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Risk estimation of bystander and residential exposure from orchard spraying based on measured spray drift data

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Summary

In Dutch municipalities there is a discussion on the safe distance between houses and agricultural activities, especially the application of plant protection products (PPP) in fruit orchards. At this moment a generic safety distance or buffer zone of 50 m is taken into account. Based on general drift reducing measures taken by growers to reduce spray drift to the surface water it is questioned whether this safety distance can be reduced. An evaluation of spray drift data of standard and drift reducing techniques in orchard spraying is analysed for spray drift deposition to the soil and airborne spray drift next to the orchard. Based on spray drift deposition and estimated concentration in the air a comparison is made with dermal, inhalatory and secondary dermal Acceptable Exposure Limits (AEL) for humans. Based on the available spray drift data for standard conventional spraying and the use of venturi low-drift nozzles safety distances are estimated for people standing in the home garden, and at the front of the house. These distances are calculated for often used fungicides and insecticides in orchard, such as captan, thiram, fenoxycarb, flonicamid, methoxyfenozide, and pirimicarb. Safety distances are calculated for both the dormant and the full leaf stage of the trees. Such safety distances are based on the most important scenario by thiram in the full leaf stage and captan in the dormant leaf stage, and range between 20 and 50 m. Safe distances are more dependent on the toxicity of the PPP than on the spray drift level.

Keywords: low-drift nozzle type, spray drift, buffer zone, exposure

Introduction

Within Dutch municipalities there is an ongoing discussion about building houses close to fruit orchards. As space is scarce building activities of homes is often planned in areas close to agricultural activities and is often within 50 m of orchards. This is not allowed however unless it can be proven that smaller buffer zones do not influence negatively the risk to human health. So it is questioned which buffer zone width is necessary between the facade of the houses and the gardens to the outside of the orchard. The width of the buffer zone is thought to be predominantly dependent on the risk of spray drift. Spray drift is a direct source of human exposure, presenting a risk for people to be contaminated with PPPs when they are in the garden or standing in front of an open window in the house. Spray drift is dependent on spray technique, the growth stage of the tree canopy, and the used plant protection product and its dose. Based on earlier Dutch measurements of spray drift for standard and drift reducing spray techniques in orchards an evaluation is therefore made for spray drift deposition on soil surface and the amount of airborne drift next to the orchard. An evaluation is made for spray drift when spraying orchards in the dormant and in the full leaf situation. For the most used plant protection products the effect of their toxicity is used in evaluating the buffer zone width related to human dermal exposure, inhalation exposure and secondary dermal contact from soil surface spray drift deposition.

Material and Methods

Spray drift

An inventory was made on available research of standard and drift-reducing spray techniques in fruit growing in the Netherlands (Zande et al., 2001; Michielsen et al., 2007; Wenneker et al., 2007, 2008). Based on spray drift measurements with standard (Southcombe et al., 1997) and drift-reducing spray nozzles (VW&LNV, 2001; Zande et al., 2007) the spray drift reduction can be estimated at 5, 10, 15 m from the last tree row and the reduction to the air at 7.5 m distance from the last tree row relative to the spray drift deposition of the reference spray technique. The reference spray technique in orchard spraying is defined in the Netherlands as an Munckhof cross-flow fan sprayer equipped with Albuz ATR Lilac hollow cone nozzles spraying at 7 bar spray pressure, at a sprayer speed of 6.5 km/h (applying 200 l/ha with 3 m tree row spacing). Based on spray drift measurements to quantify the contribution of individual rows to spray drift deposition by Wenneker et al. (2007) and Michielsen et al. (2007) the drift at 20, 30 and 40 m can also be estimated, discriminated to soil deposit and airborne spray drift. Field measurements of spray drift were done according to the Dutch protocol (CIW, 2003) following the ISO-standard (ISO22866, 2006) to certify drift-reducing spray techniques (TCT-CIW, 2009). Spray drift was quantified down-wind on soil surface (Technofil TF-290; 0.50x0.10 m and 1.00x0.10 m) and to the air (Siebauer nr.00140; diameter 0.08 m) using a fluorescent tracer (Brilliant Sulpho Flavine; 3 g/l) and quantified using fluorimetry (Perkin Elmer LS45).

Plant protection products

For a limited number of fungicides and insecticides used in fruit crop spraying an evaluation can be made on the relation between spray drift and toxicity of the product. In Table 1 specifications are given on dose rate and applied volume of some frequently used PPP in fruit crop spraying.

