek gebruikt en een 30% winddicht windbreek gaas. De metingen zijn onder praktische omstandigheden uitgevoerd met een veldspuit representatief voor bespuitingen in de bollenteelt met een fluorescerende tracer in plaats van met een gewasbeschermingsmiddel.

Door het gebruik van schermen werd de driftdepositie achter de schermen op de grond en de drift in de lucht verlaagd. Op 4-5 m achter een 30% winddicht windbreek gaas was de driftreductie bij de bespuiting van een kale grond met een standaard spleetdop (XR11004) en 50 cm dophoogte 78%. Bij gebruik van een dicht scherm was de driftreductie op de grond op deze afstand 73%.

De drift naar de lucht op 5 m achter de schermen was over 0-3 m hoogte bij een 30% winddicht windbreek gaas 83% bij een passieve meting van de luchtdrift. Bij het dichte scherm was de passief gemeten driftreductie op 5 m achter het scherm 68%. Bij een meting met actieve aanzuiging van de luchtdrift was de driftreductie door de schermen over 0-3 m hoogte op 5 m achter de schermen nihil (17%) voor het 30% winddicht windbreek gaas en was er 12% meer drift naar de lucht achter het dichte scherm.

Tegen de gevel van een denkbeeldig huis op 15 m van de laatste dop kwam gemiddeld over 0-3 m hoogte 0,25% driftdepositie bij een bespuiting van een kale grond met een standaard spleetdop en 50 cm spuitboomhoogte. Staan op 5 m van de laatste dop schermen dan kwam op 10 m achter de schermen op de gevel van het huis dezelfde hoeveelheid als een dicht scherm gebruikt werd en 57% minder als een 30% winddicht windbreek gaas als scherm gebruikt werd.

1 Introduction

In the research project “Onderzoek Bestrijdingsmiddelen Omwonenden” (OBO, 2017) the potential exposure routes of residents around flower bulb fields treated with pesticides are assessed (Gooijer *et al.*, 2019). The different exposure routes from a field as spray drift and vapour drift during application, and volatilization from a treated crop after application to the residents’ houses are quantified. In this research consortium Wageningen Plant Research quantifies spray drift during application resulting in spray drift deposition on soil surface downwind of the treated area as well as airborne spray drift.

Spray drift is defined as the quantity of plant protection product that is carried out of the sprayed (treated) area by the action of air currents during the application process (ISO22866). In the 2016 growing season, spray drift measurements were performed spraying a flower bulb field. Spray drift was quantified up to the edge of field where fences were positioned bordering the gardens of neighbouring residents’ homes (Deliverable031; Zande *et al.*, 2016). It was planned to do similar spray drift measurements also in the 2017 season including spray drift deposition and airborne drift in the resident’s garden area with and without fences and bushes at the garden border as well as deposition at the wall of the houses to quantify the potential exposure of residents present in the garden (bystander). Due to circumstances these measurements could not be done. Therefore, measurements were setup with and without shields to mimic fences and hedgerows and a plastic greenhouse tunnel as house. The aim of the research was to quantify the effect of a field edge barrier on airborne spray drift and spray drift ground deposit in front and behind the barrier; spraying a bare soil surface using a conventional boom sprayer operating at 0.50 m spray boom height, and standard flat fan nozzles (XR11004). Screens covered with 30% wind-closed windbreak shield was used to model a hedgerow and screens covered with anti-root growth cloth as a closed fence. Spray drift experiments were performed under practical circumstances, representative for applications in a flower crop, however using a fluorescent tracer instead of a Plant Protection Product.

The measurement methodology is described (chapter 2) and the results (chapter 3) are discriminated in spray drift as ground deposition, deposition on the wall of the house, and as airborne spray drift up to 3 m height; measured both with passive collectors as with active air suction system. Outcomes are discussed in chapter 4.

2 Materials and Methods

2.1 Setup and description of used spray technique

In a field experiment at 23 and 25 October 2017 spray drift of a trailed conventional boom sprayer was measured (John Deere) with and without the occurrence of shields at the edge of the field (Figure 2.1). Sprayer working width was 27 m. Spray applications were done with a spray boom height of 0.50 m using standard flat fan nozzles (TeeJet XR 11004) at a spray pressure of 3 bar. An overview of the used sprayer and its settings is in Table 2.1. Spray applications were performed at a bare soil surface field of the WageningenUR experimental farm (Unifarm; 51°59’16.3”N 5°39’29.5”E at the Bornsesteeg in Wageningen). Three measurements were done.

At 15 m downwind distance from the last nozzle was a greenhouse tunnel with a length of 69m and a height of 3.90 m. The plastic greenhouse tunnel was a surrogate for the residents’ home. The flat vertical wall (2.5 m height) of the greenhouse tunnel was than the surrogate for the wall of the residents’ house. Spray drift was assessed for the following four objects:

A- Open area – bare soil surface and flat covered surface area next to tunnel;
B- Open garden in front of tunnel;
C- Half open garden in front of tunnel – vegetation; permeable shield at field edge;
D- Closed garden in front of tunnel – screen; closed shield at edge of field.

The half open garden (object C) was simulated by using a screen with a 30% wind-closed windbreak shield (Mevolon 622 WG, mesh size 1x3 mm, wind reduction 45% at 30 m/s and 33% at 9 m/s). The closed garden (object D) was simulated using a screen with a 0% wind-open anti-root growth cloth (110 g/m^2). The screens were positioned at 5 m distance from the last nozzle. The screens were at 10 m in front of the greenhouse tunnel. A schematic overview of the experimental layout and positions of screens, greenhouse tunnel and sprayed swath is presented in Figure 2.2. An overview of the measurement setup and the individual objects is presented in Figures 2.4 and 2.5. Spray drift was assessed in front of the screens and behind the screens in the gardens, as well as spray drift deposition at ground surface as airborne spray drift. In addition, spray drift deposit at the wall of the greenhouse was measured.

Table 2.1 *Summary of used spray technique and its settings.*

sprayer	John Deere
working width	27 m
spray nozzle	TeeJet XR11004
nozzle type	standard flat fan
spray pressure [bar]	3.0
number of nozzles	54
nozzle flow rate [l/min]	1.67
forward speed [km/h]	6.4
spray volume [l/ha]	312

Figure 2.1 *Spray application of the downwind swath of a bare soil surface alongside the screens (C, D; left) and the open areas (A, B; right).*

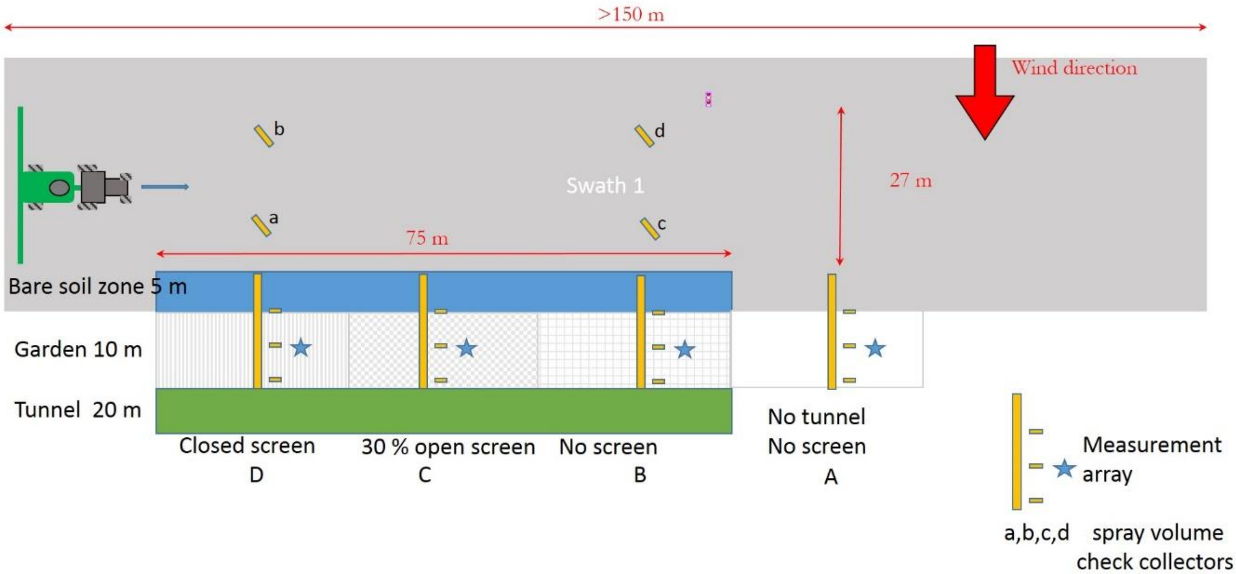

Figure 2.2 *Schematic presentation of the position of the greenhouse tunnel, spray swath and measuring area.*

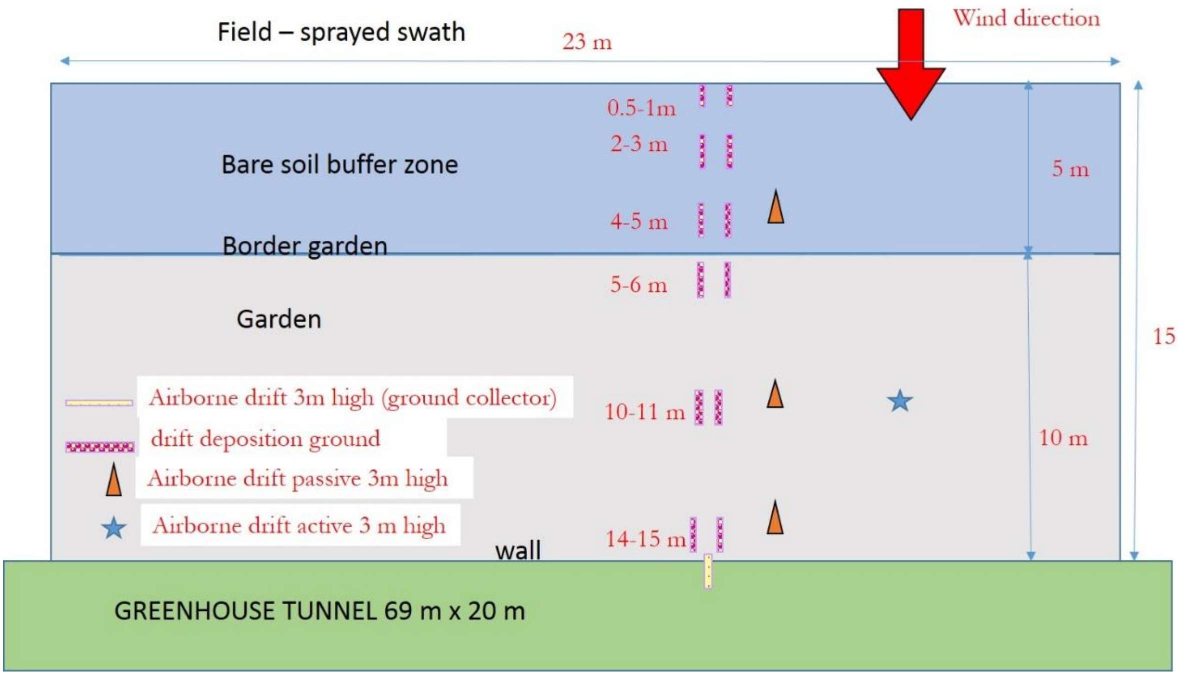

Figure 2.3 *Schematic overview of the collector positions in different collector arrays, garden border and (green) house wall per measuring object.*

