Nozzle Classification for Drift Reduction in Orchard Spraying; Identification of Drift Reduction Class Threshold Nozzles

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ABSTRACT

In fruit growing high values of spray drift are found compared to arable field applications. In arable spraying drift reducing nozzles are certified for use as drift reducing measures. The nozzles which may potentially reduce drift in fruit growing are not jet classified as drift reducing nozzles, although they are available on the market. The development of a nozzle classification system to identify the drift reduction potential of spray nozzles used in fruit crop spraying would open this market. The results of the initial setup of a nozzle classification system for spray drift reduction in orchard spraying based on drop size measurements is described. An evaluation was made of measured drop size characteristics of a series of nozzles in reference to performed field measurements of two characteristic nozzles; Albuz lilac and Lechler ID9001. Based on these anchor points the ranking of the volume fraction of drops smaller than 100 μm (V_{100}) of the nozzle to be classified could be scaled to yield a potential drift reduction, assuming a linear relationship between V_{100} and spray drift deposition. Within this system, the determination of threshold nozzles for the drift reduction classes 50%, 75%, 90% and 95% drift reduction are described. Identified threshold nozzles for these classes are TeeJet DG8002, Albuz AVI 80015, Lechler ID9001 and Albuz TVI80025 all at 7 bar spray pressure, except for the Lechler ID 9001 which is used at 5 bar pressure. These nozzles will be used in field drift measurements to validate the model.

Keywords: Spray drift, spray nozzle, orchard, fruit growing, crop protection, drift reduction, Netherlands

1. INTRODUCTION

Spray from nozzles consists of drops of different sizes. Depending on the size of the orifice, the shape of the nozzle and the pressure used the drop size distributions of alternative nozzles may differ. Classification systems have been developed to categorise drop size distributions for agricultural use (Doble *et al*., 1985; ASAE, 1999). These classification systems distinguish drop size ranges using recognisable terms such as Fine, Medium and Coarse spray qualities so that the information can be easily understood by operators. Measurements for these classification systems are predominantly performed with laser based systems (Parkin, 1993). Environmental concerns have raised the need to extend these original spray quality classification systems towards one that predicts spray drift potential (Southcombe *et al*., 1997). Porskamp *et al.* (1999) described a nozzle classification system for driftability based on Phase Doppler Anemometry and a drift model (Holterman *et al*., 1997) for arable boom sprayers. This system is used in certification of low drift nozzles for use in arable crops in the Netherlands (VW&LNV, 2001, 2005; TCT, 2007). Because of the high values of spray drift

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in orchard spraying (Zande *et al.*, 2001) compared to arable field applications (Huijsmans *et al.*, 1997), the reduction of the emission of plant protection products in fruit growing is still of major importance. However, research on emission reducing measures is costly. To prioritize research subjects and to use financial funds as economically as possible an Advisory Committee unanimously gave the highest priority to the development of a nozzle classification system for drift reduction in orchard spraying. The decisive arguments were:

- In earlier research it was shown that the combination of reduced air assistance, one-sided (inward) spraying of the outside tree row and a coarse spray quality nozzle reduced drift extensively (Wenneker *et al*., 2005);
- Low drift nozzles can be used on every (already in use) orchard sprayer;
- Low drift nozzles do not require high investments from the grower;
- Introduction of low drift nozzles for orchard spraying into practice can be fast;
- It links up with the used system of nozzle classification for drift reduction for field sprayers (Porskamp *et al.*, 1999), and international initiatives on nozzle classification (BBA, 2007; ISO/CD25358, 2007);
- It links up with the drift reduction class systematically used in the authorization procedure of crop protection products (Pesticide Act; Stienstra, 2008; CTGB, 2008) and the Water Pollution Act (VW/VROM/LNV, 2000; CIW, 2003).

