Hedgerow Filtration and Barrier Vegetation

J.C. van de Zande[1], J.M.G.P. Michielsen[1], H. Stallinga[1], M. Wenneker[2] & B. Heijne[2]
[1]Wageningen University & Research Centre - Agrotechnology & Food Innovations (WUR-A&F), P. O. Box 17,6700 AA Wageningen, The Netherlands
[2]Applied Plant Research (PPO), P. O. Box 200, 6670 AE Zetten, The Netherlands

Summary

A summary is given on results of spray drift research for the past 15 years in the Netherlands and how these data are incorporated in Dutch legislation. Results are presented for orchard spraying, and arable field spraying for the typical Dutch situation, related to defined distances and dimensions of the surface water. Spray drift research was setup in order to identify and quantify drift-reducing technologies. Results are presented for cross-flow sprayers, tunnel sprayers, and air-assisted field sprayers. The effect of nozzle type selection on spray drift is highlighted. The effect of spray drift reducing technologies in combination with crop- and spray-free buffer zones is outlined. Apart from spray drift reducing techniques also field lay-out can influence spray drift. The effect of crop-free and spray-free buffer zones and windbreak crops on spray drift is presented.

Introduction

The Dutch government formulated objectives for a reduction in plant protection products to be used and for an application practice for these products, which is safe and more compatible with the environment. The emissions of plant protection products to soil, (surface) water and air should be reduced. A general reduction in spray drift to surface water next to the sprayed field can be achieved by improvements in spray application techniques. For the last 15 years an intensive measuring programme on spray drift has been performed. The research programme consisted of laboratory measurements, field experiments and computer modelling. A stepwise approach was chosen to lower drift with: air assistance or shielding sprayer booms on a field sprayer, a tunnel sprayer, sprayer boom height and nozzle type.

In order to apply a risk assessment the results are presented on a uniform basis and expressed as percentage of the application rate per surface area (figure 1).

Standardised ditch dimensions are 1.5 m bank-length on both sides of a surface water width of 1m; total ditch width is therefore 4m (Huijsmans et al., 1999). In the Water Pollution Act (WPA), packages of drift measurements are described to be implemented on the outside 14m of the fields by Dutch farmers. For the sectors arable farming, nursery tree or fruit growing minimal spray- and crop free buffer zones are described depending on the used spray drift reducing measures. A minimum drift reducing package for arable farming is the use of low drift nozzles, a sprayer boom height of 0,5m and an end-nozzle.

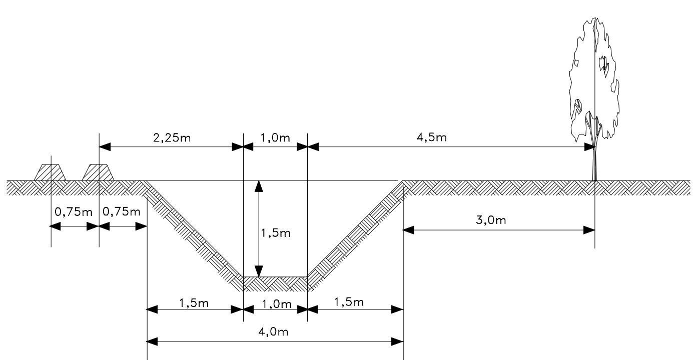


Figure 1. **Representation of the place of the ditch, embankments and water surface, and the last rows of a potato crop and a tree row in an orchard**

This buffer zone can be reduced to 1.0m with the additional use of air assistance on the sprayer, a tunnel sprayer or planting a catch crop on the field boundary. A classification system was developed to classify spray nozzles in different classes of spray drift reduction (Porskamp et al., 1999). However, the WPA only defines a low drift nozzle as a nozzle potentially reducing drift at least 50% in comparison with the Fine/Medium threshold nozzle from the BCPC nozzle classification scheme (Southcombe *et al.*, 1997). Low drift nozzles can be certified and listed (V&W/LNV, 2001b) based on drop size measurements when the volume fraction of drops smaller than 100 um is less than 50% of the BCPC Fine/Medium threshold nozzle (V&W/LNV, 2001a). The spray drift deposition level in this case is set to the 1% level, which is in accordance with the results from field experiments in potatoes (Van de Zande *et al*., 2000a).

The outlined spray drift reduction measures are in many cases overruled by the ecotoxicological requirements for the aquatic system of the Pesticide Act. Requirements to threshold levels lower than 0.2% spray drift is not exceptional and needs therefore further research. For the specific chemicals the needed width of buffer zones is quantified depending on the type of drift reducing spray technique or method that can be used. A chemical specific determined crop-free buffer zone in the Pesticide Act can therefore be wider than the one specified in the Water Pollution Act. Following international developments on spray drift reduction classification in Germany (Ganzelmeier & Herbst, 2000), the UK (Gilbert, 2000) and ISO (ISO/DIS 22369) regulation now uses a classification system with steps of 50, 75, and 90% drift reduction. Drift reducing techniques are to be evaluated following a standard measuring protocol (CIW, 2003) following ISO DIS22866 but adapted for the typical Dutch situation. Typical drift reducing measures used in European countries Germany, United Kingdom, the Netherlands and Sweden at the moment are listed in table1 for both orchard as for arable crop spraying.

Table 1. Entries for drift reduction in different countries

			D	UK	NL	S
field	50%	Nozzle-pressure-material	X	X	X	
		Twin-fluid nozzles		X	X	
		Spray quality				X
		Air assistance	X		X	X
		Boom height	X		X	X
		Sprayer speed	X		-	X
		Application zone width	X		X	X
		End-nozzle		X	X	
		Tunnel sprayer (bed-crops)			X	
		Släpduk			X	X
		Windbreak crop			X	
		Wind speed				X
		Air temperature				X
	75%	Nozzle-pressure-material	X	X	X	
		Twin-fluid nozzles		X	X	
		Air assistance	X	X	X	
		Boom height	X			
		Sprayer speed	X			
		Application zone width	X			
		End-nozzle			X	
		Shrouded boom		X		
		Släpduk			X	
	90%	Nozzle-pressure-material	X		X	
		Boom height	X			
		Sprayer speed	X			
		Application zone width	X			
		Släpduk			X	
	95%	Nozzle-pressure-material + air assistance			X	
	99%	Shielded bed sprayer			X	

Table 1. Entries for drift reduction in different countries (continued)

			G	UK	NL	S
orchard	50%	Nozzle-pressure-material	X			
		Leaf-sensor	X		X	
		Shut-off air outside direction 5 rows	X			
		Application zone width	X			
		Hail net over entire orchard	X			
		Windbreak net on edge field			X	
		Shut-off spray outside direction last row			X	
	75%	Nozzle-pressure-material	X			
		Leaf-sensor	X			
		Shut-off air outside direction 5 rows	X			
		Application zone width	X			
		Max. fan capacity	X			
		Tunnelsprayer			X	
		Windbreak crop			X	
		Hail net over entire orchard	X			
	90%	Nozzle-pressure-material	X			
		Shut-off air outside direction 5 rows	X			
		Application zone width	X			
		Max. fan capacity	X			
		Max. crop height 2.2m	X			
		Max. row width 2.2m	X			
		Windbreak crop			X	

Drift reduction in orchard spraying in the Netherlands

Orchard spraying (Figure 2; top) in the Netherlands is predominantly done using cross-flow fan sprayers. When spraying an orchard in a full-leaf situation (LAI 1.5-2) and an average wind speed of 3 m/s, the spray-drift deposition on the soil at 4.5-5.5 m downwind of the last tree is 6.8 % of the application rate per surface area.