Figure 2.4 *Overview of the measuring setup with a closed screen (D; black), permeable screen (C; light green) the open garden (B) and the full open space (A) in front of the tunnel with collectors in front and behind the screens.*

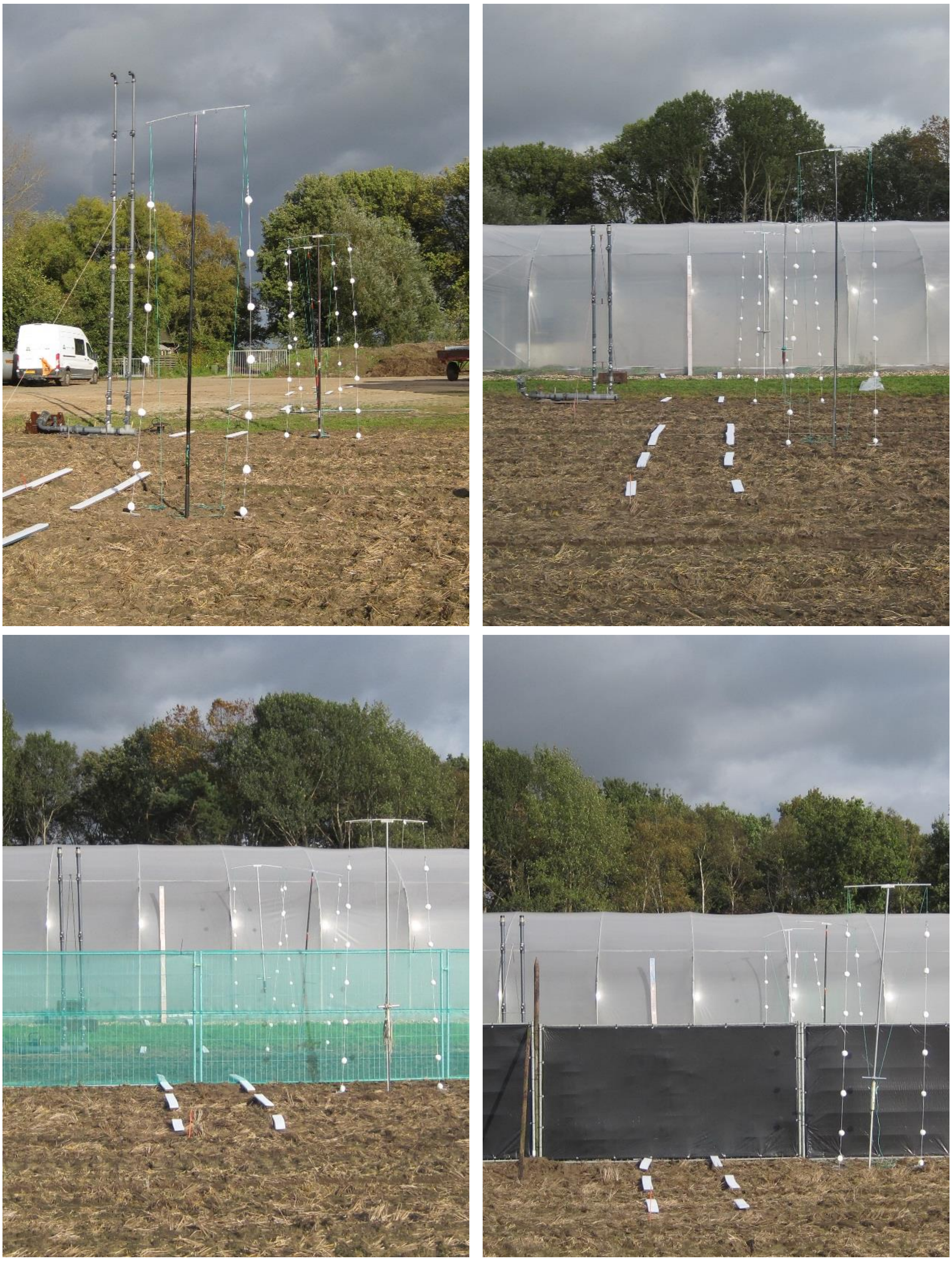

Figure 2.5 *Overview of the spray drift measuring setups: A-Open space (left top), B-Open garden in front of tunnel (right top), C-Half open garden in front of tunnel with a permeable windbreak shield (left bottom), D-Closed garden in front of tunnel with a non-permeable anti-root shield at the field edge (right bottom).*

2.2 Measurements description and data analysis

2.2.1 Ground deposition of spray drift

Ground deposition of spray drift was measured in front of the screen as well as behind the screen (in the garden). With every object collectors were laid out in a double row at a distance of 2 m from each other (Figure 2.5) perpendicular to the driving direction of the sprayer. Spray drift deposition at ground surface was measured at the following positions:

For object A:
A collector of 0,5 m length (Technofil TF290; 10x50 cm) at 0.5-1 m and collectors of 1 m length (Technofil TF 100 10x100 cm) at the distances 2-3 m, 4-5 m, 5-6 m, 10-11 m, 14-15 m, 20-21 m and 25-26 m from the last nozzle.

For objects B-C-D:
A collector of 0,5 m length (Technofil TF290; 10x50 cm) at 0.5-1 m and collectors of 1 m length (Technofil TF 100 10x100 cm) at the distances 2-3 m and 4-5 m (in front of the garden edge / screen; Figure 2.6 left) and at 5-6 m (behind the screen), 10-11 m (at the center of the garden; Figure 2.6 center) and 14-15 m (in front of the tunnel; Figure 2.6 right) in the garden.

To verify applied spray volume in the sprayed swath; at both sides of the sprayer collectors were positioned at the ground level underneath the spray boom (1 m length). A total of 4 collectors were laid out (a, b, c, d Figure 2.2).

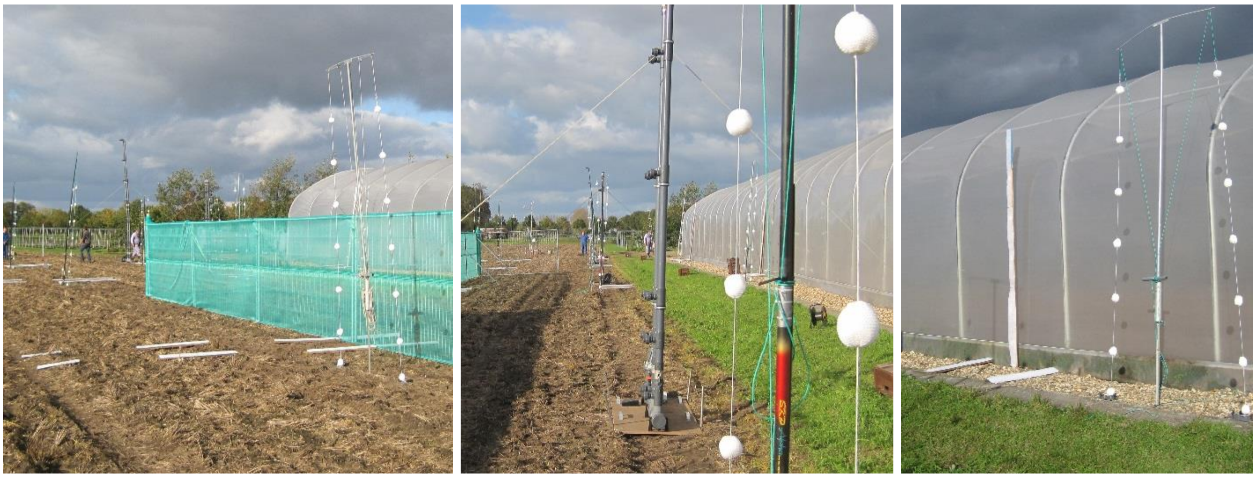

Figure 2.6 *Overview of collector positions in front of the screen (left), behind the screen in the garden (center) and in front and against the tunnel (right).*

2.2.2 Airborne spray drift

Airborne spray drift was measured with passive collectors and with active air suction heads. To measure the airborne spray drift with the passive collectors a 3 m pole was used with on two sides a line (1-3 m distance from each other) with drift collectors attached at 0, 0.5, 1.0, 1.5, 2.0, 2.5 and 3.0 m height. The passive drift collectors were ball shaped with a diameter of 7.5 cm (Siebauer Abtriftkollektoren art. nr. 00131; Figure 2.7 left). The measuring poles were positioned at 4 m (1 m in front of screen / garden), at 10 m (centre of the garden) and at 14 m (0.5 m in front of the tunnel) from the last nozzle. The passive drift collectors were attached to a nylon wire with a diameter of 5.0 mm (Oliveira Holland, Rotterdam; PP Paprika twine 1/1500).

The active sampling of airborne spray drift involved a technique developed at WPR (Stallinga *et al.*, 2008). A mast was positioned at 10 m downwind of the last nozzle with a double row of suction heads (diameter

32 mm 3 m s^{-1} air suction speed) at 0.37 m, 0.75 m, 1 m, 2 m and 3 m heights. Filters used in the suction heads were Schleicher & Schuell nr. 2282 (48 mm diam.; thickness 1.45 mm). The filtration time of the filters used was 40 s (Herzberg method) and the base weight was 450 g m^{-2}. The suction heads were attached to two PVC pipes (diameter 63 mm at lower 4 m height). The distance between the pipes was 33 cm. The two pipes with suction heads was attached to a bottom pipe (diam. 110 mm) which was coupled to a vacuum cleaner electromotor (Amatec ET 1350 forced cooling; under pressure 2400 mm/WK; air displacement 59 L s^{-1}). Just in front of the motor a T-joint valve is fit in the pipe to allow entry of free air. Adjustment of this valve allows to control the air speed through the suction heads. The construction of the pipes and motor is attached to a ground plate in such a way that the pipes could rotate at the ground plate. In this way the pipes could be lowered easily to facilitate exchanging the filters.

Suction heads were made of PVC coupling devices (Figure 2.7 right) with the filter paper fixed between head and pipe. The inside diameter of the suction head is 34 mm and the effective suction head surface diameter (and of the filter paper) is 32 mm.

The air speed through the filters in the suction heads was intended to be adjusted to approximately 3 m s^{-1}. The air speed through the suction heads were measured using a mini vane anemometer and turned out to deviate from the intended equal air speed. Recorded air speed of the suction heads is for all the filter positions at the 3 m high masts presented in Table 2.2. Recorded differences of air speeds through the filters between the masts can be dealt with in future data analysis, e.g. to present the data normalized for equal air speeds. This is not done in this report.