A project was started to develop a nozzle classification system for drift reduction in orchard spraying. The methodology used is almost identical to the development and introduction of a nozzle classification system for drift reduction on boom sprayers (Porskamp *et al*., 1999). Approaches and methods are taken from the existing nozzle classification system for boom sprayers as far as possible. International developments in this field (ISO, ASAE, BCPC, EU-FOCUS) are taken into account. The stepwise approach of the project is summarized below, identifying the following work packages:

1. Drop size measurements: spray quality parameters (D_{V10}, $D_{V50,}$ D_{V90}, V_{100}) are measured for the reference nozzle, Albuz Lilac at 7 bar spray pressure, and for the Lechler ID9001 at 5 bar. For the latter nozzle it is already known from field measurements that the reduction in drift fall-out is 55% and 78% at 4.5-5.5m distance from the last tree row in the full-leaf stage with high and low air assistance, respectively. In the dormant tree situation drift fall-out reduction for this nozzle is 0% and 88% for low air assistance and air switched off, respectively (Wenneker *et al.*, 2005).
2. Comparison of measurements: a comparison of the ID9001 with nozzles classified as drift reducing with the nozzle classification system for boom sprayers is made. A first estimation of drift reduction percentage is made based on drop size measurements assuming a linear relationship between V_{100} and spray drift.
3. Determination of threshold values between drift reduction classes: threshold values are determined following the existing Dutch and international systems (ISO22369, 2006). Suggested drift reduction classes are 25, 50, 75, 90, 95 and 99%. Nozzles already classified for arable crop spraying are evaluated where they fit in the suggested system.
4. Nozzle evaluation: an evaluation of potential drift reduction for nozzles used in orchard spraying is made. Criteria are e.g. spray volume ranging from 200 l/ha to 1000 l/ha at an average driving speed of 6.5 km/h.
5. Drop-size measurements of selected nozzles: spray quality and drop speed measurements are carried out for a range of nozzles potentially to be used as drift

reducing nozzles in orchard spraying. Nozzle-pressure combinations closest to the border of classes are identified, representing the class threshold nozzles of the classes 50, 75, 90, 95 (and 99%).

6. Field measurements of spray drift: field measurements of spray drift are done with the identified class threshold nozzles and the reference nozzle (reference, 50, 75, 90, 95, 99% nozzles). Measurements are performed with three set-ups of air assistance (no air, half and full air) of the identified reference sprayer type for orchard spraying (Munckhof cross-flow fan) in a dormant and a full canopy situation of an orchard.
7. Model development: based on the boom sprayer model a model is developed for the calculation of spray drift from orchard spraying. Essential difference from the boom sprayer model is that with cross-flow orchard sprayers spray direction is horizontal contrary to the downward direction of the spray in boom spraying. As orchard canopy density influences spray drift, by acting as a filter this should be incorporated in the model too.
8. Reporting and implementation: the results will be reported and the implementation of the nozzle classification system in the regulatory boards will be started.

This paper describes the results of the work packages 1-5; the initial setup of the system based on drop size measurements, and determination of the drift reduction class threshold nozzles that will be used in the field drift measurements to validate the model.

2. MATERIALS AND METHODS

A series of nozzles used in spray applications for fruit growing was identified to quantify drop size distribution in the spray fan (Parkin, 1993). Also potentially drift reducing nozzles were identified based on experience from arable crop spraying and those provided by spray nozzle manufacturers. The spray nozzles selected to identify drift reducing potential in orchard spraying are listed in table 1. Different hollow-cone and flat-fan nozzles were represented, of standard, pre-orifice and venturi types, covering various sizes and flow rates. Spray pressure used during the drop size measurements was 7 bar. Drop size measurements were performed

Table 1. Nozzles used in this study to evaluate drift reduction potential in orchard spraying

Manufacturer	Nozzle type	Nozzle specification
Albuz	Hollow cone	ATR80 lilac, brown, yellow, red, blue
	Venturi flat fan	AVI80015
	Venturi cone	TVI8001, TVI80015, TVI80025, TVI8003
TeeJet	Flat fan	XR8001, XR8002, XR8003, XR8004, XR8005
	Pre-orifice flat fan	DG80015, DG8002
	Venturi flat fan	AI80015, AI8002, AI80025, AI8003, AI6503
Lechler	Venturi flat fan	ID9001, ID90015

with the nozzles of the BCPC spray quality classification system (VF/F, F/M, M/C, C/VC, VC/XC) using their typical spray pressure (Southcombe *et al.,* 1997). The Lechler ID9001

was also measured at 5 bar pressure to be able to compare the data with earlier performed spray drift measurements in the orchard (Wenneker *et al*., 2005)

Spray quality was quantified using a Phase Doppler Particle Analyser (PDPA, Aerometrics). All measurements were performed on three nozzles – selected from a set of 10 – whose flow rates were closest to the median for each batch.

