Spray drift for the assessment of exposure of aquatic organisms to plant protection products in the Netherlands

Part 2: Sideways and upward sprayed fruit and tree crops

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As part of the Dutch authorisation procedure for pesticides an assessment of the effects on aquatic organisms in surface water adjacent to agricultural fields is required. This in turn requires an exposure assessment for these surface waters. So far, in the current Dutch authorisation procedure spray drift is the only source of exposure. For this reason, a new exposure scenario was developed, which includes also input by drainage and atmospheric deposition. The endpoint of the exposure assessment is the 90th percentile of the annual maximum concentration in all field ditches alongside fruit and avenue nursery-tree fields.
In this report, the state-of-the-art of the spray drift data is described for orchard spraying and avenue nursery-tree spraying. The methodology of using a matrix structure is discussed for the assessment of spray drift deposition combining classes of Drift Reducing Technology (DRT) and width of crop free zones for sideways and upward sprayed crops (fruit crops and avenue nursery-trees).
Key words: spray drift, air-blast sprayer, Drift Reduction Technology, ISO22866, surface water, crop free zone, orchard spraying, avenue nursery tree spraying

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Preface

The Dutch government decided to initiate an improvement of the methodology for the assessment of effects on aquatic organisms when applying Plant Protection Products. In order to establish a comprehensive methodology, the Dutch government initiated six working groups to cover various aspects of the new methodology:

- a working group on legal aspects, dealing amongst others with the relation between the WFD and EU directive 91/414/EC (replaced by Regulation 1107/2009);
- a working group on exposure of aquatic organisms;
- a working group on effects on aquatic organisms;
- a working group on multiple stress;
- a working group on emissions from glasshouses (currently split into two working groups);
- a working group on the feedback of monitoring results to the authorisation procedure.

As part of the revision, the Dutch government charged the working group on exposure of aquatic organisms with the development of a drainpipe exposure scenario and the update of the used spray drift data. For downward directed spraying this has been reported in Tiktak *et al.* (2012) for the scenario and in Zande *et al.* (2012a) specifically for the downward sprayed spray drift data. This report describes the base of spray drift data of fruit crop spraying and nursery tree spraying (avenue trees). Data will be used for the development of spray drift models and the parameterisation of the spray drift scenarios for fruit crop spraying and avenue nursery tree spraying. In a next step, a parameterised spray drift model, the evaluation ditch model and drainage model will be coupled. The coupled models will become part of the exposure assessment tool DRAINBOW for the environmental risk assessment procedure of pesticides used in arable crops as well as fruit orchards in the Netherlands.

This report is produced on behalf of the Dutch Ministry of Agriculture, Nature and Food Quality (LNV) under project number BO-43-011.01-003, within the framework of the working group on exposure of aquatic organisms. The following persons have been or are currently members of this working group: Paulien Adriaanse (WEnR), Jos Boesten (WEnR), Corine van Griethuysen (Ctgb), Henk Jan Holterman (WPR), Mechteld ter Horst (WEnR), Ton van der Linden (RIVM), Harry Massop (WEnR), Aaldrik Tiktak (PBL), Louise Wipfler (WEnR) and Jan van de Zande (WPR). The authors of this report acknowledge the members of this working group for discussions and suggestions for improvement.

Summary

As part of the proposed revised assessment procedure for exposure of aquatic organisms in the Netherlands an exposure scenario was developed for sideways and upward spraying in fruit crops and avenue nursery trees. This scenario corresponds to the ditch scenario that results in the 90th percentile of the annual maximum concentration in all ditches that receive input from spray drift and drainpipes.

The aim of this study is to develop a new methodology for a realistic worst-case scenario of exposure to spray drift (using a 90th percentile approach) including a methodology for the implementation of spray drift reducing technologies (DRTs) and other drift mitigation measures in fruit and avenue nursery trees. Furthermore, the aim is to make an update of spray drift exposure data to establish a state-of-the-art methodology for spray drift evaluation.

The current authorisation procedure for plant protection products (PPPs) in the Netherlands makes a differentiation in the spray drift originating from spray applications in arable crops (including field vegetables, flowers, small fruits (strawberry) and small tree nursery crops), applications in fruit crops (including soft fruit and grapes) and applications in avenue tree nursery crops. This differentiation is based on the way PPPs are applied. In arable crops a boom sprayer is used where the spray is directed downward. In fruit bushes, fruit trees and avenue nursery trees an upward or sideways directed spray technique is used. Based on the crop growth situations and the used application techniques different spray drift deposition curves are used to determine the exposure to a standardized water surface (the 'standard ditch'). This resulted in standard spray drift values for the different situations.
The state-of-the-art of the spray drift data is described for orchard spraying and avenue tree nursery spraying. Measured spray drift curves for presently used reference situations (defining nozzle type, air assistance, tree spacing, tree/crop height) and drift reducing technology (DRT) are given for fruit crop spraying and avenue nursery tree spraying. Furthermore, the methodology and classification of DRTs in spray drift reduction classes 50, 75, 90, 95, 97.5 and 99 are discussed.

Based on the crop growth situations and the used spray techniques, different spray drift deposition curves are used to determine the exposure to surface water including the 90th percentile approach. With the obligation to develop a scenario for authorisation of PPP taking into account the measures imposed by the Lozingenbesluit Open Teelt en Veehouderij (LOTV) and the Activiteitenbesluit Milieubeheer (Environmental Activity Decree; EAD) it was impossible to come up with a tiered approach. Not all DRTs lead to similar or stepwise decreasing spray drift exposure of the surface water, especially not when these are combined with different widths of crop free zones. Therefore, it was decided to develop a matrix approach combining classes of DRT and stepwise widths of crop free zones. The methodology using this matrix structure is discussed for the assessment of spray drift deposition for sideways and upward sprayed crops (fruit crops and avenue nursery tree crops).

For fruit crop spraying using a standard cross-flow fan sprayer and a crop free zone of 3 m the deposition of spray drift on a standard ditch changed from 8.6% of the applied dose (based on database 1990- 2005) to 12% (based on database 1990-2011) in the full leaf stage. In the dormant situation these figures ranged from an estimated 17% (based on database of 1990-1998) to a measured 22% (based on database 1990-2011).

Generally stated, the spray drift deposition data presented in this report (including measurements up to 2011) are higher as based on a wider range of tree sizes, tree age distribution, crop growth stages and weather conditions during the spray drift experiments.

Implementation of the exposure scenario leads therefore to more realistic exposure concentrations and thus from a scientific point of view desirable.

Samenvatting

Als onderdeel voor de Nederlandse evaluatieprocedure voor waterorganismen in waterlopen na toepassing van gewasbeschermingsmiddelen is een blootstellingscenario ontwikkeld voor zijwaartse en opwaartse bespuitingen zoals gebruikt in de fruitteelt en de laanbomenteelt. Het blootstellingsscenario heeft als doel de 90-percentiel blootstellingsconcentratie voor een bepaalde toepassing te bepalen op basis van drift en drainage.

Het doel van deze studie is om een nieuwe methodologie te ontwikkelen die moet leiden tot een realistisch blootstellingsscenario als gevolg van de drift van spuitnevel tijdens de toepassing van gewasbeschermingsmiddelen (gebruikmakend van de 90-percentiel benadering) inclusief een methodiek voor de implementatie van drift reducerende technieken (DRT) en andere driftreducerende maatregelen. Bovendien is het doel van deze studie de driftgetallen en de drift evaluatie methodiek te actualiseren op basis van nieuw uitgevoerd onderzoek.

In de Nederlandse toelatingsprocedure van gewasbeschermingsmiddelen wordt onderscheid gemaakt naar de drift van neerwaarts gerichte bespuitingen (akkerbouw, vollegrondsgroente, bollen, bloemen, aardbeien en lage boomteelt gewassen) en toepassingen in de fruitteelt (appels, peren, kleinfruit, druiven, etc.) en de laanbomenteelt (spillen, opzetters, hoge laanbomen) die zij- en opwaarts gespoten worden. Afhankelijk van het groeistadium van het gewas en de gebruikte toedieningstechniek worden verschillende drift depositie curves gebruikt om de blootstelling van het wateroppervlak in een gestandaardiseerde sloot te bepalen. Dit heeft geresulteerd in standaard driftgetallen voor de verschillende situaties.
Een actualisatie van de driftcijfers wordt in deze rapportage beschreven. De actualisatie omvat de gemiddelde drift curven voor de bespuitingen in de fruitteelt en de laanbomenteelt. De gemeten driftcurven van de huidige referentie toedieningstechnieken (met gedefinieerde doptypen, luchtondersteuning, boom afstanden, boomhoogten) en drift reducerende technieken (DRT) worden gegeven voor bespuitingen in de fruitteelt en de laanbomenteelt. De methodologie voor de indeling van DRT in de driftreductieklassen 50, 75, 90, 95, 97.5 en 99 wordt beschreven.

Op basis van de combinatie van gewas situatie en toedieningstechniek zijn driftcurven bepaald om de blootstelling van het oppervlaktewater te bepalen. Op basis van de maatregelpakketten voor driftreductie in het Activiteitenbesluit Milieubeheer is het niet mogelijk gebleken om tot een stapsgewijze verfijning van de driftdepositie op wateroppervlak te komen. Niet alle DRT en teeltvrije zone combinaties leiden tot een gelijke blootstelling. Er is daarom gekozen voor een matrix benadering waarbij de combinatie van klassen van DRT en stapsgewijze breedte van teeltvrije zone wel leiden tot gelijkwaardige blootstelling van wateroppervlak. Deze methodologie wordt uitgewerkt voor de toepassingen met zij- en opwaarts gerichte toedieningstechnieken zoals in de fruitteelt en de laanbomenteelt.

Voor bespuitingen in de fruitteelt met de referentie techniek en een 3 m brede teeltvrije zone in het volblad stadium van de fruitbomen was de driftdepositie op wateroppervlak in de standaard sloot 8,6% van het uitgebracht spuitvolume (gebaseerd op de drift database 1990-2005) en is op basis van deze studie 12% (drift database 1990-2011). In de kale boom situatie was de driftdepositie berekend op 17% (gebaseerd op de drift database 1990-1998) en wordt op basis van de gemeten drift in deze studie 22% (drift database 1990-2011).

In het algemeen kan gesteld worden dat de driftdepositie gepresenteerd in deze rapportage hoger is doordat de geactualiseerde driftdatabase (inclusief drift metingen t/m 2011) gebaseerd is op driftmetingen bij een grotere variatie in boom afmetingen, leeftijd van de bomen, gewasgroei stadia en weersomstandigheden tijdens de driftmetingen.

Implementatie van het blootstellingscenario leidt daarom tot meer realistische blootstellingsconcentraties en is dus vanuit wetenschappelijk oogpunt gewenst.

1 Introduction

1.1 Aim and background of the study

As part of the Dutch authorisation procedure for plant protection products (PPP), an assessment of exposure of aquatic organisms in surface waters adjacent to agricultural fields is required. Spray drift, atmospheric deposition, drainage and runoff are the most important processes involved in exposure of edge-of-field surface waters with PPPs (Figure 1). In the evaluation of active substances at the EU level, the importance of all these entry routes is acknowledged (FOCUS, 2001; FOCUS, 2008). In the current Dutch authorisation procedure, however, spray drift is the only pathway for active substances of PPP entering the surface water (Beltman and Adriaanse, 1999; Ctgb, 2014). Therefore, the responsible Dutch ministries requested the development of a state-of-the-art methodology to calculate the input of PPPs through spray drift, atmospheric deposition and drainage (Tiktak *et al.*, 2012). This new methodology will become part of a new exposure scenario, which was developed for downward spraying (Tiktak *et al.*, 2012) and is currently being developed for upward and sideways spraying (Boesten *et al.*, 2018).

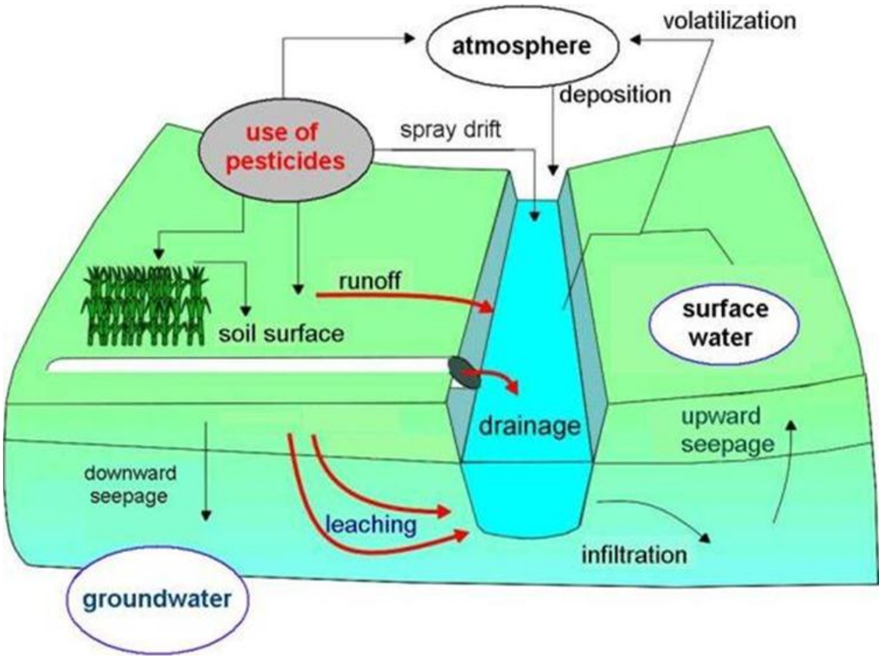

Figure 1 *Main processes involved in loading of edge-of-field surface waters with plant protection products.*

The overall aim of the study reported here is to develop a new methodology for a realistic worst-case scenario of exposure to spray drift (using a 90th percentile approach) including a methodology for the implementation of drift reducing technologies (DRTs) and other spray drift mitigation measures – specifically for sideways and upwards directed spray applications as used in fruit crop spraying and avenue nursery tree spraying.

To reach this overall goal, an update is made of the spray drift exposure data to establish a state of the art methodology for spray drift evaluation for sideways and upward directed spray applications, providing:

- an update of spray deposition data for fruit orchards and avenue tree nurseries
- and describe the methodology for the assessment of mitigation options (i.e. Drift Reducing Technology (DRT) and crop free zones).

The reported spray drift data are summed in a spray drift database and are used for the development of a spray drift model for fruit crops (SPEXUS; Holterman *et al*., 2017, 2018). The sideways- and upward directed spray drift scenario (Holterman *et al.*, 2019) will be joined with the parameterised evaluation ditch model (Wipfler *et al.*, 2018) and will be coupled to the parameterised drainage models. All models will become part of the exposure assessment tool DRAINBOW, which will be used in the environmental risk assessment procedure of PPPs used in arable crops as well as fruit orchards in the Netherlands.

1.2 Fruit and avenue nursery tree crops in the Netherlands

Fruit crops and nursery trees are grown in specific areas in the Netherlands (Figure 2).

1.2.1 Fruit crops

Total fruit crop area in the Netherlands is about 19.770 ha with the main fruit crops apple and pear having a cropped area of resp. 7600 ha and 9234 ha in 2016 (CBS, 2017). Fruit crop growing is especially concentrated in the Betuwe, Zeeland, West-Friesland, South-Limburg and in the new polder areas Flevoland and Noordoostpolder.

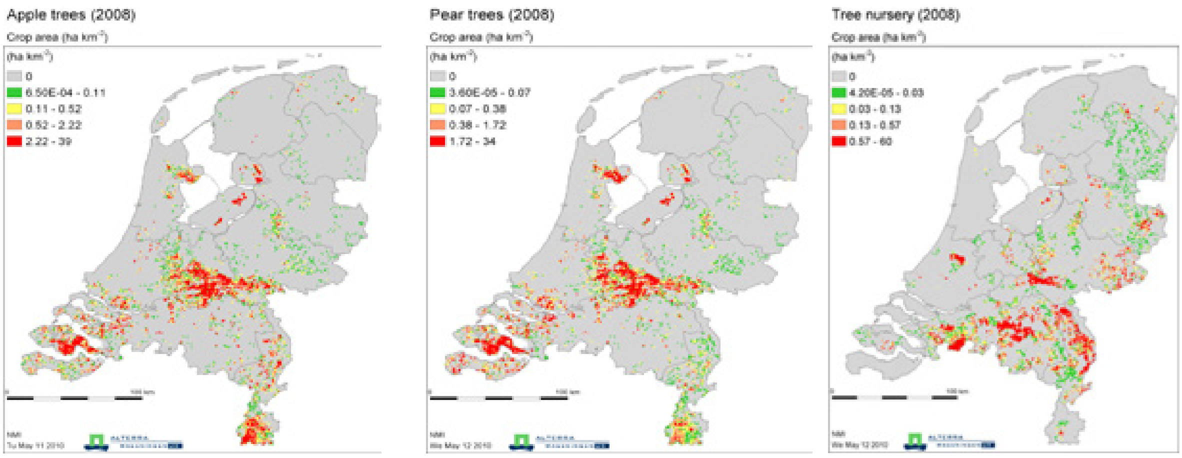

Figure 2 *Distribution of fruit crop area (apple, pear, 2008) and tree nursery in the Netherlands (source; Kruijne et al., 2012).*

Although the fruit crop area is relatively small in the Netherlands, locally the exposure of surface water can be high as a high number of spray treatments takes place in apple and pear orchards. Typical application schemes for apple and pear in the Netherlands (Figure 3) show that most PPPs are applied once per year, only a few PPPs are applied 2-3 times. However the fungicide captan is applied 14-15 times per season from spring to autumn.
Many fruit orchards are surrounded by a windbreak vegetation to protect the crop from strong winds and in the coastal area also from salt coming with the sea wind. In addition, a windbreak also limits spray drift as it operates as a filter barrier towards the surface water when positioned at the field edge. No specific data are available on the number of orchards surrounded (fully or partly) by windbreaks. Based on expert judgement the distribution of windbreaks around orchards was estimated to be 48% in 1998 and 84-95% in 2004 (Kruijne *et al.*, 2012). A more recent inventory showed some specific differences for the different fruit crop regions in the Netherlands in the number of sides around the orchard having a windbreak (Annex 3).
Small fruit crops, like red and black currants, berries and grapes are sprayed quite often. Under practical circumstances Wenneker (2013) found that on average 13 spray applications were carried out during the growing season. The period of PPP applications was between week 14 (late March/early April) and week 26/27 (late June/early July). Wenneker & Ter Steegh (2013) presented a standard

application schedule of 17 applications using 5 products for red currants. The spray applications were applied in the period between blossoming (week 14; begin April) up to 2 weeks before harvest (week 29; July) with harvest in week 31 (July/August) (Annex 5).

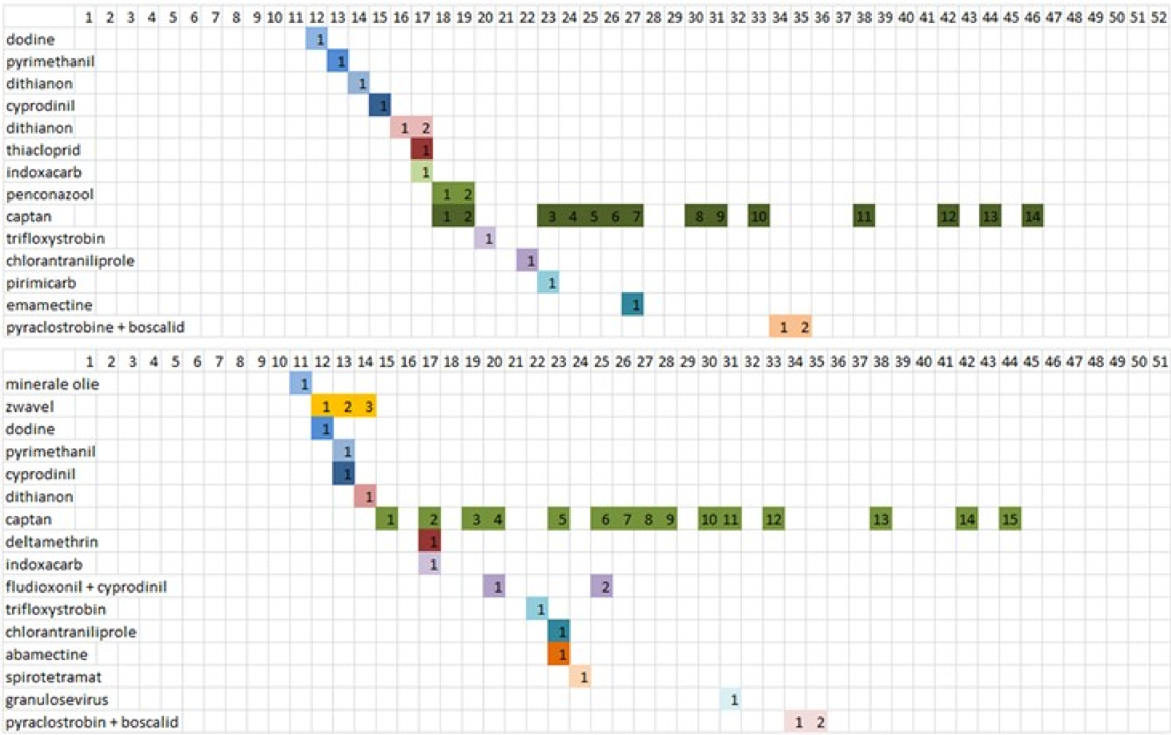

Figure 3 *Typical application schemes for different PPPs in apple (top) and pear (bottom) in the Netherlands. The columns are week numbers and each coloured cell is an application.*

1.2.2 Avenue tree nursery

The growing areas for spindle, transplanted and high avenue tree nurseries are the Betuwe (Kesteren) and areas in west and east Noord-Brabant (Zundert, Haaren) and north of Limburg (Horst, Venlo). Total area of avenue trees in the Netherlands was 4532 ha in 2012 (CBS, 2017). Avenue trees are only sprayed when they have leaves and spraying is done after an observation of an infection or for prevention. Leaf development for the tree species beech (Fagus), birch (Betula), oak (Querqus), alder (Alnus), chestnut (Aesculus) evaluated for the period 2012-2016 showed that in general leaf development starts in the period 3/3-27/5 and ends with the leaf fall in the period 15/9-30/12 (Annex 2).

1.3 Structure of report

In the current authorisation procedure for PPPs in the Netherlands a differentiation is made in the spray drift originating from spray applications in field crops (including arable crops, field vegetables, flowers, bulbs, small fruits (strawberry), and small tree nursery crops), applications in fruit crops (large and soft fruit) and applications in avenue nursery tree crops. This differentiation is based on the way PPPs are applied. In field crops a boom sprayer is used with a downward spraying direction. In fruit crops (trees and bushes) and avenue tree nurseries (spindle, transplanted, high avenue trees) an upward or sideways directed spraying technique is used. Based on the crop growth situations and the used spray techniques different spray drift deposition curves are used to determine the exposure to a standardized water surface (standard ditch). This resulted in standard drift values for the different situations. The background of the current practice (situation up to 2017) of estimating spray drift to surface water including the regulations by the Dutch Environmental Activities Decree (I&M, 2012) and the spray drift data used within the authorisation of PPP by the Board for the Authorisation of Pesticides and Biocides (Ctgb) is describes in more detail in Annex 7.

In Chapter 2 the state-of-the-art of the spray drift data is described including standard spray drift curves for orchard spraying and nursery tree spraying. Furthermore the methodology and classification of Drift Reduction Technology (DRT) is discussed.

In Chapter 3 for each of the subdivisions (crop type, spray technique) the methodology for the assessment of spray drift to surface water is described based on the combination of spray drift reduction technology (DRT) classes and width of crop free zones and crop related issues are described. The presented data are used to develop a new spray drift model for fruit crop spraying (SPEXUS; Holterman *et al.*, 2017).

In Chapter 4 discussion points are addressed and in Chapter 5 the final conclusions are given.

2 Spray drift data and Drift Reduction Technology

After an introduction on how spray drift is measured in the field this chapter deals with a historic overview on how spray drift data used in the authorisation procedure changed over time due to changes in reference situations. Measured spray drift curves for nowadays defined reference situations (nozzle type, tree spacing, tree/crop height) and drift reducing technologies are given for fruit crop spraying and high avenue nursery tree spraying. Furthermore, the differentiation of spray techniques in drift reduction technology classes is discussed.

2.1 Field measurements of spray drift in fruit crops (sideways and upward directed sprayers)

2.1.1 Field measurements

In the Netherlands spray drift experiments for orchard spraying was carried out on an uniform basis. Spray drift is expressed as percentage of the applied spray volume per surface area. Spray drift measurements were carried out according to the ISO standard (ISO 22866; 2005) adapted for the situation in the Netherlands (ground deposits, ditch, surface water next to the sprayed field) following the Dutch protocol (CIW, 2003; TCT, 2017a, 2017b). Apple trees were sprayed with a solution containing the fluorescent dye Brilliant Sulpho Flavine (BSF) and a non-ionic surfactant (Agral) (Smelt *et al.*, 1993; Stallinga *et al.*, 2012b). Spray drift deposition was measured using collectors (synthetic cloths) which were placed at several distances from the centre of the last tree row on ground surface on the downwind edge of the orchard. The spray drift was measured by quantifying the BSF deposition on the collectors. A typical field layout of the spray drift collectors and setup of the spray drift experiments in sideways and upward sprayed crops is presented in Figure 4.

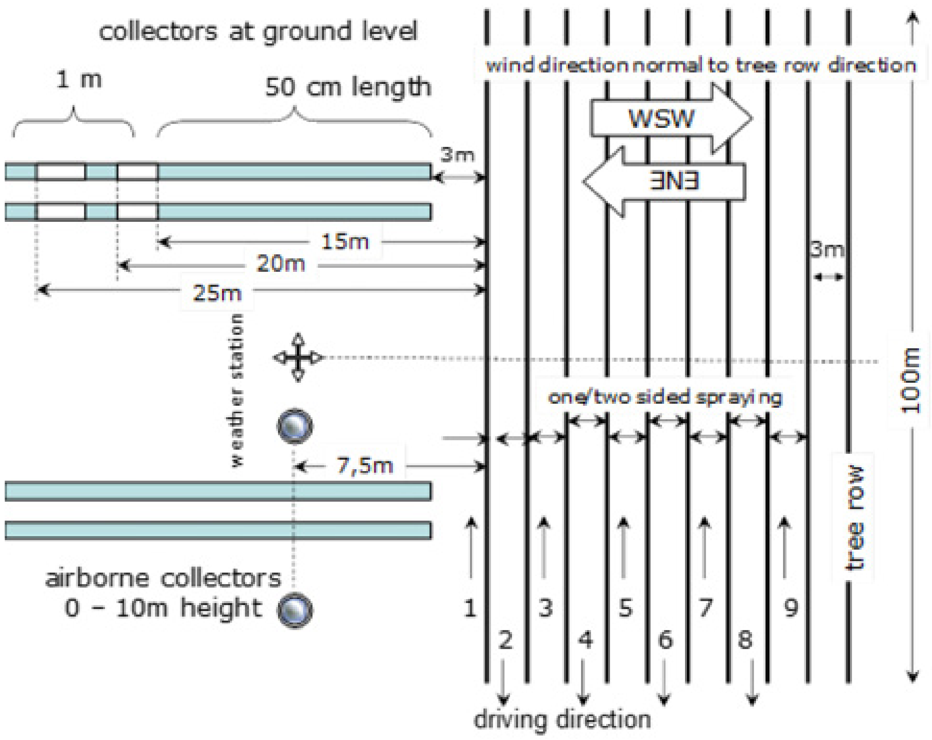

Figure 4 *Schematic layout of the experiments measuring downwind spray deposits (Stallinga et al. 2013).*

Commercial apple orchards in the Netherlands are normally planted in single rows (spindle trees on dwarfing root stocks). Trees are in general planted at 1.0-1.25 m from each other in the row and the distance between the rows is 3 m. Crown heights are 2.25 – 2.75 m. The reference technique (Figure 5) for orchard spraying is a cross-flow fan sprayer (Munckhof), equipped with Albuz ATR lilac nozzles, which at 7 bar spray pressure produces a Very Fine spray quality (Southcombe *et al.*, 1997), applying a spray volume of 200 L/ha.