Table 2.2 *Air speed (m s^{-1}) through the filters in the suction heads of the three masts used for measuring airborne spray drift with active samplers.*

Object		0.37	0.75	1	2	3	avg
A	Left	3.32	3.08	3.07	3.06	3.02	3.11
	Right	2.99	3.24	3.13	3.14	3.55	3.21
B	Left	3.19	2.88	2.90	2.71	2.64	2.86
	Right	3.28	3.12	2.95	2.74	2.56	2.93
C	Left	3.96	3.53	3.51	3.30	3.60	3.58
	Right	3.80	3.54	3.49	3.37	3.68	3.58
D	Left	3.38	3.42	3.84	3.42	3.38	3.49
	Right	3.79	3.58	3.52	3.81	3.61	3.66

On average, air speed through the filters in the suction heads was 2.9 m s^{-1} for the mast at object A and B, and 3.6 m s^{-1} for the masts at object C and D.


Figure 2.7 *Passive collector (left) and active collector in suction head (right) for measuring airborne spray drift.*

2.2.3 Spray deposition at 'wall'

In the objects B, C and D 3m high bars were positioned vertical against the wall of the greenhouse tunnel. At the bars three collectors of 1 m length (Technofil TF 100 10x100 cm) were attached at 0-1 m, 1-2 m and 2-3 m height. (Figure 2.6 right).

2.2.4 Analyses

The spray liquid was tap water with added fluorescent dye (Brilliant Sulfo Flavine; BSF, Chroma 1F 561, CI 56205, 3-5 g L^{-1}) and a non-ionic surfactant (Agral Gold; 0.075 mL L^{-1}). After spraying the collectors were put in plastic bags, labelled, collected and transported to the lab for further analysis of the deposited amount of BSF using fluorimetry. Every measuring day also samples were taken of the tank concentration of the sprayed tank mix by taking a sample from below a spraying nozzle. In the laboratory the collectors were taken from the plastic bags and put in jars to which a fixed amount of demineralised water was added (1000 mL for ground collectors TF-290; 500 mL for TF-100 and 50 mL for passive airborne collectors). The jar was shaken for 15 minutes to wash the BSF from the collector and the extracted solution was poured into tubes (10 mL) to be analysed with a fluorimeter (Perkin Elmer LS 55; λ_{ex}=450 nm; λ_{em}=500 nm) to determine the BSF concentration. The concentration of BSF in the tank samples was determined using the fluorimeter as well. The background fluorescent signal of the collectors was determined by analysing a set of blank collectors.

2.2.5 Calculations

2.2.5.1 Percentage spray drift

From the measured concentration of BSF from the washed collectors the amount of spray volume per unit area was calculated. The percentage of spray drift was calculated by expressing the spray drift deposition per unit area as a percentage of the applied spray volume in the field per unit area.

The amount of spray deposit per unit area (µl cm^{-2}) can be calculated from the reading of the fluorimeter, the calibration factor, the collector surface area, the BSF concentration in the sprayed liquid, the background signal (collector + dilution liquid) and the volume of dilution liquid.

$$D_{monster} = \frac{(F_{monster} - F_{demi} - F_{blanco}) \times f_{ijk} \times V_{spoel}}{C_{tm} \times A_{monster}}$$

D = spray deposition on collector µl cm^{-2};
F = fluorescence value;
$F_{monster}$ = fluorescence value of collector;
F_{demi} = fluorescence value of deionised water;
F_{blanco}= fluorescence value of blank collector;
f_{ijk} = calibration factor;
V_{spoel} = extraction volume in L;
C_{tm}= tracer concentration in sprayed liquid (tank concentration) in g.L^{-1};
$A_{monster}$ = collector surface area in cm^2.

Usually, spray drift deposition is expressed as a percentage of applied spray volume following:

$$P = \frac{D_m}{Q/100} \times 100\%$$

With:
P = percentage of spray drift of applied spray volume;
D_m = spray deposition on collector in µl cm^{-2};
Q = spray volume in L/ha.

2.2.5.2 Threshold value

To determine the background fluorescence several blank collectors were analysed separately. These measurements gave an average background fluorescence of the blank collectors and its standard deviation. In the calculation of the spray drift deposition (equation 1) the average value of the background fluorescence is used. In the performed experiments very low spray drift deposits were measured with values close to and even below the average background fluorescence of the blank collectors. Calculated spray drift deposition can therefore be even below 0%. The threshold value used in this report is defined by the average fluorescence value of the blanks plus two times its standard deviation. This threshold value is expressed as % spray drift deposition according to equations 1 and 2. The threshold value is dependent of the measured spray technique (applied spray volume), used extraction volume, collection surface area of the collector and the tank concentration and can therefore differ for each spray drift measurement.

In the annexes the calculated spray drift deposition values are given also when they are below the threshold value. Values below the threshold value are presented in italics. In this report such values are presented by the phrase '< threshold value' e.g. '<0.006'.

2.3 Weather conditions

During the spray drift experiments the weather conditions were recorded. Air temperature was measured at 0.5 and 4 m height (Pt100 device), the relative air humidity at 1.5 m height (% RH, Rhotronic), the wind direction (0^0 = perpendicular to the crop rows) at 4 m height and the wind speed (using cup anemometers) at 0.5 m, 2 m, 3 m and 4 m height. These weather conditions were recorded at a time interval of 5 s. The weather station was positioned at 5 m downwind of the last nozzle. Every time the sprayer passed the collector lines of the different objects (A, B, C, D) the time at the data logger display was recorded. Afterwards, from the collected weather data the data of 15 s before to 15 s after the time of passage were averaged. Next to the weather station also an ultrasonic anemometer (Metpak) was positioned at 2 m height.

Average weather conditions during the spray drift experiments are presented in Table 2.3.

Table 2.3 *Average weather conditions during the spray drift experiments.*

repetition	date	temperature [^{0}C]		% RH	wind angle to perp to driving direction (abs)	wind speed (m/s)			
		0.5 m	2 m		perp=0^0	0.5	2	3	4
1	23-10-2017	15.3	14.7	60	20	3.7	4.7	4.9	5.1
2	25-10-2017	15.0	15.2	80	24	3.7	4.7	5.1	5.5
3	25-10-2017	15.0	14.9	86	13	3.3	4.2	4.3	4.5
avg		15.1	14.9	75	19	3.6	4.5	4.7	5.0

During the spray drift measurements average temperature at 2 m height was 14.9 ^{0}C, average wind angle (absolute) perpendicular to the driving direction was 19^o and average wind speed at 2 m height was 4.5 m/s.

3 Results

The results of the spray drift deposition at ground surface downwind of the sprayed area are for the different 'garden' objects (A,B,C,D) presented in Annex 1. Results of the airborne spray drift are presented in Annex 2 for the passive collectors and in Annex 3 for the filters of the active sampling technique.

3.1 Spray deposition underneath the sprayer

The results of the measurements of the spray deposition on the ground underneath the spray booms of the passing sprayer are presented in Table 3.1.

Table 3.1 *Average spray deposition on soil surface underneath the spray boom (% of sprayed volume per unit area) for a conventional sprayer (0.50 m boom height) equipped with standard flat fan nozzles (XR11004).*

repetition	a	b	c	d	avg
1	100	94	101	110	101
2	130	119	136	116	125
3	113	106	113	115	112

Due to sprayer boom movements the spray deposition on ground surface can deviate from the intended 100% spray deposition. On average 101%-125% of applied spray volume is recovered as applied in the treated area. An acceptable range of in-field spray deposition is 80-120%. The observed spray drift measurements are within this acceptable range except for some of the second repetition. Forward speed of the sprayer and spray pressure were constant and could not explain the observed deviations of the in-field spray deposits. No correction for applied spray volume was taken up in the calculations.

3.2 Spray drift deposition at ground surface downwind of the sprayed area

Average spray drift deposition at ground surface downwind of the sprayer spraying a bare soil surface swath alongside the different 'gardens' is presented in Figure 3.1 and Table 3.2. Spray drift deposition at the Open Area (A) is highest. Spray drift deposition at the Open Garden (B) is close to the sprayed swath (1-5 m) somewhat lower than at the Open Area (A) whereas at 14-15 m distance, in front of the greenhouse tunnel, drift deposition is similar to that in the Open Area (A). Drift deposition in front of the screens of the Half Open (C) and the Closed (D) garden is lower than of both the Open Area (A) and the Open Garden (B). Just behind the screens (5-6 m) spray drift deposition in the Half Open garden and the Closed garden is lower (40%-70%) than at the same distance in the Open Area and the Open garden. Clearly drift deposit just behind the screens (5-6 m) is lower than just in front (4-5 m) of the screens. In the garden area of the Half Open garden and the Closed garden (5- 6 m behind the screens at 10-11 m from the last nozzle) drift deposit is also lower. Just in front of the greenhouse tunnel drift deposition in the Half Open garden is still lower than at the same distance in the Open Area. In the Closed garden drift deposition just in front of the greenhouse is of the same level as in the Open Area. In the centre of the garden (10-11 m) spray drift deposition in the Half Open (C) and the Closed (D) garden is clearly lower (50%) than compared to at the same distance in the Open Area and the Open Garden.