Compared to this reference situation a tunnel sprayer (Figure 2; middle) can achieve a reduction in spray drift on the soil surface of 85 % and a cross-flow fan sprayer with reflection shields of 55% (Huijsmans et al., 1993). Spraying trees without leaves increases spray drift 2 to 3 times compared to spraying trees with full foliage. The effect of a sensor-equipped cross-flow sprayer on drift reduction was compared with a standard cross-flow sprayer, equipped with the same nozzle-types (Zande *et al*., 2001). The drift reduction achieved with the sensor equipped orchard spraying was on average 22% and 50% for the no-leaf and full canopy situation respectively.

A wind-break on the outer-edge of the field (Figure 2; bottom) can reduce spray-drift also. Results are discussed in a next paragraph. Drift reducing techniques identified and used in Dutch regulation and in Europe is presented in table 2 and table 1.

Drift reduction in arable crop spraying in the Netherlands

In arable crop spraying spray technique most often used is a boom sprayer equipped with standard flat fan nozzles (XR11004 at 3 bar spray pressure) applying around 300 l/ha with a boom height of 0.50m above crop canopy. In order to assess potential drift reduction this typical equipment was chosen as a reference spray system for the Netherlands. A methodology to classify spray nozzles for driftability (Porskamp *et al*., 1999) was developed based on laboratory measurements (Phase Doppler Anemometry) and spray drift model calculations (IDEFICS; Holterman *et al*., 1997). Porskamp *et al.* (1999) showed that the combination of nozzle type, nozzle size and spray pressure defined the spray drift predominantly. The effect of nozzle type and air assistance was quantified (figure 3) in the field (Van de Zande et al., 2000b). Although with all nozzles a spray volume of either 150 l/ha or 300 l/ha was used , the difference in the range of droplet sizes resulted in drift reductions up to more than 85%

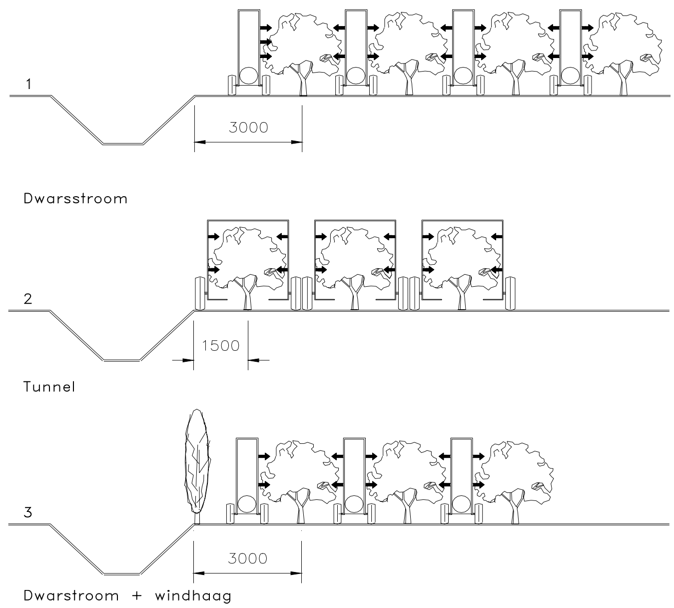


Figure 2. Representation of used spraying systems and situations in orchard spraying.
Top: cross-flow sprayer spraying last tree row towards the field
Middle: tunnel sprayer
Bottom: cross-flow sprayer with a hedgerow planted on the edge of the field

Table 2. Spray drift reduction used in the Dutch authorization procedure for orchard spraying (CTB, 2004)

Drift reducing measure	Drift reduction [%]	
	Before May 1st/ dormant	After May 1st/ full leaf
Windbreak	70	90
Tunnel sprayer	85	85
Sensor equipped sprayer	20	50
Inward spraying outside tree row	35	40
Artificial netting on ditch bank 2,5 m height	60	60
Sprayer with reflection shield	55	55
6 m crop-free zone	61	61

when compared to a XR11004 nozzle (Van de Zande et al., 2000b). The terminology ‘low-drift’ nozzle therefore needs further specification. Model calculations showed also a correlation between sprayer boom height and drift, the lower the boom height the lower the drift. The effect of sprayer boom height on spray drift was measured in the field (Jong et al, 2000). A drift reduction of around 50% was found when lowering boom height from 0.70 m to 0.50 m as well as lowering from 0.50 m to 0.30 m above crop canopy. Lowering further down will give even more drift reduction, up to 90%, as is shown with band sprayers (Zande et al., 2000) but also causes stripes in the application. Stallinga et al (2004) showed that low boom height (0.30m) above crop canopy in combination with small nozzle spacing and air assistance could reduce spray drift with more than 95%.

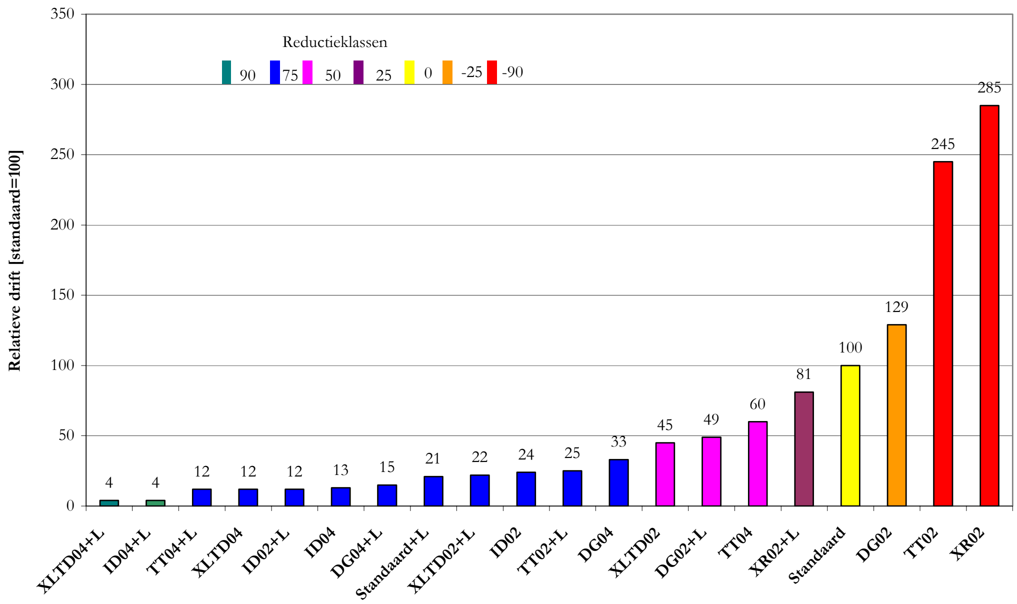


Figure 3. Relative spray drift deposition on 2-3 m distance from the last nozzle for different nozzles and nozzles in combination with air assistance (+A) when spraying potatoes with a spray volume of 300 l/ha (04 nozzles) and 150 l/ha (02 nozzles). Standard nozzle is XR 110.04 (=100)