Table 1. *Often used plant protection products in fruit crop growing with their grade of active substance, dose per unit area and applied amount of active substance per unit area (mg/m^2)*

Type of product	Product name	Active substance	Grade Active substance		Dose product		Applied amount active substance mg/m^2
Fungicide	Captan 80WG/ Malvin WG	captan	800	g/kg	1.5	kg/ha	120
Fungicide	Thiram Granuflow	thiram	800	g/kg	2	kg/ha	160
Insecticide	Insegar	fenoxycarb	267	g/kg	0.3	kg/ha	8
Insecticide	Teppeki	flonicamid	500	g/kg	0.14	kg/ha	7
Insecticide	Runner	methoxyfenozide	250	g/l	0.4	l/ha	10
Insecticide	Pirimor	pirimicarb	500	g/kg	0.5	kg/ha	25

The applied amount of active substance differs greatly from one product to another. For the insecticide flonicamid the dose is 7 mg/m2, while for the fungicide thiram the dose is 160 g/m2. Toxicity of the active substances can also differ. As for the risk assessment of bystanders or residents around PPP treated fields, no procedure is operational in the authorisation procedure. One possible setup based on measured spray drift and threshold values for the risk of PPP intake through dermal contact, inhalation or intake through food (Table 2). For the internal exposure of these PPP it is important to know the uptake through the skin, which varies per active substance (Table 2). For inhalation it is assumed that there is a 100% uptake from the air through the lungs. Secondary contact through deposited active substance through spray drift and skin contact, or even oral intake such as with small children crawling around on the grass around the house, is also a risk route. As exposure occurs on more days during the growing season, the semi-chronic exposure is used instead of toxicological end points, such as effects on body organs or LD50 values from animal studies.

Table 2. *Frequently used plant protection products in the Netherlands and their Acceptable Exposure Limit, dermal absorption level and the maximum acceptable dermal exposure level*

product	Type of product	AEL (mg/kg body.wt./day)	Dermal absorption (%)	Max. aceptable exposure (mg/m^2)
captan	fungicide	0.10	10	31.5
thiram	fungicide	0.02	10	6.3
fenoxycarb	insecticide	0.1	37	8.5
flonicamid	insecticide	0.025	50	1.6
methoxyfenozide	insecticide	0.1	8	39.4
pirimicarb	insecticide	0.035	13	8.5

Exposure

In the exposure calculations it is assumed that average adult person weight is 63 kg. It is also assumed that for the dermal risk the exposure surface area of the skin is 2 m^2. With the limits of table 2 the maximum Acceptable Exposure Level can be calculated for this person and what is deposited on the person based on the spray drift values per distance. For the person exposure the drift amount in the lower 3 m of air is averaged and curve fitted with distance to estimate the dermal exposure for people in the garden. For a person standing in the window in the house at the first floor in a similar way spray drift over distance is taken at 3-6 m height. Calculated total amounts depositing on a person can be expressed as percentage of the maximum Acceptable Exposure Level. This is done for a range of spray drift values from 0.1% to 25%. For the PPP crossing the threshold of acceptable exposure the minimum distance for a safe use is calculated.

For the inhalation exposure it is assumed that a person respires 1.25 m^3/hr air. Airborne spray drift passes the person in a relatively short time, normally less than a minute. Assuming a window where the air available for breathing passes of 1 m^2 and an average wind speed of 3 m /s the total drift amount is within an air volume of 180 m^3. From this air volume containing the PPP drift only 1/60th part is breathed in (1 minute of 1.25 m^3/hr). The uptake by a person can be quantified and compared with the AEL-systemic assuming a 100% adsorption in the lungs.

Indirect contact with spray drift deposition can e.g. occur when one is going into the garden, sunbathing, children playing outside or a baby crawling over the grass lawn after a spray event. An available model for re-entry of lawn areas after spraying the grass (Ctgb) is used for this situation (Falke, 2009).

Results

Spray drift

The spray drift deposition next to the sprayed field is for the reference spray technique in Dutch orchards presented in figure 1. Spray drift deposition on soil surface is presented for spraying an orchard in the dormant situation (before May 1st) and in the full leaf situation (after May 1st). With increasing distance downwind from the last tree row spray drift deposition decreases. In the full leaf situation spray drift deposition at 5 m distance from the last tree row is around 7%, while at 15 m and 30 m it is 0.75% and 0.2% respectively. In the dormant situation spray drift deposition at these distances is respectively 17%, 2% and 0.5%.