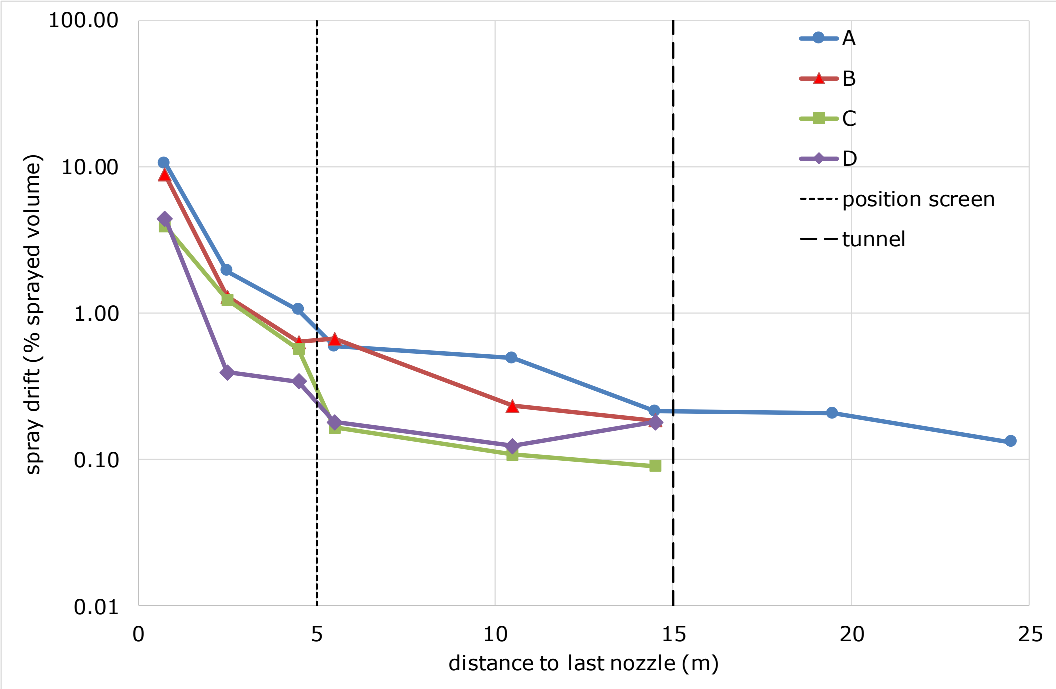

Figure 3.1 *Mean spray drift deposition (% of applied spray volume per unit area) at different distances from the last nozzle when spraying one swath (27 m) of a bare soil surface using a conventional boom sprayer equipped with a standard nozzle (XR11004) and 50 cm spray boom height per object (A=Open area; B=Open garden; C=Half Open garden; D=Closed garden).*

Table 3.2 *Mean spray drift deposition (% of sprayed volume per unit area) per object (A=Open Area; B=Open Garden; C=Half Open Garden; D=Closed Garden) at different downwind distances from the last nozzle spraying a bare soil surface area (27 m swath width) using a conventional boom sprayer equipped with XR1104 standard flat fan nozzles and at 0.50 m spray boom height.*

Distance to last nozzle (m)	A	B	C	D
½-1	10.486	8.820	3.922	4.434
2-3	1.935	1.296	1.230	0.393
4-5	1.048	0.635	0.569	0.341
5-6	0.595	0.667	0.165	0.180
10-11	0.491	0.233	0.108	0.124
14-15	0.214	0.185	0.091	0.181
20-21	0.206			
25-26	0.131			

3.3 Airborne spray drift

3.3.1 Passive measurements with spherical collectors

Average airborne spray drift measured with passive collectors when spraying a bare soil surface area alongside different gardens using a boom sprayer are for different objects and distances presented in Table 3.3 and Figure 3.2.

Airborne spray drift measured with passive collectors spraying alongside the Open Area is higher for all heights above ground level compared to spraying alongside the other gardens (Table 3.3 and Figure 3.2). At 4 m, 10 m and 14 m distance from the last nozzle airborne spray drift was resp. 3.2%, 2.2% and 1.9%. The average airborne spray drift is for the Open garden resp. 2.0%, 1.5% and 0.87% and clearly lower than in the Open Area. Airborne drift in the Half Open garden is with resp. 1.2%, 0.7% and 0.79% again lower as in the Open garden. At 4 m and 14 m airborne spray drift in the Closed Garden is lowest with resp. 1.2% and 0.68%, whereas at 10 m distance airborne spray drift is 0.37% being almost 50% lower as in the Half Open garden.

At 4 m distance of the last nozzle (in front of the screens) airborne spray drift decreases with height. At 10 m distance (behind the screens) airborne spray drift decreases with height in the Open Area and the Open Garden whereas in the Half Open garden and the Closed garden airborne drift increases with height. Airborne spray drift at 1-2 m height is in the Half Open garden and the Closed garden resp. 0.30% and 0.63% and at 2-3 m resp. 0.55% and 0.74%. It looks like the screens of the Half Open and the Closed gardens lead to another wind profile behind the screens in the centre of the garden (10 m) and therefore airborne spray drift is higher and found at higher heights. Especially in the Closed garden this is the case.

In all situations at 14 m distance and 3 m height airborne spray drift values higher than 0.70% are found. This means that in fact to catch the complete plume of spray drift passing the highest collector (3 m) was not high enough. Three meter height coincides more or less with the ground floor of a home. It can therefore be expected that at the second floor of a home (> 3 m) still spray drift deposit can occur.

Table 3.3 *Airborne spray drift (% of applied spray volume per unit area) measured with passive collectors at different heights at 4 m, 10 m and 14 m from the last nozzle spraying the outside swath (27 m) of a bare soil surface area using a boom sprayer equipped with a standard nozzle (XR11004) at 50 cm spray boom height passing different gardens (A= Open Area, B = Open Garden, C= Half Open garden, D= Closed Garden).*

	4 m				**10 m**				**14 m**			
Height (m)	**A**	**B**	**C**	**D**	**A**	**B**	**C**	**D**	**A**	**B**	**C**	**D**
3	0.875	1.534	1.208	1.223	1.471	0.974	0.760	1.012	1.122	1.121	0.913	0.696
2.5	1.686	1.992	1.556	1.256	1.639	1.554	0.519	0.602	1.423	1.430	0.729	0.649
2	2.686	2.377	1.489	1.398	1.917	1.656	0.373	0.594	1.605	0.992	1.001	0.668
1.5	3.146	2.397	1.254	1.358	2.078	1.880	0.304	0.632	2.345	0.741	0.973	0.732
1	4.667	1.734	1.271	1.119	3.442	1.735	0.232	0.658	2.316	0.679	0.812	0.692
0.5	5.161	2.329	1.040	1.175	2.657	1.751	0.252	0.798	2.584	0.585	0.625	0.635
0	3.945	1.862	0.846	0.963	1.845	1.000	0.138	0.468	2.152	0.558	0.462	0.705
0-1	4.591	1.975	1.053	1.086	2.648	1.495	0.207	0.641	2.351	0.607	0.633	0.677
1-2	3.500	2.169	1.338	1.292	2.479	1.757	0.303	0.628	2.088	0.804	0.929	0.697
2-3	1.749	1.968	1.417	1.292	1.676	1.395	0.551	0.736	1.383	1.181	0.881	0.671
Mean	3.167	2.032	1.238	1.213	2.150	1.507	0.368	0.681	1.935	0.872	0.788	0.682

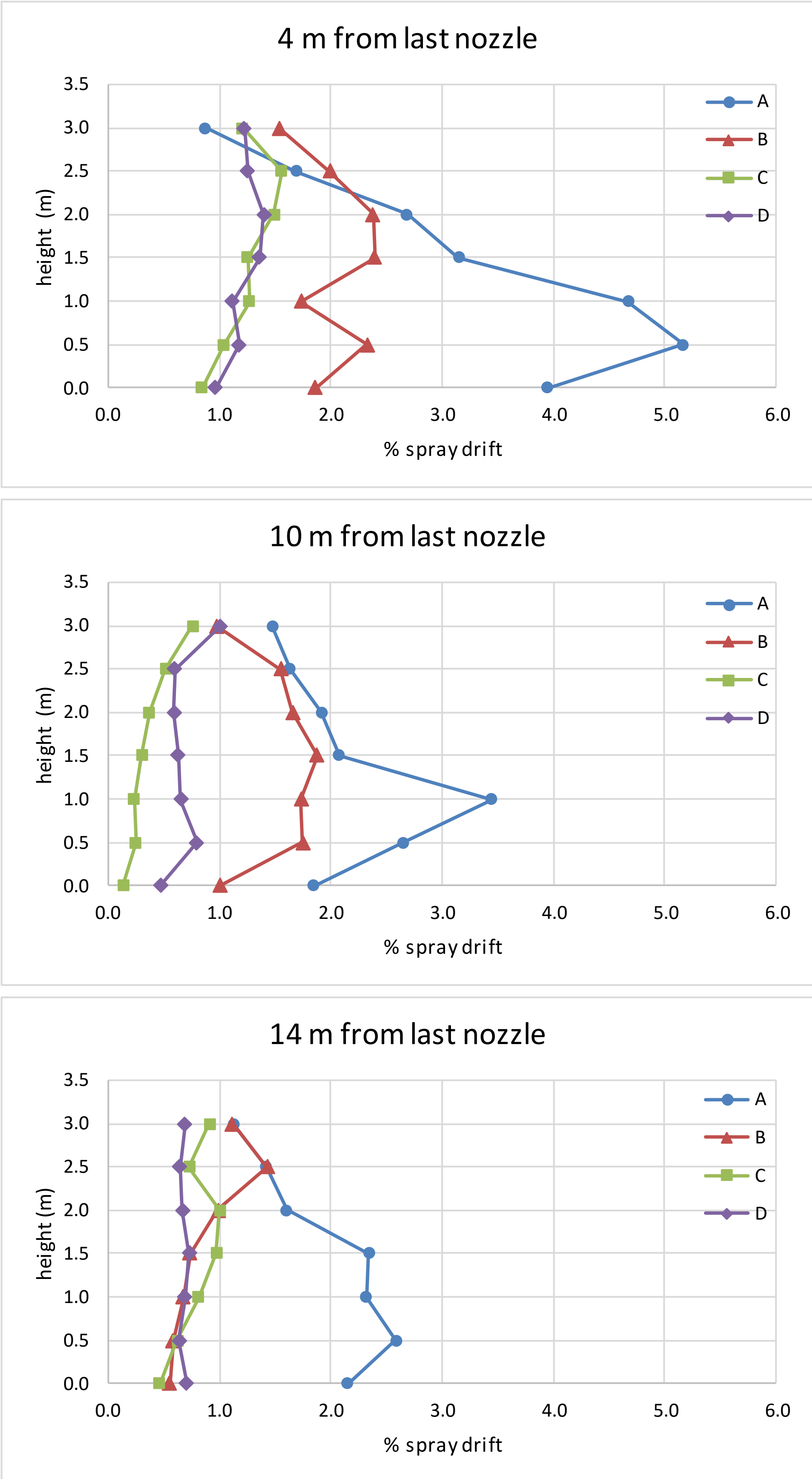

Figure 3.2 *Mean airborne spray drift (% of applied spray volume per unit area) measured with passive collectors at different heights at 4 m, 10 m and 14 m from the last nozzle spraying the outside swath (27 m) of a bare soil surface area using a boom sprayer equipped with a standard nozzle (XR11004) at 50 cm spray boom height passing different gardens (A= Open Area, B = Open Garden, C= Half Open garden, D= Closed Garden).*

3.3.2 Active measurements with suction heads

Average airborne spray drift in the centre of the garden at 10 m distance from the last nozzle measured with active suction head collectors spraying a bare soil surface alongside different gardens is presented in Table 3.4 and Figure 3.3.