Barrier vegetation

Apart from technical measures (nozzle type, sprayer boom height, shielding, air assistance) also the field layout can reduce spray drift. The introduction of a crop-free buffer zone around the crop on the field increases the distance between the sprayed crop and the surface water area. Spray deposition on surface water will therefore be reduced. When on such a crop-free buffer zone a windbreak crop is grown spray deposit on surface water will probably further reduced. The density of the windbreak crop determines the filter capacity of such a crop.

Different aspects will be highlighted, both for orchard spraying as for arable field spraying.

Barrier Vegetation in Arable Crop Spraying

Crop-free bufferzone

The effect of width of a crop-free buffer zone next to the field is presented in table3. Spray drift reduction is presented for nozzle types representing drift reduction classes of 50,75, and 90% compared to a standard flat fan (XR11004) sprayed at 3 bar spray pressure (Porskamp *et al*., 1999). Reductions are calculated based on measured spray drift deposition (Van de Zande *et al*., 2000?) on zones 4m wide, representing a standard ditch, on 1, 3, 5, and 10m distance from the last potato row (approximately 0.50m smaller distance from the edge of crop canopy).

Different classification in drift reduction classes occurs close to the edge of the field (1m crop-free buffer zone) and further away. For crop-free buffer zones wider than 3 m there is little difference in drift reduction classification. In general drift reduction classification is for the 1m crop-free zone one class lower than for the wider crop-free buffer zones (except for the DG11004 and DG11004 + end-nozzle). Depending on nozzle type large differences do occur in spray drift reduction on the same zone, especially close to the edge of field (20-89% reduction). For the mentioned nozzle types the combinations with air assistance reduced spray drift at least with 50% in the near field area (crop-free buffer zone 1m) and more than 75% with crop-free buffer zones wider than 3m. The effect of an end nozzle to prevent overspray on the crop-edge is clear. In combination with the DG11004 the use of an end nozzle changes drift reduction when used with a 1m crop-free buffer zone, from 20% to 50% and

Table3. Effect of width of crop-free buffer zone on spray drift reduction for different nozzle types (spray pressure 3 bar) with and without additional air assistance calculated for a 4m wide zone (ditch)

Nozzle type	drift reduction class	Air assistance	Crop-free buffer zone [m] 1	3	5	10
XR11004	standard	no	-	-	-	-
	standard	full	57	83	82	79
DG11004	50	no	20	42	45	48
	50	full	44	88	87	88
DG1100+end nozzle	50	no	50	47	51	58
	50	full	89	92	93	90
ID12002/XLTD11002	75	no	55	82	82	85
	75	full	65	93	94	93
ID12004/XLTD11004	90	no	63	86	88	88
	90	full	73	95	93	90

in combination with air assistance from 44% to 89%. On larger distances from the field edge the effect of an end-nozzle is not apparent anymore.

Spray-free bufferzone

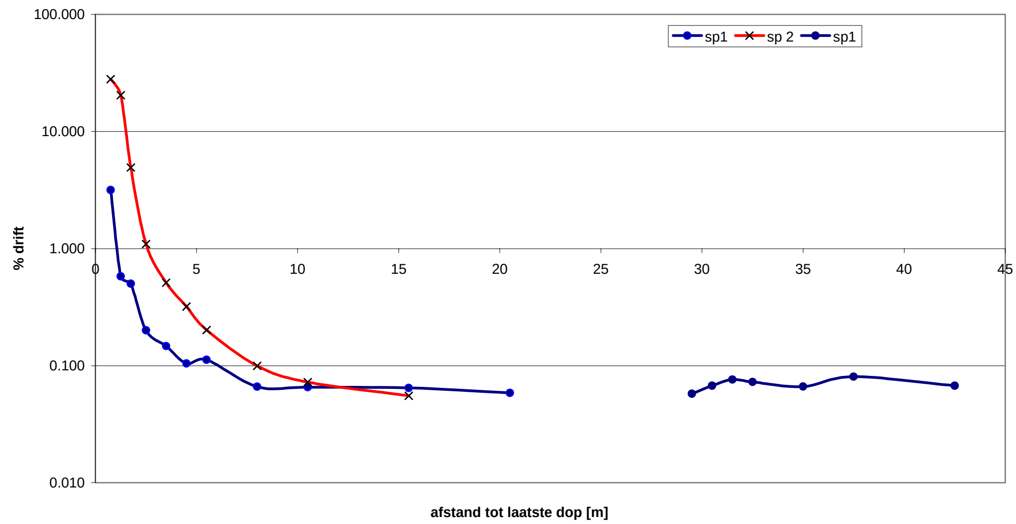
Van de Zande (2004) measured spray deposition over a wheat crop (crop height 0.45m, LAI 3.3) and to quantify spray drift next to the field and to the air on the edge of the field, the two outer downwind swathes were sprayed. The sprayer used was a trailed Dubex with a working width of 27m. Nozzles used were Agrotop TD025 (at 5-5.5 bar pressure), applying a spray volume of 200 l/ha. Average wind speed during application was 3 m/s at a temperature of 12-13 ^{o}C. Measurements were performed separately for the last and the last but one spray swath. Total measured spray drift deposition on surface water in a ditch (2-3m from the last nozzle) was 1.14%. Compared at the same distance, 2-3m from the last nozzle, measured spray drift deposition on top of canopy was significantly lower than measured outside the field on bare soil surface, being 0.20% (figure 4).

On the ditch zone, 0.5-4.5 m from the last nozzle, spray drift deposition of both spray tracks added was 7.16%. On the zone 1.0-5.5 m of the last nozzle total spray drift deposition was 3.33% and on the zone 5.5-16 m it was 0.17%. Spray drift deposition from the second swath sprayed coming over the outside swath is on average 0.07% for the total sampling area. This means that a 27m not sprayed field boundary could result in a 98% drift reduction on the zone 1.0-5.5m and 59% on the zone 5.5-16m.

Porskamp et al (2003) reported a similar research for a potato crop spraying the outer 3 swathes. The sprayer used was a trailed Dubex with a working width of 27m. Nozzles used were TeeJet XR11004 (@3.5 bar pressure), applying a spray volume of 300 l/ha. Average wind speed during application was 3.8 m/s at a temperature of 20 ^{o}C. Measurements were performed separately for the last, the last but one spray swath, and the last but two swath. Total measured spray drift deposition on surface water in a ditch (2-3m from the last nozzle) was 1.18%. Compared at the same distance, 2-3m from the last nozzle, measured spray drift deposition on top of canopy was significantly lower than measured outside the field on bare soil surface, being 0.92%.