Figure 5 *Standard cross-flow fan orchard sprayer used for fruit crop spraying (reference).*

The experiments were carried out in early (dormant; before May 1st) and late growth stage (full leaf; from May 1st onwards) of the trees. In the early growth stages (developing foliage), air assistance was supplied with low gear settings for the fan. In the fully developed foliage stage, experiments were carried out with high gear fan settings.
Spray depositions are calculated and presented as percentage of the applied spray volume per unit surface area on the different distances of the collectors. Especially important is the distance of 3.0–7.0 m from the last tree row, being the place where ditches (surface water) are commonly situated (Figure 6, Huijsmans *et al.*, 1997). Average spray drift deposition on the middle of the ditch (4.5–5.5 m from the last tree row), i.e. the water surface, is currently used in the Dutch authorisation of PPPs (see Annex 7).

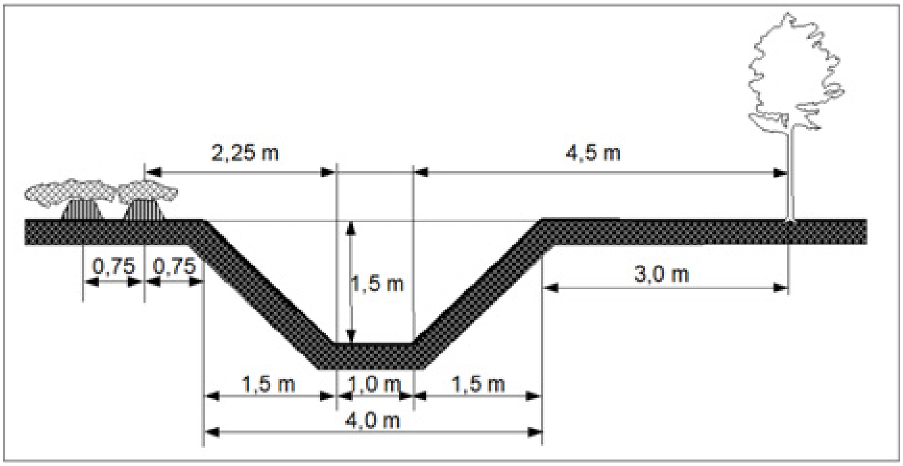

Figure 6 *Schematic presentation of the standard ditch and its dimensions in the Netherlands (after Huijsmans et al., 1997).*

2.1.2 Spray drift data in fruit crop spraying

Average spray drift deposition for the period 1990-1993 for the reference situations was 6.8% for the full leaf situation (after 1st May) (Porskamp *et al.*, 1994a, 1994b, 1994c; Huijsmans *et al.*, 1997). No measurements were available for the dormant tree situation (before 1st May) in that period. No spray drift data are available for herbicide applications in orchards. It was assumed that small fruits like strawberries and cranberries were sprayed with boom sprayers.

Spray drift reduction
To minimize spray drift in fruit crops different technical methods or field management practices are possible. Examples of technical methods are nozzle type, shielding and type or level of air assistance. A field management practice is for example an increased crop-free zone or buffer zone. Also planting a barrier vegetation or structure (windbreak) can offer additional protection against spray drift contamination of the surrounding area. A crop free zone in fruit growing is in the Netherlands defined as the distance between the last tree row and the upper edge of the ditch bank. A buffer zone in general can be described as the distance between point of direct PPP application and the nearest boundary of a sensitive area.
Based on field measurements, in which a drift reducing technique is always measured in parallel with the reference drift situation of a reference spray technique, drift reduction was determined for the spray techniques and measures:

- Single sided spraying of the outside tree row (Wenneker *et al.*, 2001b, 2004a, 2005a)
- Sensor equipped spraying – gap detection (Wenneker *et al.*, 2001c, 2003, 2013)
- Sprayer with reflection shields (Porskamp *et al.*, 1994a, 1994b; Zande *et al.*, 2001)
- Tunnel sprayer (Huijsmans *et al.*, 1993; Stallinga *et al.*,2019)
- Sprayer with reflection shields and drift reducing nozzle types (Wenneker *et al.*, 2006, 2008a)
- Coarse droplet application (Heijne *et al.*, 2002; Wenneker *et al.*, 2001d, 2004a ; Michielsen *et al.*, 2009)
- Windbreaks at the field edge (Porskamp *et al.*, 1994c; Wenneker *et al.*, 2004b; Wenneker & Van de Zande, 2008b; Zande *et al*., 2004)
- Riparian vegetation (Wenneker *et al.*, 2001a; Heijne *et al.*, 2003)
- Artificial netting at the field edge (Heine *et al.*, 1999)
- Nozzle classification for orchard sprayers (Zande *et al.*, 2007, 2008, 2012b; Stallinga *et al.*, 2011b, 2011c)
- Advanced drift reduction in orchard spraying (Wenneker *et al.*, 2012; Michielsen *et al.*, 2014, 2019; Stallinga *et al.*, 2016, 2017b)
- Spray drift reduction of multiple row sprayers (Stallinga *et al.*, 2013, 2017a, 2018; Wenneker *et al.*, 2014)

Annex 1 gives an overview of the experiments on spray drift reduction technologies and mitigation measures for orchard spraying. As the number of measurements of the reference spray technique increased over the years the average spray drift curve of the reference technique could be based on more measurements as well.

2.1.3 Generating standard and spray drift reduction technique curves for fruit crop spraying

For the period 1993-2011 measurements were done comparing drift reducing measures with the reference spray technique (316 measurements). As spray drift measurements became available for the dormant situation (before May 1st) a reference curve based on measured data could be determined for this situation as well. The assumption, based on German research (Ganzelmeier *et al.*, 1995; Huijsmans *et al.*, 1997), that the spray drift in the dormant situation was 2.5 times that of the full leaf situation could now be based on field measurements.

Spray drift reduction curves were calculated from the comparative spray drift field measurements. For the different distances the drift reduction curve value was used to obtain the new spray drift deposition value for the specific application technique relative to the curve of the new standard spray technique.

2.1.3.1 Standard spray technique (reference) in fruit crop spraying

A series of spray drift measurements were done in the period 1990-2011 for the reference situation; with in the dormant situation 100 measurements (Figure 7) and in the full leaf situation 120 measurements (Figure 8). Average weather conditions during measurements are presented in Table 1, limited for a maximum wind speed of 5 m/s (at 2 m height) and a wind angle deviation during spray drift measurements of +/- 30° of perpendicular to the tree row and driving direction of the sprayer, and a minimal treated area of 20 m width (following ISO22866, 2005).

Table 1 *Weather conditions during spray drift measurements (average and standard deviation) of the reference spray technique in fruit crop spraying (1990-2011).*

Crop	Spray technique	Number of measurements	Temperature at 2 m height [°C]	Average wind angle [°]	Average wind speed at 2 m height [m/s]
Dormant	reference	100	15 (6)	14 (9)	2.5 (0.8)
Full leaf	reference	120	18 (5)	10 (1)	3.2 (0.7)

Variation in spray drift deposition occurs due to different weather conditions and the orchard leaf situation (phenological growth stages; BBCH, 2001), age of the trees and the pruning situation during the spray drift experiments. From the measurements performed in the dormant growth situation (Figure 7), before May 1st, it is shown that e.g. at 5 m distance from the last tree row a variation in spray drift deposition of between 11% and 35% (10- and 90-percentiles, respectively) occurs with a median value of 20% (Table 2). In the full leaf situation (Figure 8), after May 1st, variation in spray drift deposition at 5 m distance from the last tree row is between 5.4% and 21% (10- and 90-percentiles, respectively) with a median value of 11% (Table 2).

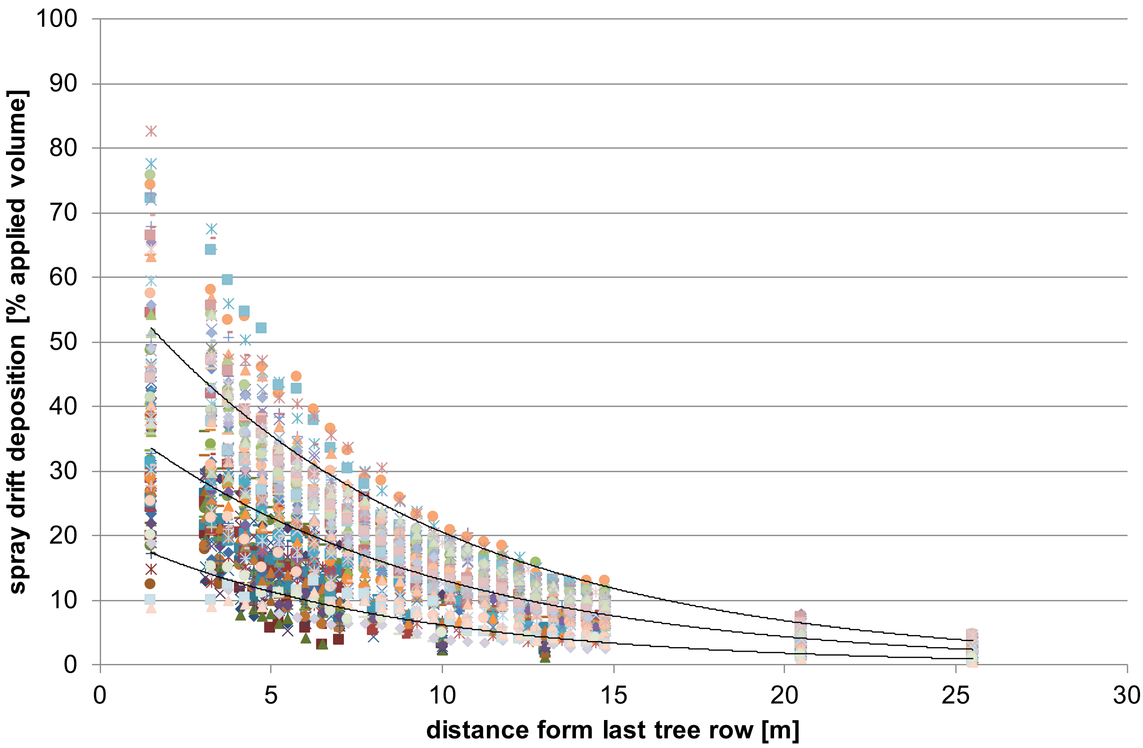

Figure 7 *Measured spray drift deposition (1990-2011; % of applied spray volume) at different distances from the last tree row when spraying an orchard with a standard cross-flow fan sprayer (reference) in the dormant situation (before May 1st);the points are the results of the 100 measurements, the lines indicate the 90-percentile, median and 10-percentile.*

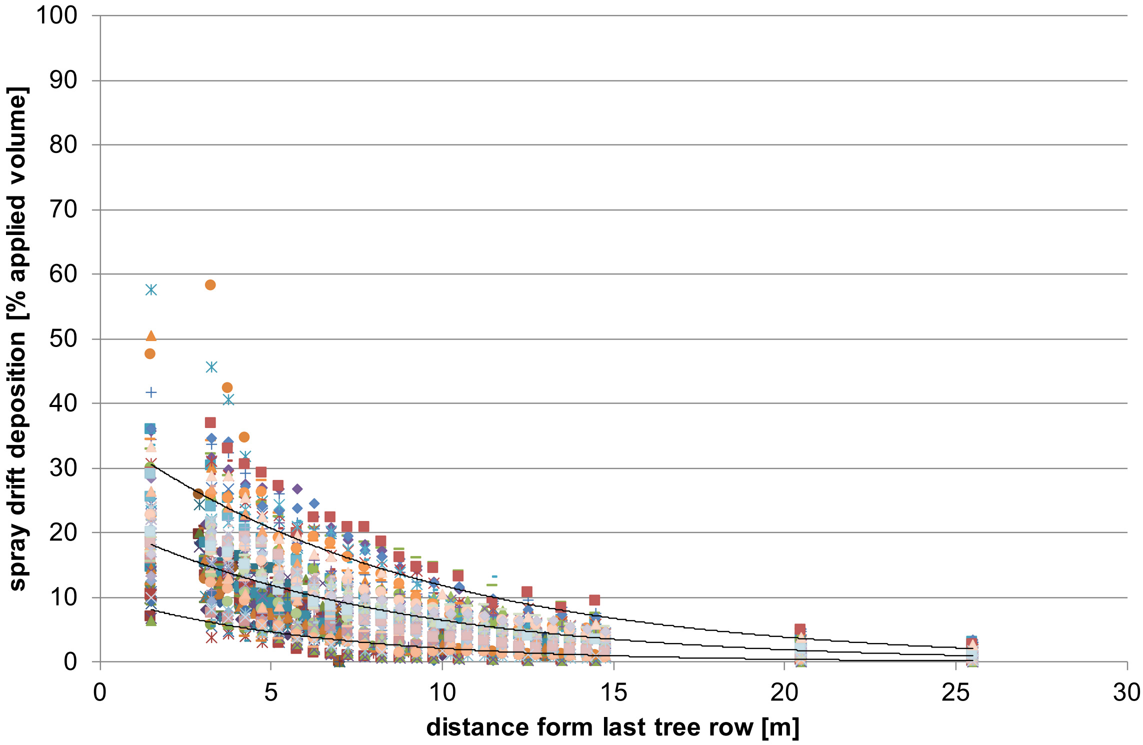

Figure 8 *Measured spray drift deposition (1990-2011; % of applied spray volume) at different distances from the last tree row when spraying an orchard with a standard cross-flow fan sprayer (reference) in the full leaf situation (after May 1st); the points are the results of the 120 measurements, the lines indicate the 90-percentile, median and 10-percentile.*

Table 2 *Mean, median, 10-percentile and 90-percentile spray drift deposition (1990-2011; % of applied spray volume) at different distances from the last tree row when spraying an orchard in the dormant (before May 1st) and the full leaf (after May 1st) situation with a standard cross-flow fan sprayer (reference).*

	Distance (m)	1.5	3.25	3.75	4.25	4.75	5.25	5.75	6.25	6.75	7.25	8.0	10.0	12.5	15.0	20.5	25.5
dormant	mean	37.6	29.7	28.8	26.5	22.7	20.8	20.8	19.0	17.1	16.7	15.8	12.6	9.9	7.7	4.0	2.7
	90-percentile	64.4	47.8	43.5	39.7	36.7	33.4	32.0	29.5	27.0	25.8	23.1	19.0	14.8	11.3	6.3	4.6
	median	33.1	27.3	28.4	26.4	20.5	19.2	19.6	18.0	16.2	16.7	16.1	12.9	9.9	7.5	3.9	2.7
	10-percentile	20.1	15.1	15.1	13.8	11.2	11.1	10.7	9.4	8.2	7.0	7.2	5.0	4.5	4.1	1.7	1.1
full leaf	mean	20.0	17.9	16.9	15.1	12.3	11.0	10.6	9.3	8.7	8.0	7.4	5.8	4.0	3.4	1.9	1.2
	90-percentile	33.4	28.9	28.9	25.5	22.4	19.2	19.4	16.7	16.4	13.9	13.9	10.5	6.9	5.9	3.9	2.7
	median	18.2	16.7	15.7	14.1	11.4	10.2	10.3	8.6	8.0	7.5	7.2	5.4	4.0	3.4	1.6	1.1
	10-percentile	9.9	8.1	6.9	7.0	5.7	5.1	3.6	3.4	2.6	3.3	1.6	1.8	1.2	0.9	0.4	0.3

Evaluation of the spray drift data of the reference spray technique up till 2011 resulted in standard spray drift curves for spraying fruit crops (Figure 9), the standard situation defines average spray drift deposition at different distances from the last tree row. As spray drift measurements have become available for the dormant situation (before May 1st) a reference curve based on measured data could be determined for this situation as well.

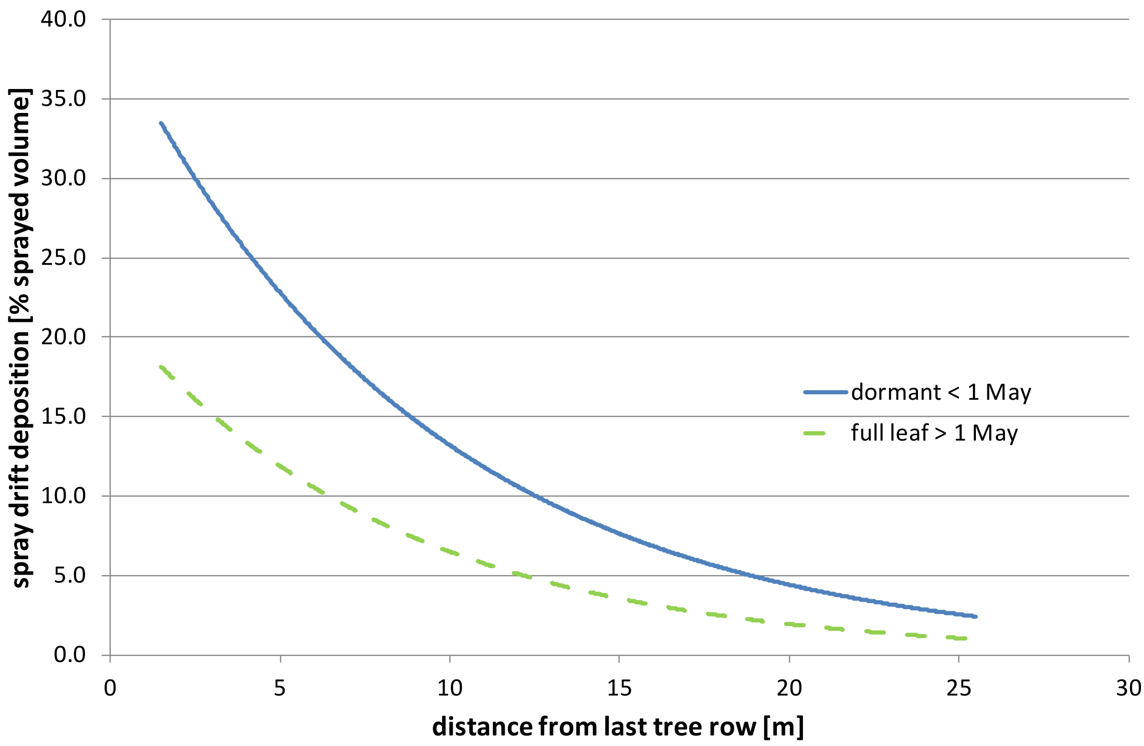

Figure 9 *Standard spray drift deposition curves (average spray drift as % of applied spray volume) next to an orchard sprayed with a reference (standard) spray technique used in authorisation procedure for the full leaf and dormant situation (data up till 2011).*

Mean spray drift deposition at the nowadays used evaluation distance for the exposure of surface water (Figure 7; 4.5-5.5 m from the last tree row) are for the data 1990-2011 therefor for the dormant situation (before May 1st) 21.8% and for the full leaf situation (after May 1st) 11.7%. Spray drift deposition when spraying in the dormant situation is about 2 times higher than when spraying in the full leaf situation.

Spray drift deposition curves can be described with an exponential function:

$y = ae^{bx}$

with y = spray drift deposition (% of sprayed volume) at distance x [m] from the last tree row and constants a and b. The parameters a and b for the presented mean, 90-percentile, median and 10-percentile spray drift deposition curves in the dormant and the full leaf situation are presented in Table 3.

Table 3 *Parameters a and b of the exponential function of the mean, median, 90-percentile and 10-percentile spray drift deposition curves for the reference spray technique in the dormant (before May 1st) and the full leaf (after May 1st) situation.*

	Dormant		Full leaf	
	a (%)	b (m^{-1})	a (%)	b (m^{-1})
mean	39.574	-0.110	21.828	-0.121
90-percentile	61.436	-0.109	36.175	-0.112
median	36.914	-0.106	20.694	-0.123
10-percentile	20.813	-0.121	10.244	-0.157

2.1.3.2 Spray Drift Reduction Technology (DRT) in fruit crop spraying

Spray drift reduction technologies and measures can be grouped in drift reduction classes of 50%, 75%, 90% and 95%, 97.5 and 99% drift reduction (ISO22369). Table 4 gives current entries in the drift reduction classes in the Netherlands for orchard spraying (based on spray drift deposition at 4.5-5.5 m from the last tree row in the full leaf situation). The results are based on comparative field measurements of the reference spray technique and the candidate DRT techniques and are grouped in the different drift reduction classes (certified through the Technische Commissie Techniekbeoordeling (TCT-CIW) operational within LOTV/EAD regulation).
The presented spray drift curves for spray deposition on soil surface (Figure 9) are the basis for determining the spray drift deposition when spraying an orchard using a cross-flow fan orchard sprayer. The spray drift deposition of classified spray drift reducing technologies (Table 4) from the drift reducing classes 50%, 75%, 90%, 95%, 97.5% and 99% (ISO 22369) is presented relative to the spray drift curves of the standard spray technique.

Table 4 *Measured Drift Reduction Technologies (DRT) for orchard spraying in drift reduction classes 50%, 75%, 90%, 95%, 97.5% and 99% as used in the Netherlands (TCT, 2019a).*

Drift reduction classes	Spray drift reduction technology in drift reduction class
50% [1)]	50% drift reducing nozzle types + one-sided outside row spraying; sensor sprayer + standard nozzles; reflection shield sprayer + standard nozzles; Wanner cross-flow +reflection shield + standard nozzles;
75%	75% drift reducing nozzle types+ one-sided outside row spraying; tunnel sprayer + standard nozzles; KWH 3-row sprayer + standard nozzles; Munckhof 3 –row sprayer + standard nozzles + outside air of outside spray element closed;
90%	90% drift reducing nozzle types + one-sided outside row spraying; cross-flow + venturi nozzles + one-sided outside row; axial fan sprayer + venturi nozzles + one-sided outside row; H.S.S. CF + H.S.S. Drift Control + 90% drift reducing nozzles + 1800 rpm fan; KWH Mistral + VLBS + low air setting + 90% drift reducing nozzles + 540 rpm PTO;
95%	90% drift reducing nozzle types + one-sided outside row + low air assistance; 95% drift reducing nozzle types+ one-sided outside row spraying + 4.5 m crop-free zone; Wanner cross-flow +reflection shield + 75% drift reducing nozzles; KWH 3-row sprayer + 90% drift reducing nozzles + VLOS; Munckhof 3 –row sprayer + 90% drift reducing nozzles + outside air of outside spray element closed; H.S.S. CF + H.S.S. Drift Control + H.S.S. AWC (Automatic Wind Control) + 90% drift reducing nozzles + 1800 rpm fan; KWH Mistral + VLBS + low air setting + 90% drift reducing nozzles + 400 rpm PTO;
97.5%	KWH 3-row sprayer + 90% drift reducing nozzles; KWH 3-row sprayer + 90% drift reducing nozzles + variable air assistance outside 6 rows; Munckhof 3 row sprayer VARIMAS + 90% drift reducing nozzles + reduced air assistance (400 rpm) + variable air assistance outside 6 rows; Lochmann cross-flow + Air Closing System + 90% drift reducing nozzles + reduced air assistance (300 rpm) + variable air assistance outside 3 rows;
99%	KWH 3-row sprayer + 90% drift reducing nozzles + reduced variable air assistance (400 rpm PTO); Munckhof 3 row sprayer VARIMAS + Endrow setting+ 90% drift reducing nozzles + reduced air assistance (400 rpm) + variable air assistance outside 6 rows; Lochmann 2 row-tunnel sprayer +90% drift reducing nozzles.

[1)] Following the EAD (2017) a minimal DRT75 is to be used in fruit crops

Within the drift reduction class 95 a further distinction can be made in spray techniques giving 97.5% and 99% spray drift reduction. As especially spray drift deposition on surface water in fruit crop spraying is high there is a need for these higher reduction classes and therefore these additional classes are introduced in the systematics of drift reduction technology (DRT) classification system. For each of these spray drift reduction classes a typical spray drift deposition curve was identified representing the class threshold line as presented in Figure 10 and Figure 11 for respectively the full leaf and the dormant tree situation (after and before 1st May). At the moment, identified best fit class threshold curves are:

- sensor sprayer + standard nozzles for the 50% class;
- cross-flow sprayer + 75% drift reducing nozzles + one-sided outside row spraying for the DRT75 class;
- cross-flow sprayer + 90% drift reducing nozzles + one-sided outside row spraying for the DRT90 class;
- cross-flow sprayer + 90% drift reducing nozzles + low air setting + one-sided outside row spraying for the DRT95 class;
- KWH 3-row sprayer + 90% drift reducing nozzles for the DRT97.5 class;
- and the KWH 3-row sprayer + 90% drift reducing nozzles + reduced (400rpm) variable air assistance for the DRT99 class.

Spray drift reduction in spray deposition at soil surface downwind of the sprayed orchard at different distances from the last tree row for the typical application techniques as identified for the drift reducing technologies (DRT 50, 75, 90, 95, 97.5, 99) is presented when spraying in the full leaf stage (Table 5) and the dormant leaf stage (Table 6). Spray drift reduction to soil surface for the DRTs 50, 75, 90, 95, 97.5 and 99 at 5 m distance from the last tree row is in the full leaf stage 52%, 78%, 88%, 96%, 98.6% and 99.4%, respectively. For the dormant leaf stage the drift reduction at 5 m distance is for the DRTs 24%, 50%, 86%, 92%, 91% and 96.2%, respectively, showing that under different circumstances the classified drift reducing techniques produce other spray drift reductions. For the spray drift reduction on soil surface in the dormant situation for the DRT75 class the KWH 3-row sprayer equipped with the standard nozzle type is chosen as a reference technique instead of nozzle class 75%+one-sided spraying in the full leaf stage as for the nozzle class 75%+one-sided spraying no measurements were done in the dormant stage so no data were available. For the DRT90, DRT95 and DRT99 classes the air setting is in the dormant situation one step lower than in the full leaf stage as this is common practice. The choice for the typical application techniques per DRT class is mainly based on a spray drift reduction close to the threshold value of the DRT reduction class at 4.5-5.5 m from the last tree row and being a good available and a practical to use technique in practice.

Table 5 *Spray drift reduction (%) at soil surface downwind of the sprayed orchard at different distances from the last tree row for the typical application techniques of the drift reducing technologies (DRT 50, 75, 90, 95, 97.5, 99) when spraying in the full leaf stage of the fruit trees.*

full leaf		distance from last tree row [m]							
		3	4	5	6	7	10	13	further
DRT50	sensor sprayer standard nozzle	42	54	52	53	54	56	56	55
DRT75	nozzle class 75%+one-sided	62	71	78	79	83	85	85	84
DRT90	nozzle class 90%+one-sided	78	86	88	89	91	93	94	93
DRT95	nozzle class 90%+one-sided- low air	88	94	96	95	96	95	94	95
DRT97.5	KWH-3r-TVI 80.015	97.4	98.0	98.6	98.6	98.7	98.8	98.8	98.5
DRT99	KWH-3r-TVI 80.015-manual air-400 rpm	98.4	99.3	99.4	99.4	99.3	99.3	99.2	99.0

Table 6 *Spray drift reduction (%) at soil surface downwind of the sprayed orchard at different distances from the last tree row for the typical application techniques of the Drift Reducing Technologies (DRT 50, 75, 90, 95, 97.5, 99) when spraying in the dormant stage of the fruit trees.*

		distance from last tree row [m]							
		3	4	5	6	7	10	13	further
DRT50	sensor sprayer standard nozzle	9	18	24	25	31	38		35
DRT75	KWH 3-row standard nozzle	36	41	50	52	53	57	52	54
DRT90	nozzle class 90%+one-sided-low air	71	79	86	89	92	93	95	93
DRT95	nozzle class 90%+one-sided-no air	82	90	92	94	95	98	95	96
DRT97.5	KWH-3r-TVI 80.015	77.2	87.6	90.8	92.1	92.7	94.4	95.6	96.5
DRT99	KWH-3r-TVI 80.015-manual air-400 rpm	91.0	93.4	96.2	97.3	97.8	98.5	98.7	98.7

Based on the standard spray drift deposition curves for the full leaf and dormant tree situation (Figure 9) and the spray drift reduction at different distances for the typical application techniques of the Drift Reducing Technologies (DRT 50, 75, 90, 95, 97.5, 99) as presented in Table 5 and Table 6 the logarithmic of the spray drift deposition is presented in Figure 10 and Figure 11 for the full leaf and dormant fruit crop situation, respectively.