Table 3.4 *Airborne spray drift (% of applied spray volume per unit area) measured with suction head collectors at different heights at 10 from the last nozzle spraying the outside swath (27 m) of a bare soil surface area using a boom sprayer equipped with a standard nozzle (XR11004) at 50 cm spray boom height passing different gardens (A= Open Area, B = Open Garden, C= Half Open garden, D= Closed Garden).*

Height (m)	A	B	C	D
3	1.758	1.334	2.294	3.718
2	2.345	1.239	1.960	3.659
1	2.895	1.971	2.303	2.983
0.75	2.901	2.143	1.768	2.018
0.37	2.863	2.551	2.283	1.924
0.37-1	2.886	2.222	2.118	2.308
1-3	2.052	1.287	2.127	3.689
Mean	2.552	1.848	2.121	2.860

Average airborne spray drift over 3 m height measured with the active suction head collectors at 10 m distance from the last nozzle (centre of the garden); is highest in the Closed Garden (2.9%). Airborne spray drift is a little lower in the Open Area (2.6%) and again lower in the Half Open garden 2.1%. Lowest airborne spray drift is measured in the Open garden (1.8%). Airborne spray drift at 1-3 m height is in the Open Area lower than at 0.37-1 m height. In the Open Garden airborne drift at these heights is similar. Whereas in the Closed Garden airborne drift at 1-3 m height is higher than at 0.37-1 m height. It looks like that because of the screens at the garden edge the wind profiles change (to higher heights) causing in the center of the garden behind the screen a higher airborne spray drift at higher heights.

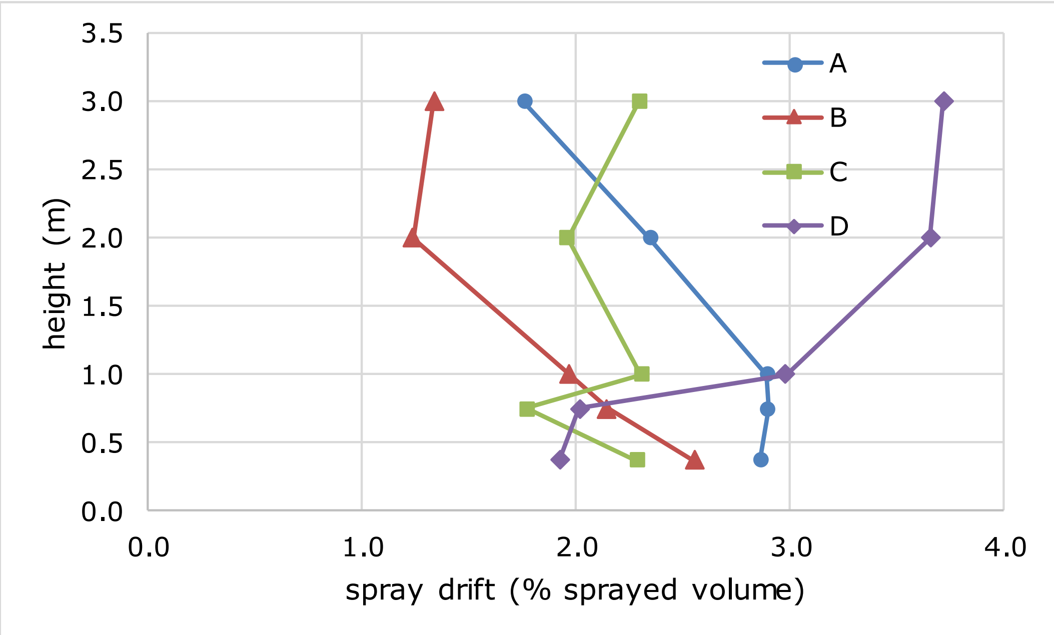

Figure 3.3 *Mean airborne spray drift (% of applied spray volume per unit area) measured with suction head collectors at different heights at 10 from the last nozzle spraying the outside swath (27 m) of a bare soil surface area using a boom sprayer equipped with a standard nozzle (XR11004) at 50 cm spray boom height passing different gardens (A= Open Area, B = Open Garden, C= Half Open garden, D= Closed Garden).*

3.4 Spray deposition at 'wall'

Average spray drift deposition at the wall of the greenhouse at 14 m distance from the last nozzle spraying a bare soil surface alongside different gardens is presented in Figure 3.4 and Table 3.5.

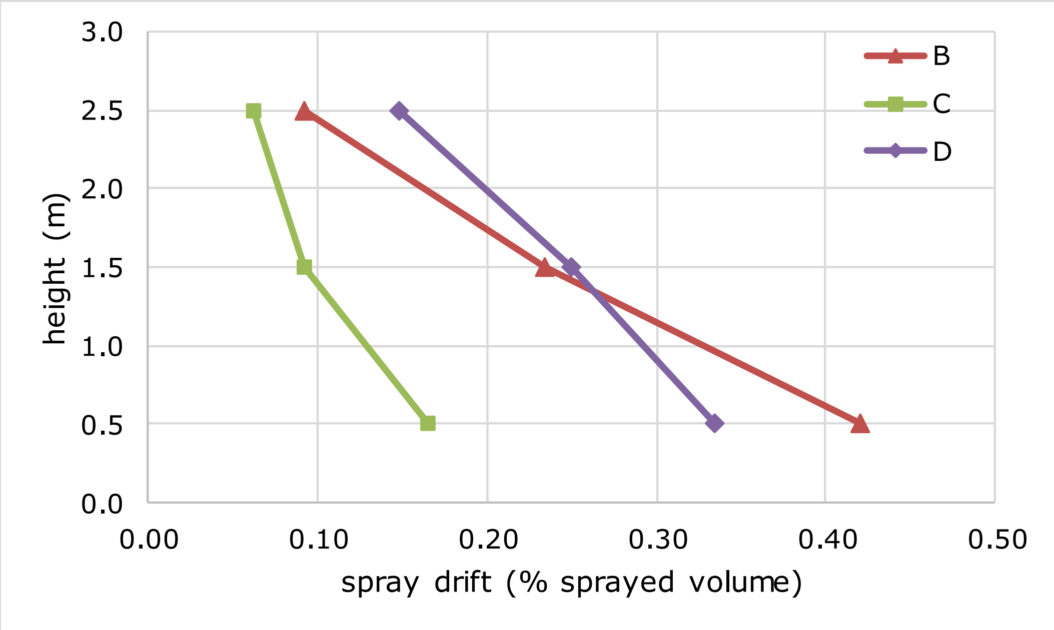

Figure 3.4 *Mean spray drift deposition (% of applied spray volume per unit area) at the wall of the greenhouse at different heights at 14 m from the last nozzle spraying the outside swath (27 m) of a bare soil surface area using a boom sprayer equipped with a standard nozzle (XR11004) at 50 cm spray boom height passing different gardens (B = Open Garden, C= Half Open garden, D= Closed Garden).*

Table 3.5 *Mean spray drift deposition (% of applied spray volume per unit area) at the wall of the greenhouse at different heights at 14 m from the last nozzle spraying the outside swath (27 m) of a bare soil surface area using a boom sprayer equipped with a standard nozzle (XR11004) at 50 cm spray boom height passing different gardens (B = Open Garden, C= Half Open garden, D= Closed Garden).*

Height (m)	**B**	**C**	**D**
2-3	*0.092*	*0.062*	*0.148*
1-2	*0.233*	*0.093*	*0.249*
0-1	*0.420*	*0.166*	*0.335*
Mean	*0.249*	*0.107*	*0.244*

At all heights, spray drift deposition at the wall of the greenhouse is lowest in the Open garden (B; 0.11%). Average over height (0-3 m) there is no difference in spray drift deposition between the Open Garden (B) and the Closed Garden (D). However, differences do occur depending on the height looked at. At 0-1 m height spray drift deposition against the wall of the greenhouse is in the Open Garden with 0.42% higher than of the 0.34% in the Closed Garden. At 2-3 m height however, the spray drift deposition against the wall is in the Closed Garden higher (0.15%) compared to the Open Garden (0.092%).

4 Discussion

Spray drift measurements with a barrier crop

Earlier spray drift measurements with elephant grass (Miscanthus) as a barrier crop at the field edge of a sprayed field showed a reduction in spray drift behind the barrier crop (Zande *et al.*, 2000). Spray applications were done with a boom sprayer equipped with standard flat fan nozzles (XR11004) at 0.50 m spray boom height spraying potato and a sugar beet crop. The barrier crop was cut at different levels; equal to crop height (0.50 m), equal to spray boom height above crop canopy (1.0 m) and to 1 m above crop height (1.50 m barrier crop height). Spray drift reduction for the three barrier crop heights was resp. 50%, 70% and 90% at a distance of 2-3 m behind the barrier crop (4-5 m from the last nozzle). Spray drift reduction to the air (0-6 m height) was for all three heights of the barrier crop 80%. In this study, spray drift reduction in the Half Open garden (C) and the Closed Garden (D) was at 4-5 m behind the screens resp. 78% and 75%. Reduction in average airborne spray drift (0-3 m height) measured with the passive collectors was resp. 83% and 68%. The measurements with the 30% wind-closed windbreak shield in the Half Open garden seems to give similar results as of the measurements with the elephants grass as a barrier crop.

Collection of spray drift in the screens

For the spray drift measurements in the Half Open garden (C) and the Closed garden (D) airborne average spray drift (0-2 m height) at 4 m from the last nozzle (1 m in front of the screen) is 62%-62% lower than in the Open Area. The airborne drift over the height of the screens (2.5-3.0 m height) is almost equal for both the situations (1.2%-1.4%). This can be an indication that part of the airborne spray drift is collected in the screens itself. This can also be concluded from the decrease in spray deposition on ground surface close behind the screens (C: 70% - D: 50%). The amount of spray drift collected in the screens is not measured. For future research, it is recommended to measure also the potential spray drift deposition on the screens and shields to get a better view on the mode of action of shields and screens on spray drift reduction and the actual process.

Spray drift measurement near a fence

In spray drift measurements in a practical situation, with a fence on the field edge next to the sprayed field (Zande *et al.*, 2016; OBO-Deliverable 031), it was showed that especially airborne spray drift from the outside swath above fence-height (2.5-3.0 m) was higher than averaged over fence-height (0-2 m). It looked as if airborne spray drift was lifted in the air. The field measurements were performed at wind speeds of 1.5-2.5 $m.s^{-1}$ (at 2 m height). In this study with a closed screen (Closed Garden; D) the lifting of spray drift to higher heights is less pronounced. This could be because of the higher wind speeds occurring during spray drift measurements in this study (4.5 $m.s^{-1}$ at 2 m height). In future research on the effect of screens it is recommended to do the spray drift measurements at more wind speeds and over a wider range. It also can be that the more lift effect in the practical spray drift measurements was accounted for the nozzle type used as a drift-reducing nozzle was used. Therefor the offered number of small drops vulnerable to spray drift is lower (75%-90% lower) in the air currents around a barrier (screen) and can easier follow the air stream than with a larger number as with a standard flat fan nozzle as used in this study. In future research it is recommended to take up also drift-reducing nozzle types, more wind speeds and different screen types in the spray drift measurements to quantify the effect of screens on spray drift reduction.

Spray drift spraying a bare soil surface

From spray drift measurements spraying a bare soil surface using a standard flat fan nozzle (XR11004) at 0.50 m spray boom height (Zande *et al.*, 2018), it is concluded that spray drift deposition at ground surface over distances of 1 m to 25 m from the last nozzle is about 2 to 4 times lower than the results in this study. This is mainly because of the lower wind speeds (2-2.5 $m.s^{-1}$ at 2 m height) in comparison to the 4.5 $m.s^{-1}$ in this study. Zande *et al.* (2012) found spray drift deposition values of equal height as in this study whereas their wind speeds were on average 3.2 $m.s^{-1}$ at 2 m height. Downwind spray drift deposition when spraying a developed crop canopy (> 0.20 m height) shows always higher values than when spraying a bare soil surface (Zande *et al.*, 2012, 2018).