On the ditch zone, 0.5-4.5 m from the last nozzle, spray drift deposition of the three spray tracks added was 3.38%. On the zone 1.0-5.5 m of the last nozzle total spray drift deposition was 1.63% and on the zone 5.5-16 m it was 0.40%. Spray drift deposition from the second swath sprayed coming over the outside swath is on average 0.03% for the total sampling area. This means that a 27m not sprayed field boundary could result in a 98% drift reduction on the zone 1.0-5.5m and 92% on the zone 5.5-16m.

Figure 4. Spray drift deposition (% of dose) next to the sprayed swathe spraying a wheat crop. Spray track 1 is measured on top of canopy and next to the field spraying the last but one spray swathe. Spray track 2 is measured next to the field spraying the last (outside) swathe.



Vegetation on bufferzone

It is recognised that the structure of both target crop and plants in the margin between the sprayed swath and water can have a large influence on rates of deposition to surface waters.

In a series of field experiments spray drift was assessed when spraying a sugar beet crop and a potato crop (Van de Zande et al., 2000; Michielsen et al., 2003). Next to the crop, the field margin was planted with a 1.25m wide strip of *Miscanthus* (Elephant grass). To evaluate the effect of different heights of such a windbreak crop on spray drift it was cut at different heights just before spraying. Heights varied between: not planted (0m), at crop height level (0.5m), 0.5m above crop height (being sprayer boom height, 1.0m) and 1m above crop height (1.5m). Spraying was performed with a conventional and an air-assisted sprayer. Spray volume was 300 l/ha using Medium spray quality nozzles. The height of the windbreak had a clear effect on spray drift deposit (figure 5). Spray deposit at 3-4m distance from the last nozzle decreased significantly with increasing heights of the *Miscanthus*. Spray drift reduction is not the same on all distances measured, close behind the windbreak crop spray drift reduction is highest (60-90%). On larger distances (7,5 m) spray drift reduction is lower. Possibly this is the effect of a changing wind profile around the windbreak crop. When *Miscanthus* was cut to equal height as the crop height spray drift reduction was 55% compared to spray drift on the same distance when no windbreak was grown (table 4). With the 0.5m and 1.0 above crop height levels of *Miscanthus* spray drift was reduced by respectively 75% and 90%.

Air assistance on the field sprayer reduced spray drift with 70-80% in 1999 and with more than 90% in 2000, irrespective of the distance to the crop edge and the height of the windbreak crop. The combination of a higher windbreak crop than the arable crop (sugar beet or potatoes) and an air-assisted field sprayer reduced spray drift with 95-99%.

De Snoo (1995) found that the creation of a 3-m spray-free buffer zone in the field decreased drift deposition in the ditch by a minimum of 95%. Adjacent to the buffer zone there was no longer any risk to aquatic organisms. With a 6-m no-spray buffer zone in the field alongside the waterway no drift deposition in the ditch could be measured.

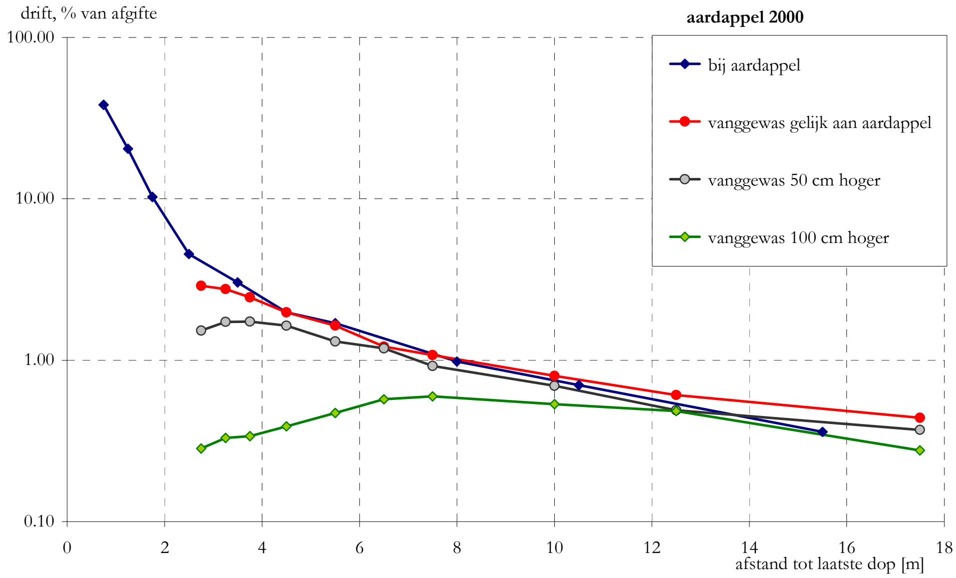


Figure 5. Spray drift when spraying a potato crop (2000) with a windbreak crop of different heights next to it (equal height as the potato crop, +50 and +100 cm higher than potato crop canopy), without air assistance (after: Michielsen et al., 2003)

Table 4. Reduction in spray drift deposition on surface water zone when spraying an arable crop with next to the field a crop-free strip of 2 m, or a windbreak crop grown on this strip of equal height as the arable crop, +50 cm higher or +100 cm higher, and drift reduction using an air-assisted sprayer in combination with the windbreak crop (Michielsen et al., 2003)

	conventional		air assistance	
object	1999	2000	1999	2000
2m crop-free	35	56	92	98
Miscanthus, equal height	53	56	91	98
Miscanthus, + 0.5m high	83	64	95	98
Miscanthus, + 1.0m high	88	91	98	99

Miller & Lane (1999) present the results of wind tunnel experiments examining the distribution of airborne spray from simulated boom sprayer application systems simulating operation over bare ground or short crop conditions. Results from these measurements showed that the risk of drift with a grass and wild flower mixture compared with a 200 mm cut stubble was reduced by up to 34.7 %.

In a summary of observations from field studies prepared by Mackay *et al.* (2002) on behalf of UK Pesticides Safety Directorate it is mentioned that in studies conducted by Taylor *et al.* (1999) a boom sprayer operating over a tall grass surface gave levels of drift in the range of 138% to 270% (1.0 – 2.0 m downwind of the sprayed swath) of those for an equivalent sprayer operating over a short grass surface. At greater distances (4.0 – 5.0 m downwind) the drift reduced to between 56% and 62% of the comparative short grass figures. The mitigation afforded by a margin comprised of grass and wild flower mixture with a base canopy height of 700 mm with elements extending to 1300 mm high was on the order of 60 – 85% relative to drift observed with a 150 mm mown grass margin (Miller *et al*., 2000).