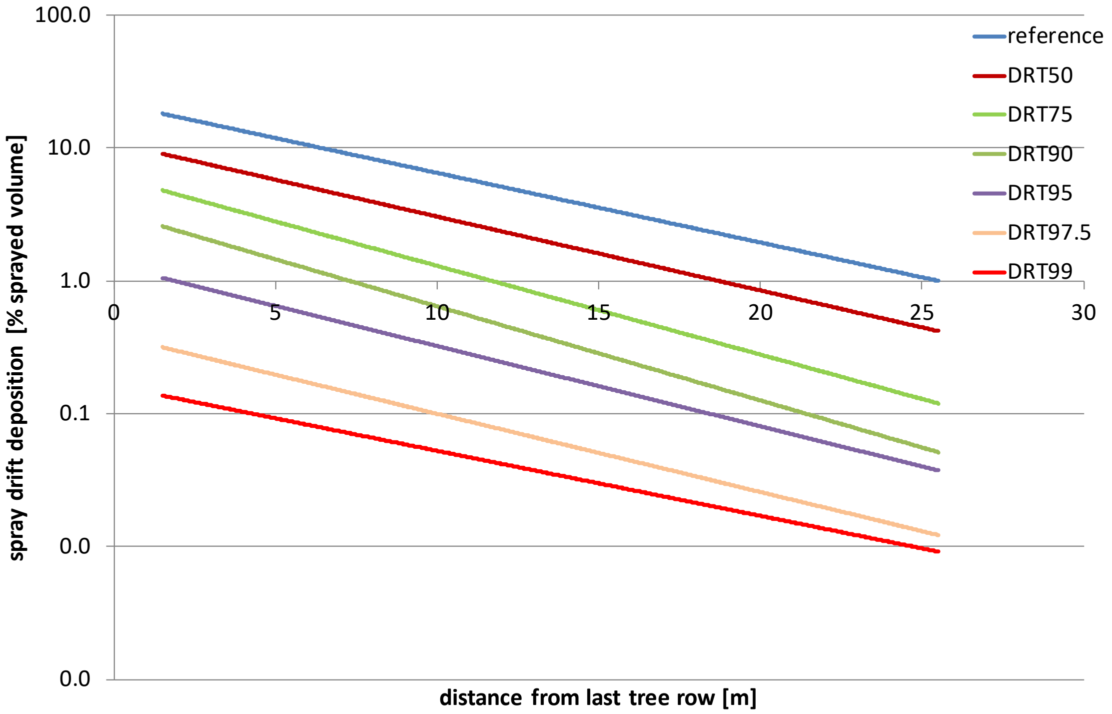

Figure 10 *Spray drift deposition curves (log) for the reference and typical application techniques for the Drift Reduction Technology classes 50, 75, 90, 95, 97.5 and 99 in orchard spraying (full leaf situation).*

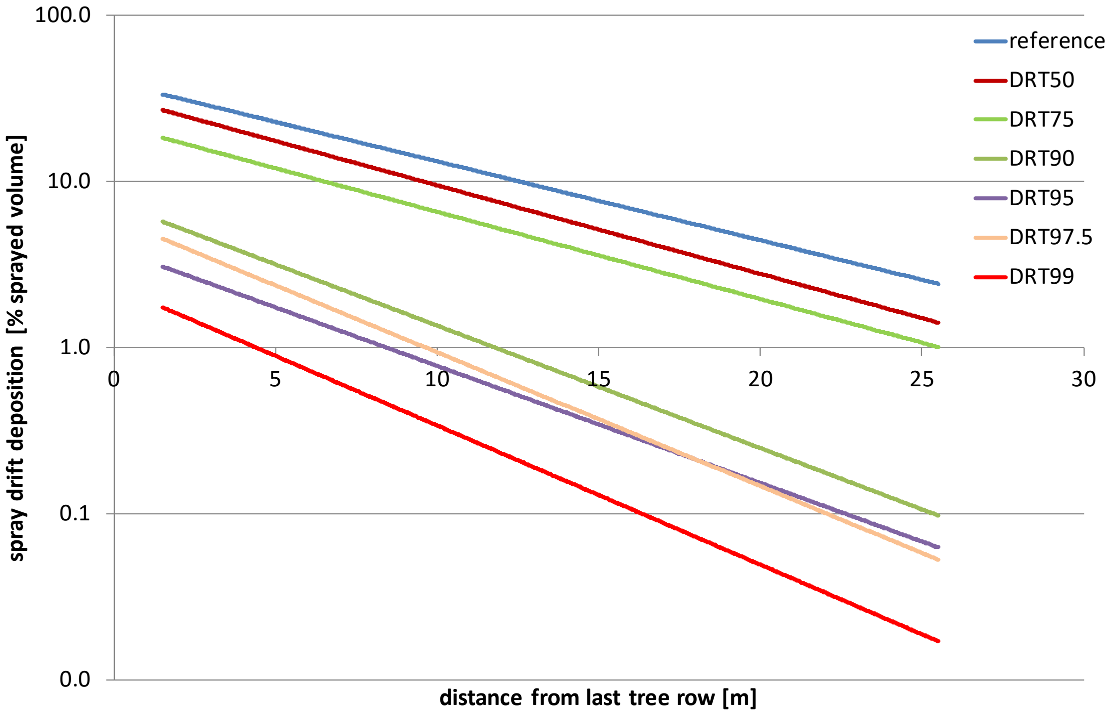

Figure 11 *Spray drift deposition curves (log) for the reference and typical application techniques for the Drift Reduction Technology classes 50, 75, 90, 95, 97.5 and 99 in orchard spraying (dormant situation).*

Due to the difference in single row and one-sided spraying of the outside row without air assistance for the DRT95 application technique the spray drift deposition curve in the dormant leaf stage is crossing with the one for the DRT97.5 technique being applied with a three-row sprayer with limited air to the outside from the fourth tree row onward.

2.2 Development of spray drift model for fruit crop spraying

From the large number of NL spray drift measurements in which a reference spray technique is compared with drift-reducing spray techniques, it is possible to evaluate the spray drift in relation with the crop growth stage and leaf development throughout the growing season. For practical reasons nowadays only a distinction is made between before and from May 1st onwards as a typical dormant and full leaf situation. In Figure 12, the leaf development and canopy density of the outside three tree rows of a typical apple orchard is presented.

Figure 12 *Crop growth development (BBCH stage) of apple trees (Elstar) at different dates during the 2011 growing season (Randwijk, The Netherlands). View through outer three tree rows.*

It is obvious that throughout the year the canopy remains more or less open depending on the phenological development stages of the fruit crop (BBCH, 2001). The date during the year can be coupled to the BBCH growth stage. This has been done for all spray drift measurements dates based at data from apple variety research at Randwijk during the period 1999-2011(unpublished data). Typical growth stages determined in apple variety development are presented in Table 7 and in Table 8. An example is given of the variation in day number found for the different apple varieties for the specific BBCH growth stages in the orchards of the Fruit experimental station of Randwijk (The Netherlands) for the period 1999-2010.

Table 7 *Phenological stages used in apple variety research used for the determination of the BBCH code and the Dutch description related to the date of spray drift measurements in the different years (after BBCH, 2001).*

BBCH	English	Dutch
00	dormancy	winterrust
51	bud swelling	zwellende knop
52	end of bud swelling	schuivende knop
53	budburst	openbrekende knop
54	mouse-ear	muizenoor
56	green bud	groene knop
57	pink bud	roze knop
59	balloon	ballonstadium
60	start flowering	begin bloei
65	full flowering	volle bloei
67	flowers fading	afbloei, kroonbladval
69	end of flowering	einde bloei
72	hazelnut - fruit size up to 20mm	hazelnootgrootte *
73	second fruit fall	junirui
74	walnut - fruit diameter up to 40mm	walnootgrootte *
87	fruit ripe for picking	plukrijp
93	beginning of leaf fall	begin bladval
95	50% of leaves discoloured	50% blad verkleurd **
97	all leaves fallen	einde bladval

Table 8 *Variability of day number during the year for the different phenological stages (BBCH) in different years of apple variety research (Randwijk, The Netherlands).*

Year	0	51	52	53	54	55	56	57	60	65	67	69	72	74
1999		75	81	85	92	94	97	102						
2000		75	84	92	96	100	108	111	113	118	124	132	136	139
2001	58	79	92	99	110	115	120	122	124	131	132	142	146	150
2002	43	63	70	74	77	87	96	99	104	114	120	139	141	146
2003	51	84	87	90	98	105	107	109	111	116	118	135	137	145
2004	42	75	88	93	96	103	109	112	114	121	123	139	143	147
2005	47	81	86	91	96	101	108	110	114	118	121	132	139	146
2006	72	93	99	102	108	114	122	124	125	127	128	133	137	143
2006	72	92	99	102	109	115	118	123	124	126	127	133	138	145
2007	53	74	81	88	91	97	104	104	105	109	113	121	127	132
2008	39	63	71	91	95	99	104	107	115	123	126	131	134	
2009	61	75	84	91	94	100	103	107	107	112	115	125	130	135
2010	78	82	85	89		97	103	110	117	120	122	140	142	
min	39	63	70	74	77	87	96	99	104	109	113	121	127	132
max	78	93	99	102	110	115	122	124	125	131	132	142	146	150
avg	56	78	85	91	97	102	108	111	114	120	122	134	138	143

Table 8 shows that the discrimination between the 'dormant' and the 'full leaf' situation as defined in the Netherlands as before and after May 1st (day number 121) can vary in growth stage. BBCH around day 121 varies between the green bud stage BBCH56 (in 2006) and end of flowering BBCH69 (in 2007). Start flowering (BBCH60) shows a variation over these 10 years of 21 days (day no 104-125) being on average at day 114. However as can be seen from Figure 13 in 2011 the development between BBCH56 and BBCH69 can be within only a fortnight.

As a result, Figure 13 shows the relation between the spray drift deposition at 5 m distance from the last tree row for all the spray drift measurements in the dataset. Each data point in Figure 13 is from a specific spray drift curve measured at a certain date and growth stage during the period 1992-2011.

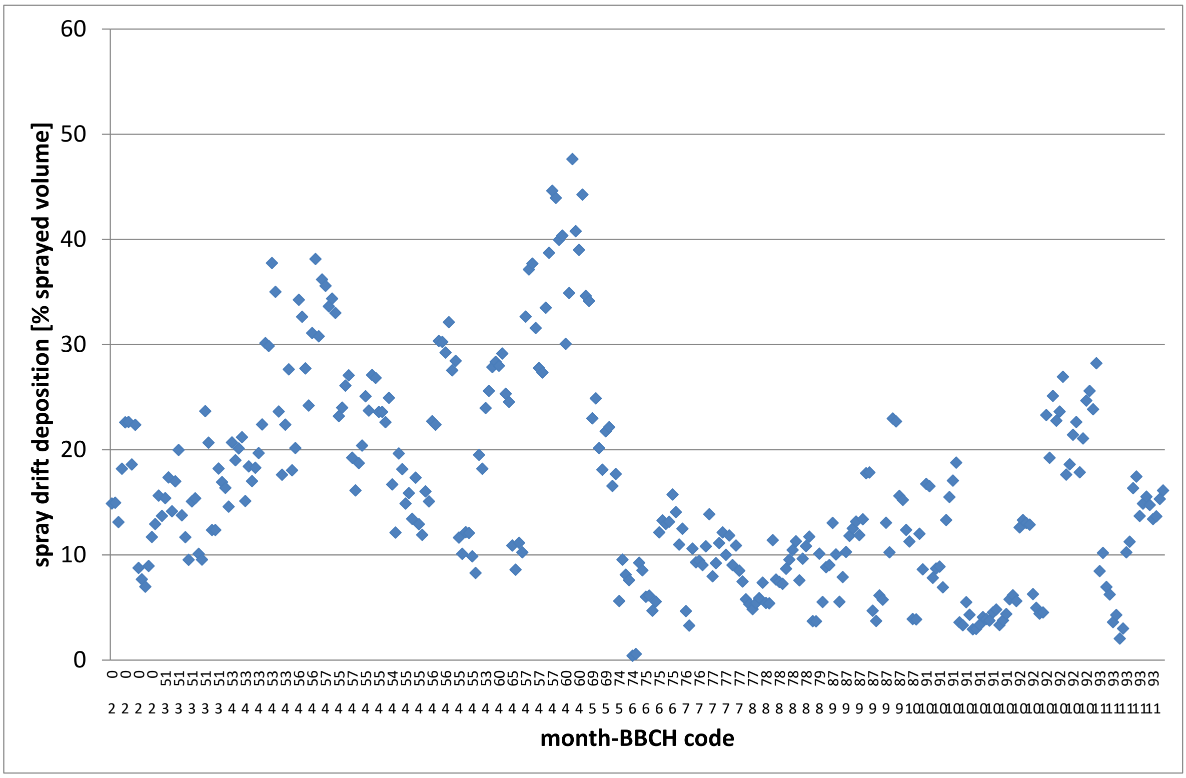

Figure 13 *Spray drift deposition [% sprayed volume] at 4.5-5.5 m distance from the last tree row for all spray drift measurements related to month and BBCH growth stage code.*

This relation between BBCH stage and spray drift deposition at 5 m distance from the last tree row is not yet very clear as spray drift deposition is apart from the crop growth stage also influenced by wind speed, wind direction, temperature and humidity during the measurement. A further analysis of these parameters influencing spray drift deposition is performed on the dataset and is used as the basis for the new orchard spray drift model (SPEXUS) as developed by Holterman *et al.* (2017, 2018).
As a first exercise a discrimination between real dormant (BBCH 0-60) and full leaf (BBCH 74-92) crop growth stages was determined (Zande *et al.*, 2014), with an intermediate period (BBCH 61-73, 93-0) in between them describing the leaf development and leaf fall crop growth stages. Mean spray drift deposition downwind of the orchard for these three growth stage periods are for the reference cross-flow fan orchard sprayer presented in Figure 14.
At 5 m distance from the last tree row spray drift deposition was 11% in the full leaf, 15% in the intermediate and 23% in the dormant period. Spray drift deposition decreases with distance from the orchard. From the spray drift deposition data exponential functions were fitted for the spray deposition with distance for the dormant (BBCH 0-60), intermediate (BBCH 61-73, 93-0) and full leaf (BBCH 74-92) situation. The functions and its parameters for the three growth stages are:

Dormant: $y = 38.797e^{-0.104x}$
Intermediate: $y = 26.928e^{-0.124x}$
Full leaf: $y = 19.036e^{-0.118x}$

With y = spray drift deposition (% of sprayed volume) at distance x m from the last tree row.

When discriminating to these three periods spray drift deposition in the full leaf situation is a little lower (11%) and for the dormant situation a little higher (23%) than when separating in the two periods before/after May 1st (resp. 21.8% and 11.7%; Figure 9). For the SPEXUS orchard spray drift model it was decided to vary spray drift deposition over the whole year based on the crop phenological development stage (BBCH) and day of the year (Holterman *et al.*, 2017) and will be as such implemented in the exposure scenario for upward and sideways spray applications (Boesten *et al.*, 2018).

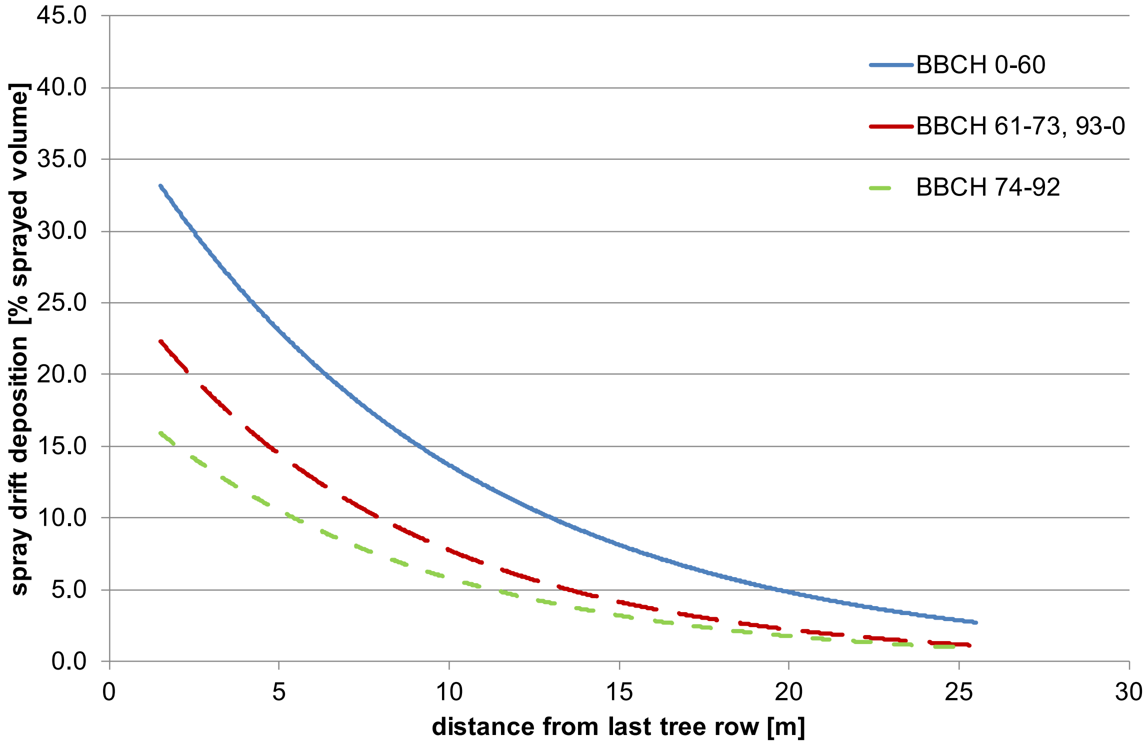

Figure 14 *Mean spray drift deposition (1990-2011; % of sprayed volume per unit area) downwind of the sprayed orchard for the reference sprayer at dormant (BBCH 0-60), intermediate (BBCH 61-73, 93-0) and full leaf (BBCH 74-92) periods (apple).*

2.3 Field measurements of spray drift in avenue nursery tree crops (sideways and upward directed sprayers)

2.3.1 Field measurements

For insecticides and fungicides spraying in avenue nursery trees a differentiation is made between spindle trees, transplanted trees and high (>5 m) nursery trees (Figure 15). These trees are only sprayed in the full leaf stage, so no distinction is made between the full leaf and the dormant situation of the tree. Each tree crop group (spindle, transplanted and high trees) has its own typical spray drift curve based on field measurements with a typical reference spray technique. Weather conditions during these spray drift measurements are indicated in Table 11. The total crop free zone as defined by the LOTV/EAD is 5.0 m (Figure 16).
Herbicides in nursery tree crops are sprayed downward (Stallinga *et al.*, 2012a) and have their own spray drift curves, hence are not covered by the methodology described in this report. Spray drift research for herbicide application techniques in tree nursery was performed for a defined reference application technique (low boom spraying) and drift reducing techniques.

Figure 15 *From left to right schematic presentation of the size and canopy structure of a spindle, transplanted and ornamental (high avenue) nursery tree.*

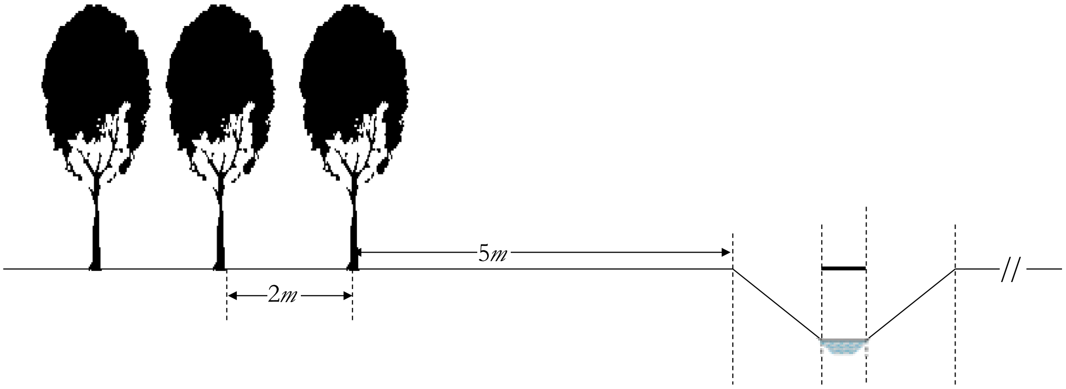

Figure 16 *Schematic presentation of the situation when spraying a tree nursery crop. Total crop free zone is 5.0 m, last tree row distance to the edge of the ditch (top of bank) is 5.0 m.*

Defined reference spray techniques (Figure 20) in avenue tree nursery are:
Spindle and transplanted avenue nursery trees: axial fan sprayer equipped with hollow cone nozzles (Albuz ATR yellow, 12 bar spray pressure) having a Very Fine spray quality (Southcombe *et al.*, 1997), applying a spray volume of 400 l/ha - 550 l/ha (8-12 nozzles open) for spindle trees and 300 l/ha - 400 l/ha (4-6 nozzles open) for transplanted trees. Forward speed was 2.5-4.5 km/h.
High avenue nursery trees (>5 m): axial fan sprayer equipped with hollow cone nozzles (TeeJet TXB8003, 8 bar spray pressure) having a Very Fine spray quality (Southcombe *et al.*, 1997), applying a spray volume of 410 l/ha - 460 l/ha (6 nozzles open). Forward speed was 4-4.3 km/h.

Figure 17 *Standard spray techniques in spindle and transplanted avenue nursery trees (left, centre) and high avenue nursery trees (right).*

2.3.2 Spray drift data in avenue nursery trees

In a series of experiments in the period 1996-1997 in avenue nursery trees, a conventional axial fan sprayer equipped with flat-fan nozzles was compared with a conventional axial fan sprayer with hollow cone nozzles (Porskamp *et al.*, 1999a). The comparison was made for two tree types: spindles and transplanted avenue trees. The level of spray drift deposition next to the sprayed field did not differ for the two nozzle types. The spray drift deposition at surface water distance (6.5-7.5 m from the last tree row), taking into account a 5 m total crop free zone as implemented by the LOTV/EAD, was calculated to be 0.8% for the spindle trees and 2.8% for the transplanted avenue nursery trees. The spray drift deposition data are presented in Figure 18, Figure 19 and Figure 20 for the spindle trees, the transplanted trees and the high avenue trees, respectively. Mean, median, 90-percentile and 10-percentile spray drift deposition data are presented in Table 9 for the spindle trees, transplanted nursery trees and Table 10 for the high avenue nursery trees.
In 2006-2008 a series of spray drift measurements were performed (Stallinga *et al.*, 2011d) in which a comparison was made between a standard axial fan sprayer equipped with hollow cone nozzles and a prototype mast sprayer developed for high (>5 m) avenue nursery trees equipped with standard flat fan nozzles and drift reducing venturi flat fan nozzles. The effect of a 5 m spray-free buffer zone was also taken into account for both the sprayer setups. The effect of a 5 m spray free buffer zone was obvious for all spray techniques; it reduced spray drift deposition at 5-9 m by 71% (mast sprayer XR110015), 89% (Axial fan sprayer TXB03) and 96% (mast sprayer ID90015). In the standard situation the mast sprayer equipped with standard flat fan nozzles reduced spray drift deposition at 5-9 m from the last tree row by 25% and when equipped with the venturi flat fan nozzles (ID90015) by 71%.