Because of the higher number of spray drift vulnerable drops at higher height above ground surface when spraying a crop canopy the spray drift plume can hit the screens at a higher height (crop height + spray boom height) and therefor the results from this study can differ when a crop canopy is sprayed. In future research the effect of canopy and bare soil spraying and the reduction of screens is to be addressed.

Air movements around a screen
To get an impression of the air movements around the screens covered with 30% wind-closed windbreak shield and with 100% wind-closed anti-root growth cloth air speed measurements were done (Annex 4). At 10 m in front of the screens and at 7.5 m behind the screens for a period of 2 hours airspeed was measured using cup anemometers at 0.50 m, 1.00 m, 2.00 m and 4.00 m height. Average wind speed are for both situations (C, Half Open garden with 30% wind-closed windbreak shield; D, Closed garden with 100% wind-closed anti-root cloth) presented in Figure 4.1 (left). With the windbreak shield air speed at all heights (0.50-4.0 m) at 7.5 m behind the screen was lower than at 10 m in front of the screen. On average air speed at 0.5 – 2.0 m height was 50%-60% lower behind the windbreak shield than at the same height in front of the screen. With the wind-closed screen a lower air speed was measured at 7.5 m behind the screen at 4 m height, a larger decrease in air speed at 2 m height and an increase in air speed at 1 m and 0.5 m height (Figure 4.1 left) compared to the same heights at 10 m in front of the screen. Air speed at 4 m and 2 m height behind the screen was resp. 80% and 60% of the air speed at the same height in front of the screen while at 1 m and 0.5 m height the measured air speed behind the screen was resp. 7% and 10% higher (Figure 4.1 right).

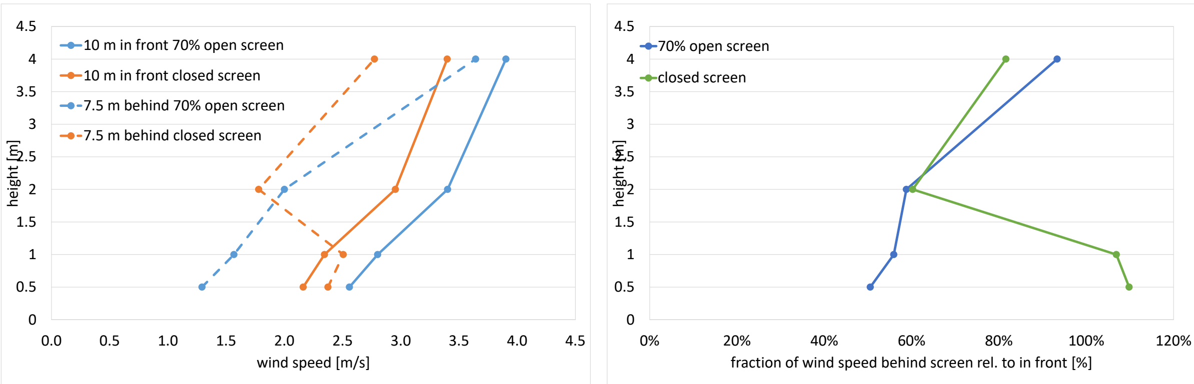

Figure 4.1 *Air speed (m.s^{-1}) at different heights measured at 10 m in front and at 7.5 m behind a 30% wind-closed screen and a closed screen (left) and the relative air speed at 7.5 m behind the screen as percentage of the air speed at the same height of 10 m in front of the screen (right).*

During the 2-hour measuring period every 15 minutes air speed was also measured at points in between the 10 m in front and 7.5 m behind the screen using ultrasonic anemometers (Metpak) at 0.50 m and 2.0 m height. Relative air speeds compared to the air speed at 4 m height in front and behind the screens is presented for the 30% wind-closed windbreak shield (C, Half Open garden; Figure 4.2 left) and the 100% wind-closed anti-root cloth (D, Closed garden Figure 4.2 right).

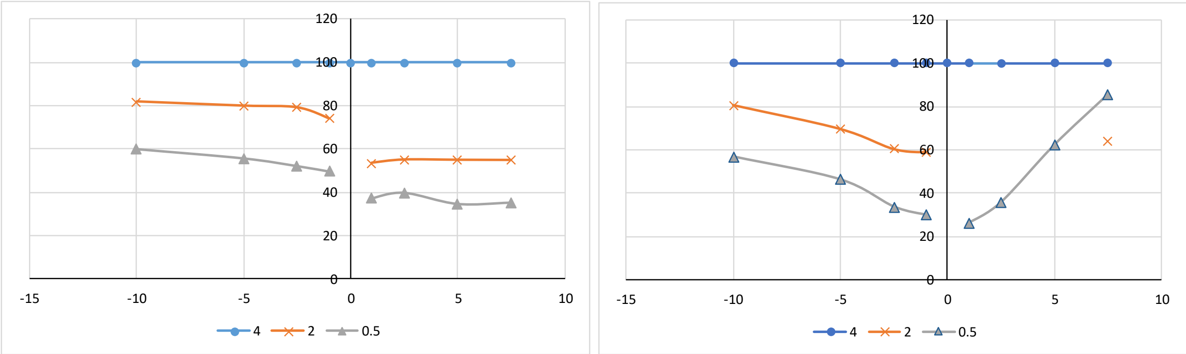

Figure 4.2 *Relative air speed (% of wind speed at 4 m height) at 2 m and 0.5 m height in front and behind a screen with 30% wind-closed windbreak shield (left) and 100% wind-closed anti-root growth cloth (right).*

The air speeds around the 30% wind-closed windbreak shield are different from those around the 100% wind-closed anti-root cloth. With the 30% wind-closed windbreak shield there is a small decrease in air speed at 0.5 m and 2.0 m height in front of the screen and decrease behind the screen which is maintained at the different distances (Figure 4.2 left). With the anti-root cloth there is a strong decrease in air speed at 0.5 m and 2.0 m height in front of the screen and a strong increase in air speed at 0.5 m height behind the screen at the distances 1-7.5 m behind the screen.

Reduction in air speed and spray drift reduction behind a screen
It looks as if there is a relation between decrease in air speed behind the screens (40%-50%) and a decrease in spray drift deposition at ground (75%-78%) and airborne spray drift (68%-83%) behind the screens. Why this decrease occurs remains unclear. The decrease in spray drift deposition behind the screens can occur because of a change in air currents around the screens (Jacobs, 1983), as through active collection of spray drift at the screens itself. This process is to be further assessed with screens and natural vegetative barriers.

Air circulation can occur in the area just in front of a closed screen (0.5 x height of screen) to 6 times the height of the screen behind the screen (Jacobs, 1983). The air speed shows large variations and should be measured with 3D anemometers to obtain not only the average wind speed in x,y direction but also the speeds in three directions (x, y, z) as close to ground surface also air movements against the wind direction can occur (in the direction of the screen behind the screen). With future air speed measurements around screens and vegetative barriers 3D ultrasonic anemometers should be used instead of the now used 2D ultrasonic Metpak anemometers.

Jacobs (1983) found that the average air speed within an area of three times the height of the screen in front of the screen up till 30 times the screen height behind the screen is influenced by the closed screen (lower air speeds). Strongest effects in decrease in air speed were direct behind the screen (1-2 x screen height). Within the limited distances measured in this study; 5 times height of screen in front of the screen and behind the screen (2 m high) similar effects do occur as found by Jacobs (1983). Highest reduction in horizontal air speed was measured at 2 m height (is screen height). Jacobs (1983) found highest reductions in air speed at 1.8 times the height of the screen. In this study, this differentiation in height cannot be made as measurements were only at 0.25 and 2.0 times screen height, however results look very similar.

Use of results in a spray drift model
Results from this study about spray drift and the use of different screens can be used in the further development of the IDEFICS spray drift model (Holterman *et al.*, 1997). It is advised however to do more detailed measurements first about air movements around screens, the effect on air speed and direction, and the use of drift reducing nozzles on spray drift reduction.

5 Conclusions

The effect of a field edge barrier on airborne spray drift and spray drift ground deposit in front and behind the barrier was measured, spraying a bare soil surface using a conventional boom sprayer operating at 0.50 m spray boom height, and standard flat fan nozzles (XR11004). Screens covered with 30% wind-closed windbreak shield were used to model a hedgerow and screens covered with anti-root growth cloth as a closed fence. Spray drift experiments were performed under practical circumstances, representative for applications in a flower crop, however using a fluorescent tracer instead of a Plant Protection Product.

The use of screens at the field edge reduces spray drift ground deposit as well as airborne spray drift behind the screens. At 4-5 m behind a 30% wind-closed windbreak screen spray drift reduction was 78% when spraying a bare soil surface using standard flat fan nozzles (XR11004) at 0.50 m boom height. Using a closed screen spray drift reduction at this distance was 73%.

Airborne spray drift at 5 m distance behind the screens over 0-3 m height was for the 30% wind-closed windbreak screen 83% when measured with passive collectors. Airborne spray drift reduction for the closed screen was for this situation 68%.

Using active sampling techniques measuring airborne spray drift, almost no spray drift reduction (17%) because of usage of screens at the field edge was over 0-3 m height measured for the 30% wind-closed windbreak screen. Using the closed screen at the field edge resulted in an increase in airborne spray drift measured with active sampling techniques of 12%.

Spray drift deposition at 0-3 m height collectors positioned at the wall of the (green)house at 15 m distance from the last nozzle was on average 0.25%. When screens are positioned at 5 m distance from the last nozzle; spray deposit at the wall 10 m behind the screens was similar for the closed screen and 57% lower using a 30% wind-closed windbreak screen.