Koch et al (2002) indicated that the spray drift deposition on field crop edge or boundary vegetation differs from deposition on the ground (soil surface). As spray drift consists mainly of droplets smaller than 100 μm and drift deposits are single droplet patterns retained on any surface, coverage defines the effect of spray drift on vegetation. Drifting particles are mainly retained in the upper zone of a canopy according to wind and air movement. Droplets do almost not penetrate into lower canopy regions. Drop distribution is very scattered and therefore the effect of spray drift on boundary vegetation is more variable than suggested from the figures of spray drift deposition measurements in drift trials. Koch et al (2002) concludes that dose response from spray application is different from dose response from drift deposition. Effects of smaller portions of droplets < 100 μm in the spray from low-drift nozzles is shown to have its effect in a decreasing desiccation from herbicide spraying in the drift area next to the sprayed field.

Barrier Vegetation in Orchard Spraying

Foliage density

Wenneker et al. (2004) found on average a spray drift deposition of 9.0% on 5.5 m distance from the last tree in the full leaf stage. Before May 1st when trees are dormant or have little leaves on the branches spray drift deposition was 17.8%. On average spray drift deposition was in the dormant stage two times higher than at full leaf stage. With the outside row only sprayed orchard inwards this ratio was the same.
Ganzelmeier et al. (1995) found on average 2-3 times higher spray drift deposition on 5-7m distance (fig. 4) from the last tree-row when spraying dormant instead of foliated apple trees (resp. 12.0% and 4.9% drift deposition).

Crop-free zone

When changing the width of the standard crop-free buffer zone, distance between the top of the bank of the ditch and the first tree row in the orchard, from 3m to 6 m width spray drift is reduced by 60%.

Spray-free zone

The contribution of individual orchard row sprayings to spray drift deposition on soil surface and to the air next to an apple orchard was measured by Wenneker et al. (2004c). From the preliminary data available yet it is shown that the contribution to the airborne drift of a spraying end of March (figure 6) from path 8 and 11 (resp 24 and 33m from the outside tree row) is still more than 5% of total catched amount, depending on measuring height.

Windbreak

Spray drift to the soil and air next to the orchard might also be reduced by a wind-break of trees around the orchard. In a series of experiments the effect of a wind-break on the emission outside the orchard was evaluated. 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 3m distance behind the

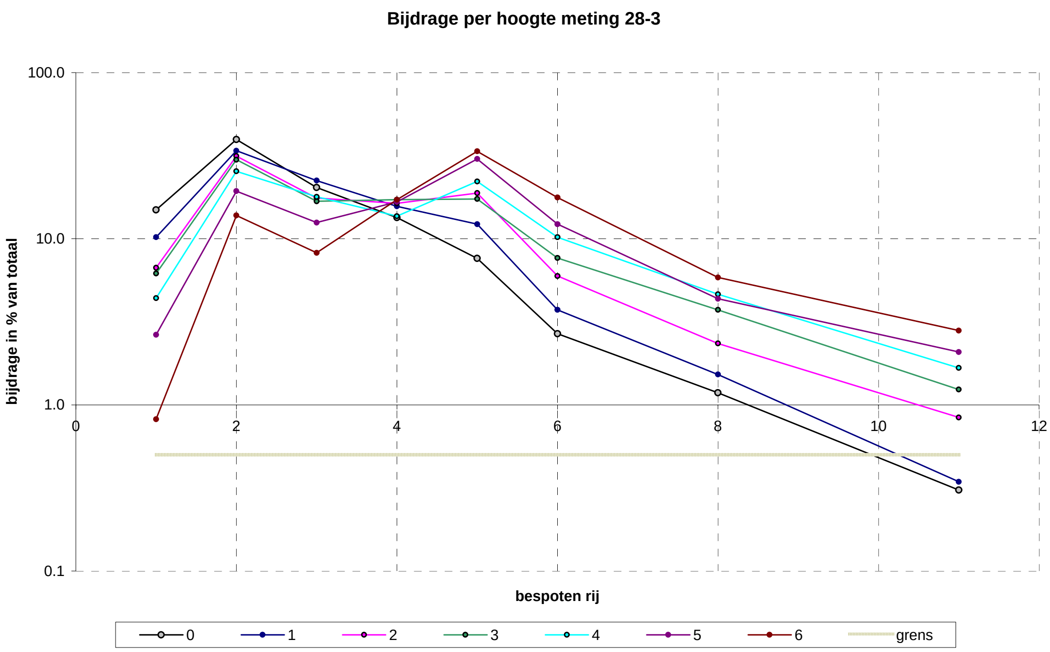


Figure 6 Contribution of individual row sprayings (1-11) to airborne spray drift on 5m distance from the last tree row in an apple orchard averaged for different heights (0-6m)

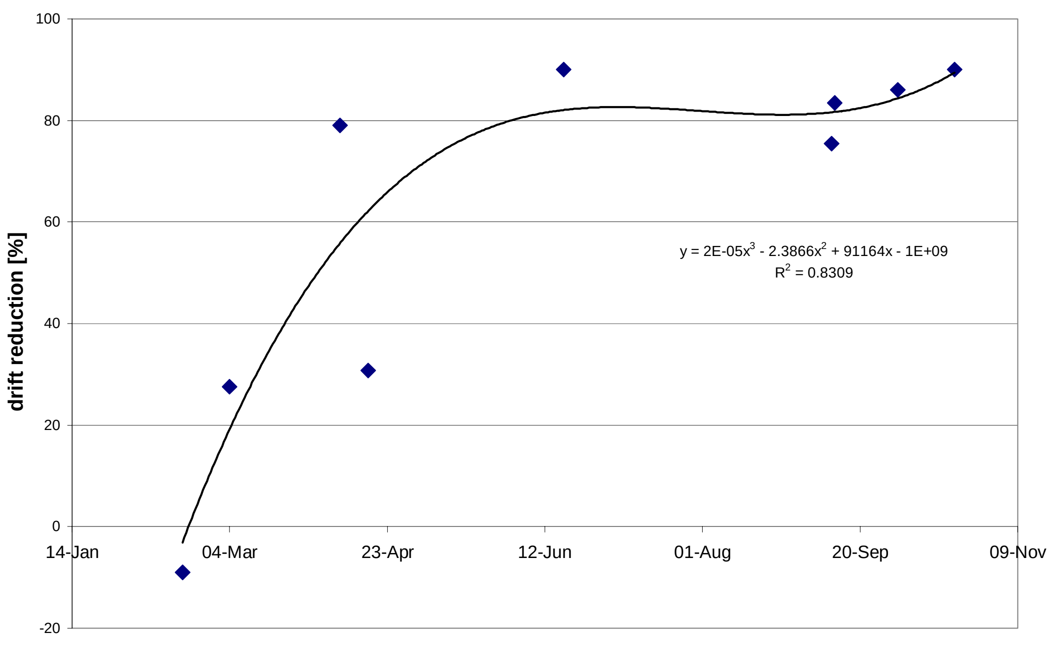


Figure 7 Spray drift reduction of an alder windbreak at different dates during the growing season when spraying an apple orchard (based on data of Porskamp *et al*., 1994; Wenneker *et al*., 2004a)

trees. Showing 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 (figure 7).