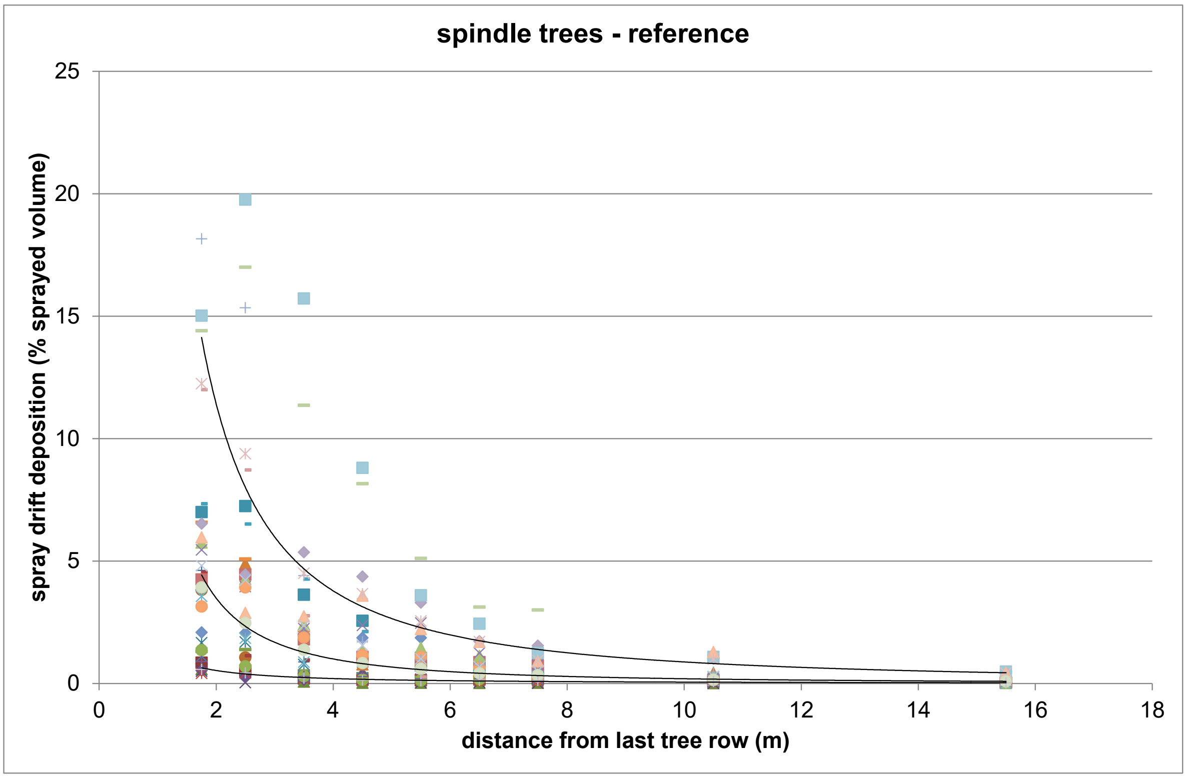

Figure 18 *Spray drift deposition (% of applied spray volume) spraying spindle avenue nursery trees using a standard axial fan sprayer (reference), including 90-percentile, median and 10-percentile lines.*

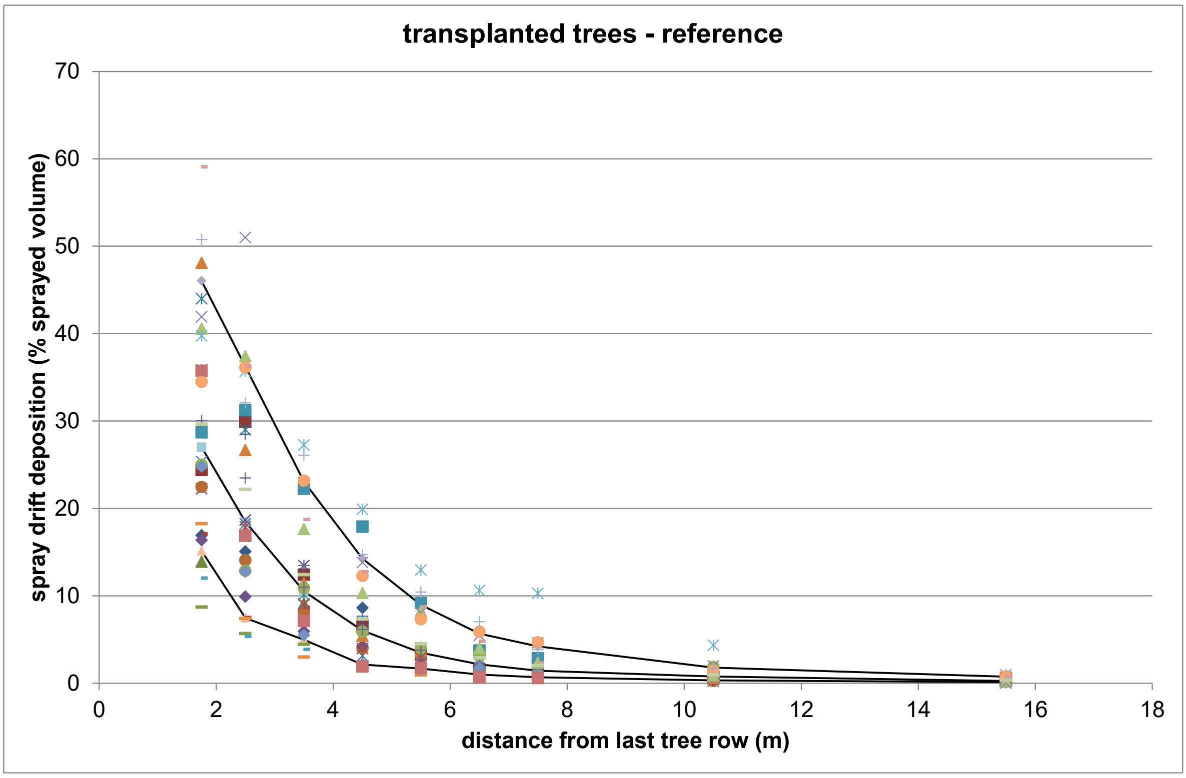

Figure 19 *Spray drift deposition (% of applied spray volume) spraying transplanted avenue nursery trees using a standard axial fan sprayer (reference), including 90-percentile, median and 10-percentile lines.*

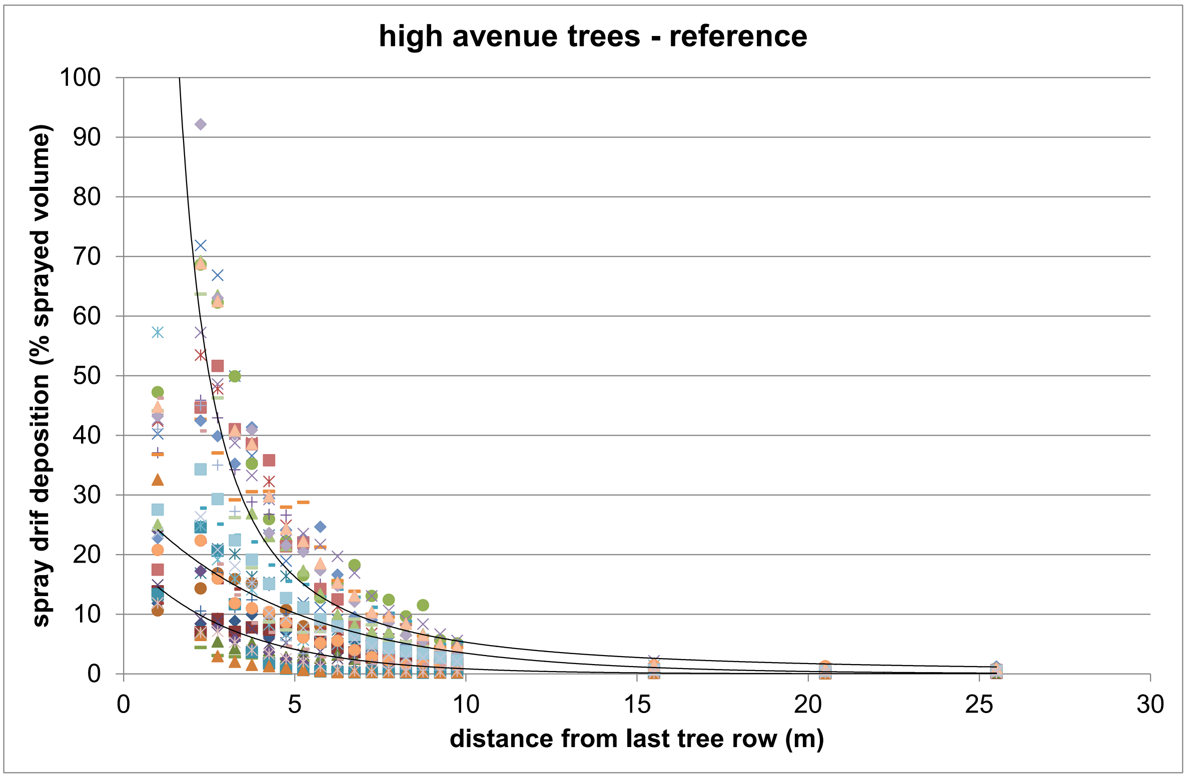

Figure 20 *Spray drift deposition (% of applied spray volume) spraying high avenue (>5 m) nursery trees using a standard axial fan sprayer (reference), including 90-percentile, median and 10-percentile lines.*

The mean spray drift deposition curves next to the tree nursery for the standard spray technique in the avenue nursery tree situations spindle, transplanted and high avenue nursery tree are presented in Figure 21.

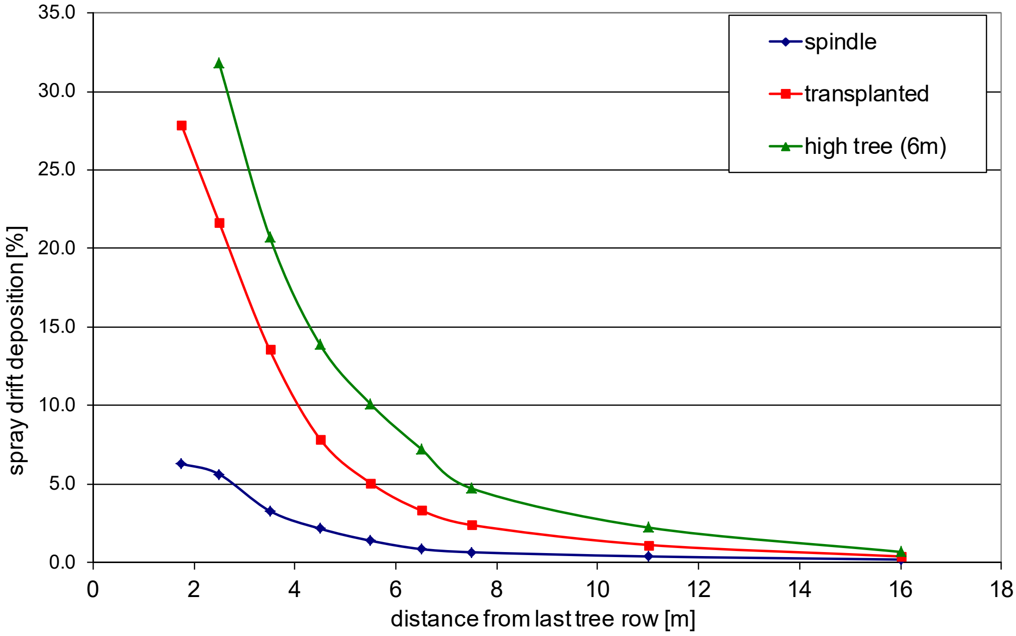

Figure 21 *Mean spray drift deposition (% of applied spray volume) curves for the standard axial-fan spray techniques used in spindle, transplanted and high (>5 m) avenue nursery trees.*

Minimal agronomic crop free zone widths are 1.5 m for the spindle and 2.0 m for the transplanted and high avenue nursery trees.

Table 9 *Spray drift deposition (% sprayed volume) at different distances from the last tree row when spraying spindle and transplanted avenue nursery trees with a standard axial fan (reference). Mean, median, 90-percentile and 10-percentile values.*

		Distance from last tree row (m)								
		1,5-2	2-3	3-4	4-5	5-6	6-7	7-8	10-11	15-16
spindle	mean	4.8	4.2	2.4	1.5	1.0	0.67	0.51	0.28	0.13
	90-perc	12.2	9.4	4.5	3.7	2.5	1.7	0.93	1.00	0.42
	median	3.9	2.5	1.4	0.83	0.60	0.41	0.34	0.15	0.09
	10-perc	0.57	0.43	0.21	0.14	0.11	0.13	0.12	0.07	0.02
transplanted	mean	29.6	22.2	12.4	7.3	4.5	2.9	2.0	0.94	0.36
	90-perc	46.0	36.2	23.0	14.3	9.0	5.7	4.2	1.8	0.75
	median	27.0	18.4	10.5	6.0	3.5	2.2	1.4	0.76	0.26
	10-perc	15.1	7.5	5.0	2.1	1.7	0.99	0.67	0.33	0.13

Table 10 *Spray drift deposition (% sprayed volume) when spraying high avenue (>5 m high) nursery trees with a standard axial fan (reference). Mean, median, 90-percentile and 10-percentile values.*

	Distance from last tree row (m)																		
	2-2½	2½-3	3-3½	3½-4	4-4½	4½-5	5-5½	5½-6	6-6½	6½-7	7-7½	7½-8	8-8½	8½-9	9-9½	9½-10	15-16	20-21	25-26
mean	34.3	29.3	22.4	19.1	15.1	12.7	11.1	9.1	8.0	6.5	5.1	4.3	3.8	3.4	2.7	2.2	0.69	0.46	0.51
90-perc	68.8	62.5	40.8	38.6	29.8	24.3	22.3	18.5	15.3	13.1	10.3	9.7	8.4	6.5	4.9	4.6	1.4	0.81	0.91
median	26.3	20.8	18.0	15.2	10.2	9.3	7.7	7.7	7.6	5.8	4.4	3.2	2.7	2.7	2.5	2.0	0.55	0.45	0.48
10-perc	6.9	7.1	5.3	3.9	3.3	2.5	2.0	1.2	0.70	0.49	0.41	0.42	0.36	0.33	0.33	0.39	0.14	0.09	0.14

Table 11 *Weather conditions during spray drift measurements of reference spray technique in avenue tree nursery spraying (average and (standard deviation)).*

Crop	Spray technique	No measurements	Temperature at 2 m height [°C]	Average wind angle [°]	Average wind speed at 2 m height [m/s]
spindle	reference	30	19.2 (3.5)	4 (16)	2.6 (0.6)
transplanted	reference	26	18.8 (1.8)	2 (15)	2.5 (0.5)
high avenue	reference	28	18.2 (2.5)	11 (9)	1.3 (0.3)

2.3.3 Spray Drift Reduction Technologies in avenue nursery trees

For spindle, transplanted and high avenue nursery trees spray drift reduction technologies and measures can be grouped in drift reduction classes of 50%, 75%, 90% and 95% drift reduction (Table 12). Entrance in the different drift reduction technology classes is based on measured spray drift deposition at 6.5-7.5 m from the last tree row. For the identified drift reducing techniques the spray drift reduction was determined with distance from the last tree row (Table 13) and shows that spray drift reduction is not the same at all distances. Up till today however only a limited number of techniques have entries in the drift reduction classes based on performed research and adaptation of the nozzle classification system for orchard sprayers (Zande *et al.*, 2008, 2012b). No techniques were so far certified by the TCT as no reduction in width of the total crop free zone of 5 m is possible in nursery tree spraying.

Table 12 *Spray drift reduction technologies in different drift reduction classes for avenue nursery trees (spindle, transplanted and high trees).*

Drift reduction classes	Spray drift reduction technology in drift reduction class
50%	50%, 75%, 90% drift reducing nozzle types (spindle, transplanted) mast sprayer + drift reduction 90 nozzles (high trees)
75%	Mast sprayer + standard nozzles + gap-detection sensor (high trees)
90%	95% drift reducing nozzle types (spindle, transplanted)
95%	Mast sprayer + 90% drift-reducing nozzles + gap-detection sensor (high trees)

Table 13 *Spray drift reduction (%) at different distances (m) from the last tree row for different Drift Reduction Technology (DRT) classes spraying spindle, transplanted and high (>5 m) avenue nursery trees.*

									Distance from last tree row (m)
spindle	1.75	2.5	3.5	4.5	5.5	6.5	7.5	11	16
DRT50	-23	24	44	66	69	62	55	58	42
DRT90	-14	39	68	93	91	90	85	87	64

									Distance from last tree row (m)
transplanted	1.75	2.5	3.5	4.5	5.5	6.5	7.5	11	16
DRT50	-11	14	42	53	59	60	64	65	50
DRT90	-2	29	65	79	91	93	94	94	72

																			Distance from last tree row (m)
high	1	2.25	2.75	3.25	3.75	4.25	4.75	5.25	5.75	6.25	6.75	7.25	7.75	8.25	8.75	9.25	9.75	15.5	20.5	25.5
DRT50	54	45	30	31	42	44	53	63	64	69	72	71	71	73	75	72	71	65	63	69
DRT75	86	86	86	81	81	77	75	76	74	77	78	75	70	67	62	56	45	40	16	4
DRT95	90	94	95	93	93	93	94	95	94	95	95	95	95	95	94	93	92	87	84	80

3 Proposed exposure assessment for crop groups using a matrix approach for drift reduction technology

Crops sprayed with sideways and upward directed spray techniques are fruit trees and avenue nursery trees. For fruit trees a further distinction is made between the application of PPP before May 1st and from May 1st onwards, relating to a dormant and a full leaf situation of the fruit trees (Figure 22). A typical situation for fruit crops having a minimal agronomic crop free zone of 3.0 m is presented in Figure 23. Avenue nursery trees are distinguished in spindle, transplanted and high avenue trees with respectively 1.5 m, 1.5 m and 2.0 m minimal agronomic crop free zones.

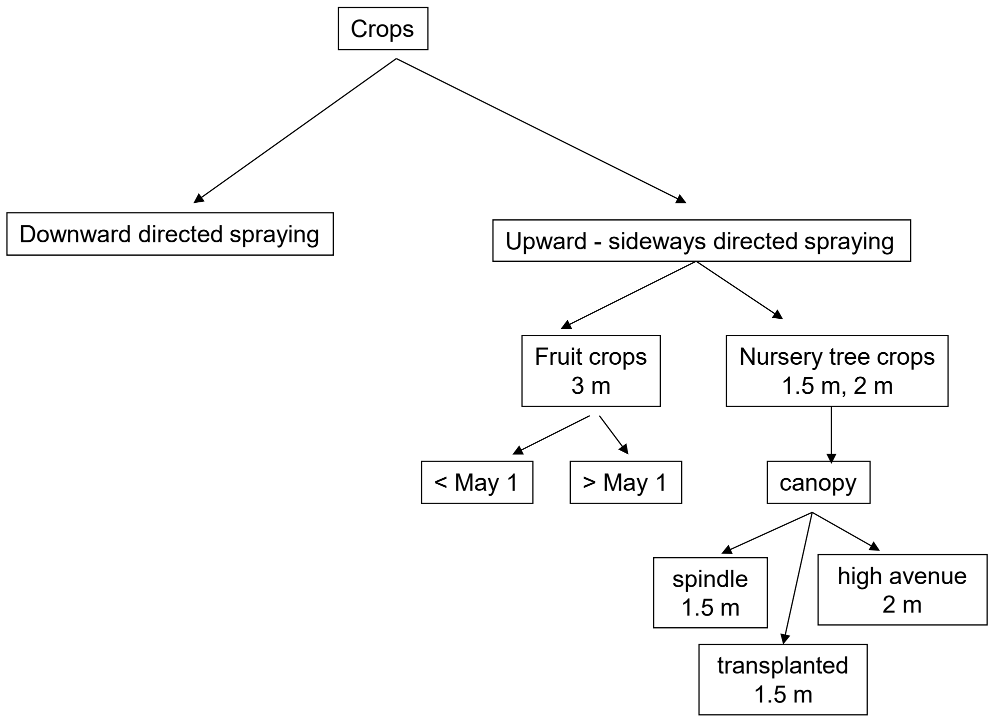

Figure 22 *Differentiation in crop categories and growth situations for crops sprayed with sideways and upward directed application techniques.*

In this chapter the methodology is discussed of a matrix structure for the assessment of spray drift deposition combining classes of DRT and width of crop free zones for fruit crops and avenue nursery trees. Based on the crop growth situations and the used spray techniques, different spray drift deposition curves are used (Chapter 3) to determine the exposure to surface water. It was decided to develop a matrix approach combining classes of drift reduction technology (DRT) and stepwise increasing widths of crop free zones.

3.1 Fruit crops

For fruit crops all crop categories from the cultivation category fruit crops (large fruits, nuts, other fruits) are evaluated for the fungicide and insecticide treatments, hence excluding herbicide treatments which are done with downward directed application techniques (Zande & Ter Horst, 2019; Stallinga *et al.*, 2012a). From the crop category 'small fruits' the subcategory strawberries and the crop cranberries are also excluded for all treatments are done using downward application techniques.

Some of crops of the crop category 'small fruits' (e.g. Black currants) fungicide and insecticide treatments are in the first two years after planting applied using downward application techniques (boom sprayer). However, all fungicide and insecticide applications in small fruits are evaluated as done with sideways- and upward application techniques. Although crop adapted spray techniques are used for small fruit crops (Zande *et al.*, 2011) no specific spray drift data are available for the situation in the Netherlands and they are therefore evaluated similar to pome fruit.
From the crop category "Other arable crops" the crop 'Common hop' is for fungicide and insecticide applications included in this evaluation for sideways- and upward spray application techniques (Annex 4).

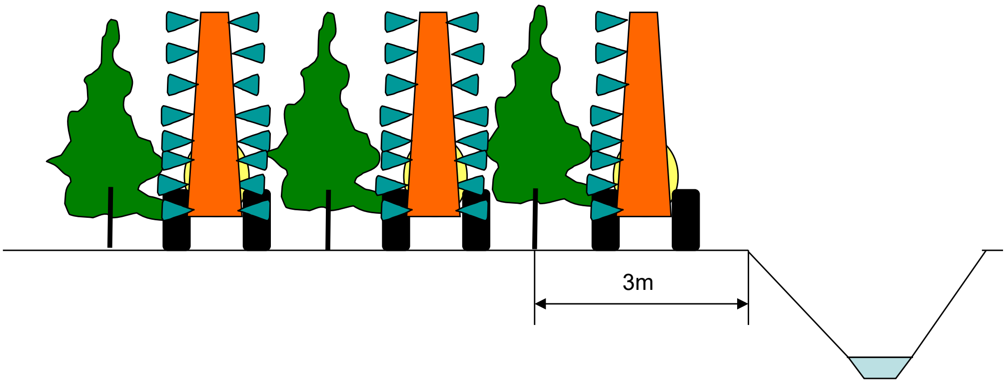

Figure 23 *Schematic presentation of the situation when spraying a fruit crop. Minimal agronomic crop-free zone is 3.0 m, row spacing and last tree row distance to the edge of the ditch is 3.0 m.*

The estimation of spray drift deposition at surface water can be evaluated in a matrix approach. First the spray drift deposition is determined for the standard spray technique; secondly for drift reducing spray techniques and measures; thirdly for all spray techniques with step-wise wider crop free zones (Figure 24).

The spray drift deposition values are based on the standard spray drift curves for the dormant and full leaf situation (Chapter 3). Because the spray drift deposition values for the 3 m minimal agronomic crop free zone are, based on all measurements 1990-2011 (Figure 9), renewed into 12% for the full leaf situation and 22% for the leafless situation, as derived from the spray drift curves at the distance 4.5-5.5 m (i.e. the location of the surface water in the standard ditch; Figure 6).

The evaluation of spray drift deposition starts at the top left cell of the matrix (Figure 24) with the evaluation of the standard application technique. This is the nowadays used practical standard situation, a standard width of the minimal agronomic crop free zone of 3 m is used for the determination of the spray drift deposition onto surface water for the standard (reference) spray technique and crop growth situations (12% full leaf – 22% dormant situation).

Spray drift reduction classes	**Total crop free zone (m)**						
	3.0	**4.0**	**5.0**	**6.0**	**7.0**	**8.0**	**9.0**
Standard	→	→					
DRT 50	↓						
DRT 75	↓						
DRT 90							
DRT 95							
DRT97.5							
DRT99							

Figure 24 *Matrix structure of spray Drift Reduction Technology (DRT) classes and total crop free zone width (m) for the calculation of spray drift deposition on surface water for upward directed spray techniques in fruit crops.*

After the standard application technique a next step evaluation can be performed taking into account the drift reducing aspects of additional crop free buffer zones and drift reduction technology running the evaluation in the cells of the matrix from top left to bottom right. If for an agrochemical the spray drift deposition level leads to a predicted environmental concentration (PEC) that is higher than the regulatory acceptable concentration (RAC, ecotoxicological threshold value) in the standard situation a next cell may be evaluated. The preferred direction of evaluation in the matrix is per total crop free zone in for example steps of 1.0 m from 3.0 m to 12 m per spray drift reduction class application technique.

For each of the spray drift reduction classes 50%, 75%, 90%, 95%, 97.5% and 99%, in combination with a 3 m minimal agronomic crop free zone, the spray drift deposition is calculated at the surface water level of the standard ditch (4.5-5.5 m from last tree row). Spray drift values can be compared to the required ecotoxicological threshold value (RAC) of the plant protection product.

In addition if the ecotoxicological threshold value (RAC)in the surface water is not met with a certain drift reduction class an additional total crop free zone width; being the sum of the minimal agronomic crop free zone and the additional crop free buffer zone (Figure 25), of 4 m up till 13 m (in steps of 1.0 m) can be evaluated.

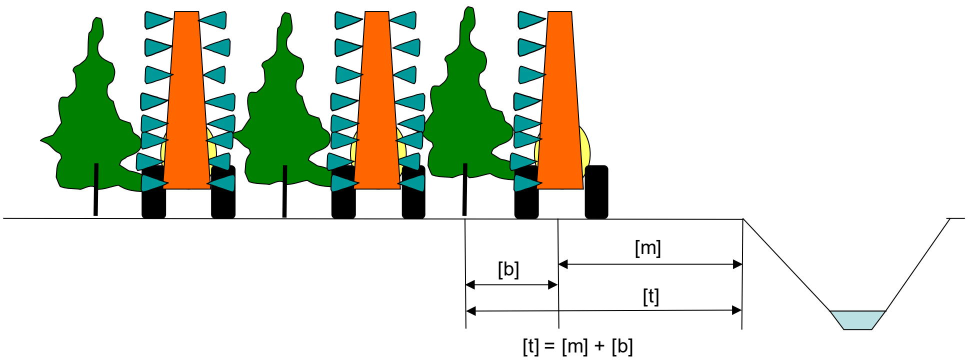

Figure 25 *Schematic representation of the Ditch in the Dutch scenario for sideways and upward spray applications. [t] is the total crop free zone and the sum of [m] the minimal agronomic crop free zone and [b] the crop free buffer zone.*

This will result in a table of total crop free zones required for the standard spray technique and the spray techniques certified in the drift reduction classes 50%, 75%, 90%, 95%, 97.5% and 99%. For these typical spray drift deposition curves the width of the total crop free zone can be calculated to meet the ecotoxicological threshold value of drift deposition on surface water area by following the spray drift deposition curve until the distance for which spray drift deposition at the water surface width is below the threshold level. Results of spray drift deposition for the standard ditch dimensions (bank to bank distance 4 m, water surface width 1.0 m) with an average water table level and average wind conditions during measurements are presented in Table 14 for the full leaf and in Table 15 for the dormant situation.

Table 14 *Spray drift deposition (% of applied dose) of stepwise selection of classes of spray drift reduction technologies (DRT) and width of total crop free zone (m) to meet a certain level of acceptable spray drift deposition in surface water in the full leaf situation (standard ditch dimensions).*

Spray drift reduction classes	Total crop free zone (m)						
	3.0	4.0	5.0	6.0	7.0	8.0	9.0
Standard	11.7	9.9	8.3	7.4	6.6	5.8	5.0
DRT 50	5.7	4.7	3.8	3.4	3.0	2.5	2.2
DRT 75	2.7	2.0	1.5	1.3	1.1	0.9	0.7
DRT 90	1.4	1.1	0.8	0.7	0.5	0.41	0.32
DRT 95	0.5	0.44	0.31	0.27	0.27	0.26	0.25
DRT97.5	0.17	0.14	0.11	0.10	0.08	0.07	0.06
DRT99	0.07	0.06	0.06	0.05	0.05	0.04	0.04

Table 15 *Spray drift deposition (% of applied dose) of stepwise selection of classes of spray drift reduction technologies (DRT) and width of total crop free zone (m) to meet a certain level of acceptable spray drift deposition in surface water in the dormant situation (standard ditch dimensions).*

Spray drift reduction classes	Total crop free zone (m)						
	3.0	4.0	5.0	6.0	7.0	8.0	9.0
Standard	21.8	19.8	16.9	15.7	14.1	12.6	11.4
DRT 50	16.8	14.9	11.7	10.8	9.2	7.9	7.0
DRT 75	11.0	9.5	8.0	7.3	6.3	5.5	5.1
DRT 90	3.2	2.1	1.4	1.3	1.0	0.8	0.7
DRT 95	1.8	1.2	0.8	0.7	0.44	0.31	0.38
DRT97.5	2.0	1.6	1.2	1.1	0.9	0.7	0.6
DRT99	0.9	0.5	0.4	0.3	0.3	0.20	0.16

From Table 14 and Table 15 it follows that if an agrochemical is to be evaluated with a required maximum spray drift deposition value on surface water of for example 1% this can be realised in the full leaf situation (from May 1st onwards) for the standard and DRT50 spray techniques only with wider total crop free zones than 9 m (Table 16). For the DRT75 this threshold value can be realised in combination with a total crop free zone of 8 m, for the DRT90 of 5 m, whereas for the DRT95, DRT97.5 and DRT99 no wider crop free zone is needed than the agronomic minimal crop free zone of 3 m. For the dormant situation of the trees (before May 1st) the threshold level of 1% is met at 5 m for the DRT95, at 7 m for the DRT97.5 and at 3 m for the DRT99. Hence there are various ways to mitigate the emission by spray drift; by wider crop free zones, by higher levels of drift reduction or by the combination of the both. The inconsistency with reducing crop free zone width with higher DRT classes in the dormant leaf situation for the 97.5 class is based on the limited number of technique entries in this class. This has to be adapted when more entries are available for this class by e.g. choosing another reference technique for this class.