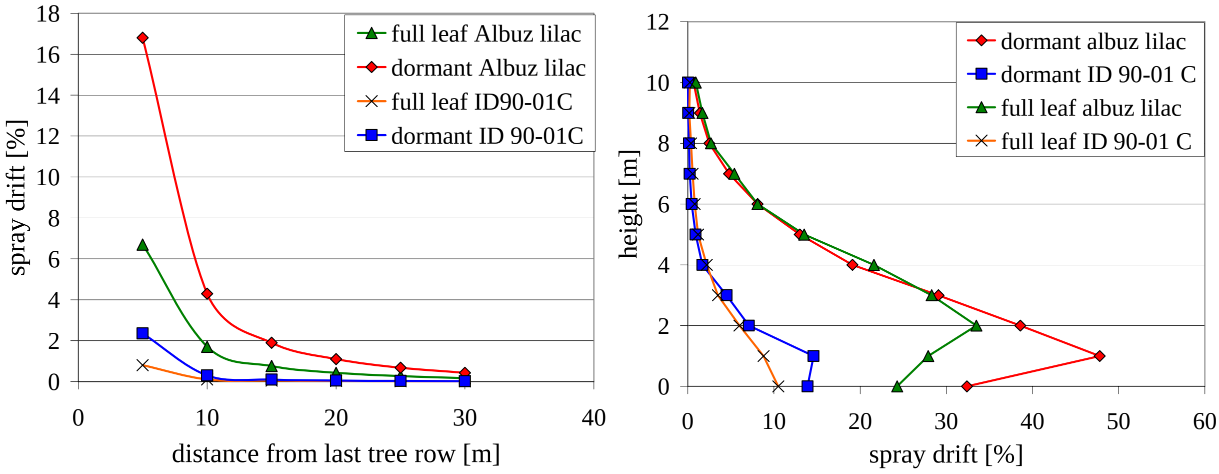

Figure 1 Airborne spray drift (% of sprayed volume) at 7.5 m from the last tree row (right) and spray drift deposition downwind (left) of a sprayed orchard with a standard cross-flow fan sprayer equipped with conventional hollow cone nozzles (Albuz lilac) and drift-reducing venturi nozzles (Lechler ID90-01C) in the dormant and in the full-leaf situation.

Drift reducing venturi nozzles (Lechler ID9001 at 5 bar spray pressure) and single sided application of the last tree row drift reduction measured by Wenneker *et al.* (2004) was used to calculate the drift deposition downwind of the orchard. Spray drift deposition for this drift-reducing technique was in the full leaf situation at 5 m, 15 m, and 30 m distances respectively 0.80%, 0,05%, and 0.01 % and in the dormant situation respctively 2.4%, 0.10% and 0.02%. Airborne spray drift at 7.5 m distance passing the measuring pole is presented in Figure 1. From individual tree row drift measurements (Michielsen et al., 2007) the two dimensional distribution of spray drift with height and distance from the last tree row outside the orchard could be generated (figure 2).

It is clear that airborne spray drift is not homogeneous but has in the full leaf situation higher values at tree top height than near soil surface. This is because the drift cloud is coming out of the orchard flowing over the top of the trees and is filtered through the tree canopy at heights lower than 3 m. For the dormant situation there is a strong decrease with distance from one central point onwards, the position of the sprayer. Whereas in the full leaf situation there is a steep decrease just next to the orchard because of the canopy filter and a slow decrease with distance. A 1% level is reached for the full leaf situation at 32 m distance from the last tree row and at more than 35 m for the dormant situation.

Exposure

Dermal

By comparing the total amount of deposited PPP on the human skin with the maximal allowable amount based on the internal exposure leading to effect, the fill-in level of this threshold can be given. In Table 3 the fill-in levels are given for the different PPP. With a spray drift level of 5% the dermal AEL for captan, flonicamid and pirimicarb are too high (>100). This is also the case for thiram at a spray drift level of 0.5% and of fenoxycarb at a level of 15%. The fill-in level for methoxyfenozide is not met even at the 25% spray drift level. For the active substance with the highest risk, being thiram, the effect of the different spray techniques on airborne spray drift passing at a height of 0-3 m and 3-6m were evaluated. For these heights, representing the height where persons can stand, and the first floor facade of a house the minimal distance needed to get below the critical threshold level for dermal AEL is calculated. These distances are presented in Table 4 for the dormant and the full leaf situation for a standard sprayer equipped with standard hollow cone nozzles and drift-reducing venturi flat fan nozzles. As thiram is only allowed to be used in the full leaf season the safety distances are also

Table 3. Fill-in level of the dermal AEL (%) of un uncovered person of $2m^2$ surface for different active ingredients at different levels of spray drift (0.1%-25%)