Spray liquid was tap water of 20^{o}C. Measurements were performed in a conditioned room at 20^{o}C and 70% RH. Nozzle height above the measuring volume of the laser was 0.50 m. Nozzle to floor distance was 1.20 m. During measurements the nozzle was moved in a 3D-traverse system. Nine tracks were made at distance intervals of 0.04m, sampling the complete fan (Figure 1). Traversing speed was 0.04 m s^{-1}. Results of the drop size measurements are presented as:

- D_{V10} [µm]; 10% of the spray volume consists of drops with a diameter smaller than the value of D_{V10};
- D_{V50} [µm] = VMD [µm] (Volume Median Diameter); 50% of the spray volume consists of drops with a diameter smaller than the value of D_{V50};
- D_{V90} [µm]; 90% of the spray volume consists of drops with a diameter smaller than the value of D_{V90};
- V_{100} [%]; percentage of volume of drops having a diameter smaller than 100 µm.

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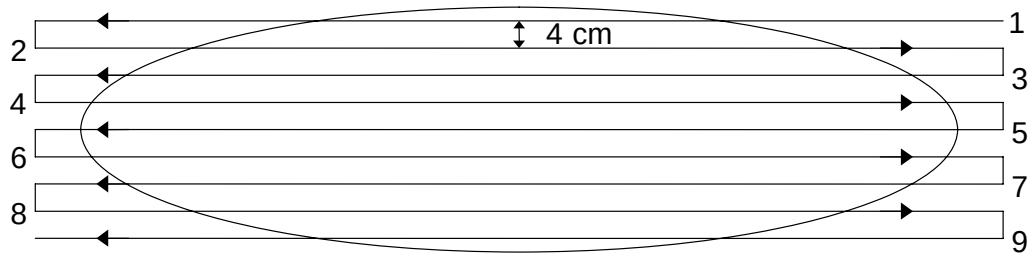

Figure 1. Pattern of tracks sampling the spray in a horizontal plane 0.50m below the nozzle for spray quality

Based on the ratio between the values of the V_{100} of the reference nozzle ($V_{100\ ref}$) and the candidate nozzles ($V_{100\ nozzle}$) the potential in spray drift reduction based on V_{100} (DR_{V100}) is estimated as:

$$DR_{V100} = (1 - V_{100\ nozzle} / V_{100ref}) * 100 \quad [\%]$$

These potential drift reduction values based on V_{100} are also compared to the measured drift reductions from spray drift field experiments (Wenneker *et al.*, 2005) for the reference nozzle and the Lechler ID9001 nozzle sprayed at 5 bar spray pressure. Measurements were performed in the full leaf stage with a cross-flow fan sprayer with a high and a low fan capacity. In the dormant, leaf developing growth stage drift measurements were performed with the same orchard sprayer with a low fan capacity setting and with the fan shut off.

3. RESULTS

Results of the drop size measurements (PDPA Aerometrics) show a large variation in drop sizes over the different nozzle types (Table 2). Whereas the finest spray in these measurements produce a D_{V50} of 143 μm (Albuz; lilac/brown) the coarsest spray produces one of 671 μm (Albuz; TVI 80025). Also the fraction of spray volume with drops smaller than 100 μm (V_{100}) differs between 23.3% for the finest spray and 0.6% for the coarsest spray

Table 2. Drop size specifications of different nozzles used in fruit crop spraying, arranged for increasing V_{100}.