Table 16 *Width of total crop free zone (m) needed for standard and DRT techniques of different spray drift reduction classes to meet a threshold value of 1% spray drift deposition at surface water (standard ditch) in the dormant (before May 1st) and the full leaf situation (from May 1st onwards).*

Spray drift reduction classes	Total crop free zone (m)	
	Full leaf	dormant
Standard	>9	>9
DRT 50	>9	>9
DRT 75	8	>9
DRT 90	5	8
DRT 95	3	5
DRT97.5	3	7
DRT99	3	3

In practice, a fruit grower most probably may prefer to maximise his usable area of orchard and therefore he wants to minimise the width of the crop free zone. As a 3 m crop free zone is nowadays very common in fruit growing areas in the Netherlands the grower has to use a DRT99 spray technique in order to fulfil the requirements of the agrochemical when using it both in full leaf and the dormant situation of the trees when the threshold value for authorisation of the agrochemical would have been 1% spray drift deposition at surface water area (4.5-5.5 m distance from the last tree row).

3.2 Avenue nursery trees

For avenue nursery trees a distinction is made between the application of PPP in spindle, transplanted and high avenue trees. A typical situation for high avenue trees having a minimal agronomic crop free zone of 2.0 m is presented in Figure 26.
From the DTG Cultivation category "Ornamental crops", of the Crop category "Tree nursery crops", the Crop avenue trees (to be further distinguished in the different stages spindle trees, transplanted trees and high avenue trees) is evaluated for the treatments fungicide and insecticides (Zande & Ter Horst, 2019). Herbicide treatments in the cultivation of avenue nursery trees are done with downward application techniques (Stallinga *et al.*, 2012a).

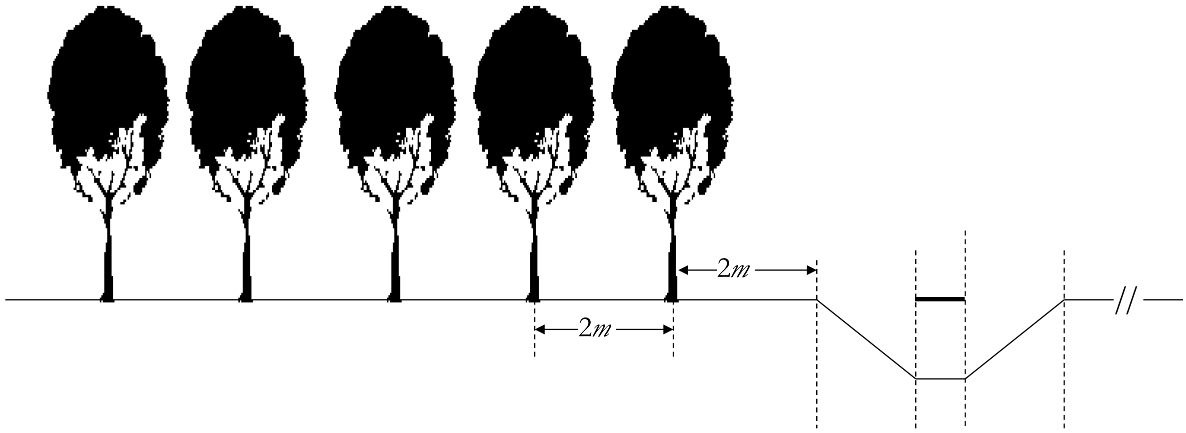

Figure 26 *Schematic presentation of the situation when spraying a high avenue tree crop. Minimal agronomic crop free zone is 2.0 m, row spacing and last tree row distance to the edge of the ditch (top of the bank) are 2.0 m.*

The estimation of spray drift deposition at surface water is evaluated in a matrix approach following the procedure described for fruit crops in Paragraph 4.1. The effect of the standard drift situation for avenue nursery tree crop spraying and of drift reducing measures is also based on the standardized ditch (Figure 6). The evaluation of spray drift deposition starts with the nowadays used practical standard situation with a minimal agronomic crop free zone of 2 m for the determination of the spray drift deposition at surface water. The evaluation in the matrix covers different total crop free zones (being the sum of the minimal agronomic crop free zone and the additional crop free buffer zone) in steps of for example 1.0 m ranging from 2.0 m to 14 m for each class of application techniques.
For the standard (reference) spray technique and minimal agronomic crop free zones and tree size situations, the spray drift deposition is 3.4% for the spindle trees, 10.4% for the transplanted trees and 17% for the high avenue nursery trees. For the mandatory 5 m total crop free zone (EAD) the spray drift deposits on the standard ditch are 0.76%, 2.8% and 5.9% for the spindle, transplanted and high avenue nursery trees, respectively.

The evaluation results in a table of total crop free zones required for the standard spray technique and the different DRT spray techniques. For these typical spray drift deposition curves the width of the total crop free zone can be calculated to meet the ecotoxicological threshold value of spray drift deposition on surface water by following the drift deposition curve until the distance for which spray drift deposition at the water surface width is below the threshold level. Results of spray drift deposition for the standard ditch dimensions (bank to bank distance 4 m, water surface width 1.0 m) with an average water level and average wind conditions during measurements is presented in Table 17 for the spindle trees, in Table 18 for the transplanted trees and in Table 19 for the high (>5 m) avenue nursery trees in the full leaf stage.

Table 17 *Spray drift deposition (% of applied dose) of stepwise selection of classes of spray drift reduction technologies and width of total crop free zone to meet a certain level of acceptable spray drift deposition in surface water for spindle avenue nursery trees in the full leaf situation.*

Spray drift reduction classes	Total crop free zone (m)								
	1.5	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0
Standard	3.4	2.7	1.8	1.1	0.76	0.63	0.54	0.47	0.40
DRT 50	1.9	1.2	0.54	0.37	0.32	0.28	0.24	0.20	0.17
DRT 75									
DRT 90	0.43	0.17	0.063	0.053	0.051	0.049	0.047	0.045	0.042
DRT 95									

Table 18 *Spray drift deposition (% of applied dose) of stepwise selection of classes of spray drift reduction technologies and width of total crop free zone to meet a certain level of acceptable spray drift deposition in surface water for transplanted avenue nursery trees in the full leaf situation.*

Spray drift reduction classes	total crop free zone (m)								
	1.5	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0
Standard	13.5	10.4	6.3	4.1	2.8	2.2	1.8	1.5	1.2
DRT 50	8.0	5.4	2.8	1.7	1.1	0.79	0.64	0.51	0.41
DRT 75									
DRT 90	4.6	2.5	0.89	0.29	0.19	0.14	0.13	0.12	0.11
DRT 95									

Table 19 *Spray drift deposition (% of applied dose) of stepwise selection of classes of spray drift reduction technologies and width of total crop free zone to meet a certain level of acceptable spray drift deposition in surface water for high (>5 m) avenue nursery trees in the full leaf situation.*

Spray drift reduction classes	Total crop free zone (m)							
	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0
Standard	17	11.9	8.6	5.9	4.1	3.1	2.2	1.8
DRT 50	9.8	5.1	2.9	1.7	1.2	0.8	0.63	0.53
DRT 75	3.6	2.9	2.1	1.4	1.3	1.24	1.15	0.98
DRT 90								
DRT 95	1.2	0.68	0.47	0.28	0.22	0.2	0.18	0.16

4 Discussion

For spray application in fruit crops and avenue tree nurseries, spray drift data are presented which are based on all field measurements done up till 2011 in the Netherlands. Compared to the spray drift data that is currently used in the authorisation procedure of PPPs (Ctgb, 2019) the new spray drift deposition data is higher for the upward and sideways directed spray applications. Due to a wider range of tree sizes, tree age distribution, crop growth stages (including dormant and full leaf) and weather conditions during the field experiments the spray drift deposition data presented in this report for fruit crop spraying are higher than currently used in the authorisation procedure.
For avenue nursery tree spraying presented spray drift data are more or less similar as data were recently updated in the authorisation procedure (Ctgb, 2019).

Variation of spray drift deposition alongside field edge
Deposits of spray drift downwind from the treated field is in general presented as a declining deposition curve over distance. The variation at a certain distance is not only depending on the weather conditions during application but also on the variation in canopy structure alongside the downwind treated area in tree and leaf canopy structure. Stallinga *et al.* (in prep) found that spray drift deposition at e.g. 5 m distance from the last tree row alongside 100 m row length of a treated apple orchard was 8.8% and 4.0% at the headland (6 repetitions) as measured in the standard setup (ISO22866). When measured in 50 cm steps over 50 m length at the headland and over 100 m length alongside the downwind tree row the spray drift deposition was 5.9% and 9.2%, respectively. This shows little difference between the different measuring methodologies in mean spray drift deposition alongside the field but does so for the headland measurements. Variation in spray drift deposition over 100 m length was large at the side parallel to the tree rows, having peak values in spray drift deposition of 4.9%-33.7% and of 1%-12% in mean values between repetitions. Coefficient of variation values ranged therefore from 40% to 80%, meaning that peak values in spray drift deposition are 1.5-6.7 times higher than mean measured values at standard surface water distance. As an example, Figure 27 shows the measured variation in spray drift deposition at the side parallel to the tree rows of the treated apple orchard.

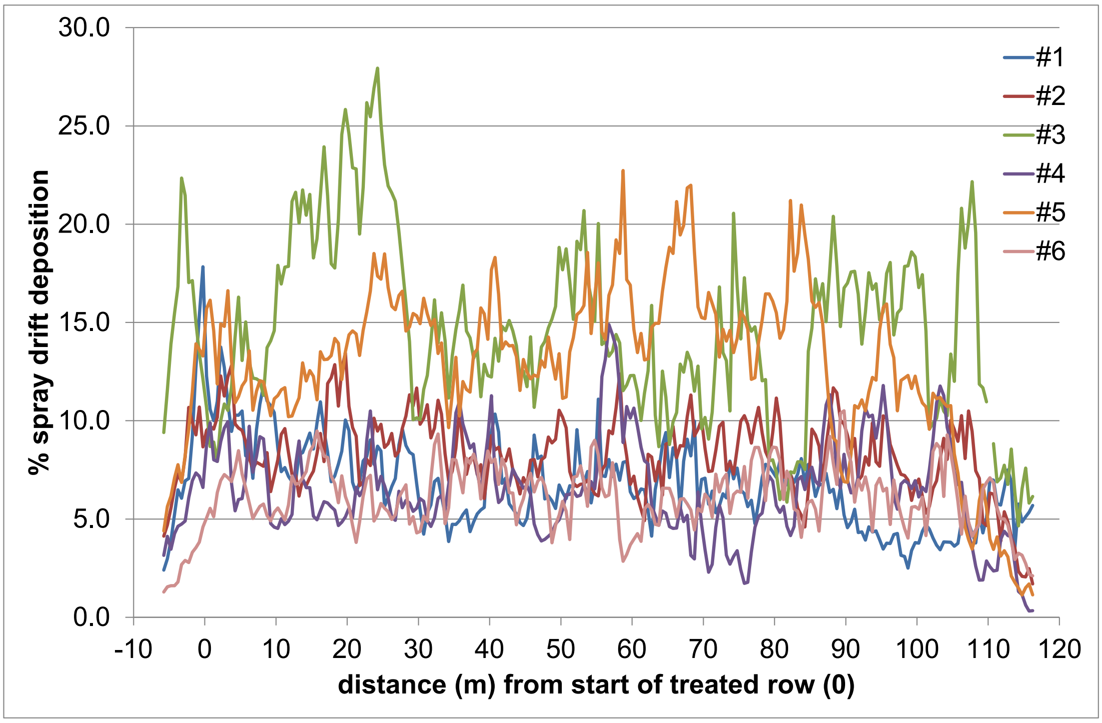

Figure 27 *Spray drift deposition (% of sprayed volume) at 5 m distance from the last tree row over 100 m length alongside a treated field for 6 repetitions in time (50 cm resolution).*

Comparison of NL and German spray drift data for early and late fruit
Limited data are available to compare the spray drift data of fruit crop sprayers. Apart from the Ganzelmeier *et al.* (1995, 2000) and Rautmann *et al.* (2001) data some data are found from the UK (Cross *et al.*, 2001a, 2001b, 2003). However, the UK measurements are only related to potential airborne spray drift and not to downwind spray drift sedimentation outside the treated orchard as the measurements were done inside the orchard on a vertical pole downwind of the sprayed tree rows.

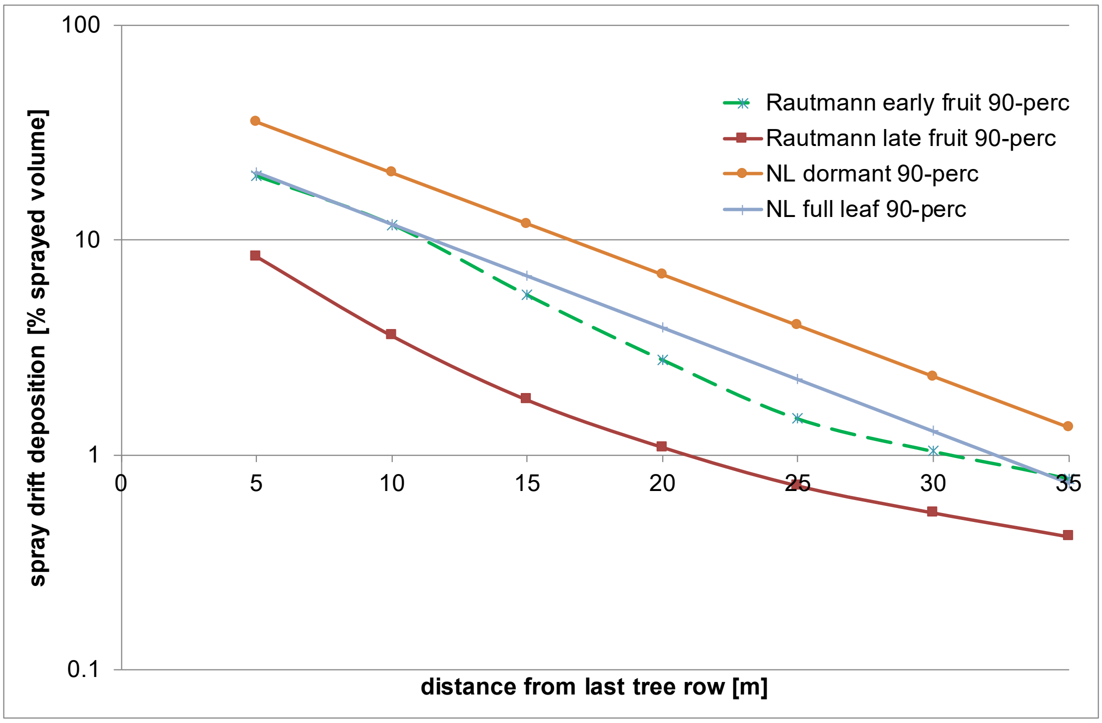

Figure 28 *Comparison of the NL dormant and full leaf 90-percentile spray drift deposition curves and the German (Rautmann) basic drift values (90-percentiles) for early and late fruit crop spraying.*

For both the Dutch and German datasets the spray drift deposition in the dormant situation is about 2 times higher than that in the full leaf situation; resp. 1.7 to 1.8 in the Netherlands and 2.3 to 1.4 in Germany at 5 to 35 m distance from the last tree row. Figure 28 shows that the 90-percentile spray drift curve for the full leaf situation (after May 1st) in the Netherlands is of the same order as the basic drift curve for the early fruit crop in Germany (Rautmann *et al.*, 2001). The 90-percentile spray drift deposition for orchard spraying in the dormant tree situation (before May 1st) is about two times higher than the 90-percentile values for the German early fruit situation.

New orchard spray drift model
Based on the 20 years of experimental data of downwind spray drift deposition of a conventional cross-flow spray application presented in this report, an empirical spray drift model for fruit crop spraying (SPEXUS) is developed (Holterman *et al.*, 2016a, 2016b, 2017, 2018). The model reveals the major factors affecting downwind spray drift deposits: wind speed, wind direction, air temperature and density of the tree canopy. Modelling the canopy density of the trees as a continuous function of time is an innovative approach. Fruit tree canopy density is uniquely related to growth stage (through the phenological BBCH (2001) index). With this SPEXUS model it will be possible to shift from two periods of spray drift curves to a set of continuous spray drift curves throughout the year based on application date and phenological growth stages of the fruit crop in the authorisation procedure (Boesten *et al.*, 2018). The SPEXUS spray drift model for fruit crop spraying opens the way to build a 90-percentile probabilistic exposure model for surface water for spraying PPP on all fruit crop fields in the Netherlands (Holterman *et al.*, 2016c, 2019). This gives way to taking into account more realistic situations of drift reduction technology and spray drift, widths of the crop free zones, environmental conditions, regional distribution of fruit crop fields and their orientation in the Netherlands, the waterways around the fruit orchards, and the regional variation of weather conditions during

application of PPP. The outcome of the probabilistic model in surface water exposure can be different from the here presented spray drift values, as upwind ditches are also taken into account in such a probabilistic approach and application time of PPP is not always under average weather conditions.

Dose expression

On the product label the allowed dose of Plant Protection Product (PPP) is in the Netherlands nowadays often expressed in: % concentration of the product, ml/100 L spray volume and L or kg per ha of the product. These expressions are all surface area based whereas a fruit crop differs very much in size and leaf amount between crops (apple, pear, cherry, etc), in pruning system, over the years and also within the year regarding tree size and leaf density. As a result fruit growers adapt their spray technology to the crop height, size, leaf density and growth stage. Nozzles are shut or opened depending on height of trees (apple vs pear, pruning system, early – late in growing season) or area of interest to be sprayed, therefore changing spray volume. Spray volume is also changed by choice of nozzle sizes depending on the canopy thickness or based on forward sprayer speed and the sprayer routing in the orchard (spraying through every path or alternating paths). In general, however, the applied spray volume for fruit crops (apple, pear) is around 200 L/ha (varying between 150 L/ha and 350 L/ha).
The risk assessment is done with the highest dose, highest frequency of spray applications and smallest spray interval. The highest dose concentration of product mentioned on the label is in the risk assessment based on 1500 L/ha spray volume applied. As some PPP labels mention also a maximum dose per application based on the maximum 1500 L/ha in the authorisation procedure, growers adapt their tank concentration, based on this information, to the total PPP amount of 1500 L/ha but dissolved such as to apply 200 L/ha. This means their tank concentration is 7.5 times higher than authorised based on the allowed concentration. It is suggested to leave the surface area based dose expressions on the PPP label for fruit crops and adapt the dose expression in fruit crops to the amount of tree leaf canopy and the row spacing at the moment of spray application e.g. based on Leaf Wall Area (LWA) (Annex 6).

In-field spray deposition

Spray deposition in canopy changes during the growing season depending on crop development (Zande *et al.*, 2003), and therefore spray deposition on soil surface underneath the fruit crop changes also depending on the part of the soil covered with tree crop canopy and its canopy density. The Leaf Area Index (LAI) characterises the leaf canopy and is defined as the amount of leaf area (m^2 leaf surface one sided measured) per unit ground surface (Wertheim, 2005). For mature apple orchards, including alleys, LAI can vary from 1.5 to 4.6 (Wertheim, 2005). Wagenmakers (1995) mentions LAI values in the range 2 to 5 depending on the planting density, cultivar and tree management (pruning systems). For the cultivar Cox individual tree leaf areas are measured from 0.24 to 0.68 m^2 in the period 7 May – 22 August (Wagenmakers, 1995) whereas for the cultivar Alkmene these values range from 0.29 to 1.07. With a common plant density of 3000 trees per ha in Dutch orchards this however results in maximum LAI values of 0.21 and 0.32 for the Cox and Alkmene cultivars respectively. In spray deposition measurements evaluating innovative new application techniques in fruit crops Michielsen *et al.* (2014, 2017) measured LAI of 1.0 to 1.5 in apple and of 0.8 to 1.3 in pear trees with variations per individual apple tree between 1.0 and 2.1.

In Table 20 spray interception in an apple tree canopy is given for different growth stages during the year (adapted from Linders *et al.*, 2000; Olesen and Jensen, 2013) and extended for the growth stages 90 to 97. At the end of the growing season, the leaf canopy changes again from full leaf canopy (BBCH 90) back to without leaves (BBCH 97). Spray deposition underneath the crop tree rows is not just the subtraction of the fully applied dose and the spray interception in tree canopy but is different on the grass strips in between the tree crop rows (paths) and underneath the trees row strips.

Table 20 *Spray interception (%) of the bush or tree canopy for different upward – sideways sprayed crops depending on growth phase (adapted from: Olesen and Jensen, 2013).*

Crop	Growth Stage						
	BBCH 0–9	BBCH 10–69	BBCH 70–75	BBCH 76–89	BBCH 90–95	BBCH 96	BBCH 97
	without leaves	flowering	early fruit development	full canopy	Full canopy till 50% leaf fallen	60% leaf fallen	All leaf fallen
Apples (pome)	50	60	65	65	65	60	50
Small fruit	40	60	60	75	75	60	40
Vines	40	11-13: 50; 14-69: 60	75	75	75	50	40
Avenue trees; spindle, transplanted	40	50	60	75	75	50	40
Avenue trees; high trees	50	60	65	65	65	60	50
hop	0	10-19: 20; 20-39: 50 39-69: 60	70	70	70	40	0

Different patterns do occur in paths between trees and the tree row strips underneath the tree rows. Spray deposition also differs for standard application techniques and different types of drift reducing techniques, especially those using a coarse spray quality. E.g. Michielsen et al (2014) found underneath the treated tree row 3-4 times higher spray deposits than on the grass strips in between the tree rows. Further research and data analysis is needed to be able to distinguish in spray techniques, especially higher classes of DRT and spray deposition in between and underneath tree rows.
Following Olesen and Jensen (2013) for small fruit crops the interception data of Bushberries are taken adapted for the further distinction in growth stages at the end of the growing season. Similarly, the interception data of vines are taken over as of hop. For Avenue trees spindle and transplanted, it is assumed that the mixture of the interception data of small fruit crops and vines is the best estimate whereas for high avenue trees the interception data of pome fruit is taken over.

Windbreaks around orchard
Windbreaks (mainly alder trees, Alnus glutinosa and A. cordata in the Netherlands) are commonly grown to protect orchards against wind damage and to improve micro-climate inside the orchard. Barrier vegetation like windbreaks and hedgerows can however also reduce spray drift, and offer therefore additional protection against spray drift contamination of the surrounding area. The spray drift reducing effect of a windbreak (alder) was measured with a standard cross-flow fan spray technique (Porskamp *et al.*, 1994c; Wenneker *et al.*, 2005b; Wenneker & Zande, 2008b). However, the filtering capacity of a windbreak depends strongly on the plant species used. Also the leaf development of the windbreak relative to the leaf development of the fruit trees is important for the filtering capacity at moment of application (Annex 3). No spray drift measurements in the presence of windbreaks are known using drift reduction technologies, especially not in the higher drift reduction classes. At the moment it is unknown whether the filtering capacity of the windbreak is affected by the DRT technique used. Therefore, further research is needed before a windbreak can be accepted as a drift reduction measure with other spray techniques than the standard technique.

Spray free crop area in avenue nursery trees
When growing avenue nursery trees it is allowed to grow a non-sprayed crop at the 5 m wide mandatory crop free zone. A list of specific tree species allowed to grow in this zone is available (CIW/CUWVO, 1998). This spray free crop can reduce spray drift similar to a windbreak around fruit orchards. For a standard spray technique and a drift reducing technique the effect of a 5 m wide spray free zone on spray drift reduction has been measured in field experiments. These experiments resulted in a 85% drift reduction for the standard sprayer and 94% for the mast sprayer equipped with venturi flat fan nozzles (DRT50) for the combination of a 5 m crop free zone and a 5 m wide

spray free crop at the downwind edge of the avenue nursery tree crop (Stallinga *et al.*, 2011d). These additional spray drift reduction data of the 5 m spray free zone can be used in combination with the DRT classes of the high avenue nursery trees and can result in two classes higher spray drift reduction entries. So the DRT50 in combination with a 5 m spray free crop zone and a 5 m crop free zone results in a 90% drift reduction at surface water distance (6.5-7.5 m from the last tree row). However, following the implementation of a minimal requirement of DRT75 on the total field (EAD), for application techniques DRT75 and higher it is uncertain if and how much drift reduction can increase when spray free buffer zones are used. More research is needed for higher class DRT techniques combined with spray free buffer zones in avenue nursery tree spraying.

Small fruit crops
Small fruit crops (currants, raspberries, blue berries, grapes) are grown at about 1700 ha (CBS, 2017) in the Netherlands. Crop protection in small fruit crops is done with other application techniques than in large fruit crops (apple, pear). The sprayers are adapted (air assistance, nozzle positions) to the bush sizes and the row and plant distances of the crop. No spray drift measurements are done to quantify the spray drift of standard and DRT application techniques as used in small fruit crops in the Netherlands (Zande *et al.*, 2011). Therefore, small fruit crops are in the authorisation procedure nowadays dealt with as large fruit crops and the spray drift curve of the full leaf stage is used (Ctgb, 2019), which probably overestimates the drift.

Hop crop
Hop is grown only on a small area in the Netherlands (about 30 Ha). Currently, hop is implemented in the Dutch authorisation procedure (ctgb, Evaluation Manual 2018) following the spray drift data of the fruit crop in the dormant leaf stage. The German early hop drift curve is very similar to the high avenue nursery tree spray drift curve in the Netherlands (Annex 4). The German late hop drift curve is very similar to the Dutch fruit full leaf drift curve. The drift curve of the NL fruit dormant situation is at all distances higher than both German hop drift curves.
As there is a clear distinction between early growth stage spraying and late growth stage spraying in hop as with fruit crop spraying it is suggested to follow the procedure of the fruit crop scenario also for hop. The change in growth stage from early to late and therefore from a high spray drift level to a lower spray drift level can be simulated with the SPEXUS model (Holterman *et al.*, 2017). Based on the application date of the PPP spray drift varies in this period from high to low based on leaf development of the fruit trees (April-September) as implemented in the model. Resultant effects are very similar for spraying hops.

5 Conclusions

For the evaluation of spray drift deposition, the reference spray technique for fruit crop spraying is a cross-flow fan sprayer (Munckhof); equipped with Albuz ATR lilac nozzles, which at 7 bar spray pressure produces a Very Fine spray quality, and a spray volume of 200 L/ha at 6.5 km/h forward speed. Air assistance is supplied with a low gear fan setting in the dormant tree situation (before May 1st), and a high gear fan setting in the full leaf situation (from May 1st onwards).

Defined reference spray techniques in avenue tree nursery cultivation are:
Spindle and transplanted trees: axial fan sprayer equipped with hollow cone nozzles (Albuz ATR yellow, 12 bar spray pressure) having a Very Fine spray quality, applying a spray volume of 400 l/ha - 550 l/ha (8-12 nozzles open) for spindle trees and 300 l/ha - 400 l/ha (4-6 nozzles open) for transplanted trees. Forward speed in field experiments was 2.5-4.5 km/h.
High avenue trees (>5 m): axial fan sprayer equipped with hollow cone nozzles (TeeJet TXB8003, 8 bar spray pressure) having a Very Fine spray quality, applying a spray volume of 410 l/ha - 460 l/ha (6 nozzles open). Forward speed in field experiments was 4-4.3 km/h.

Based on the latest developments, PPP spray applications in fruit crops using a standard cross-flow fan sprayer with a crop free zone of 3 m resulted in the deposition of spray drift on a standard ditch of 12% in the full leaf situation and 22% in the dormant leaf situation.
Generally stated, the spray drift deposition data presented in this report for fruit crops are higher than currently used in the authorisation procedure, because data are based on a wider range of tree sizes, tree age distribution, crop growth stages and weather conditions during the spray drift experiments.

With avenue nursery trees, the reference spray technique for the spindle, transplanted and high avenue trees resulted in spray drift deposition on a standard ditch of 0.8%, 2.8% and 5.9%, respectively, when used in combination with a 5 m wide crop free zone.