PPP	Active ingredient	spray drift %							
		0,1%	0,5%	1%	5%	10%	15%	20%	25%
Captan 80WG/ Malvin WG	captan	3,8	19	38	**190**	381	571	762	952
Thiram Granuflow	thiram	25	**127**	254	1270	2540	3810	5079	6349
Insegar	fenoxycarb	0,9	5	9	47	94	**141**	188	235
Teppeki	flonicamid	4	22	44	**222**	444	667	889	1111
Runner	methoxyfenozide	0,25	1,3	2,5	13	25	38	51	63
Pirimor	pirimicab	2,9	15	29	**147**	295	442	590	737

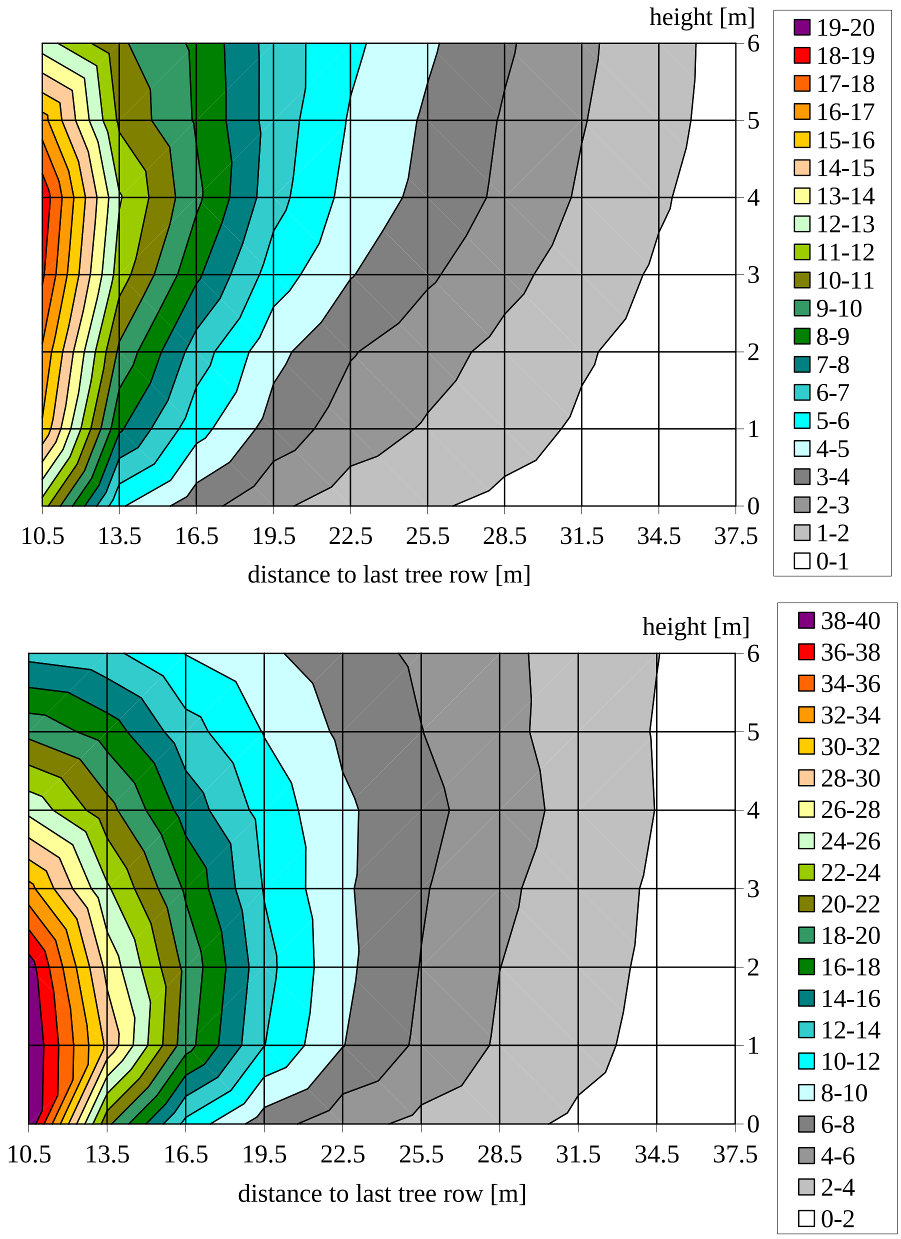

Figure 2. Gradients of airborne spray drift (% of sprayed volume) over distance from the last tree row and height downwind of a sprayed orchard with a standard cross-flow fan sprayer equipped with conventional hollow cone nozzles (Albuz lilac) in the full-leaf (top) and dormant (bottom) situation.

estimated for captan which is also allowed to be used against apple scab in the dormant situation.