Manufacturer +nozzle	Flat fan/ Cone	Venturi	Spray Pressure [bar]	Flow rate [l/min]	D_{V10} [μm]	D_{V50} [μm]	D_{V90} [μm]	V_{100} [%]
Albuz; TVI 80025	C	x	7	1.49	289	671	1095	0.6
Albuz; TVI 8003	C	x	7	1.82	239	555	947	1.0
Albuz; TVI 8001	C	x	7	0.63	224	563	972	1.1
Albuz; TVI 80015	C	x	7	0.91	214	493	852	1.2
Lechler; ID 9001	F	x	5	0.49	190	465	811	2.0
BCPC VC/XC	F		2	4.64	180	454	801	2.6
Lechler; ID 90015	F	x	7	0.88	161	399	703	3.1
Teejet; AI 80025	F	x	7	1.50	159	397	734	3.2
Lechler; ID 9001	F	x	7	0.58	156	378	685	3.2
Teejet; AI 8003	F	x	7	1.83	156	387	701	3.4
Teejet; AI 6503	F	x	7	1.82	157	399	717	3.5
Teejet; AI 80015	F	x	7	0.96	145	345	630	4.0
Teejet; AI 8002	F	x	7	1.23	143	341	627	4.2
BCPC C/VC	F		2.5	2.88	147	373	656	4.2
BCPC M/C	F		2	2.00	126	288	525	5.6
Albuz; AVI 80015	F	x	7	0.90	123	283	524	6.1
Teejet; DG 8002	F		7	1.20	106	236	433	8.7
BCPC F/M	F		3	1.32	99	220	409	10.3
Teejet; XR 8005	F		7	3.02	90	220	416	12.6
Teejet DG 80015	F		7	0.90	88	195	354	13.4
Teejet; XR 8004	F		7	2.44	87	207	393	13.7
Albuz; blue	C		7	2.88	86	205	381	14.0
Teejet; XR 8003	F		7	1.83	81	189	355	16.0
Albuz; red	C		7	1.67	77	173	321	18.5
Teejet; XR 8002	F		7	1.23	76	171	316	18.8
BCPC VF/F	F		4.5	0.48	72	155	276	21.8
Albuz; lilac	C		7	0.44	71	143	238	23.1
Albuz; brown	C		7	0.56	71	143	241	23.2
Teejet; XR 8001	F		7	0.63	69	151	278	23.3
Albuz; yellow	C		7	0.85	71	146	255	23.3

(Figure 2). The large differences in V_{100} suggest that large differences between nozzles can occur with respect to spray drift.

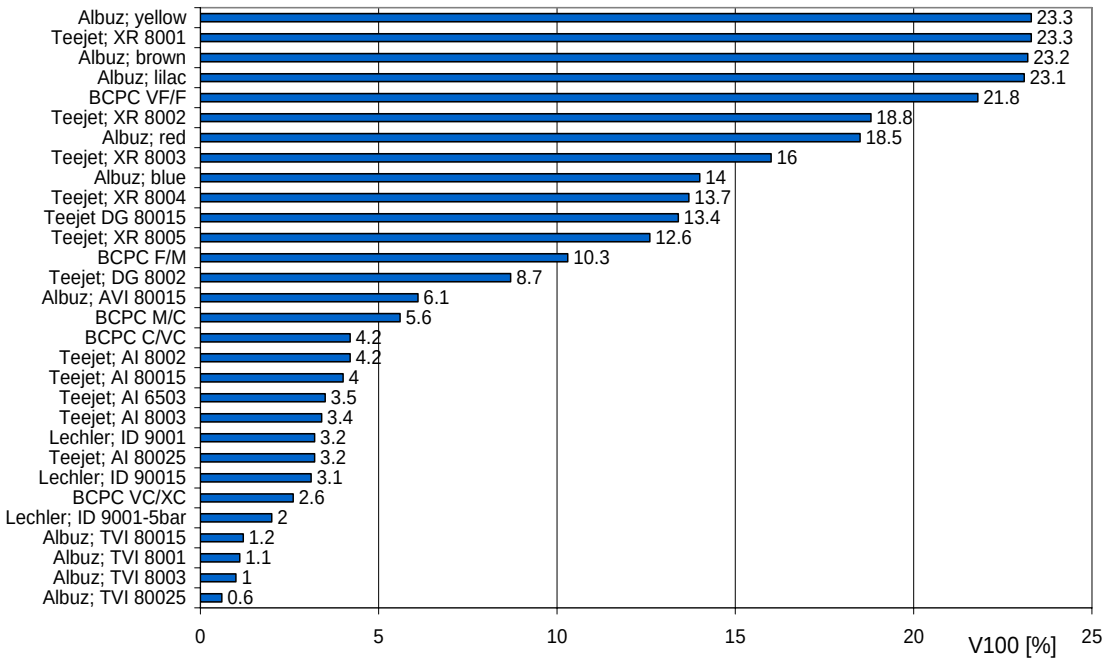

Figure 2. Ranking of measured nozzles used in orchard spraying based on volume of drops smaller than 100 μm (V_{100})