A drift reduction technology (DRT) classification method was developed to facilitate the implementation of presently available and new spraying techniques into a system of generic drift reduction classes. DRT classes distinguished are DRT50, DRT75, DRT90, DRT95, DRT97.5 and DRT99. For spray techniques in fruit crops the spray drift reduction is evaluated against spray drift deposition of the reference spray technique at 4.5-5.5 m distance from the last tree row in the full leaf situation, taking into account a crop free zone of 3 m. For spray techniques used in avenue nursery trees the reduction is evaluated against the deposition of the reference spray techniques for spindle, transplanted and high avenue trees at a distance of 6.5-7.5 m from the last tree row, taking into account a crop free zone of 5 m. For each DRT class, a representative drift curve is established to compute spray drift deposits as a function of downwind distance. Spray drift deposition of the standard and representative DRT techniques is calculated and presented for different distances.

A matrix approach, consisting of combinations of spray techniques (standard sprayer, DRT classes) and crop free zones, was developed to describe the effects of drift reducing measures and techniques and width of buffer zones on spray drift deposition onto surface water. This matrix approach includes knowledge of spray drift deposition for different application techniques and crop free zones.

The spray drift data presented in this report are used for the development of a spray drift model (SPEXUS) for the reference and representative DRT class spray techniques used at different growth stages (BBCH) during the growing season of fruit crops. Presented data can be used to update spray drift exposure data for fruit and avenue tree crops in the authorisation procedure of PPP.

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Annex 1 Overview of the separate drift researches on drift reducing technologies and mitigation measures for orchard spraying

Single sided spraying

Normally, in orchard spraying with axial and cross-flow fan sprayers, tree(-rows) are sprayed two-sided. Driving along all alleys, each tree is sprayed from two sides, including the last or outer tree row. Spraying from the second last alley in the direction out of the orchard causes most drift, especially down-wind. Spraying of the last tree row only from the outer alley into the orchard, and not from the second last alley in the direction out of the orchard results in one-sided spraying of the outer tree row. Drift reduction of 40% – 45% was measured for the early growth stage and the fully developed foliage stage, respectively.

Although it is a simple and cheap method for growers to apply, this technique should not adversely affect biological efficacy of the spray application.(Wenneker *et al.*, 2004).

Sensor equipped sprayers

In orchard spraying part of the spraying liquid is not applied on the target tree, due to gaps in the leaf canopy between the trees. Spraying of these gaps contributes significantly to the drift deposition outside the orchard. With (infrared) sensors these gaps in the tree fruit wall can be detected. Nozzles, connected to the sensors, are closed when no target is detected and opened when leaf canopy is in front of the nozzle. Spray drift reductions of 20% and 50% were achieved for nearly bare (dormant) trees and fully developed canopy, respectively. Biological efficacy against apple scab is comparable to conventional application methods. Depending on the proportion of gaps in the fruit wall, spray volume savings (and financial savings for the farmer) can be quite high. In experiments savings were on average 26% for a young orchard and 28% for an old orchard (Wenneker *et al.*, 2003).

Tunnel sprayer

Tunnel sprayers are at this moment classified as 85% drift reducing machines, when equipped with standard Albuz lilac hollow cone nozzles. These results were obtained in experiments in 1992-1993 (Porskamp *et al.*, 1994a, 1994b, Huijsmans *et al.*, 1993).

Stallinga *et al.* (2019) presented results of spray drift measurements of the Lochmann two-row tunnel orchard sprayer in The Netherlands. The Lochmann two-row tunnel orchard sprayer was equipped with 90% drift reducing nozzles (Albuz TVI 8001; 7 bar spray pressure). Spray drift experiments were performed at the full leaf stage (BBCH 90/92). For the Lochmann two-row tunnel orchard sprayer equipped with 90% drift reducing nozzles spray drift reduction at 4.5-5.5 m distance from the last tree row was 99.4% in comparison with the reference spray application. Airborne spray drift was reduced by 97.8% for the Lochmann two-row tunnel orchard sprayer equipped with 90% drift reducing nozzles.

Sprayer with reflection shields

Sprayers with reflection shields are at this moment classified as 55% drift reducing machines, when equipped with standard Albuz lilac hollow cone nozzles. These results were obtained in experiments in 1992-1993 (Porskamp *et al.*, 1994a, 1994b). In 2005, experiments were performed with a modified sprayer (Wanner sprayer with reflection shields). In these trials also the effect of venturi nozzles (Lechler ID 90-015C; 300 l ha-1) in combination with reflection shields on drift deposition was evaluated.

For the Wanner sprayer with reflection shields and Albuz lilac nozzles (Wenneker *et al.*, 2006, 2008a) the spray drift was reduced in the area 3.0 – 7.0 m downwind of the last tree row with 69% and 58%, respectively for the early growth stage (developing foliage; before 1st of May) and the fully developed foliage stage (after 1st of May). At 4.5 – 5.5 m downwind of the last tree row the spray drift

deposition was reduced with 71% and 62%, respectively for the early growth stage (developing foliage; before 1st of May) and the fully developed foliage stage (after 1st of May).
Very high drift reduction levels were obtained with the Wanner sprayer with reflection shields and Lechler ID 90-015C (venturi) flat fan nozzles. In this situation spray drift was reduced in the area 3.0–7.0 m downwind of the last tree row with 95% and 94%, respectively for the early growth stage (developing foliage; before 1st of May) and the fully developed foliage stage (after 1st of May). At 4.5–5.5 m downwind of the last tree row the spray drift deposition was reduced with 95%, both for the early growth stage (developing foliage; before 1st of May) and the fully developed foliage stage (after 1st of May).
Additional advantage for growers is the possibility to spray two complete tree rows from one driving alley. In this way time (and money) is saved. Also, spray volume savings (and financial savings) are possible as the shields are equipped with recollection systems.

Coarse droplet application
In the Netherlands growers are using low spray volumes (200 – 250 l ha-1), mainly due to economic considerations, and use fine spray quality nozzles (e.g. Albuz ATR lilac and Teejet TXB800067 olive green). However, these nozzle types generate in general finer droplet spectra. It is assumed that droplets smaller than 100 μm are very prone to drift. The drift reducing effect of coarse spray quality nozzles in orchard spraying is generally accepted. From the experiments it was clear that the air induction nozzle reduces soil deposition in a considerable way. However, in all situations the level of drift reduction of coarse droplets was strongly related to the measuring points outside the orchard. The ballistic behaviour of bigger droplets resulted in an off crop soil deposit peak close to the orchard, which is however, in many cases within the field margins of the orchard. The drift reducing effect is therefore small or absent near the orchard boundaries, as found by Heijne *et al.* (2002).
In 2002 – 2003 series of experiments were performed with coarse spray quality nozzles, i.e. the air induction (flat fan) nozzle Lechler 90-01C (5 bar), compared to the (hollow cone) Albuz lilac nozzle (7 bar). Applications were made with a spray volume of approximately 200 l ha-1. Effect of air assistance (fan speed, air velocity) and one-sided spraying of the outer tree row on spray drift was determined.
Spraying with coarse droplets resulted in high soil deposit outside the orchard at short distance from the last tree row. The bigger droplets produced by the air induction nozzles behave in a ballistic way, once the air support drops below a critical value. One-sided spraying with coarse droplets resulted in very low drift deposits. In the early growth stages (dormant trees, or developing canopy) the drift reducing effect of coarse droplet application was absent, due to the high soil deposit at short distance from the last tree row. However, one-sided spraying and switching off air assistance resulted in more than 80% drift reduction in the dormant situation.
With fully developed canopies a drift reducing effect of coarse droplets was found of 55%, due to the filtering capacity of the trees. Again, this effect was enhanced by lowering the level of air assistance (78% drift reduction) and by one-sided spraying of the last tree row (88% drift reduction). Combining both methods resulted in a drift reduction of 96% at 4.5 – 5.5 m from the last tree row. From the experiments it is concluded that the combination of drift reducing methods consisting of coarse droplets, one-sided spraying of the last tree row and adjustment of air assistance is an effective method to reduce spray drift in the Netherlands.

Nozzle classification for drift reduction with orchard spraying
Based on these coarse droplet experiments new research (Michielsen *et al.*, 2009; Stallinga *et al.*, 2011) was started to develop a nozzle classification system based on driftability and a spray drift model (Zande *et al.*, 2007, 2008; Holterman *et al.*, 1997), comparable to the system that is available for arable farming (Porskamp *et al.*, 1999b; Zande *et al.*, 2000). This nozzle classification system for orchard sprayers was launched in 2012 and is now used for certifying drift-reducing nozzles for orchard spraying (Zande *et al.*, 2007, 2012). Drift reducing nozzle classes identified are 50%, 75%, 90% and 95% relative to the spray drift of the reference nozzle Albuz ATR lilac (7 bar). Threshold nozzles for these drift reduction classes are resp. TeeJet DG8002 (7 bar), Albuz AVI80015 (7 bar), Lechler ID9001 (5 bar) and Albuz TVI 80015 (7 bar).

Advanced orchard spray techniques
In a series of experiments the reduction in spray drift deposition on the soil surface outside an apple orchard was measured (Wenneker *et al.*, 2012). Measurements were done for a reference situation in the Netherlands, i.e. a cross-flow fan sprayer, equipped with Albuz lilac hollow cone nozzles, and a spraying volume of approximately 200 l/ha, and a prototype air-assisted sprayer (ISAFRUIT CASA sprayer) that is able to adjust air assistance, change nozzle type and adapt spray volume to measured tree canopy size and density. The effect of air assistance and nozzle type was determined. From the experiments it is concluded that the combination of drift reducing methods consisting of coarse droplets and adjustment of air assistance is an effective method to reduce spray drift in the Netherlands. During the measurements the temperature was between 16°C and 24°C, Relative Humidity was between 35% and 65%, wind speed between 1.0 m s^{-1} and 2.5 m s^{-1} and wind angle between 6º and 40º perpendicular to the tree row direction. In total three repetitions were measured of all objects. The spray drift of the Casa sprayer equipped with the Albuz ATR Lilac nozzles is lower than of the standard Munckhof sprayer equipped with Albuz ATR Lilac nozzles. The effect of the EDAS system in combination with the Albuz ATR Lilac nozzles results in a slightly lower spray drift curve than of the CASA sprayer with fixed air settings and Albuz ATR lilac nozzles. When the CASA sprayer is equipped with Albuz TVI 800075 nozzles in combination with the EDAS system the spray drift is lower than of the standard Munckhof sprayer equipped with 95% drift reducing Albuz TVI80025 nozzles. At surface water distance in the Netherlands (4.5–5.5 m from the last tree row) the drift reduction of the CASA sprayer equipped with Albuz TVI 800075 nozzles and EDAS system in use is 95% compared to the reference, the Munckhof sprayer equipped with Albuz ATR lilac nozzles.
Results of spray drift experiments of the KWH Mistral crossflow fan sprayer, which measures the wind direction with a sensor and adjusts the air support to the left and right hand side of the sprayer accordingly are reported in Stallinga *et al.*, 2016. The principle of this system is that when spraying against the wind more air assistance is given and in the downwind direction of the wind less air assistance, the Variable Air Balance System (VLBS). The KWH Mistral with VLBS, equipped with 90% drift reducing nozzles and utilizing a lower level of air assistance (with 400 rpm instead of 540 rpm PTO) obtains a drift reduction of 91.2% or even 96.5% at 4½-5½m distance from the last tree row compared to the reference spray system for fruit crop spraying in the Netherlands although the outer row of the orchard is sprayed from both sides.
Measurement of airborne spray drift averaged over 0-10 m height at 7.5 m distance from the last tree row resulted in a spray drift reduction of 91,1% when spraying with the KWH Mistral and VLBS system combined with 90% drift reducing nozzles and 540 rpm PTO. Spraying with 400 rpm PTO resulted in a 97.3% reduction of airborne spray drift.
Results of spray drift experiments of the H.S.S. CF crossflow fan sprayer are reported in Stallinga *et al.*, 2017b. The H.S.S. CF is equipped with a H.S.S. Drift Control system and a H.S.S. Automatic Wind Control (AWC) system to adjust and control air fan speed and the air spout direction based on measured wind direction. When spraying against the wind the air spouts are set rectangle to the driving direction and downwind in an backwards angle giving less air support through tree leaf canopy. The H.S.S. CF equipped with Drift Control and AWC, equipped with 90% drift reducing nozzles and utilizing a lower level of air assistance (1800 rpm fan) obtains a spray drift reduction of 90.6% at 4½-5½m distance from the last tree row compared to the reference spray system for fruit crop spraying in the Netherlands although the outside row of the orchard is sprayed from both sides. When the outside tree row is sprayed only from the outside this H.S.S. CF combination and adapted air spout direction (H.S.S. AWC) obtains a 95.0% spray drift reduction at 4½-5½m distance from the last tree row.
Measurement of airborne spray drift averaged over 0-10 m height at 7.5 m distance from the last tree row resulted in a spray drift reduction of 94.4% when spraying with the H.S.S. CF equipped with Drift Control, 90% drift reducing nozzles and utilizing a lower level of air assistance (1800 rpm fan) and two-sided spraying of the outside tree row. Using these settings of the H.S.S. CF in combination with automatic air spout direction of H.S.S. AWC and one sided spraying of the outside tree row resulted in 92.1% reduction of airborne spray drift.
Michielsen *et al.* (1999) presented results of spray drift measurements of the Lochmann cross-flow fan orchard sprayer equipped with an Air Closing System (ACS) in The Netherlands. The Lochmann cross-flow fan orchard sprayer with ACS was equipped with 90% drift reducing nozzles (Albuz TVI 8001; 7 bar spray pressure). Spray drift experiments were performed at the full leaf stage (BBCH 90/92). For the Lochmann cross-flow fan orchard sprayer equipped with Air Closing System and 90% drift

reducing nozzles spray drift reduction at 4.5-5.5 m distance from the last tree row was 98.4% in comparison with the reference spray application. Airborne spray drift was reduced by 97.0% for the Lochmann cross-flow fan orchard sprayer equipped with Air Closing System and 90% drift reducing nozzles.

Multiple row sprayers
The use of multiple row orchard sprayers is increasing in the Netherlands. These type of sprayers reduce labour costs and improve pest and disease control. The latter because less time is needed to spray an orchard compared to standard axial fan and cross flow fan sprayers. Timeliness is higher and anticipation to weather conditions and disease development improves when using multiple row sprayers. It is assumed that multiple row sprayers could reduce spray drift significantly (Stallinga *et al.*, 2013; Wenneker *et al.*, 2014). This is due to the spraying system that sprays tree rows from both sides at the same time, in contrast to standard orchard sprayers that spray the tree row only from one side. In a series of experiments a comparison was made between the standard cross flow orchard sprayer (Munckhof) and a three row sprayer (KWH). Several nozzle types and settings for air assistance were included in the experimental set up. The spray drift measurements were conducted in the dormant leaf stage and in the full leaf stage of the apple trees. From the experiments, it could be concluded that in the dormant stage spray drift reduction of the KWH three row orchard sprayer equipped with Albuz ATR Lilac nozzles was 50% when compared to the Munckhof cross-flow fan sprayer equipped with the same nozzle and spray pressure and a 3 m crop free zone. Spray drift reduction increased to 81% in the full leaf stage.
The KWH three row orchard sprayer equipped with the Albuz TVI 80015 venturi nozzle resulted in spray drift reductions of 91% in the dormant and 98.6% in the full leaf stage.
Using the three row KWH variable air assistance system (VLOS) in combination with the TVI80015 nozzles resulted in a spray drift reduction of 96% in the dormant and 95% in the full leaf stage. Similar effects were found for airborne spray drift. It is therefore advised to setup additional spray drift reduction classes of 97.5% and 99% in the spray drift reduction classification system.

Results of spray drift experiments of the Munckhof MAS 3-row orchard sprayer in comparison with a reference spray technique for fruit crop spraying in The Netherlands are presented in Stallinga *et al.*, 2017a. The Munckhof MAS 3-row orchard sprayer was equipped with two nozzle types; a standard hollow cone nozzle (Albuz ATR lilac; 7 bar spray pressure) and a 90% drift reducing nozzle (Lechler ID9001; 5 bar spray pressure). During the spray drift experiments the downwind outside 24 m of an apple orchard was sprayed at the full leaf stage (BBCH 91/92) using the fluorescent tracer Brilliant Sulpho Flavine. Spray drift deposition was collected downwind on a mowed grass area up till 25 m distance from the last tree row. Airborne spray drift was measured at 7.5 m distance from the last tree row on a pole at which two lines with collectors were attached at 1 m spacing up to 10 m height. The Munckhof MAS 3-row orchard sprayer equipped with standard Albuz ATR lilac hollow cone nozzles and closure of the outside air assistance outlet of the outside spray element spray drift reduction at 4.5-5.5 m distance from the last tree row was 80.0% in comparison with the reference spray application. For the Munckhof MAS 3-row orchard sprayer equipped with 90% drift reducing Lechler ID9001 nozzles and closure of the outside air assistance outlet of the outside spray element spray drift reduction was 96.7%.
Airborne spray drift was for the Munckhof MAS 3-row orchard sprayer equipped with standard Albuz ATR lilac hollow cone nozzles and closure of the outside air assistance outlet of the outside spray element reduced by 33.8% and 95.5% when equipped with 90% drift reducing Lechler ID9001 nozzles.
Stallinga *et al.* (2018) presented spray drift experiments of the Munckhof MAS 3-row orchard sprayer in The Netherlands. The Munckhof MAS 3-row orchard sprayer was equipped with a 90% drift reducing nozzle (Albuz TVI8001; 7 bar spray pressure), low level of air assistance (400 rpm PTO) and the VARIMAS variable air system and an Edge-Row setting. The spray drift experiments showed that spraying an apple orchard at the full leaf stage (BBCH 91/92) with a Munckhof MAS 3-row orchard sprayer equipped with 90% drift reducing Albuz TVI8001 nozzles (7 bar), low level of air assistance (400 rpm PTO) and VARIMAS-system (last tree row sprayed from both sides) spray drift reduction at 4.5-5.5 m distance from the last tree row was 98.9% in comparison with the reference spray application. Using the VARIMAS-system with EdgeRow-setting the spray drift reduction was 99.5%. Airborne spray drift reduction at 7.5 m distance from the last tree row averaged over 10 m height was

for the Munckhof MAS 3-row orchard sprayer equipped with 90% drift reducing Albuz TVI8001 nozzles (7 bar), low level of air assistance (400 rpm PTO) and VARIMAS-system 98.8% and for the VARIMAS-system with EdgeRow-setting 98.6%.

Windbreaks

In the Netherlands windbreaks (mainly alder trees, Alnus glutinosa and A. cordata) are commonly grown to protect orchards against wind damage and to improve micro-climate. Barrier vegetation like windbreaks and hedgerows can however also reduce spray drift and offer therefore additional protection against drift contamination of the surrounding area. Natural windbreaks of broad-leaved trees can also reduce the risk of surface water contamination caused by spray drift during orchard spraying. Point of concern is the growth stage of the barrier vegetation at moment of spraying. Data show that the risks of drift contamination are very high during the early stages of the growing season for dormant trees.

In the experiments drift to the soil and air next to the orchard were measured (Porskamp *et al.*, 1994a). Spraying was carried out with a conventional cross flow fan sprayer. The recovery was measured by means of adding a fluorescent dye to the spray liquid. The recovery is presented as a percentage of the spray dose (nozzle output per ha) on a certain orchard area. The alder tree wind-break around the orchard resulted in significantly lower drift to the soil and air at the places behind the wind-break. The reduction in emission to the soil and air can be calculated and compared with a situation without a wind-break. On the soil next to the orchard the wind-break gave an emission reduction in the range of 68 (in the growth stage before May 1st) to more than 90% (full leaf stage) at a distance of 0-3 m behind the wind-break. The emission to the air next to the orchard was reduced by 84 to more than 90%, in the height range of 0-4 m above the soil surface. Results depended on the leaf density of the wind-break and the wind speed during the experiments.

Research of Wenneker et al (2004a) shows the effect of leaf density of an alder tree windbreak on drift reduction. A bare windbreak resulted in a drift reduction of 20% measured at 3 m distance behind the trees. Spray drift deposition on ground behind a windbreak shows much resemblance with the projected surface area of the stem and branches. When leaves start to develop drift reduction increases to the values (83%) found by Porskamp et al (1994) at full leaf stage. Large differences do however occur between species of windbreak trees. Canopy density varies between leaf trees as Alnus glutinosa (alder), Ligustrum vulgare (liguster), Deutzia scabra and Acer campestre (Wenneker *et al.*, 2004b) but also between needle-like foliage, which captures two to four times more spray than broad-leaves (Ucar *et al.*, 2003). Wenneker *et al.* (2004b) however found no difference in spray drift deposition between the four mentioned tree and bushes at 3.0 m behind the hedgerow, although the total area of branches, stems and leaves throughout the season differed. Especially the startup of leafiness differs but also the leaf development in time. Alder trees remain relatively for a long period with low amounts of leaves in the early growing season. First orchard spray applications are already carried out in this stage. Acer, Lonicera, Syringa, Crataegus, Sambucus and Carpinus species will develop much earlier than alder trees, develop higher canopy densities on an earlier date and give a therefore a better drift reduction in the early season (Wenneker *et al.*, 2005).From the experiments it was concluded that the risk of drift contamination is high during the early developmental stages of the growing season. The 70% drift reduction at early season as determined in initial experiments (Porskamp *et al.*, 1994c), appears to be valid only for windbreaks with a certain degree of developed leaves. At full leaf stage 80% – 90% drift reduction by the windbreak was measured. The use of evergreen windbreaks or windbreak species that develop in early season can reduce the risk of drift contamination considerably. Also, the combination of drift reducing methods, such as one-sided spraying of the last tree row and a windbreak is an effective method to reduce spray drift in the Netherlands in early season.

Riparian vegetation

Some of the smaller ditches in the Netherlands have natural high vegetation. Reed (Phragmites spp.) can dominate this vegetation. The vegetation acts as a filter for airborne droplets but also gives impedance to air flow. The height of the vegetation can be over 2.5 m. Measurements revealed that drift is reduced between 50% - 90% at the position in the middle of the ditch (Gildemacher *et al.*, 2000). The drift reduction was variable during the winter season, when both reed and apple trees are leafless (Heijne *et al.*, 2003). Bare reed canes will reduce wind speed, but have limited droplet filtration or entrapment capacity. However, in contrast to windbreaks, riparian vegetation (reeds) is not accepted as a drift reducing measure. Because PPP residues in riparian vegetation have the potential to be washed off with precipitation or to affect wildlife. As reeds also grow at a distance of 3.0–7.0 m from the last tree row, being the place where ditches (surface water) are commonly situated, all spray drift deposit in this area should be avoided.

Artificial netting

Windbreaks of trees have some disadvantages like reduction of cropping space and maintenance costs. An alternative might be a wind-screen made out of nylon netting around the orchard. In a series of experiments with a cross-flow sprayer and a nylon netting screen (60% closed) a significant drift reduction was observed (Heijne *et al.*, 1999). It was concluded that artificial netting of at least 2.5 m height results in a drift reduction of 60%, both for the dormant and fully developed canopy.

Annex 2 Avenue Nursery trees – phenological development

To get a picture of the phenological development stages of avenue nursery trees during the growing season an inventory was made of different available sources. In these sources a differentiation is often found in the following development stages and their accompanying BBCH codes (BBCH, 1991):

Leaf development	10-19
Flowering	60-69
Fruits ripe/seed fall	81-89
Fully in autumn leaf colour	91-96
End leaf fall	97

Of the avenue nursery trees mentioned by Goudzwaard (2013)a clear distinction can be made between trees blossoming in spring and in summer. Spring blossoming trees have flowers in the months February-May while summer blossoming trees have their flowers in June-July. Seed fall for the spring blossoming trees is in the period May-July whereas for the summer blossoming trees seed fall is often in September-October.

Hiemstra (2012) and Exterkate & de Beer (2010) mention avenue nursery trees spring blossoming trees having flowers in March-May and summer blossoming trees having their flowers in June-July. Of those spring blossoming trees some do even have their flowers in the period February-March, March-April before any leaf development. Some of the summer blossoming trees are noted to be late in their period of having flowers (July-September).

The Nature's Calendar (www.naturetoday.com) gives a very complete picture of the phenological development of trees in general, discriminating in the stages: leaf development, flowering, fruit ripe, fully in autumn colour and end of leaf fall. With the help of volunteers the Dutch phenological network of the Nature's Calendar maps how changes in weather and climate influence the timing of annual phenomena in nature. Of the tree species beech, birch, oak, alder, horse chestnut an inventory is made of the phenological recordings in the Nature's Calendar for the years 2012-2016. Leaf development for the 5 tree species is in the period 3/3-27/5 and end of leaf fall is in the period 15/9-30/12. The mentioned period of flowering of the 5 tree species is in the Nature's Calendar similar to these mentioned by Goudzwaard (2013), Hiemstra (2012) and Exterkate & de Beer (2010). The leafy period of those 5 tree species is therefore very similar to those of the fruit trees.

Sources:

Exterkate, B. & G. de Beer, 2010. Bosplantsoen. Bomen en struiken in bos en landschap. IPC Groene Ruimte, Arnhem. 2010.

Goudzwaard, L., 2013. Loofbomen in Nederland en Vlaanderen. KNNV, Zeist. 2013. 432p.

Hiemstra, J.A. (eds), 2012. De juiste boom op de juiste plaats. Een samenvatting van 15 jaar onderzoek naar de gebruikswaarde van straatbomen. PPO-BBF, Lisse. 2012

Uit: Goudzwaard, L., 2013. Loofbomen in Nederland en Vlaanderen. KNNV, Zeist. 2013. 432p.

Genus/geslacht		Variëteit	Bloeiperiode	Zaadval
latin	nl			
Acer	Esdoorn		Februari-mei	Oktober/mei
	Spaanse aak	campestre	April-mei	oktober
	Kolchische esdoorn	cappadocicum	April-mei	oktober
		acerxfreemanii	maart	mei
	grootbladige	macrophyllum	April-mei	oktober
	noorse	platanoides	Maart-april	oktober
	rode	rubrum	Maart-april	mei
	Witte/zilver	saccharinum	Februari-maart	mei
Aescukus	paardenkastanje		April-juni	oktober
	rode	aesculusxcarnea	mei	oktober
Alnus	Els		Februari-maart	oktober
	zwarte	glutinosa	maart	oktober
Betula	berk		april	Juli-augustus
Carpinus	haagbauk		april	September-oktober
Castanea sativa	Tamme kastanje		juni	oktober
Catalpa	trompetboom		Mei-augustus	Oktober-maart
Crataegus	meidoorn		mei	September-oktober
Fagus	beuk		April-mei	oktober
Fraxinus	es		Maart-april	oktober
Juglans	walnoot		mei	oktober
malus	appel		April-mei	September-oktober
platanus	plataan		mei	oktober
populus	populier		Maart-april	juni
	ratel	Tremula	maart	juni
prunus	Kers-pruim		April-mei	Juni-september
	abrikoos	armeniaca	Maart-april	juni
	boskers	avium	April	Juni-juli
	Europese pruimenboom	domestica	april	Juni-juli
	perzik	persica	april	augustus
pyrus	peer		Maart-april	September-oktober
	Gewone perenboom	communis	april	september
	mantsjoerijse	ussuriensis	maart	september
quercus	eik		April-mei	oktober
salix	wilg		April-mei	juli
	laurierwilg	pentandra	Mei-juni	juli
sorbus	lijsterbes		mei	September-oktober
	wilde	aucuparia	mei	Juli-augustus
tilia	linde			oktober
	Amerikaanse	americana	juni	oktober
	winter	cordata	juni	oktober
	hollandse	europaea	juni	oktober
	zilver	tomentosa	juli	oktober
ulmus	iep		maart	April-mei

Uit: Hiemstra, J.A. (eds), 2012. De juiste boom op de juiste plaats. Een samenvatting van 15 jaar onderzoek naar de gebruikswaarde van straatbomen. PPO-BBF, Lisse. 2012.