Large differences do however occur between species of windbreak trees. Canopy density varies between leaf trees as alder (*Alnus glutinosa*), liguster (*Ligustrum vulgare*), *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 (table 5). 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. Acer, Lonicera and Syringa are compared to alder more developed with higher canopy densities on an earlier date.

Table 5. Total area of stems, branches and leaves (optical density, fully closed canopy = 100) measured at 4 dates during the early growing season (spring 2003) of different tree and bush crops identified for drift reducing windbreaks (after Wenneker et al, 2004b)

Date	Acer	Alnus	Deutzia	Ligustrum	Lonicera	Syringa	Taxus
04-Apr	42	42	52	57	91	49	90
18-Apr	74	43	58	65	97	74	90
02-May	99	77	74	85	98	99	89
16-May	100	93	77	97	98	99	90

Walklate (2001) measured passing spray cloud in front and behind a 7m high row of alder trees. A single avenue of trees was sprayed in the orchard. In the early season an open structure resulted in a distribution similar on both sides of the windbreak. In a full leaf canopy situation the spray cloud was moved more upwards behind the windbreak to have a maximum at 7.5m height. Typical reductions of 86-91% for a 7m alder tree were found. Richardson et al. (2002) found a drift reduction of an alder tree hedgerow of 50% when in full leaf. Large differences do occur between the measured effects of windbreaks on spray drift reduction (Ucar & Hall, 2001) especially because of geometrical construction of the leaf canopy leading to differences in capture efficiency of passing droplets and redirection of the wind profile around the windbreak.

Emission shield

An emission shield (gauze 40 % permeability; Rovero Systems, Raamsdonkveer) of equal height as the fruit trees (2,5 m), placed on the edge of the field, reduced spray drift in a full leaf orchard by 60 % (Heijne *et al*., 1999; Zande et al., 2001). Crop-free zone between the last tree row and the ditchbank was 3.0 m. The emission shield was placed 0.50m from the top of the ditchbank. Gauze heights of 1m and 1.75 m reduced spray drift on the center of the ditch (5m from the last tree row) respectively 11% and 35% (figure 8). In the nearly leaf free orchard drift reduction measured was variable.

<u>Single sided spraying of outer tree rows</u>

The effect of single sided spraying of the outer tree row, an emission shield on the edge of the field and the growing of reeds in the ditch on drift reduction were reported by Wenneker et al., 2001b, Van de Zande et al., 2001.

Cross-flow sprayers, commonly used in the Netherlands by Dutch fruit growers, were used to measure the effect of drift when the outside tree row was sprayed only from one side, i.e. directed inwards only from the ditch, in comparison with treating the outside tree row from both sides. Drift reduction of 45 % and 40 % was measured for a fully developed leaf (figure 9) and a bare canopy situation (figure 10), respectively in the middle of the ditch (4,5 to 5,5 m from the last tree row).

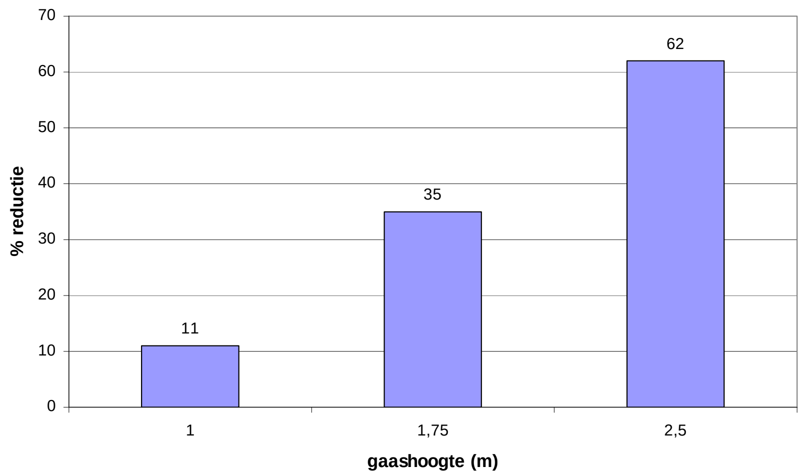


Figure 8. Mean drift reduction at surface water when spraying the onward 1,5 tree rows and different heights (1, 1.75, 2.5 m) of artificial netting at the edge of the field in a full developed canopy situation. (after Van de Zande et al., 2001).

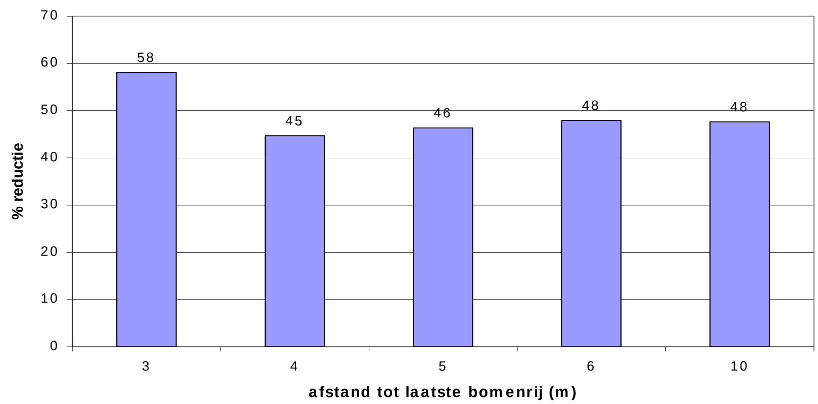


Figure 9. Mean drift reduction (session 1-3) at different distances from the last tree row when spraying the outward three rows and the last row only from the outside in a full developed canopy situation (after Wenneker *et al*., 2001b)

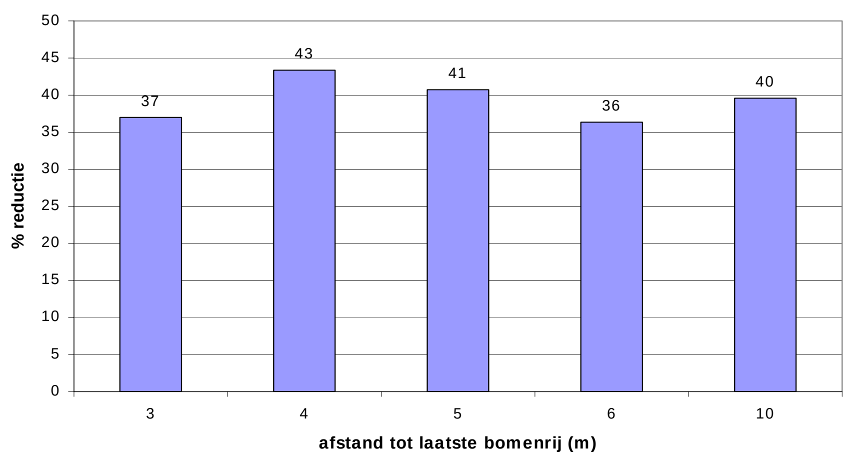


Figure 10. Mean drift reduction (session 1-3) at different distances from the last tree row when spraying the outward three rows and the last row only from the outside in a nearly bare tree situation (after Wenneker *et al*., 2001b)

A similar approach was used in Germany (Schmidt, 2001). When the last 5 rows at the edge of the orchard are sprayed without air assistance in the wind and drift direction and coarse nozzles are used with the nozzles on the downwind side mounted on a vertical boom a drift reduction of 75-85% can be reached.