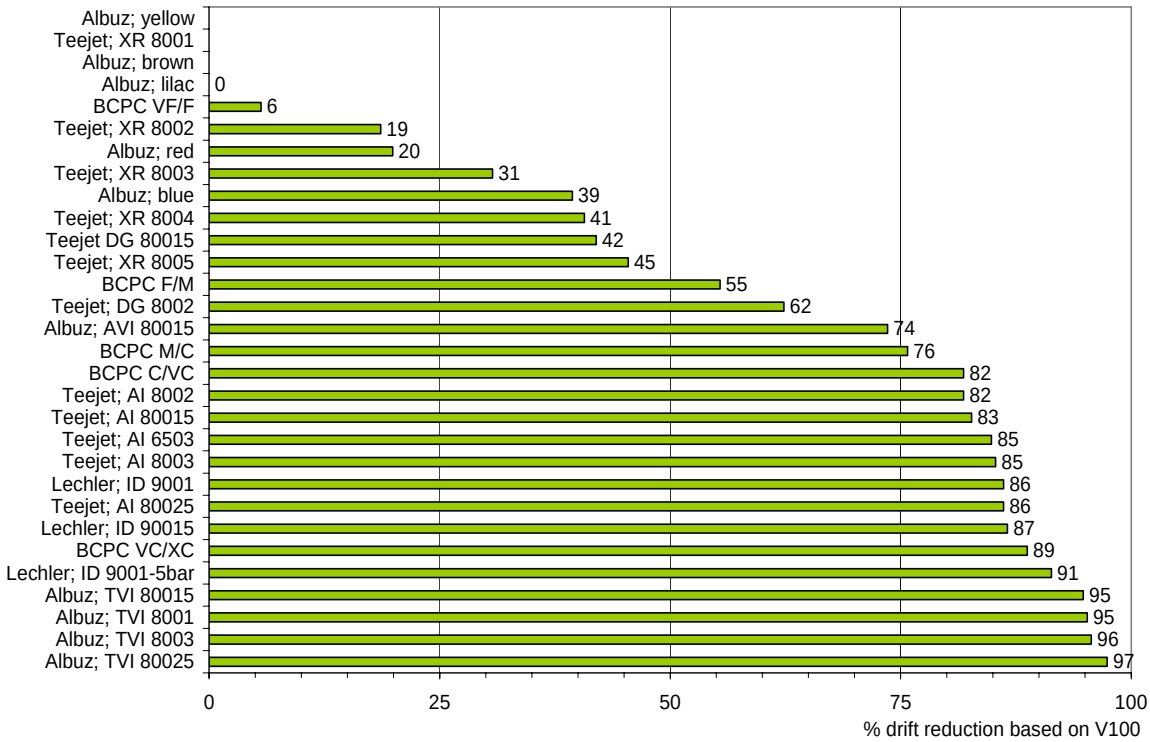

Figure 3. Potential in spray drift reduction based on V_{100} (DR_{V100}) relative to the reference nozzle Albuz Lilac (7 bar spray pressure)

The potential in spray drift reduction based on V_{100} (DR_{V100}) is estimated and presented in Figure 3. Based on the reduction in V_{100} between reference and candidate nozzle it is estimated that the highest drift reduction can be obtained with the Albuz TVI 80025 being 97%. The ID9001 sprayed at 5 bar which was used in the spray drift field tests (Wenneker *et al*., 2005) reduces spray drift based on V_{100} potentially by 91%. Compared to the Albuz Lilac reference nozzle (7 bar) the threshold nozzles of the BCPC nozzle classification system (Southcombe *et al.,* 1997) would reduce spray drift potentially by 6% for the VF/F threshold nozzle, 55% for the F/M, 76% for the M/C, 82% for the C/VC and 89% for the VC/XC threshold nozzle. Because the M/C threshold nozzle of the BCPC system is not easily available for field testing and large differences do occur in commercial available nozzles of a similar flow rate (Zande *et al*., 2002) this nozzle is not chosen as a 50% threshold nozzle for the orchard nozzle classification system, although close to the threshold value (55%). As the BCPC VC/XC has a flow rate beyond what is practically used in orchard spraying this nozzle is also not chosen as a 90% reference nozzle for the orchard nozzle classification system although its drift reduction value is estimated as 89%.