Genus/geslacht	Variëteit	Bloeiperiode
Acer	Campestre 'Huibers Elegant'	mei
	Pseudoplantanus 'Bruchem'	april
	rubrum 'October Glory'	Maart/april voor bladontwikkeling
Amelanchier	arborea 'Robin Hill'	april
Celtis	australis	April-mei
Cercidiphyllum	japonicum	April voor bladontwikkeling
Fagus	sylvatica 'Rohan Obelisk'	mei
Fraxinus	ornus 'Paus Johannes-Paulus II' (OBELISK)	Mei-juni
	pennsylvanica 'Bergeson'	april
Gleditsia	triacanthos 'Skyline'	Mei-juni
Liquidambar	styraciflua 'Worplesdon'	April-mei
Magnolia	acuminata	Juni-juli
	'Spectrum'	april
Malus 'Rudolph'	'Rudolph'	mei
Ostrya	carpinifolia	april
Parrotia	persica 'Vanessa'	Februari-maart voor bladontwikkeling
Platanus	orientalis 'Digitata'	mei
Prunus	×schmittii	April-mei
	'Umineko'	april
Quercus	×hispanica 'Wageningen'	Mei-juni
Sophora	japonica 'Regent'	Juli-september
Tilia	cordata 'Rancho'	Juni-juli
	platyphyllos 'Naarden'	juni-juli
Ulmus	'Columella'	Maart-april
Zelkova	serrata 'Flekova' (GREEN VASE)	April-mei

Uit: Exterkate, B. & G. de Beer, 2010. Bosplantsoen. Bomen en struiken in bos en landschap. IPC Groene Ruimte, Arnhem. 2010.

Genus/geslacht		Variëteit	Bloeiperiode	Vruchten
latin	nl			
Acer	veldesdoorn	campestre	April-juni	September-december
	Noorse esdoorn	platanoides	April-mei vb	september
	Gewone esdoorn	pseudoplatanus	April-mei tb	september
Alnus	Zwarte els	glutinosa	Februari-maart vb	?winter
Betula	Gewone berk	pendula	April-mei	oktober
Carpinus	haagbeuk	betulus	April-mei	oktober
Castanea	Tamme kastanje	sativa	Juni-juli	oktober
Corylus	hazelaar	avellana	Januari-maart	September-oktober
crataegus	meidoorn		April-mei	September-oktober
fagus	Gewone beuk	sylvatica	mei	September-oktober
fraxinus	es	excelsior	April-mei	winter
malus	appel	sylvestri	mei	September-november
populus	populier		Maart-april	Mei-juni
prunus	kers		April-mei	juli
pyrus	peer		April-mei	September-oktober
quercus	eik		mei	September-oktober
Ribes	Zwarte bes	nigrum	April-mei	juli
	aalbes	rubrum	April-mei	augustus
	kruisbes	Uva-crispa	April-mei	augustus
rubus	braam	fruticosus	Mei-augustus	Juli-oktober
salix	wilg		April-mei	Juni-juli
sambucus	vlier	nigra	juni	September-oktober
Tilia	linde		juni	Augustus-september
Ulmus	iep		Maart-april	Mei-juni

Vb = voor bladontwikkeling

Tb = tijdens bladontwikkeling

Natuur kalender
fenologische parameters van bomen en fruitbomen
https://www.naturetoday.com/intl/nl/observations/natuurkalender/view-sightings

Genus/geslacht	jaar	Blad ontplooiing	Bloei periode	Vruchten rijp	Volledige herfsttint	Einde bladval
nl						
beuk	2016	21/3-2/5		22/8-10/10	24/10-28/11	14/11-5/12
	2015	6/4-18/5		14/9-28/9	19/10-16/11	2/11-10/11
	2014	19/3-26/5		11/8-6/10	20/10-8/12	10/11-22/12
	2013	15/4-20/5		9/9-4/11	4/11-9/12	18/11-23/12
	2012	19/3-21/5			15/10-19/11	5/11-17/12
berk	2016	21/3-9/5	21/3-25/4		17/10-31/10	31/10-14/11
	2015	6/4-4/5	13/4-11/5		21/9-19/10	5/10-9/11
	2014	17/3-7/4	31/3-21/4		1/9-1/12	15/9-29/12
	2013	15/4-27/5	15/4-13/5		14/10-9/12	14/10-23/12
	2012	19/3-30/4	19/3-23/4	24/9-8/10	15/10-19/11	29/10-24/12
eik	2016	28/3-25/4			4/1	25/1-8/2
	2015	13/4-11/5		31/8-14/9	19/10-2/11	30-11-21/12
	2014	24/3-26/5		8/9-22/9		
	2013	22/4-13/5		23/9-7/10	23/9-7/10	9/12-30/12
	2012	19/37/5			1/10-19/11	
els (zwarte)	2016		5/1-30/3			9/11-23/11
	2015		5/1-30/3			9/11-21/12
	2014		6/1-14/4			17/11-1/12
	2013		7/1-13/5			9/12-23/12
	2012		2/1-26/3			12/11-17/12
paarden kastanje	2016	7/3-16/5	28/3-16/5	8/8-3/10	26/9-14/11	17/10-21/11
(witte)	2015	9/3-1/6	20/4-1/6	7/9-16/11	26/10-16/11	19/10-14/12
	2014	3/3-5/5	31/3-26/5	18/8-6/10	8/9-1/12	20/10-22/12
	2013	25/3-27/5	22/4-3/6	2/9-21/10	30/9-2/12	21/10-30/12
	2012	5/3-30/4	12/3-21/5	6/8-8/10	3/9-19/11	15/10-5/12

Annex 3 Windbreak crops around orchards

An inventory about how many orchards are fully or partially surrounded by windbreaks among experts from the Applied Research Station for Fruit crops (Randwijk), extension services and the Dutch Fruit Growers Association (NFO) indicated that no data are available. Based on expert judgement (Bruchem, 2017) the following estimation was given:

Zeeland, Noord-Holland and Flevoland 40% of the fruit growing area in the Netherlands
- 80% area fully surrounded with windbreak
- 20% area surrounded for 50% at two sides with a windbreak

Utrecht/ Noord-Brabant and Zuid-Holland 20% of the fruit growing area in the Netherlands
- 40% area fully surrounded with windbreak
- 40% area surrounded for 50% at two sides with a windbreak
- 20% area without a windbreak

Gelderland and Limburg 40% of the fruit growing area in the Netherlands
- 20% area fully surrounded with windbreak
- 40% area surrounded for 50% at two sides with a windbreak
- 40% area without a windbreak

In the Nation Environmental Indicator (NMI3; Kruijne *et al.*, 2012) an inventory is made based on expert judgement by the NVWA (Mol & Wingelaar, 2010) indicating that in 1998 48% of the apple crop area sprayed with a cross-flow fan sprayer, axial fan sprayer or tunnel sprayer has a windbreak and 46% of the pear crop area. In 2004 this was 94.7% for apple and 83.9% for pear area whereas in 2008 these estimations were resp. 41% and 39%.

Windbreak and spray drift

A limited number of data are available on the drift reducing effect of a windbreak surrounding an orchard. Spray drift field measurements are done using a standard cross-flow fan sprayer using standard hollow-cone nozzles (Albuz ATR Lilac; Very Fine spray quality) spraying the outside 3-5 tree rows of an orchard with and without an alder windbreak at the field edge. Spraying was done as two sided (Porskamp *et al.*, 1994) and one-sided spraying of the outside fruit tree row (Wenneker *et al.*, 2004, 2005). Spray drift field measurements were done before and after 1st May, defining a dormant and a full leaf stage. The amount of leaves or the canopy density or filter capacity for wind of the alder trees during the spray drift experiments were not recorded. Summarised spray drift reduction of these measurements are presented in Fig. 1. Nowadays the drift reducing effect of a windbreak is used in the authorisation procedure (Ctgb, 2017) as a specific measure in combination with a standard spray application technique and one-sided spraying of the outer tree row, having a 58% drift reduction in the dormant stage and 90% in the full leaf stage. The drift reducing effect of a windbreak in combination with spray drift reducing techniques (DRT) is however unknown.

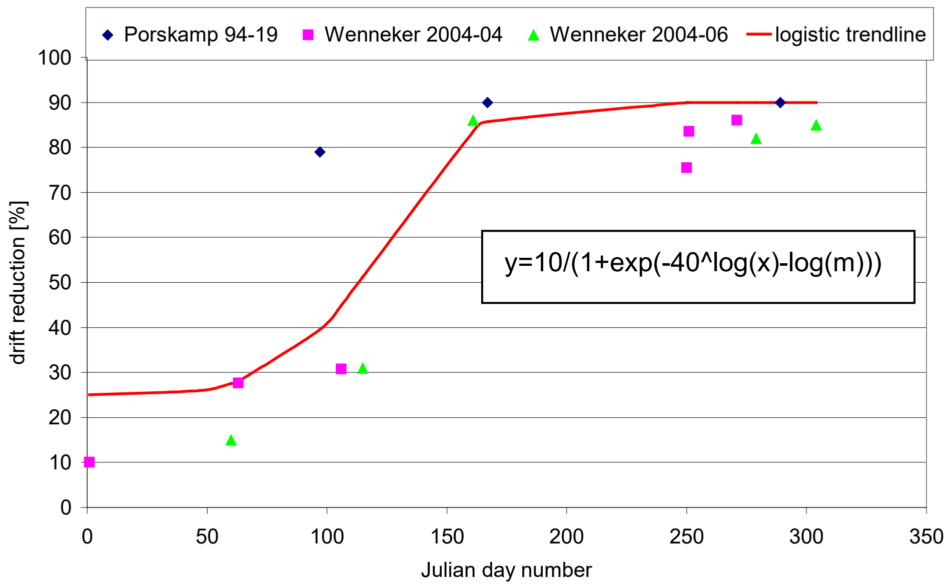

Figure 1 *Spray drift reduction of an alder windbreak at different days during the growing season when spraying an apple orchard using a cross-flow fan sprayer and standard hollow cone nozzles (from: Zande et al., 2004; Porskamp et al., 1994; Wenneker et al., 2004, 2005).*

Referenties

Bruchem, 2017. Personal communication Jaco van Bruchem; Dutch Fruit growers Association (NFO)

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Annex 4   Hop Crop

Growth stages of hop, period of pest and disease in hop during the growing season and use of Plant Protection Products (Locher, 1981; Figure 3 p.11)

Hop crop growth stages.
April –Emergence- shoot growth
May – stem elongation, growth along wire
June – full development (end June) max length along wire (6-8 m); in 70 days (mid-April – end June) the plant growth (10-35 cm per day) to its full size
July- leaf development, start of flowering; leaf area can increase from 5 m^2/plant at mid-July up to 30 m^2/plant mid-August (although being at its maximum length)
August – flowering and cone formation
September (end)– harvest (taking away full plant from the field)
October – crop cut down

Occurring pests and diseases and their period in the growing season in hop.
Peronospora/ downy mildew; start April – harvest in September
Mildew; mid-May – mid-August
Aphids; mid-May – begin-August
Spider mite; mid-May – mid-August
Weed control; begin-May – mid-August, October

For fungicide and insecticide applications in hop the spray drift is higher in the period April-June than July –September because of the dense leafwall of the plants from July onwards. Spray applications generally occur in the period April-September.

Spray application techniques

Fungicides, insecticides
Standard spray application is done with axial fan sprayers using high air amounts to lead the small drops (Fine spray quality) up to the highest area in the plant (5-8 m). air amounts of 30000 m^3/h - 120000 m^3/h are common with air speeds at the air outlet of 35-40 m/s. As forward speed is in the range of 0.5-3 km/h spray volumes are in the range of 300-3000 l/ha.

Weed control
Weed control is done with spray applications similar as in fruit crops and high avenue nursery trees using downward directed spray booms.

Spray drift
Spray drift deposition downwind of the treated area (Locher, 1981) was measured up to 30 m distance (above detection threshold). At the 5 m measuring point (from the last treated row) spray drift deposition was for the treatment in June (7 m high, LAI 3) 2 times higher than in August (7 m high, LAI 6). Measured values were resp. 1.7 ug/cm2 and 0.9 ug/cm2 whereas in both situations 4000 g/ha was applied.

Spray drift deposition (% of applied spray volume) downwind on ground outside treated hop area (m from last treated row) from: Locher, 1981.

	5	10	15	20	25	30
LAI 3	4.3	1.0	0.5	0.25	0.13	0.03
LAI 6	2.3	0.6	0.25	0.13	0.05	0.03

Lüders (1979) found that of the applied spray volume about 20% was found at the hop plants and 80% did not reach the target. Spray drift was measured up to 15 m distance from the treated field.

Spray drift data from Ganzelmeier *et al.*, 1995 show also a differentiation in early (BBCH 45-50) and late (BBCH 75-80) growth stage of hop. The spray drift curves for late and early growth stage cross each other around 5 m distance from the treated field. In the early stage spray drift is higher at close distances from the crop whereas at the late growth stage spray drift is higher at larger distances from the crop.
But as no products are on the market with a differentiation to these early and late crop growth stages only one average curve was suggested to be used in the German authorisation procedure (Ganzelmeier *et al.*, 1995).

Spray drift deposition (% of applied spray volume) downwind on ground outside treated hop area (m from treated field) from: Ganzelmeier et al., 1995.

	1	2	3	4	5	7.5	10	15	20	30	40	50
overall	18.3	14.3	12.0	8.5	6.9	4.1	2.9	1.5	0.8	0.30	0.08	0.07
early	25.6	18.8	13.1	8.8	6.8	3.0	1.9	0.7	0.31	0.11	0.04	0.04
late	11.7	10.3	10.9	8.2	7.1	5.2	3.7	2.2	1.2	0.5	0.11	0.10

References:

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Possible implementation of hop in the NL authorisation procedure

Now hop is implemented in the NL authorisation procedure (ctgb, Evaluation Manual 2016) following the spray drift data of the fruit crop in the dormant leaf stage. The DE early hop drift curve is very similar to the NL high avenue nursery tree spray drift curve (Fig. 1). The DE late hop drift curve is very similar to the NL fruit full leaf drift curve. The drift curve of the NL fruit dormant situation is at all distances higher than of the both hop drift curves.
As there is a clear distinction between early stage spraying and late stage spraying in hop as with fruit crop spraying it is suggested to follow the procedure of the fruit crop scenario also for hop. The change in growth stage from early to late and therefor from high spray drift to lower spray drift levels can be adapted from the SPEXUS fruit drift model based on the application date (April-September) as implemented in the model.

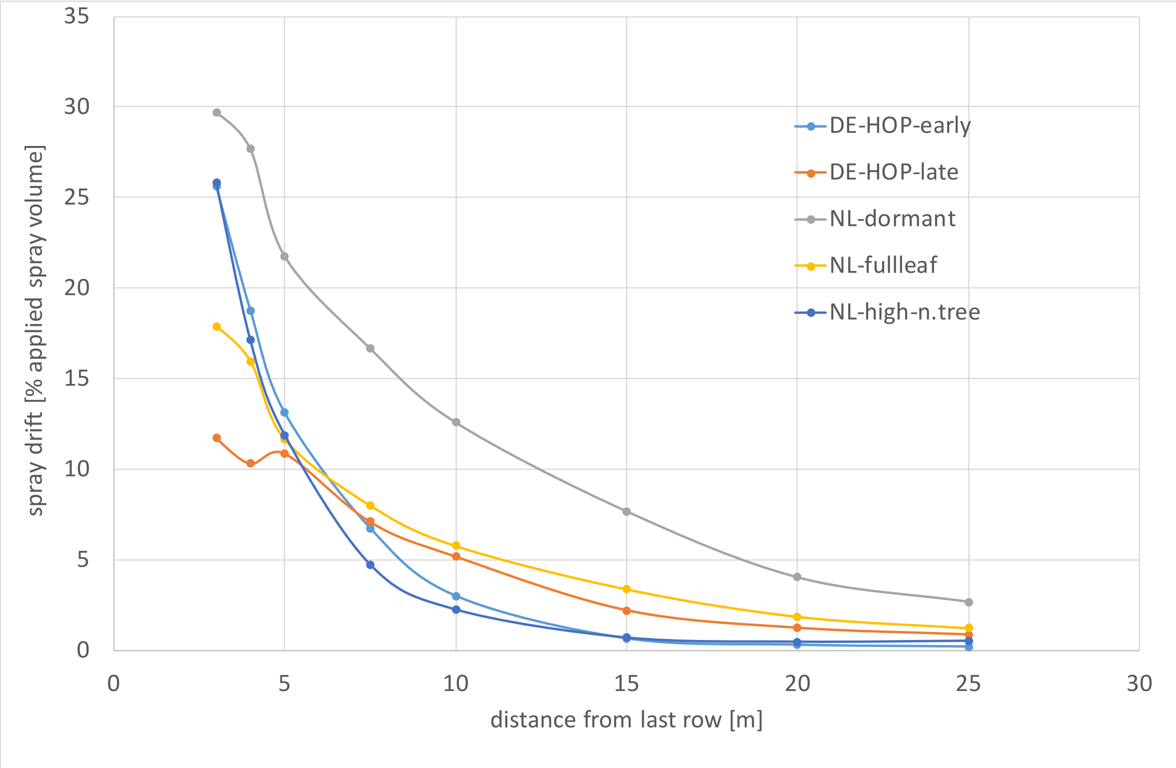

Figure 1 *Comparison of spray drift deposition downwind of treated fields; fruit crops, high avenue nursery trees and hop in early and late growth stages.*

Note:
At this moment for hops no spray drift reducing techniques are measured. When the hop plants are not grown higher than 4 m spray drift reducing techniques as used in in fruit crops and avenue nursery trees can be used. If these techniques will give similar spray drift reduction figures as when used in fruit and avenue nursery tree crops is not known. Examples of application techniques that potentially can be used in hops are e.g. tunnel sprayer, multiple row orchard sprayer, and a mast sprayer equipped with 90% drift reducing nozzle types. The mandatory use of a 75% drift reducing technique following the Environmental Activity Decree from 2018 onward is therefore difficult.

Annex 5 Small fruit crops

Fruit crops are distinguished in Large fruit crops being pome and stone fruit crops and small fruit crops identified as; strawberries, berries and currants, grapes and blackberry and raspberries (Ctgb, 2015). Strawberries and cranberries are sprayed with downward directed spray techniques like boom sprayers. Red and black currants are also in the first two years of development sprayed with boom sprayers. The other fruit crops are sprayed with sideways and upward spray techniques.

For small fruit crops like red currants under practical circumstances on average 13 spray applications were made during the growing season (Wenneker, 2013). The number of spray applications per grower/field varied however between 4 and 20 applications. Products applied per field varied between 3 and 8 varying between 4 fungicides against fruit rot, 2 fungicides against mildew and 2 insecticides against aphids. Some products were applied up to 6 times (captan) or 4 times (teldor). Period of application of the products was between week 14 (late March/early April) and week 26/27 (late June/early July). Tank mixtures of up to 4 products (3 fungicides +1 insecticide) were recorded to be applied in one week. Examples of typical spray schemes are given below (Table 1).

Wenneker & Van der Steegh (2013) looked at the variety in spray schedule strategies to reduce PPP residu in red currants. A comparison was made between a standard application schedule of 17 applications using 5 products. Highest number of the same product applied during the growing season was 5. The spray applications were applied in the period between blossoming (week 14; begin April) up to 2 weeks before harvest (week 29; July) with harvest in week 31 (July/August).

Table 2 *Standard application schedule in red currants (Wenneker & Van der Steeg, 2013).*

Stage	Week	Product
flowering	wk14	captan
flowering	wk15	cyprodinil & fludioxonil
flowering	wk16	iprodion + captan
flowering	wk17	boscalid & pyraclostrobin + fenhexamide
flowering	wk18	cyprodinil & fludioxonil
flowering	wk19	iprodion
	wk20	captan
	wk21	iprodion
	wk22	fenhexamide
	wk23	fenhexamide
	wk24	
	wk25	boscalid & pyraclostrobin
	wk26	fenhexamide
	wk27	iprodion
	wk28	cyprodinil & fludioxonil
	wk29	iprodion
	wk30	
harvest	wk31	

Van Oosten & Balkhoven-Baart (2007) show the difference in growing season of the different varieties of black currants. They saw that on average in 2002-2006 the starting date of flowering was between April 9th and May 2nd. Harvest dates varied between 10th and 19th of July for the 2nd production year, 3rd and 22nd of July for the 3rd production year, 28th June-16th July for the 4th production year and 4th-22nd July for the 5th production year.

Table 1 *Spray schedules of three fields of small fruits - red currants (after Wenneker, 2013).*

Field A	Wk 13	Wk 14	Wk 15	Wk 16	Wk 17	Wk 18	Wk 19	Wk 20	Wk 21	Wk 22	Wk 23	Wk 24	Wk 25	Wk 26	total
captan	0	1	1	0	0	0	0	0	0	0	0	0	0	0	2
cyprodinil & fludioxonil	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1
fenhexamide	0	0	0	1	1	0	1	1	0	0	0	0	0	0	4
iprodion	0	0	0	0	0	1	0	0	0	0	1	0	1	0	3
kresoxim-methyl	0	0	0	0	1	1	1	0	0	0	0	0	0	0	3
triadimenol	0	0	0	0	0	0	0	0	0	1	1	0	0	0	2
thiacloprid	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1
pirimicarb	0	0	0	0	1	0	0	0	0	0	1	0	0	0	2
total fungicides fruit rot	0	1	1	1	1	1	1	1	0	1	1	0	1	0	10
total fungicides mildew	0	0	0	0	1	1	1	0	0	1	1	0	0	0	5
total insecticides	0	1	0	0	1	0	0	0	0	0	1	0	0	0	3
Field B	**Wk 13**	**Wk 14**	**Wk 15**	**Wk 16**	**Wk 17**	**Wk 18**	**Wk 19**	**Wk 20**	**Wk 21**	**Wk 22**	**Wk 23**	**Wk 24**	**Wk 25**	**Wk 26**	**total**
captan	0	1	1	2	1	1	0	0	0	0	0	0	0	0	6
cyprodinil & fludioxonil	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1
fenhexamide	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1
iprodion	0	0	0	0	0	0	1	0	1	1	0	0	0	0	3
kresoxim-methyl	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
triadimenol	0	0	0	0	1	1	0	0	1	0	0	0	0	0	3
thiacloprid	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
pirimicarb	0	0	0	0	0	1	0	0	0	1	0	0	0	0	2
total fungicides fruit rot	0	1	1	2	1	2	1	0	1	1	0	0	1	0	11
total fungicides mildew	0	0	0	0	1	1	0	0	1	0	0	0	0	0	3
total insecticides	0	0	0	0	0	1	0	0	0	1	0	0	0	0	2

Field C	Wk 13	Wk 14	Wk 15	Wk 16	Wk 17	Wk 18	Wk 19	Wk 20	Wk 21	Wk 22	Wk 23	Wk 24	Wk 25	Wk 26	total
captan	0	0	0	1	1	0	0	0	0	0	0	0	0	0	2
cyprodinil & fludioxonil	0	0	0	0	0	1	0	0	0	0	0	0	0	1	2
fenhexamide	0	0	0	0	0	0	1	0	1	0	0	0	1	0	3
iprodion	0	0	0	0	0	0	0	0	0	0	1	1	0	0	2
kresoxim-methyl	0	0	0	0	0	0	1	0	1	0	0	0	0	0	2
triadimenol	0	0	0	1	0	1	0	0	0	0	0	0	0	0	2
thiacloprid	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1
pirimicarb	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
total fungicides fruit rot	0	0	0	1	1	1	1	0	1	0	1	1	1	1	9
total fungicides mildew	0	0	0	1	0	1	1	0	1	0	0	0	0	0	4
total insecticides	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1

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Annex 6 Dose expression and Leaf Wall Area (LWA)

On the product label the allowed dose of Plant Protection Product (PPP) is nowadays often expressed in: kg per ha or L per ha ground area, % of concentration of the product, mL product per 100 L spray volume soluted, kg product per 100 m tree row length (Bjugstad & Stensvand, 2002), kg product per m tree crown height, kg product per 10000 m^3 tree row volume (Weisser & Koch, 2002), maximum dose per application and maximum dose per year (Toews *et al.*, 2016). Specifically in the Netherlands dose expressions on the label are as: % concentration of the product, ml/100 L spray volume and L or kg per ha of the product. These expressions are all surface area based whereas a fruit crop differs very much in size and leaf amount over the years and varies also within the year in tree size and leaf density. As a result fruit growers adapt their spray technology to the crop height, size, leaf density and growth stage. Nozzles are shut or opened depending on height of trees (apple vs pear, pruning system, early – late in growing season) or area of interest to be sprayed (single or multiple row planting systems), therefore changing spray volume. Spray volume is also changed by choice of nozzle sizes depending on the canopy thickness. Spray volume is also adapted based on forward sprayer speed and the sprayer routing in the orchard; spraying through every path or alternating paths. In general applied spray volume for fruit crops (apple, pear) is however around 200 L/ha.

In the authorisation procedure of PPP for fruit crops in the Netherlands (Ctgb, 2016) it is assumed that spray volume is variable and in the range of 200-1500 L/ha. The risk assessment is done with the highest dose, highest frequency of spray applications and smallest spray interval. Highest dose concentration of product mentioned on the label is based therefor on 1500 L/ha spray volume applied. When concentration is mentioned on the label and no additional information on the label is mentioned about maximum dose per application or year in kg/ha the intention is that this concentration is used for all usable spray volumes. However as some PPP labels mention also a maximum dose per application based on the maximum 1500 L/ha in the authorisation procedure, growers adapt their tank concentration, based on this information, to the total PPP amount of 1500 L/ha but soluted in the to be applied 200 L/ha. This means their tank concentration is 7.5 times higher than authorised. From plant protection advisers it is known that for apple orchards often an advised dose to be sprayed (in e.g. 200 L/ha) is given based on a spray volume of 1000 L/ha instead of the maximum 1500 L/ha. This suggests that not all applications are done with maximum dose as evaluated in the risk assessment. For pear however the nowadays maximum allowed dose soluted in 1200 L/ha is always advised to be used irrespective of the application volume by the grower.

For many years it is suggested to leave the surface area based dose expressions on the PPP label for fruit crops. An adaption of the dose expression in fruit crops to the amount of tree leaf canopy and the row spacing at the moment of spray application is advised (Codis *et al.*, 2012; Toews & Friessleben, 2012; Toews *et al.*, 2016; Koch, 1993; Koch & Weisser, 1995; Koch & Weisser, 2000; Koch, 2007; Walklate & Cross, 2012). A parameter developed to do so is the Leaf Wall Area (LWA; EPPO, 2012). Leaf wall area is defined as:

Leaf Wall Area (m^2 per ha ground) = 2 ∗ Treated Canopy Height (m) ∗ (10.000 m^2)/Row Spacing (m))
With:
Treated canopy height is defined as the average distance from the highest leaf to the lowest leaf of a tree.
Row spacing is the distance between the rows of stems of the individual tree rows.