Reeds in the ditch
The effect on drift reduction by reeds (*Phragmites australis*) in the ditch (banks and surface water) was measured in a commercial orchard, having a 3 m path around the orchard (crop-free bufferzone); a situation considered representative for a standard Dutch orchard (Gildemacher et al., 2000; Wenneker et al., 2001a). In the fully developed leaf canopy, reeds reduced drift by 56% (figure 11) above the ditch (ground level). In the nearly leaf free orchard no significant drift reduction was measured.

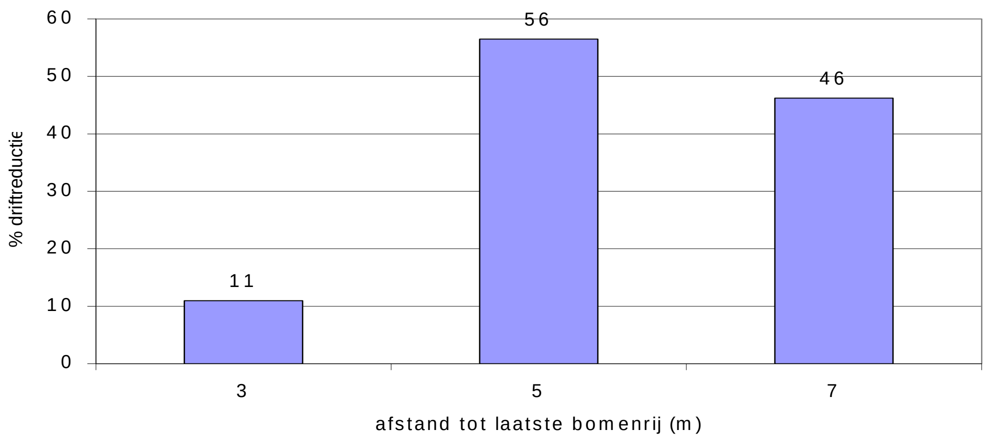


Figure 11: Mean drift reduction of a reed vegetation in the ditch at different distances from the last tree row when spraying the outward 2 rows of trees with a cross-flow sprayer (full-leaf situation) (Van de Zande et al., 2001)

Conclusions

From the presented data it can be concluded that barrier vegetation like hedgerows, windbreaks and field edge vegetation can reduce spray drift. In combination with drift reducing techniques effects add-up. Point of concern is always the growth stage of the barrier vegetation at moment of spraying. Especially early season sprayings with still little leaf development on the windbreak trees needs adaptation of the variety of trees alongside the orchard. With arable crops few windbreak crops are known that develop earlier than the field crop to produce an advantage in height during the spray season. Regulations in the Netherlands mention the use of barrier vegetation to prevent spray drift. It is assumed that on the moment of spraying the barrier crop has at least the same height as the highest nozzle position. This means for arable crops that a lead of at least spray boom height (0.50m) is required. Penetration rate of the barrier changes during the season. To discriminate in two steps as now is done for windbreaks alongside orchards is not enough. At least three periods can be detected: bare trees, full leaf stage, and a transition period between bare tree and full leaf stage is advised.

References

Anonymus, 1991. Regeringsbeslissing Meerjarenplan Gewasbescherming 21667, nrs 3-4, 298 pp.

Anonymus, 1998. Wijziging Regeling uitvoering milieutoelatingseisen bestrijdingsmiddelen. Staatscourant 153, 1998.

Anonymus, 2000a. Besluit 43, 27 januari 2000 (Lozingen besluit open teelt en veehouderij). Staatsblad van het Koninkrijk der Nederlanden, besluit 43, artikel 13-15. (p. 10-12).

Anonymus, 2000b. Sechste Bekanntmachung über die Eintragung in das Verzeichnis "Verlustmindernde Geräte". Biologische Bundesanstalt für Forst- und Landwirtschaft, Braunschweig. 2000. 3p.

CIW, 2003. Beoordelingsmethodiek Emissiereducerende maatregelen Lozingenbesluit open teelt en veehouderij. Commissie Integraal Waterbeheer, Werkgroep 4 Water en milieu, Den Haag. 82pp.

CTB, 2004. Drift reduction measures used in the Dutch authorisation procedure for agrochemicals. Web-site: www.ctb-wageningen.nl

Ganzelmeier, H., Rautmann, D., Spangenberg, R., Streloke, M., Herrmann, M., Wenzelburger, H.J., Walter, H.F., 1995. Studies on the drift of plant protection products. Results of a test program carried out throughout the Federal Republic of Germany. Mitteilungen aus der Biologischen Bundesanstalt für Land- und Forstwirstschaft Berlin-Dahlem, Heft 305, Blackwell Wissenschaftsverlag GmbH Berlin-Wien, 111 pp.

Ganzelmeier, H & Rautmann D, 2000. Drift, drift reducing sprayers and sprayer testing. Aspects of Applied Biology 57, Pesticide application, 2000. 1-10

Gilbert, A.J., 2000. Local Environmental Risk Assessment for Pesticides (LERAP) in the UK. Aspects of Applied Biology 57, Pesticide Application, 2000. 83-90

Gildemacher, P.R., Heijne, B., Zande, J.C. van de, 2000. Een rietkraag als emissiebeperkende maatregel in de fruitteelt. FPO-rapportnr. 2000/18, 26 pp.

Heijne, B., Meijer, A.C., Anbergen, R.H.N., Rooijen, H.J.M. van 1999 Emissiebeperking in de fruitteelt door een gazen scherm. FPO-rapportnr. 99/15, 35 pp.

Holterman H J, Zande J C van de, Porskamp H A J, Huijsmans J FM. 1997. Modelling spray drift from boom sprayers. *Computers and Electronics in Agriculture* 19:1-22.

Huijsmans JFM, Porskamp HAJ & Heijne B, 1993. Orchard tunnel sprayers with reduced emission to the environment. Results of deposition and emission of new types of orchard sprayers. Proceedings A.N.P.P.-B.C.P.C. Second International Symposium on Pesticides Application, Strasbourg, 22-24 sept. 1993, BCPC, Vol. 1/2, p. 297-304.