From figure 3 the suggested threshold nozzles for the drift reduction classes 50%, 75%, 90% and 95% are respectively; TeeJet DG8002 (62%), Albuz AVI 80015 (74%), Lechler ID9001 (91%) and Albuz TVI80025 (97%) all at 7 bar spray pressure, except for the Lechler ID 9001 which is used at 5 bar pressure.

From the series of measured nozzles used in fruit crop spraying it is clear that entries do already exist in the different suggested drift reduction classes. In the drift reduction class 50% no nozzles have been measured, but in the 75% drift reduction class entries are TeeJet AI80015, AI8002, AI 8003, AI6503 and the Lechler ID9001 at 7 bar spray pressure. In the 90% drift reduction class entries are Albuz TVI80015, TVI8001 and TVI8003. The Albuz TVI80025 has a slightly coarser spray and is suggested to be the threshold nozzle for the 95% drift reduction class. A classification into drift reduction classes based on drop size measurement and potential drift reduction estimation based on the volume fraction of drops smaller than 100 μm in the spray fan seems to be possible.

4. DISCUSSION

The results of the drop size measurements (V_{100}) are used to make a comparison with results from spray drift measurements in the field (Wenneker *et al.,* 2005). In the Netherlands the Albuz lilac sprayed at 7 bar pressure is part of the reference spray system used in spray drift evaluation for orchard spraying (Huijsmans *et al.,* 1997). The orchard reference spray system is a cross-flow fan sprayer used with a high air capacity in the full leaf situation (after May 1st) and in the low air capacity setting in the dormant and developing foliage situation (before May 1st). This reference sprayer is used for comparative reasons in order to make spray drift data exchangeable between tests and is used in the certification procedure for low drift spray techniques (CIW, 2003; TCT, 2007) and in the authorization procedure for agrochemicals used in tree crops in the Netherlands (Stienstra, 2008; CTGB, 2008). One of the certified drift reducing spray techniques in orchard spraying is the use of venturi flat fan nozzles (Lechler ID 9001) sprayed at 5 bar spray pressure (Wenneker *et al.*, 2005; VW, 2008). The set-up involving venturi type nozzle at 5 bar spray pressure, maximum air capacity and one-sided spraying of the last tree row (only towards the orchard not in the direction of the water surface) with a cross-flow fan orchard sprayer gave in the full leaf situation a drift reduction of 88% on the surface water next to the orchard (4.5-4.5 m from the last tree row). In the

dormant situation the set-up involving venturi nozzle type, two-sided spraying, without air assistance gave a drift reduction of 88% as well. Used with half air settings and spraying in both directions the drift reduction of the ID9001 nozzle (5 bar) was 78% in the full leaf situation and 0% in the dormant situation. Spraying with full air towards both sides of the sprayer in the full leaf situation resulted in a drift reduction of 55% compared to the Albuz lilac nozzle (7 bar). This shows that not only the driftable fraction of drops in the spray is an important factor in spray drift but also the configuration of the sprayer, mainly the air settings.
These spray drift results can be used to estimate the potential drift reduction by scaling the expected drift reduction based on V_{100}. After scaling, the threshold nozzles identified above would reduce spray drift by 60% for the DG8002, 71% for the AVI80015, 88% for the ID9001 (5 bar) and 94% for the TVI80025 (Table 3) when used in the full leaf situation spraying with full air capacity and single sided spraying of the outside tree row. Spray drift measurements in the field are set-up to confirm this theory for the reference Munckhof cross-flow axial-fan sprayer. Estimated potential drift reductions for the different nozzles for the full leaf situation with either full air or half air capacity and full air with one-sided spraying of the last row is given in Table 3. Note that the column for full air, one-sided spraying in the full leaf situation coincides with the data for one-sided spraying without air assistance in the dormant situation.
Presented drop size characteristics of the nozzles of the BCPC nozzle classification system (Southcombe *et al.,* 1997) make it possible to exchange nozzles classified in other classification systems such as the one which is already in use for nozzles used on boom sprayers in the Netherlands (Porskamp et al., 1999; TCT, 2007; VW&LNV, 2001, 2005) and in Germany (BBA, 2007). For boom sprayers nozzles are certified as being low drift when the volume fraction of drops smaller than 100 μm (V_{100}) is less than 50% of that of the BCPC F/M threshold nozzle (VW&LNV, 2001). From series of nozzles used in orchard spraying it is clear that the reference nozzle in the certification system for low drift for boom sprayers, the threshold nozzle BCPC F/M, already has a 50% drift reduction compared to the
reference nozzle (Albuz lilac) of the nozzle classification system for orchard sprayers. The orchard reference nozzle (Albuz lilac) is almost as Fine as the VF/F nozzle of the BCPC nozzle classification system.
Based on the drop size spectra the nozzles used in orchard spraying are much finer and therefore the drift potential based on V_{100} is higher for nozzles used in fruit crop spraying than of the nozzles used in arable crop boom spraying, irrespective of whether the spray is directed downward for arable crops or upward for orchard crops and the amount of air assistance.