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Annex 1 Spray drift deposition (% of applied spray volume per unit area) at ground surface downwind of sprayed swath

Open area

Distance to last nozzle (m)	#1		#2		#3	
	Row 1	Row 2	Row 1	Row 2	Row 1	Row 2
25-26	0.038	0.029	0.112	0.055	0.278	0.275
20-21	0.061	0.059	0.057	0.068	0.482	0.512
14-15	0.080	0.057	0.183	0.326	0.350	0.288
10-11	0.149	0.204	0.534	1.248	0.461	0.353
5-6	0.276	0.294	1.174	0.627	0.522	0.676
4-5	0.340	0.330	3.442	0.910	0.671	0.593
2-3	3.050	0.463	2.085	3.040	1.191	1.783
½-1	9.380	7.956	24.689	8.369	7.506	5.018

Open garden

Distance to last nozzle (m)	#1		#2		#3	
	Row 1	Row 2	Row 1	Row 2	Row 1	Row 2
14-15	0.106	0.065	0.075	0.217	0.363	0.284
10-11	0.156	0.121	0.167	0.387	0.288	0.279
5-6	0.104	0.510	1.778	0.606	0.585	0.420
4-5	0.450	0.301	0.604	1.425	0.661	0.367
2-3	1.078	1.319	2.467	1.386	0.651	0.877
½-1	6.793	9.482	7.150	10.686	5.140	13.671

Half Open garden

Distance to last nozzle (m)	#1		#2		#3	
	Row 1	Row 2	Row 1	Row 2	Row 1	Row 2
14-15	0.062	0.053	-0.001	0.118	0.146	0.165
10-11	0.057	0.099	0.080	0.149	0.123	0.140
5-6	0.082	0.212	0.137	0.161	0.257	0.142
4-5	0.578	0.611	0.394	0.550	0.783	0.497
2-3	1.001	1.359	1.167	1.170	1.661	1.026
½-1	3.805	3.709	3.493	4.596	5.073	2.858

Closed garden

Distance to last nozzle (m)	#1		#2		#3	
	Row 1	Row 2	Row 1	Row 2	Row 1	Row 2
14-15	0.208	0.144	0.126	0.163	0.200	0.241
10-11	0.132	0.109	0.079	0.089	0.186	0.148
5-6	0.076	0.197	0.207	0.157	0.169	0.272
4-5	0.223	0.227	0.374	0.357	0.448	0.414
2-3	0.242	0.260	0.458	0.315	0.521	0.562
½-1	1.740	0.810	7.351	7.793	3.472	5.436

Annex 2 Airborne spray drift (% of applied spray volume per unit area) passive measurement; spherical collectors

Open area

4m from last nozzle

Height (m)	#1		#2		#3	
	Row 1	Row 2	Row 1	Row 2	Row 1	Row 2
3	0.420	0.830	1.571	0.847	0.699	0.880
2.5	0.846	1.403	2.765	2.297	0.950	1.856
2	1.411	1.342	4.256	3.862	2.223	3.025
1.5	2.525	1.034	2.936	4.833	3.499	4.049
1	5.443	1.658	7.678	5.910	2.681	4.632
0.5	5.901	2.100	10.300	5.850	3.817	2.996
0	4.605	2.386	6.013	5.765	2.676	2.228

10m from last nozzle

Height (m)	#1		#2		#3	
	Row 1	Row 2	Row 1	Row 2	Row 1	Row 2
3	0.931	0.564	1.484	1.898	3.118	0.835
2.5	1.091	0.897	1.590	1.372	3.468	1.413
2	1.280	1.102	2.595	1.701	3.079	1.745
1.5	1.357	0.842	3.209	1.634	4.127	1.297
1	1.352	1.148	4.764	5.222	5.187	2.977
0.5	1.342	1.042	3.878	3.646	3.600	2.432
0	0.867	0.976	2.770	1.320	2.257	2.881

14m from last nozzle

Height (m)	#1		#2		#3	
	Row 1	Row 2	Row 1	Row 2	Row 1	Row 2
3	0.909	0.715	0.749	1.129	1.862	1.369
2.5	1.187	0.990	1.246	1.905	1.565	1.644
2	1.004	1.002	1.938	1.682	2.380	1.622
1.5	1.502	0.872	1.301	2.954	4.187	3.252
1	0.683	1.041	1.528	2.221	3.527	4.895
0.5	1.196	1.178	1.455	1.923	5.602	4.150
0	0.974	0.738	1.486	1.326	4.996	3.391

Open garden

4m from last nozzle

Height (m)	#1		#2		#3	
	Row 1	Row 2	Row 1	Row 2	Row 1	Row 2
3	2.008	1.131	0.439	0.495	1.603	3.527
2.5	2.710	1.640	0.836	0.764	3.404	2.599
2	1.755	3.946	1.130	1.375	3.230	2.828
1.5	1.486	2.757	1.457	2.474	3.465	2.744
1	*	*	2.213	3.020	2.779	2.500
0.5	0.587	*	3.315	4.380	3.488	2.265
0	0.927	*	3.886	2.211	2.587	1.617

10m from last nozzle

Height (m)	#1		#2		#3	
	Row 1	Row 2	Row 1	Row 2	Row 1	Row 2
3	0.596	1.200	0.459	0.370	1.670	1.550
2.5	1.464	1.623	0.603	0.497	2.884	2.253
2	1.584	1.770	0.833	1.086	2.672	1.989
1.5	1.810	2.400	0.920	1.244	2.872	2.035
1	1.566	2.206	0.895	1.375	2.313	2.055
0.5	2.341	1.992	0.453	1.258	2.641	1.822
0	1.190	0.880	0.378	0.527	1.688	1.338

14m from last nozzle

Height (m)	#1		#2		#3	
	Row 1	Row 2	Row 1	Row 2	Row 1	Row 2
3	0.704	0.978	0.556	0.920	2.093	1.475
2.5	1.831	1.075	0.400	0.673	3.450	1.151
2	1.562	0.901	0.338	0.420	1.529	1.200
1.5	0.873	0.559	0.283	0.519	1.433	0.775
1	0.911	0.658	0.193	0.310	0.826	1.177
0.5	0.952	0.733	0.205	0.288	0.647	0.684
0	0.553	0.782	0.191	0.243	0.875	0.705

Half Open garden

4m from last nozzle

Height (m)	#1		#2		#3	
	Row 1	Row 2	Row 1	Row 2	Row 1	Row 2
3	1.196	1.157	0.588	0.333	2.045	1.927
2.5	1.904	1.889	0.514	0.242	2.124	2.662
2	1.464	1.685	0.302	0.193	2.569	2.721
1.5	1.746	2.238	0.234	0.129	1.297	1.879
1	1.481	1.925	0.185	0.141	1.815	2.082
0.5	1.527	1.208	0.177	0.188	1.277	1.865
0	1.453	1.493	0.191	0.198	0.750	0.992

10m from last nozzle

Height (m)	#1		#2		#3	
	Row 1	Row 2	Row 1	Row 2	Row 1	Row 2
3	0.719	0.391	0.880	0.680	1.204	0.688
2.5	0.432	0.438	0.566	0.467	0.661	0.550
2	0.426	0.485	0.274	0.231	0.444	0.375
1.5	0.512	0.440	0.259	0.216	0.196	0.201
1	0.358	0.288	0.192	0.213	0.158	0.185
0.5	0.289	0.505	0.180	0.166	0.126	0.244
0	0.272	0.168	0.094	0.116	0.076	0.102

14m from last nozzle

Height (m)	#1		#2		#3	
	Row 1	Row 2	Row 1	Row 2	Row 1	Row 2
3	0.626	0.579	1.822	1.327	0.665	0.457
2.5	0.791	0.473	1.425	1.036	0.274	0.373
2	0.499	0.631	2.134	2.209	0.312	0.223
1.5	0.474	0.730	1.912	2.161	0.273	0.284
1	0.531	0.524	1.976	1.296	0.241	0.306
0.5	0.541	0.437	1.169	1.185	0.248	0.171
0	0.376	0.232	1.032	0.705	0.194	0.231

Closed garden

4m from last nozzle

Height (m)	#1		#2		#3	
	Row 1	Row 2	Row 1	Row 2	Row 1	Row 2
3	0.953	0.909	0.446	2.343	1.405	1.281
2.5	0.813	0.876	0.906	2.407	1.613	0.921
2	1.250	0.849	1.329	2.210	1.805	0.947
1.5	1.307	0.758	1.651	1.266	1.804	1.363
1	0.782	0.908	1.601	1.107	0.882	1.437
0.5	0.546	0.792	3.124	0.596	0.766	1.227
0	0.467	0.629	2.946	0.442	0.558	0.738

10m from last nozzle

Height (m)	#1		#2		#3	
	Row 1	Row 2	Row 1	Row 2	Row 1	Row 2
3	1.633	0.874	1.388	1.526	0.416	0.237
2.5	0.868	0.639	0.628	0.889	0.302	0.286
2	0.742	0.669	0.714	0.895	0.190	0.352
1.5	0.815	1.003	0.512	0.902	0.212	0.346
1	0.633	0.747	0.862	1.190	0.274	0.240
0.5	0.947	1.124	1.047	1.177	0.310	0.183
0	0.434	0.632	0.539	0.923	0.212	0.069

14m from last nozzle

Height (m)	#1		#2		#3	
	Row 1	Row 2	Row 1	Row 2	Row 1	Row 2
3	1.317	1.046	0.580	0.746	0.222	0.263
2.5	0.908	0.975	0.585	0.788	0.372	0.263
2	1.126	0.901	0.739	0.553	0.370	0.319
1.5	0.932	1.036	0.857	0.810	0.364	0.394
1	0.881	1.250	0.602	0.507	0.486	0.424
0.5	0.865	0.720	0.670	0.634	0.519	0.405
0	0.820	0.885	0.857	1.025	0.277	0.364

Annex 3 Airborne spray drift at 10 m from last nozzle (% of applied spray volume per unit area) active measurement; suction head collectors

Open area

Height (m)	#1		#2		#3	
	Row 1	Row 2	Row 1	Row 2	Row 1	Row 2
3	0.850	1.124	3.607	4.005	0.497	0.469
2	1.526	1.824	4.188	4.092	1.113	1.327
1	2.231	2.208	5.020	4.789	1.397	1.725
0.75	2.563	2.457	4.484	4.274	1.692	1.936
0.37	2.495	3.672	4.396	3.204	1.654	1.753

Open garden

Height (m)	#1		#2		#3	
	Row 1	Row 2	Row 1	Row 2	Row 1	Row 2
3	1.268	4.005	*	2.080	0.285	0.508
2	2.315	4.092	*	*	0.819	0.505
1	3.099	4.789	0.455	0.533	1.465	1.486
0.75	3.132	4.274	0.881	0.809	1.855	1.910
0.37	3.548	3.204	1.856	2.072	2.451	2.178

Half Open garden

Height (m)	#1		#2		#3	
	Row 1	Row 2	Row 1	Row 2	Row 1	Row 2
3	1.620	1.786	2.339	1.936	3.151	2.928
2	1.831	1.779	*	2.084	3.246	2.982
1	2.565	2.526	*	3.090	2.912	2.890
0.75	3.027	2.280	*	*	2.815	2.790
0.37	3.030	3.019	0.752	0.687	3.121	3.086

Closed garden

Height (m)	#1		#2		#3	
	Row 1	Row 2	Row 1	Row 2	Row 1	Row 2
3	5.812	5.354	2.130	3.892	2.621	2.501
2	5.675	4.493	3.103	4.112	2.383	2.189
1	3.745	2.902	3.840	4.054	1.648	1.713
0.75	2.953	2.222	*	3.661	1.719	1.699
0.37	2.263	2.415	*	3.432	1.641	1.937

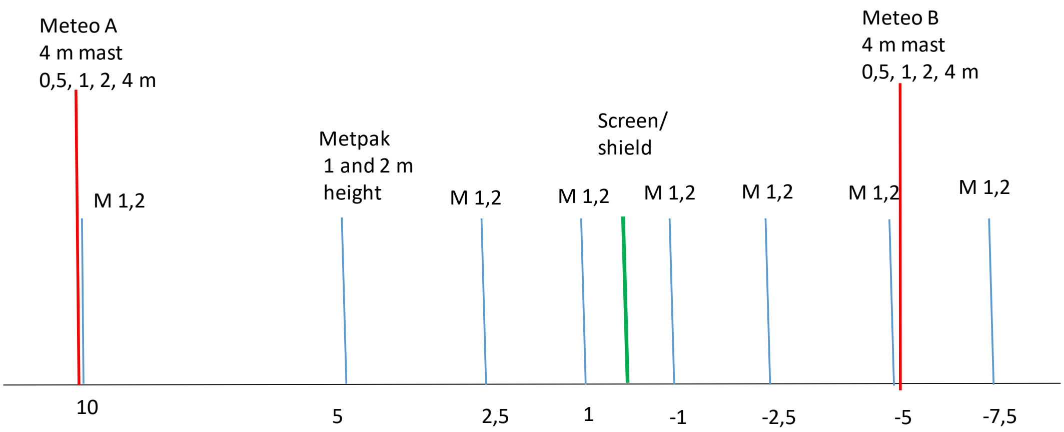
Annex 4 Air speed measurements around screens

Used measurement instruments:
Weather stations Meteo A and Meteo B were positioned at fixed positions 10 m in front of the screen and at 7,5 m behind the screen.