Huijsmans, JFM, Porskamp HAJ & Zande JC van de, 1997. Spray drift reduction in crop protection application technology. Evaluation of spray drift in orchards, field crops and nursery tree crops spraying (state-of-the-art December 1996). Institute of Agricultural and Environmental Engineering, IMAG-DLO Report 97-04, Wageningen. 41p. (in Dutch with English summary)

ISO, 2001. Draft standards on spray drift measuring protocol and spray drift classification. International Standardisation Organisation, TC23/SC6/WG4&WG7.

ISOCD 22866; Equipment for crop protection – Methods for the field measurement of spray drift. ISO/TC23/SC6N464 dated 01-09-2003

Jong, A de, Michielsen J M G P, Stallinga H & Zande J C van de. 2000. Effect of sprayer boom height on spray drift. *Mededelingen Faculteit Landbouwwetenschappen Rijksuniversiteit Gent* 65/2b:919-930.

Koch, H., Knewitz, H., Fleischer, G., 2001. Untersuchungen zur Abdriftreduzierung und biologischen Wirksamkeit im Obstbau bei grobtropfiger Applikation. Gesunde Pflanzen 53 (4): 120-125.

Michielsen, J.M.G.P., H. Stallinga & J.C. van de Zande, 2001. Spray drift reduction: effect of spray quality and air assistance. Landbouwmechanisatie 52(2001)4: 16-17 (in dutch)

Porskamp, H A J, Zande J C van de, Holterman H J & Huijsmans J F M. 1999. Classification of spray nozzles based on driftability. Institute of Agricultural and Environmental Engineering. IMAG-DLO Report 99-02. Wageningen. 22pp. (in Dutch with English summary)

Porskamp, HAJ, Michielsen, JMGP & JFM Huijsmans, 1994. The reduction of the drift of pesticides in fruit growing by a wind-break. Institute of Agricultural and Environmental Engineering, IMAG-DLO Report 94-29, Wageningen. 29p. (in Dutch with English summary)

Southcombe. E S E, Miller P C H, Ganzelmeier H, Zande J C van de, Miralles A & Hewitt A J. 1997. The international (BCPC) spray classification system including a drift potential factor. *Proceedings of the Brighton Crop Protection Conference* - *Weeds. 1997. November 1997.* Brighton. UK. p.371-380

Stallinga, H., J.C. van de Zande, J.M.G.P. Michielsen & P. van Velde, 2004. Fine nozzles can be used and reduce spray drift; when used at low boom height and smaller nozzle spacing. *Aspects of Applied Biology 71, International advances in pesticide application*, pp. 141-148.

Ucar, T., F.R. Hall, J.E. Tew & J.K. Hacker, 2003. Wind tunnel studies on spray deposition on leaves of tree species used for windbreaks and exposure of honey bees. Pest Management Science 59(2003): 358-364

Ucar, T. & F.R. Hall, 2003. Windbreaks as a pesticide drift mitigation strategy: a review. Pest Management Science 57(2001): 663-675

V&W/VROM/LNV, 2000. *Surface water pollution act arable farming and animal husbandry*. Ministry of Waterways and traffic, Public affairs, Agriculture Nature Management and Fisheries, Staatsblad 2000 43, The Hague. 114p. (in Dutch)

V&W/LNV, 2001a. Test method low drift nozzles water pollution act arable farming and animal husbandry. Ministry of Waterways and Traffic, Ministry of Agriculture Nature Management and Fisheries, Staatscourant 2001- 43, The Hague. P.18-21 (in Dutch)

V&W/LNV, 2001b. List of low drift nozzles according to the water pollution act arable farming and animal husbandry. Ministry of Waterways and Traffic, Ministry of Agriculture Nature Management and Fisheries, Staatscourant 2001- 297, The Hague. P.11 (in Dutch)

Wenneker, M., Heijne, B., Zande, J.C. van de 2001a Emissiebeperking door een rietkraag; metingen op maaiveldniveau en wateroppervlak. PPO-fruit Rapport 2001-10, Praktijkonderzoek Plant & Omgeving (PPO) - sector fruit, 2001. 36pp.

Wenneker, M., Heijne, B., Zande, J.C. van de 2001b Emissiebeperking door éénzijdig spuiten van de laatste bomenrij. PPO- fruit Rapport 2001-11, Praktijkonderzoek Plant & Omgeving (PPO) - sector fruit, 2001. 41pp.

Wenneker, M., Heijne, B., Zande, J.C. van de 2001c Emissiebeperking in de fruitteelt met behulp van sensortechniek. PPO- fruit Rapport 2001-13, Praktijkonderzoek Plant & Omgeving (PPO) - sector fruit, 2001. 47 pp.

Wenneker, M., Heijne, B., Zande, J.C. van de 2001d Emissiebeperking in de fruitteelt door venturispuitdoppen en uitvloeier. PPO- fruit Rapport 2001-14, Praktijkonderzoek Plant & Omgeving (PPO) - sector fruit, 2001. 39 pp.

Wenneker, M., Heijne, B., Zande, J.C. van de, 2004a. Emissiebeperking door combinatie van windhaag en het éénzijdig bespuiten van de laatste appelbomenrij. PPO-fruit Rapport 2004-04, Praktijkonderzoek Plant & Omgeving (PPO) - sector fruit, 2004. 47pp.

Wenneker, M., Anbergen, R., Heijne, B., 2004b. Mogelijke alternatieve haagsoorten voor emissiebeperking bij gewasbespuitingen in de fruitteelt: case-study Zeeland. PPO-fruit Rapport 2004-18, Praktijkonderzoek Plant & Omgeving (PPO) - sector fruit, 2004. 33pp.

Wenneker, M., Michielsen, J.M.P.G, Heijne, B., Zande, J.C. van de 2004c Bijdrage van individuele bomenrij bespuiting op de drift bij een bespuiting van een appelboomgaard.. PPO-fruit Rapport 2004-??, Praktijkonderzoek Plant & Omgeving (PPO) - sector fruit, 2004. ??pp. (in preparation)

Wenneker, M., 2004-06 windhagen

Zande J C van de, Porskamp H A J, Michielsen J M G P, Holterman H J, Huijsmans J F M. 2000a. Classification of spray applications for driftability, to protect surface water. *Aspects of Applied Biology 57, Pesticide application*, pp. 57-65.

Zande J C van de, Michielsen J M G P, Stallinga H. 2000b. Spray drift when applying herbicides in sugar beet and maize using a band sprayer. *Mededelingen Faculteit Landbouwwetenschappen Rijksuniversiteit Gent* 65/2b:945-954.

Zande, JC van de, Michielsen JMGP, Stallinga H & Jong A de, 2000c. Ranking of low-drift nozzles and air assistance for spray drift. Paper 00-PM-066 presented at AgEng 2000, Warwick, UK. 2000. 9pp.

Zande, JC van de, B. Heijne & M. Wenneker, 2001. Spray drift reduction in orchard spraying. (state-of-the-art December 2001). Institute of Agricultural and Environmental Engineering / PPO-fruit, IMAG Report 2001-19, Wageningen. 38p. (in Dutch with English summary)