Table 3. Estimated drift reduction for spray applications in dormant and full-leaf trees, for a cross-flow orchard sprayer with half or full capacity air settings and without air based on the ratio of volume fraction of drops in the spray fan smaller than 100 μm (Albuz lilac at 7 bar – Lechler ID9001 at 5 bar spray pressure) and available spray drift deposition data of those nozzles on the water surface area next to the orchard (4.5-5.5m from the last tree row)

Manufacturer + nozzle	Flat fan / cone	Venturi	Spray pressure [bar]	Flow rate [l/min]	Drift reduction % Based on V_{100}	Scaled drift reductions [%]		
						Full leaf, full air	Full leaf, half air	Full leaf full air one-sided = Dormant no air
Albuz; TVI 80025	C	x	7	1.49	**97**	**59**	**83**	**94^{+})**
Albuz; TVI 8003	C	x	7	1.82	96	58	82	92
Albuz; TVI 8001	C	x	7	0.63	95	57	81	92
Albuz; TVI 80015	C	x	7	0.91	95	57	81	91
Lechler; ID 9001 (5bar)	F	x	5	0.49	**91**	**55*)**	**78*)**	**88*$^{+}$)**
BCPC VC/XC	F		2	4.64	89	53	76	85
Lechler; ID 90015	F	x	7	0.88	87	52	74	83
Teejet; AI 80025	F	x	7	1.50	86	52	74	83
Lechler; ID 9001	F	x	7	0.58	86	52	74	83
Teejet; AI 8003	F	x	7	1.83	85	51	73	82
Teejet; AI 6503	F	x	7	1.82	85	51	72	82
Teejet; AI 80015	F	x	7	0.96	83	50	71	80
Teejet; AI 8002	F	x	7	1.23	82	49	70	79
BCPC C/VC	F		2.5	2.88	82	49	70	79
BCPC M/C	F		2	2.00	76	46	65	73
Albuz; AVI 80015	F	x	7	0.90	**74**	**44**	**63**	**71^{+})**
Teejet; DG 8002	F		7	1.20	**62**	**38**	**53**	**60^{+})**
BCPC F/M	F		3	1.32	55	33	47	53
Teejet; XR 8005	F		7	3.02	45	27	39	44
Teejet DG 80015	F		7	0.90	42	25	36	40
Teejet; XR 8004	F		7	2.44	41	25	35	39
Albuz; blauw	C		7	2.88	39	24	34	38
Teejet; XR 8003	F		7	1.83	31	19	26	30
Albuz; red	C		7	1.67	20	12	17	19
Teejet; XR 8002	F		7	1.23	19	11	16	18
BCPC VF/F	F		4.5	0.48	6	3	5	5
Albuz; lilac	C		7	0.44	**0 #)**	**0 #)**	**0 #)**	**0 #$^{+}$)**
Albuz; brown	C		7	0.56				
Teejet; XR 8001	F		7	0.63				
Albuz; yellow	C		7	0.85				

*) field measurements #) by definition $^{+}$) suggested threshold nozzle

5. CONCLUSIONS

For a series of nozzles used in fruit growing droplet characteristics were measured. Measured volume fractions of drops smaller than 100μm (V_{100}) ranged from 0.6% to 23%. An evaluation was made in reference to performed field measurements of two characteristic nozzles; Albuz lilac and Lechler ID9001, and based on these anchor points the V_{100} of the nozzles could be ranked to potential drift reduction assuming a linear relation between V_{100} and spray drift deposition. Nozzle-pressure combinations closest to the border of classes were identified, representing the class threshold nozzles of the classes 50, 75, 90, and 95%. Suggested threshold nozzles for these drift reduction classes are respectively; TeeJet DG8002, Albuz AVI 80015, Lechler ID9001 and Albuz TVI80025 all at 7 bar spray pressure, except for the Lechler ID 9001 which is used at 5 bar pressure.