In the full leaf situation spraying thiram the spray drift at a height of 0-3 m for both spray techniques the fill-in level is below 100 at a distance of 40 m. In the dormant situation this safe distance is 50 m. At 3-6 m the required distance to keep below the threshold level of the dermal AEL is more than 50 m for the standard spray technique equipped with standard hollow cone nozzles. If the sprayer is equipped with drift-reducing venturi nozzles the distance is 40m. In the dormant situation for both techniques a distance of 40 m is required.

For captan applied in the full leaf situation both the standard and the drift-reducing spray techniques need a distance of 30 m to get below the threshold dermal AEL. In the dormant situation for captan these distances are 40 m for the standard technique and 30 m for the drift-reducing nozzles.

Inhalation

In a similar way as for dermal exposure the risk for inhalation exposure can be presented. However, based on the assumption done for thiram no risk is calculated for distances wider than 10 m from the last tree crop row of the orchard. Also for the other mentioned PPP no risk was estimated for inhalation exposure.

Indirect dermal

Spray drift deposition at 10 m distance is 1.7 % for the conventional orchard spraying in the full leaf situation and 4.3% for the dormant situation. Using these spray drift figures for thiram in the full leaf and captan in the dormant situation never results in crossing the threshold values for dermal uptake. This means that for indirect dermal exposure 10 m distance is to be regarded as safe.

Discussion

With increasing width of the spray free buffer zones the spray drift deposition outside the field decreases. Therefore the risk for dermal, inhalatory and indirect dermal exposure reduces with distance from the sprayed orchard. The gradients with distance are, however, different for the soil surface spray drift deposit, spray drift in the lower air layers (0-3 m) where persons move around and the higher air layers (3-6 m) representing the facade of housing where a person is standing in front of an open window. It is shown that large differences do occur between plant protection products in toxicity, and in combination with applied dose results in different risks for individual PPP. Therefore minimum required buffer zone to have no risk for too high levels of dermal exposure are for thiram in the full leaf stage wider than for captan in the dormant orchard leaf situation despite the higher spray drift levels in the dormant situation.

The width of buffer zones to safeguard the bystanders and residents can be lessened by using drift reducing techniques, as presented. Nowadays drift reducing techniques are available classified in drift reduction classes of more than 95% (nozzle types, shielding in combination with drift-reducing nozzles; Wenneker & Zande, 2008a) and even 99% like tunnel sprayers equipped with drift-reducing venturi nozzles (JKI, 2009; TCT-CIW, 2009). Also shown to be effective can be a windbreak at the edge/surrounding the orchard, filtering the plant protection product blown away by the wind. Spray drift reductions of more than 90% in the full leaf situation were measured (Wenneker & Zande, 2008b). Use of these drift reducing techniques in combination with windbreaks or hedgerows would be beneficial to secure the surroundings of orchard.

Table 4. *Airborne spray drift (% of spray volume) and fill-in level (%) of the dermal Acceptable Exposure Level (AEL) for the active ingredients thiram and captan at two heights and different distances downwind from the last tree row when spraying an orchard with a standard cross-flow fan sprayer equipped with standard hollow cone nozzles (Albuz lilac) and venturi flat fan nozzles (Lechler ID90.01C) in the full leaf and the dormant situation*

	distance [m]	Airborne spray drift [%]				fill-in level of the dermal AEL of thiram [%]				fill-in level of the dermal AEL of captan [%]			
		Full leaf		dormant		Full leaf		dormant		Full leaf		dormant	
		cross-flow	cross+ venturi	cross-flow	cross+ venturi	cross-flow	cross+ venturi	cross-flow	cross+ venturi	cross-flow	cross+ venturi	cross-flow	cross+ venturi
Lower 0-3 m	10	15,6	11,5	39,7	29	3962	2922	10083	7378	594	438	1512	1107
	20	3,9	2,9	10,9	8,0	990	730	2768	2026	149	110	415	304
	30	1,3	1,0	3,1	2,3	330	243	787	576	50	37	118	86
	40	0,3	0,2	0,7	0,5	63	47	165	121	10	7	25	18
	50	0,1	0,1	0,2	0,1	20	15	43	32	3	2	6	5
3-6 m height	10	16,4	12,1	22,7	17	4165	3071	5765	4219	625	461	865	633
	20	6,3	4,6	10,4	7,6	1600	1180	2641	1933	240	177	396	290
	30	2,3	1,7	3,9	2,9	584	431	990	725	88	65	149	109
	40	0,6	0,4	1,1	0,8	152	112	279	204	23	17	42	31
	50	0,4	0,3	0,2	0,1	102	75	51	37	15	11	8	6

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