Wind speed was measured with cup anemometers at 0.50, 1.00 m, 2.00 m and 4.00 m height. Measurements were every 5 seconds (0.2 Hz).

Movable measuring poles with at 2.0 m and 4.0 m height Metpak ultrasonic anemometers were positioned for 15 minutes at different positions in front and behind the screens. Measurement frequency was one measurement per second (1 hz). See below for overview of measured positions.

Schematic overview of the fixed measuring positions with cup anemometers (Meteo A and Meteo B) and of the variable positions with the Metpak ultrasonic anemometers (M1,2).



Measurement times at the different positions at 31-10-2017:

30% closed windbreak shield			
position	**Start time**	**Stop time**	**order**
10 m in front	10:55:00	11:10:00	1e
5 m in front	11:11:00	11:26:00	2e
2,5 m in front	11:27:00	11:47:00	3e
1 m in front	11:43:00	11:58:00	4e
1 m behind	12:04:00	12:19:00	5e
2,5 m behind	12:26:00	12:41:00	6e
5 m behind next to 4 m mast	12:42:00	12:57:00	7e
7,5 m behind	Not measured		
position	**Start time**	**Stop time**	**order**
10 m in front	15:01:00	15:16:00	8e
5 m in front	14:45:00	15:00:00	7e
2,5 m in front	14:29:00	14:44:00	6e
1 m in front	14:12:30	14:28:00	5e
1 m behind	13:53:00	14:08:00	4e
2,5 m behind	13:36:30	13:52:00	3e
5 m behind next to 4 m mast	13:02:00	13:18:00	1e
7,5 m behind	13:19:00	13:35:00	2e

Wind speed measurements Meteo A at 10 m in front of screen and Meteo B at 7,5 m behind screen with 30% wind closed windbreak shield and 100% closed anti-root cloth

			MeteoMast A 10 m in front of screen					**MeteoMast B 7.5 m behind screen**			
			Box A	**Box A**	**Box A**	**Box A**		**Box A**	**Box A**	**BoxB**	**BoxB**
position			**0.5m**	**1m**	**2m**	**4m**		**0.5m**	**1m**	**2 m**	**4m**
Metpaks			**AC1m/s**	**AC2m/s**	**AC3m/s**	**AC4m/s**	**Wind angle from perp.**	**AC5m/s**	**AC6m/s**	**AC7m/s**	**AC8m/s**
10 m	end 30%	avg	2.6	2.8	3.3	3.7	-36	1.5	1.8	2.2	3.4
		stdev	0.59	0.65	0.69	0.75	13	0.62	0.63	0.58	0.63
5m	end 30%	avg	2.4	2.6	3.2	3.7	-27	1.2	1.5	1.8	3.4
		stdev	0.66	0.71	0.75	0.85	14	0.50	0.51	0.59	0.73
2.5m	end 30%	avg	2.5	2.7	3.5	4.0	-21	1.0	1.3	1.9	3.9
		stdev	0.6	0.7	0.8	0.9	14	0.5	0.5	0.6	0.8
1 m	end 30%	avg	2.6	2.8	3.5	4.0	-22	1.1	1.4	1.9	3.7
		stdev	0.64	0.73	0.86	0.91	16	0.49	0.46	0.56	0.73
- 1 m	end 30%	avg	2.7	2.9	3.6	4.1	-25	1.2	1.4	1.9	3.8
		stdev	0.68	0.74	0.80	0.86	14	0.51	0.49	0.52	0.72
- 2.5 m	end 30%	avg	2.6	2.8	3.3	3.7	-37	1.6	1.9	2.2	3.5
		stdev	0.71	0.80	0.89	0.94	13	0.76	0.77	0.79	0.85
- 5 m	end 30%	avg	2.7	3.0	3.5	4.0	-33	1.4	1.7	2.1	3.8
		stdev	0.77	0.86	0.89	0.92	13	0.56	0.59	0.63	0.86
		avg run1	2.6	2.8	3.4	3.9		1.3	1.6	2.0	3.6
10 m	end 100%	avg	2.0	2.1	2.7	3.0	-32	2.2	2.2	1.8	2.7
		stdev	0.57	0.61	0.68	0.69	12	0.80	0.71	0.45	0.63
5 m	end 100%	avg	1.9	2.1	2.6	3.0	-33	2.3	2.3	1.7	2.7
		stdev	0.50	0.55	0.61	0.66	14	0.77	0.64	0.44	0.65
2.5 m	end 100%	avg	2.0	2.2	2.8	3.3	-21	2.1	2.2	1.8	2.9
		stdev	0.67	0.81	0.92	0.97	13	1.02	0.93	0.59	0.87
1m	end 100%	avg	1.9	2.0	2.6	2.9	-26	2.4	2.4	1.8	2.7
		stdev	0.52	0.58	0.61	0.67	14	1.12	0.95	0.54	0.74
- 1 m	end 100%	avg	2.1	2.3	2.9	3.3	-26	2.2	2.4	1.9	2.9
		stdev	0.62	0.70	0.78	0.75	13	0.95	0.91	0.57	0.77
-2.5 m	end 100%	avg	2.1	2.3	2.9	3.4	-28	2.4	2.5	1.8	2.9
		stdev	0.57	0.61	0.67	0.73	12	1.00	0.85	0.59	0.87
-5m	end 100%	avg	2.6	2.8	3.5	4.1	-27	2.6	2.8	1.7	2.7
		stdev	0.67	0.71	0.81	0.87	12	1.21	1.05	0.44	0.65
- 7.5 m	end 100%	avg	2.7	2.9	3.6	4.2	-28	2.9	3.2	1.8	2.7
		stdev	0.68	0.80	0.95	0.97	13	1.25	1.17	0.45	0.63
		avg run2	***2.2***	***2.3***	***3.0***	***3.4***		***2.4***	***2.5***	***1.8***	***2.8***

Wind speed measurements at different distances in front of and behind screen with 30% wind closed windbreak shield and 100% closed anti-root cloth using ultrasonic anemometer (Metpak) at 2.0 m and 0.5 m height above ground surface

From 10 m in front to 5 m behind												
Metpak A	2 m measuring height						Metpak B 0.5 m measuring height					
Position Metpaks	shield	Measuring time (sec)		Wind angle [deg]	Wind Speed [m/s]	Wind angle from perpend	position	shield		Wind angle [deg]	Wind Speed [m/s]	Wind angle from perpend
10 m	end 30%	900	avg	229	3.0	-41	10 m	end 30%	avg	224	2.2	-46
			stdev	15.6	0.7	16			stdev	17.3	0.6	16
5 m	end 30%	806	avg	238	3.0	-32	5m	end 30%	avg	230	2.1	-40
			stdev	16.1	0.9	16			stdev	17.1	0.7	17
2.5 m	end 30%	883	avg	243	3.2	-27	2.5 m	end 30%	avg	235	2.1	-35
			stdev	15.9	0.8	16			stdev	20.0	0.7	20
1 m	end 30%	900	avg	238	3.0	-32	1 m	end 30%	avg	228	2.0	-42
			stdev	19.8	0.8	20			stdev	23.2	0.6	23
- 1m	end 30%	900	avg	240	2.2	-30	-1m	end 30%	avg	238	1.5	-32
			stdev	18.9	0.7	19			stdev	18.2	0.4	18
-2.5m	end 30%	900	avg	220	2.1	-50	-2.5 m	end 30%	avg	222	1.5	-48
			stdev	19.9	0.8	20			stdev	17.7	0.5	18
-5 m	end 30%	no measurement					-5 m	end 30%	avg	221	1.4	-49
									stdev	25.8	0.5	26
10 m	end 100%	860	avg	237	2.5	-32	10 m	end 100%	avg	231	1.7	-39
			stdev	15.3	0.6	17			stdev	16.7	0.5	17
5m	end 100%	877	avg	233	2.1	-37	5 m	end 100%	avg	221	1.4	-49
			stdev	17.0	0.7	17			stdev	19.9	0.5	20
2.5 m	end 100%	869	avg	241	2.0	-29	2.5 m	end 100%	avg	218	1.1	-52
			stdev	19.5	0.8	20			stdev	43.8	0.5	44
1m	end 100%	837	avg	232	1.7	-38	1m	end 100%	avg	192	0.9	-78
			stdev	22.9	0.6	23			stdev	50.0	0.4	50
-1 m	end 100%	no measurement					-1 m	end 100%	avg	198	0.9	-72
									stdev	46.9	0.5	47
- 2.5m	end 100%	no measurement					-2.5m	end 100%	avg	179	1.2	-91
									stdev	43.8	0.7	44
-5 m	end 100%						-5m	end 100%	avg	157	2.5	-113
									stdev	33.3	1.1	33
-7.5 m	end 100%	no measurement					- 7.5m	end 100%	avg	152	2.9	-118
									stdev	41.6	1.3	42

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Report WPR-838

The mission of Wageningen University & Research is “To explore the potential of nature to improve the quality of life”. Under the banner Wageningen University & Research, Wageningen University and the specialised research institutes of the Wageningen Research Foundation have joined forces in contributing to finding solutions to important questions in the domain of healthy food and living environment. With its roughly 30 branches, 7,200 employees (6,400 fte) and 13,200 students and over 150,000 participants to WUR’s Life Long Learning, Wageningen University & Research is one of the leading organisations in its domain. The unique Wageningen approach lies in its integrated approach to issues and the collaboration between different disciplines.

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