Table 4. Identified threshold nozzles for drift reduction classification in orchard spraying

Spray drift reduction class	Spray nozzle	Pressure (bar)	Reduction to Albuz lilac (%)
reference	Albuz lila	7	0
50%	TeeJet DG8002	7	62
75%	Albuz AVI 80015	7	74
90%	Lechler ID9001	5	91
95%	Albuz TVI80025	7	97

From the series of measured nozzle types used in spraying for fruit growing it is clear that entries are available for the different drift reduction classes. Although no representatives were measured in the 50% drift reduction class, except the DG8002; in the 75% drift reduction class the nozzle types TeeJet AI80015, AI8002, AI8003 en AI6503 and the Lechler ID9001 and ID90015 venturi flat fan nozzles at 7 bar spray pressure were identified. In the drift reduction class 90% already the nozzle types Albuz TVI 80015, TVI8001 and TVI8003 were measured. The Albuz TVI 80025 was even coarser and gave the highest drift reduction potential at the moment and is therefore used as threshold nozzle for the 95% drift reduction class. Drift measurements are planned to verify the model approach for the nozzle classification in orchard spraying.

6. ACKNOWLEDGEMENT

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7. REFERENCES

ASAE, 1999. *Spray nozzle classification by droplet spectra*. American Society of Agricultural Engineers, ASAE S572 AUG99, St. Joseph, 1999. 3p.

BBA, 2007. *Verzeichnis Verlustmindernde Geräte*. www.bba.de

CIW, 2003. *Beoordelingsmethodiek emissiereducerende maatregelen Lozingenbesluit open teelt en veehouderij*. Ministerie van Verkeer en Waterstaat, Commissie Integraal Waterbeheer, Werkgroep 4 Water en milieu, Den Haag. 2003. 82p.

CTGB, 2008. *Used low drift application techniques in the authorization procedure of crop protection products*. www.ctb-wageningen.nl

Doble, S.J., G.A.Mathews, I. Rutherford & E.S.E. Southcombe, 1985. A system for classifying nozzles and other atomizers into categories of spray quality. *Proc. British Crop Protection Conference - Weeds*, 1125-1133.

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

Huijsmans, J.F.M., H.A.J. Porskamp & J.C. van de Zande, 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-22369, 2006. *Crop protection equipment – Drift classification of spraying equipment. Part 1. Classes.* International Organization for Standardization, Geneva.

ISO/CD25358, 2007. *Crop protection equipment – Measurement and classification procedure for droplet size spectra from atomizers*. ISO/TC23/SC6/WG13

Parkin, C.S., 1993. *Methods for measuring spray droplet sizes*. In: Mathews G.A. & E.C. Hislop, Application technology for crop protection. CAB International, Wallingdorf. 1993. 57-84

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

Southcombe, E.S.E., P.C.H. Miller, H. Ganzelmeier, J.C. van de Zande, A. Miralles & A.J. Hewitt, 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. 371-380

Stienstra, Y.J., 2008. Spray drift mitigation measures in the authorisation of pesticides – The Dutch Approach. *Aspects of Applied Biology 84, International Advances in Pesticide Application, 2008.* 115-122

TCT, 2007. *Beoordeling emissiebeperkende maatregelen*. www.helpdeskwater.nl

VW, 2008. *List of certified low drift spray techniques.* www.wateremissies.nl

VW & LNV, 2001. *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. 18-21 (in Dutch)

VW & LNV, 2005. Wijziging Regeling driftarme doppen Lozingenbesluit open teelt en veehouderij (actualisatie lijst driftarme doppen). Staatscourant 7 november 2005. nr. 216, 15 p.

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

Wenneker M., B. Heijne & J.C. van de Zande, 2005. Effect of air induction nozzle (coarse droplet), air assistance and one-sided spraying of the outer tree row on spray drift in orchard spraying. *Annual Review of Agricultural Engineering,* 4(2005)1: 116 – 128

Zande, J.C. 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).

Zande, J.C. van de, H.A.J. Porskamp & H.J. Holterman, 2002. Influence of reference nozzle choice on spray drift classification. *Aspects of Applied Biology 66, International advances in pesticide application.* Wellesbourne, 2002. 49-56