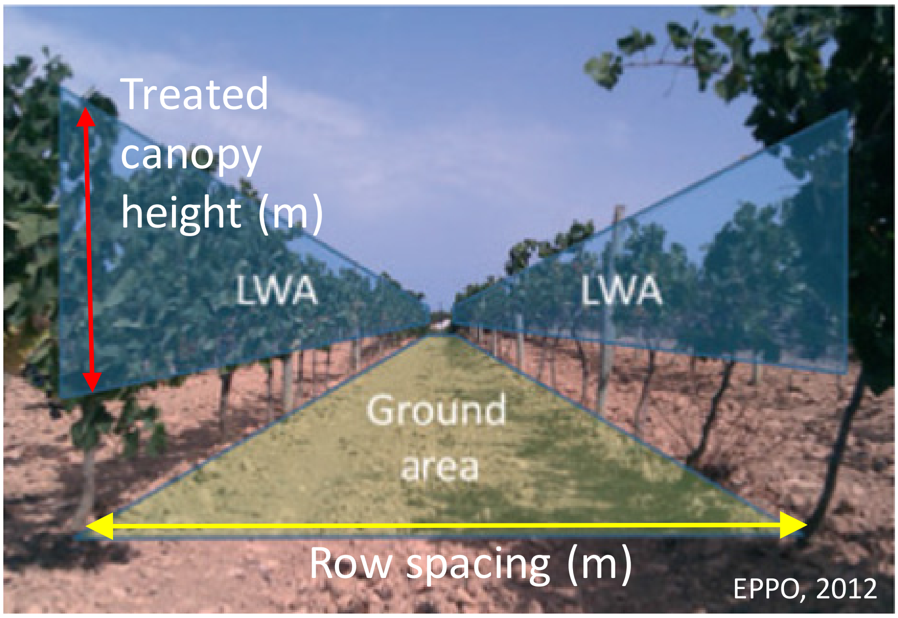

Figure *Presentation of the defined parameters Leaf Wall Area (LWA) and ground area in an fruit crop (EPPO, 2012).*

The dose expression of the PPP following the LWA concept is presented as the L product per 10.000 m^2 LWA. So depending on row spacing (fruit crop row length per ha) and tree height the allowable dose soluted in the sprayer tank can be adapted following label recommendations when LWA is used. EPPO supports this trajectory and agreed LWA as an appropriate dose expression for plant protection products (EPPO, 2016) in pome fruit, grapevine and high growing vegetables. EPPO concluded therefor:

- Kg or L/ha ground dose expression is not to be used in the zonal efficacy evaluation of plant protection products as it is not linked to any crop structure parameters. However, dose/ha of ground area is to be reported in the GAP table;
- Conversion of different dose expressions should always be possible;
- Clear definitions of the terms used when expressing doses in high growing crops are needed; Two different situations should be distinguished: 1) crops that form 'walls' and 2) crops that form 'globular (isolated) trees' (i.e. trees/crops that do not form walls such as citrus, olive, stone fruit trees). For 'globular trees' further data should be collected to enable calculation of canopy width (i.e. the 3rd dimension);
- Any proposal for further harmonization should be discussed and validated by the European Evaluators;
- Further discussion on dose expression of the reference product is needed.

When LWA is used in the risk assessment of the PPP in the authorisation procedure, the highest treated canopy height and the narrowest tree row spacing defines the highest amount of product to be used in the field. This implicitly defines again the maximum dose per unit area. So a maximum allowable dose rate per unit surface area of the field is however still needed based on the risk assessment in the authorisation procedure.
With a row distance of 3 m and a leaf wall height of 3.5 m the maximum LWA in Dutch fruit crops is about 24 000 m^2/ha whereas a median LWA (2 m leaf wall height) is likely to be about 13 000 m^2/ha. So in principle switching to the LWA-based approach could lead to reduction of the total use of plant protection products in Dutch fruit crops by something like a factor 2. This would of course also decrease the total drift deposition onto the ditches by this factor.
On the other hand it opens also the potential use of the distribution of tree sizes in the probabilistic evaluation methodology as the frequency distribution of the LWA for Dutch apples and pears can possibly be determined on the planting time (jonge aanplant) distribution of the apple, pear, and other fruit crops per year from CBS statistics (CBS, 2017).

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Annex 7 Current Dutch legislation procedures to assess spray drift

This Annex gives an overview of the use of spray drift deposition data and drift reducing technology options to mitigate spray drift in the current authorisation procedure of Plant Protection Products. The relation with the implementation of compulsory crop free zones according to the Surface Water Pollution Act (LOTV; V&W *et al.*, 2000, 2007), which are now taken up in the Environmental Activities Decree (Activiteitenbesluit Milieubeheer - EAD, I&M, 2012) in the authorisation procedure is addressed. Furthermore, the certification procedure for spray drift reducing technology, to be used alongside waterways following the EAD, is addressed. Spray drift reduction packages being combinations of Spray drift reducing technologies and width of crop free zones are discussed.

Current evaluation with regard to crop differentiation for estimating spray drift deposition on surface water

In the authorisation procedure for PPPs in the Netherlands, a differentiation is made in the spray drift amount originating from spray applications in field crops (including arable crops, field vegetables, flowers, small fruits (strawberry) and small tree nursery crops), fruit crops (large and soft) and avenue nursery tree crops (Figure 1). Basis for this differentiation is the way PPPs are applied. In arable crops and small nursery tree crops a field sprayer is used with a downward spray direction. In fruit trees, fruit bushes (currants, berries, grapes) and avenue nursery trees upward or sideways directed spray techniques are used. Based on the crop growth situations and the used spray techniques different spray drift deposition curves are used to determine the spray deposition on surface water, which is schematised as a standard ditch.
This resulted in standard spray drift values for the different situations. For arable crops the standard drift value is 1% spray drift deposition on surface water, relative to the applied dose. This is based on the situation described by the Environmental Activities Decree (I&M, 2012) requiring a minimal low drift technique using spray nozzles of the drift reduction class 50, a maximal spray boom height of 0.50 m above crop canopy, the use of an end-nozzle to prevent overspray at the crop edge and a crop free zone of 1.50 m. The spray drift deposition value on surface water is 0.88% for the low drift spray technique, which is used as 1% in the authorisation procedure, irrespective of the crops and cropping situation. From 2018 onwards the minimum requirement is the use of a 75% spray drift reducing technique on the total field for all fields sprayed (I&W, 2017).

For fruit crops, a differentiation is made between the situation before the first of May when trees are dormant or have little leaf development and from the first of May onwards when trees are considered at full leaf stage. Used spray drift deposition values are 16.6% for the situation before May 1st and 8.6% for the situation after May 1st using a standard spray technique without spray drift reduction options. The spray drift deposition is based on measured spray drift data in the full leaf stage and estimated spray drift in the dormant situation based on literature (Huijsmans *et al.*, 1997). Spray drift deposition in the dormant situation was estimated as 2.5 times the spray drift deposition in the full leaf situation (the latter being 6.8% in drift database 1993-1998). The standard crop free zone in the fruit crop situation is 3 m (EAD).

For nursery trees, a differentiation is made between spindle, transplanted and high (>5 m) avenue trees having standard spray drift values of respectively 0.8%, 2.8% (Porskamp *et al.,* 1999a) and 5.8% (Stallinga *et al.,* 2011d) with a standard crop free zone for avenue nursery tree crops of 5 m adjacent to surface water bodies (EAD).

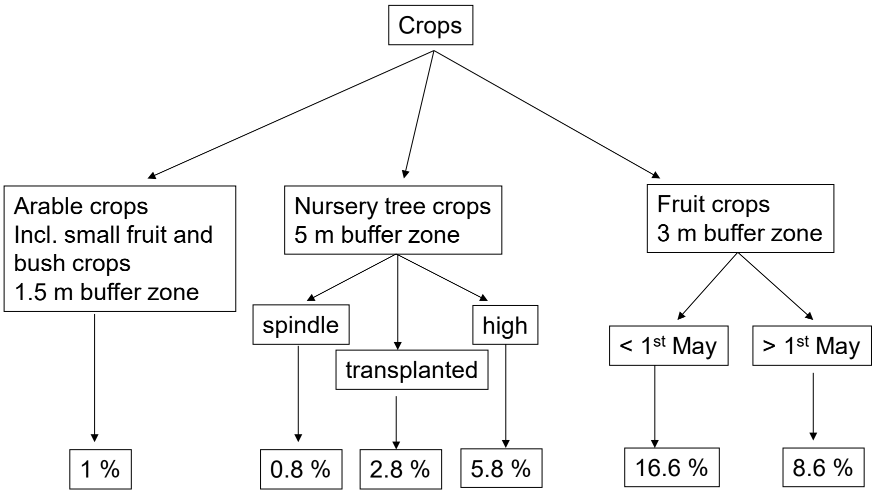

Figure 1 *Differentiation in crop types and growth situations in the authorisation procedure of PPP based on spray drift and the currently used spray drift values for surface water exposure (Ctgb, 2014).*

Spray drift values mentioned for fruit crop (orchard) spraying originate from 1993-2005 (Porskamp *et al.*, 1994a, 1994b, 1994c; Huijsmans & Zande, 2011), for nursery tree spraying from 1999 and 2011 (Porskamp *et al.*, 1999a; Stallinga *et al.*, 2011d) and for arable crop spraying from 1999 (Huijsmans *et al.*, 1999).

Results of spray drift research are incorporated in Dutch legislation. In the Surface Water Pollution Act / Environmental Activities Decree and the Plant Protection Products and Biocides Act (LNV *et al.*, 2007) criteria for spray drift deposit on surface water are used, depending on the spray technique, buffer zone and period of use during the growing season. The spray drift data for fruit crops used in the Authorisation Procedure (Ctgb, 2014) are summarized in Table 1 for fruit crops and Table 2 for avenue tree nursery. Up till now the Ctgb performs risk assessment based on spray drift values for orchard spraying of 16.6% for the early growth stage (dormant or developing foliage; before 1st of May), and 8.6% for the fully developed foliage stage (full leaves; from the 1st of May onwards). A standard 3 m buffer zone is taken into account (= driving alley of the sprayer), defining the water surface at 4.5–5.5 m from the last tree row. This standard assessment determines whether the risk is acceptable using the standard technique or whether restrictions for application of PPPs are required (on the label) by using drift reducing technologies and/or a larger crop free zone.

The reduction effect of the use of spray drift reducing technologies in fruit culture is described further in Section 3.1.2.

The spray drift deposition values for fruit crops for the different spray techniques and measures were obtained by calculating the spray drift deposition on the surface water area (4.5-5.5 m and 6-7 m from the last tree row for 3 m and 4.5 m crop free zone, respectively) for the standard spray technique and reducing the amount with the spray drift reduction according to the measurements on that distance. Similarly the spray drift deposition at surface water was given for standard and drift reducing techniques as used in avenue nursery trees (Table 2). The resulting drift deposition values for use in aquatic exposure assessment by Ctgb at standard crop free zones are in Annex 8 presented for fruit crops and avenue tree nurseries.

Since 2005 new spray drift data have become available which will lead to an adaptation of the spray drift values for the different crop types (See Chapter 3). Moreover new legislation has become into force on the width of crop free zones (LOTV, VW *et al.*, 2000 adapted in 2007; EAD, I&M, 2012 I&W, 2017) and commonly used drift reduction technology for the different crop types, making it necessary to differentiate more for these situations in the authorisation procedure. A further differentiation is described in the next sub-paragraph.

Environmental Activities Decree packages for spray drift reduction alongside waterways

In the Surface Water Pollution Act/ Environmental Activities Decree (LOTV; VW *et al.*, 2000, 2007; EAD; I&M, 2012) combinations of crop free zones and drift reducing measures are mentioned for fruit crop and nursery tree spraying (upward and sideways spraying) and arable crop spraying (downward - boom spraying). In the Environmental Activities Decree (I&M, 2012) measures are described to reduce the emission of PPP to surface water. The measures to be taken in the field are adapted to the different crops; the other measures are of a general nature to be applied at all farms. The EAD specifies that when spraying a crop alongside surface water with boom sprayers, the outer 14 m of the field is to be sprayed using drift reducing nozzle types and end nozzles. However, from 1st January 2018 onward a minimal 75% drift reducing technique is to be used on the whole field irrespective whether these fields are adjacent to surface water (I&W, 2017).

Fruit crops

The drift reducing packages of the EAD (I&M, 2012) for fruit crop spraying are defined by combinations of crop free zone, windbreak crops, direction of spray and spray technique. The packages are:

- A crop free zone of 9 m in combination with a standard application technique;
- A crop free zone of 4.5 m in combination with a cross-flow fan sprayer equipped with a reflection shield;
- A crop free zone of 3 m and a tunnel sprayer;
- A crop free zone of 3 m, any application technique and a windbreak crop at the edge of the field;
- A crop free zone of 3 m in combination with a cross-flow fan sprayer and a shield (artificial net) at the edge of the field;
- A crop free zone of 3 m in combination with a cross-flow fan sprayer equipped with venturi type nozzles (drift reduction class 90%) and one-sided spraying of the last tree row (not in the direction of the surface water);
- A crop free zone of 3 m and organic growing of the fruits.

With the 2018 amendments of the EAD (I&W, 2017) following the implementation of the Sustainable Use Directive (2009/128/EC; EC, 2009) in the Sustainable Crop Protection II plans (EZ, 2013) the Dutch policy implies the mandatory use of 75% drift reducing techniques on all fields sprayed. For fruit crops this 75% drift reducing technique is to be combined with a minimal 4.5 m wide crop free zone along waterways. In combination with a 3 m wide crop free zone alongside waterways, at least a 90% drift reducing technique is required.

Nursery tree crops

In avenue tree nursery (spindle, transplanted, high avenue trees) a general crop free zone of 5 m is mandatory irrespective of the application technique. According to the Nursery Tree Agreement (convenant; CIW/CUWVO, 1998) specific varieties of trees are allowed to be grown on this outside 5 m but these trees are not allowed to be sprayed (spray free buffer zone of 5 m).

Certification of Drift Reduction Technologies

To prevent stagnation of new developments, the LOTV/EAD allows application techniques with equivalent drift reducing capacities to be used. LOTV (VW *et al.*, 2000) created a possibility to advise the Waterboards to accept the use of new drift reducing techniques in combination with reduced width of buffer zones. As it is not efficient to evaluate these new techniques separately by each individual Waterboard the Technical Committee on Technology evaluation (Technische Commissie Techniekbeoordeling - TCT) was installed to evaluate potential drift reduction technology on a national scale. TCT consists of representatives of Unie van Waterschappen (chair), Rijkswaterstaat-Waterdienst, Fedecom, Wageningen University – Agrarische Bedrijfs Technology (WU-ABT), Food

Safety Authority (NVWA), Dutch Farmers Association (LTO) and Board for the Authorisation of Plant Protection Products and Biocides (Ctgb).

A guidance document on the evaluation of Drift Reduction Technology was developed and published by the Commission on Integral Water management (CIW) (CIW, 2003). With this guidance document the water authorities can evaluate in a uniform way whether an alternative application technique or spray drift reducing measure gives at least a similar emission reduction as the prescribed drift reducing measures in the EAD (article 1.8 of the EAD/ article 3 of LOTV).

The TCT evaluates requests for use of drift reducing application techniques. The TCT evaluates whether the presented drift reducing capacity is in accordance with the requirements of the EAD. The drift reduction technology can either be a spray nozzle or a spray system as used in the field. The TCT advises the Waterboards on the documented request. The Waterboards are autonomous in their decision whether or not to accept the TCT advise.

Drift reducing nozzles and spray techniques
The TCT evaluates complete spray technique systems (measure packages in the EAD) equipped with specific nozzle types as well as drift reduction capabilities of new drift reducing nozzle types. To quantify the drift reducing capacity of a spray technique results of field measurements need to be presented comparing the candidate system with a reference system or an already certified drift reducing measure under comparable field conditions (CIW, 2003) as used in field spraying of arable crops, fruit crops or tree nursery.
The reference spray technique for orchard spraying is a cross-flow fan sprayer (Munckhof) equipped with Albuz ATR lilac hollow cone nozzles sprayed at a spray pressure of 7 bar with high air settings in the full leaf stage of the trees and low air setting in the dormant situation of the fruit trees.

For requests for the use of new spray drift reducing spray nozzles to be implemented on orchard sprayers, research results need to be presented of measurements under conditioned circumstances in the laboratory (Zande *et al.*, 2008). Based on drop size measurements in the laboratory a comparison is made with the reference nozzle and typical nozzles identifying the threshold values for spray drift reduction of the classes 50%, 75%, 90%, 95% following ISO22369 (2006) or based on field measurements (Zande *et al.*, 2012b). The volume fraction of droplets smaller than 100 μm in the spray fan is a measure of the driftability and is used for the classification in drift reduction classes. The list of spray drift reducing nozzles allowed to be used in orchard sprayers is available from the TCT website (TCT, 2015).

Adaptation of crop free zones
The grower may, for economic reasons, always choose a minimal width of the crop free zone. The use of higher classes of drift reducing nozzle types will allow the use of a smaller width of the crop free zone, e.g. 3.0 m instead of 4.5 m or even 9 m. On the website www.helpdeskwater.nl the actual list of certified drift reducing techniques and nozzle types is available (TCT-CIW, 2017). The list indicates, apart from the mentioned drift reduction potential in the EAD, also to what reduction of the crop free zone it can lead to e.g. from 6.0 m to 4.5 m or 3.0 m (Annex 9).

With the 2018 amendments of the EAD (I&W, 2017) a new guidance document on the evaluation of Drift Reduction Technology was developed (TCT, 2017a) with protocols classifying specifically spray drift reducing techniques in DRT classes (TCT, 2017b) and drift reducing nozzles (TCT, 2017c) in drift reduction classes. Following these new protocols lists of DRT (TCT, 2019a) and DRN (TCT, 2019b) are published.

Authorisation of PPP and EAD

In the authorisation procedure of PPP further restrictions can be prescribed to the use of PPP when this is necessary to achieve an acceptable risk for aquatic organisms. For a number of PPPs it is mandatory to use spray nozzles or spray techniques from the 75% and/or 90% drift reduction class when spraying the PPP. Based on these requirements the farmer has to equip his sprayer with the appropriate drift-reducing nozzles or use an appropriate Drift Reduction Technique.

Apart from the regulations of the EAD also requirements on the use of the correct drift reducing nozzles and techniques based on the Plant Protection Products and Biocides Decree (LNV *et al.*, 2007) are set. The application of specific PPP requires a crop free zone to be implemented at the edge of the field alongside waterways as described on regulation based on the Plant Protection Act. Following the EAD some of these crop free zones can be reduced when using specific drift reducing nozzle types and techniques; this option is however not included in the authorisation procedure. The Ctgb uses a specific list of drift reducing nozzle types and drift reducing techniques (Table 1) for fruit crop spraying and avenue nursery trees (Table 2), based also on the EAD drift reducing nozzle list (TCT, 2015). Following the amendments of LOTV (VW *et al.*, 2007) the publication of the drift reducing nozzle list is no longer in the State Gazette. The TCT is now responsible for updating the drift reducing nozzle list (www.wateremissies.nl). The TCT and Ctgb agreed to have one list of drift reducing nozzles and technique classes to be used, set up by the TCT (TCT-CIW, 2017).

The TCT has certified spray techniques and classified nozzle types (Table 3), which are also used in the authorisation procedure of PPP. Based on the evaluation of surface water exposure and the toxicity of the product the PPP authorisation prescribes the minimum requirements with regard to the combination of drift reduction technology class and width of crop free zone. These requirements are also mentioned in the authorisation decision and on the user label of the PPP. In the adaptation of LOTV in 2007 (VW *et al.*, 2007) especially new requirements were set for fruit crops based on drift reduction capabilities in the full leaf stage of the orchard. The standard authorisation of PPP up to date (until 2018) used the standard drift values of 8.6% and 16.6% in the full leaf and the dormant crop stage, respectively, of fruit crops for first tier risk assessment, based on the data for the cross flow fan sprayer and a 3 m crop free zone.
With the 2018 amendments of the EAD (I&W, 2017) also the authorisation procedure is adapted to take into account the minimal required Drift Reduction Technique to be used for fruit crops is from the DRT75 class with a minimal crop free zone of 4.5 m and a minimal DRT90 for a 3 m crop free zone (Ctgb, 2019). This leads to spray drift deposition values on surface water used in the authorisation procedure of 5.0% and 1.2% for the DRT75 (4.5 m buffer zone) before and after May 1st, respectively, and of 2.5% and 1.0% for the DRT90 (3 m buffer zone) before and after May 1st, respectively. These spray drift deposition values are still based on the standard drift values of 8.6% and 16.6% in the full leaf and the dormant crop stage, respectively, of fruit crops for the standard cross flow fan sprayer and a 3 m crop free zone. As mentioned earlier, these spray drift data are not anymore state-of-art as will be discussed in this report.

Annex 8 Spray drift reducing measures and spray drift deposition values for fruit crop and avenue nursery tree spraying

The spray drift reducing measures and spray drift deposition values for fruit crop and avenue nursery tree spraying as used by Ctgb in the authorisation procedure until 2018 are presented in respectively Table 1 and Table 2.

Table 1 *Spray drift reducing methods for fruit crops in the Netherlands as used by Ctgb (Evaluation Manual 2.0; Ctgb, 2014).*

Drift percentage [% of applied dose]				
Drift-mitigation technique top fruit	Crop-free zone of 3 m		Crop-free zone of 4.5 m	
	without leaves (dormant)	with leaves (full-leaf)	without leaves	with leaves
Standard orchard sprayer [x]	16.6	8.6	10.3	6.3
Standard orchard sprayer + 6 m crop-free zone [x]	6.9	4.7	n.a	n.a.
Standard orchard sprayer + 9 m crop-free zone [x]	3.6	2.7	n.a.	n.a.
Standard orchard sprayer[x] in combination with windbreak on the edge of the driving track and one-sided spraying of the last tree row	7.0	0.9	7.0	0.9
Standard orchard sprayer[x] and Emission shield (2.5 m high)	6.7	3.4	6.7	3.4
Standard orchard sprayer[x] and One-sided spraying of last tree row	9.8	4.7	6.5	3.3
Tunnel sprayer	2.5	1.3	1.6	1.0
Sensor-controlled spraying	12.8	4.1	7.4	3.0
Cross flow fan sprayer with reflection shields	7.5	3.9	4.6	2.8
Venturi nozzle (90% drift reduction)+ one-sided spraying last tree row and reduced air fan setting [xx]	1.3	0.36	0.6	0.26
Wanner equipment with reflection shield and standard nozzles	4.8	3.4	3.3	2.8
Wanner equipment with reflection shield and 90% drift reducing nozzles (Lechler ID 90-015C)	0.8	0.41	0.42	0.29
50% drift reducing nozzle and one-sided spraying of the last tree row	-	2.7	-	1.8
75% drift reducing nozzle and one-sided spraying of the last tree row	-	2.0	-	1.2
90% drift reducing nozzle and one-sided spraying of the last tree row	2.5	1.0	1.0	0.7
95% drift reducing nozzle and one-sided spraying of the last tree row	-	0.8	-	0.31
KWH k1500-3R2 VLOS 3-row sprayer with variable air support system and standard nozzles	8.3	1.7	5.0	1.4
KWH k1500-3R2 VLOS 3-row sprayer with variable air support system and 90% drift reducing nozzles	0.70	0.43	0.32	0.25
KWH k1500-3R2 VLOS 3-row sprayer with variable air support system and 90% drift reducing nozzles and low air setting (400 rpm pto)	0.65	0.05	0.23	0.04

[x] valid for cross-flow fan and axial fan orchard sprayer

[xx] fan setting off in dormant and low in full-leaf stage

Table 2 *Spray drift reducing methods in the Netherlands in tree nursery as used by Ctgb (Evaluation Manual 2.0; Ctgb, 2014).*

Drift-mitigation technique avenue trees	Drift percentage [% of applied dose] Crop-free zone of 1.5 m (agronomic minimum zone)	Crop-free zone of 2 m (agronomic minimum zone)	Crop-free zone of 5 m (EAD)
	(3.0-4.0 m)	(3.5-4.5 m)	(6.5-7.5 m)
High avenue trees (>5 meter)			
Standard axial fan sprayer (TXB8003)		17.1	5.8
Mast sprayer (XR80015)		11.0	4.9
Mast sprayer (venturi ID90015)		9.8	1.6
Standard axial sprayer + 5 m crop-free*		2.3	0.9
Mast sprayer (XR80015) + 5 m crop-free*		2.2	1.7
Mast sprayer (venturi ID90015) + 5 m crop-free*		0.12	0.09
Transplanted trees			
Standard axial fan sprayer		10.4	2.8
Standard axial fan sprayer + 5 m crop-free*)		1.1	0.33
Axial sprayer + 50% drift reducing nozzles**		5.4	1.1
Axial sprayer + 75% drift reducing nozzles**		4.8	1.5
Axial sprayer + 90% drift reducing nozzles**		6.7	0.72
Axial sprayer + 95% drift reducing nozzles**		2.5	0.19
Spindle trees			
Standard axial fan sprayer	3.4	2.7	0.76
Standard axial fan sprayer + 5 m crop-free*)	0.35	0.28	0.09
Axial sprayer + 50% drift reducing nozzles**	1.5	1.2	0.32
Axial sprayer + 75% drift reducing nozzles**	1.2	1.1	0.43
Axial sprayer + 90% drift reducing nozzles**	1.2	0.17	0.05
Axial sprayer + 95% drift reducing nozzles**	0.43	0.17	0.05

* in this 5 m crop free zone only non-sprayed crops of the same height can be grown. These crops are eligible from CIW report referred to in the explanatory notes of LOTV, Article 13: based on Commissie Integraal Waterbeheer, 1998, Protocol opwaarts spuiten (laan)bomen

** extrapolated from fruit

Annex 9 Overview of certified upward- and sideway directed spray techniques and adaptation of the standard crop free zone (9 m) for fruit crops (TCT-CIW, 2017)

Upward and sideway directed spray techniques	Crop free zone (m)	Remarks
Wanner sprayer equipped with reflection shields and venturi nozzle types	3.0	Spray pressure max. 7 bar, Lechler ID90-015, fan 1400 rpm
Cross flow fan or axial fan sprayer equipped with 90% or 95% drift reducing nozzle types and one-sided spraying of the outside tree row	3.0	Spray pressure as indicated in drift reducing nozzle table
Cross flow fan or axial fan sprayer equipped with 50% or 75% drift reducing nozzle types and one-sided spraying of the outside tree row	4.5	Spray pressure as indicated in drift reducing nozzle table
KWH multirow orchard sprayer, type k1500-3R2, equipped with Variable Lucht Ondersteunings Systeem (VLOS)	3.0	Albuz ATR lilac nozzles or comparable or coarser nozzle types, spray pressure max. 7 bar, forward speed max. 6 km/hr. In outside path (on the outside of the last tree row) nozzles and air assistance are shut off in the direction of the surface water using the VLOS system.
KWH Mistral equipped with Variabel Luchtondersteuning Balans Systeem (VLBS)	3.0	90% drift reducing nozzles, low air setting and max. 540 rpm PTO. Two-sided spraying of outside tree row allowed.
Munckhof MAS 3-row orchard sprayer equipped with standard nozzles.	3.0	In outside path (on the outside of the last tree row) nozzles and air assistance are shut off in the direction of the surface water, max. 540 rpm PTO. Two-sided spraying of outside tree row allowed.
Munckhof MAS 3-row orchard sprayer equipped with 90% or 95% drift reducing nozzles	3.0	In outside path (on the outside of the last tree row) nozzles and air assistance are shut off in the direction of the surface water, max. 540 rpm PTO. Two-sided spraying of outside tree row allowed.
H.S.S. CF orchard sprayer equipped with met H.S.S. Drift Control and 90% or 95% drift reducing nozzles	3.0	low air setting and max. rpm of fan is 1800 rpm. Two-sided spraying of outside tree row allowed.

See for updates ‘DRT-lijst’ at:
https://www.helpdeskwater.nl/onderwerpen/emissiebeheer/agrarisch/open-teelt/driftreducerende/

Corresponding address for this report:
P.O. Box 16
6700 AA Wageningen
The Netherlands
T +31 (0)317 48 07 00
www.wur.eu/plant-research

Report WPR-564

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Corresponding address for this report:
P.O. Box 16
6700 AA Wageningen
The Netherlands
T +31 (0)317 48 07 00
www.wur.eu/plant-research

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