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Improved spray deposition in full-leaf orchard spraying by sprayer type, nozzle type and air setting

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Summary

To improve the current practice of spray application in pome fruit crops a research programme was setup assessing spray and liquid distribution of nowadays commonly used orchard sprayers. Improved spray deposition can lead to reduced use of agrochemicals and therefore reduced emission to the environment while maintaining high levels of spray drift reduction and biological efficacy Spray deposition and distribution in full-leaf apple trees was assessed for single row cross-flow fan sprayers (Munckhof, HSS), multiple-row sprayers (Munckhof, KWH) and a two-row tunnel sprayer (Lochmann). For the single and multiple row sprayers a distinction is made in the air delivery system; designed as a continuous slot and as spouts. Potential pathways of improvement identified are: (i) air amount, (ii) air distribution, and (iii) nozzle type, and therefore liquid distribution as the spray is transported by the moving air into the tree canopy. In a series of experiments, spray deposition measurements were carried out comparing the different sprayers and settings against a standard spray application, following the ISO-22522 protocol. Higher levels of spray deposition in tree canopy were observed with the use of 90% drift reducing venturi type nozzles, lower air assistance levels, multiple row spray applications, and its combinations. With optimised settings of the sprayer spray deposition at the leaves in the tree canopy at full leaf stage can be up to more than 50% higher compared to the standard settings of the sprayer in a similar situation. Overall results of the research are discussed, as well as how data may be presented following increased in-tree spray deposition. The results open the way to a classification system of sprayers with levels of improved spray deposition.

Key words: Orchard sprayer, spray deposition, air assistance, nozzle type, full leaf growth stage

Introduction

Despite many years of spray drift research and the mandatory implementation of Drift Reducing Techniques (DRT) of at least 75% for arable crops and 90% for fruit crops alongside waterways in the Netherlands, measured plant protection products (PPP) in surface water show that the current legislation and measures taken are insufficient to protect the surface water (Tiktak *et al*., 2019). So, regarding surface water quality, more is to be done than spray drift reduction alone. The reduction of PPP input can be a perspective route to meet todays and future goals of minimal emission and use of PPP.

To improve the current practice of spray application in fruit crops a research programme was setup. The objective was to find the optimum combination of application parameters for different stages of fruit tree canopy development to reduce spray drift while improving spray deposition. In a series of trials, spray deposition measurements were carried out following the ISO-22522 protocol. In the experiments multiple row orchard sprayers of several manufacturers (Munckhof, KWH, Lochmann) were compared to conventional cross-flow fan sprayers (Munckhof, Hol Spraying Systems). Different levels of air assistance and nozzle types were included in the experimental set up. Spray and liquid distribution of these nowadays often used single- and multiple-row orchard sprayers were assessed, and spray deposition and distribution were measured in an apple orchard (Michielsen *et al*., 2019, Wenneker *et al*., 2012, 2014, 2016, 2018, Zande *et al*., 2018). Improved spray deposition may lead to reduced use of agrochemical and reduced emission to the environment while maintaining high levels of spray drift reduction and biological efficacy.

In this paper results are presented of the spray deposition at the leaves in the tree canopy at the full leaf development stage of a fruit crop using single row and multiple row orchard sprayers.

Materials and Methods

Experimental set up

Spray deposition measurements and sampling procedure were carried out following the ISO22522 standard, adapted for the orchard layout, equipment used and research questions, picking leaves from the different tree compartments and measuring ground spray deposition. Apple trees were sprayed with a solution containing the fluorescent dye Brilliant Sulpho Flavine (BSF; 0,5–1 g L^{-1}) and a non-ionic surfactant (Agral; 7,5 mL 100 L^{-1}). The spray deposition experiments were carried out in the full leaf situation of the apple trees (June–October 2016–2018; BBCH 72–91) in an apple orchard (cv. Elstar) at WageningenUR Experimental Station for Fruit Crops in Randwijk The Netherlands. Tree height was about 2.75 m, tree row spacing 3.0 m and tree spacing in the row 1.10 m. Four repetitions were made, i.e. spraying 30 m of a single tree row from both sides for the standard sprayer and two rows for the multiple row sprayers, and analysing leaves samples from four individual trees. Leaf samples were taken by counting all leaves in seven tree sections (P1–P7; Fig. 2): Top (P7), Mid West (P5), Mid East (P6), Bottom Outside West (P1), Bottom Inside West (P2), Bottom Inside East (P3), Bottom Outside East (P4), and putting every 10^{th} leaf in a bag. The picked leaves were analysed in the laboratory for spray deposition of the sprayed fluorescent tracer BSF. The leaf surface areas were determined, and the spray specific deposition (µL cm^{-2}) was calculated. Spray deposition on ground surface was measured underneath the tree rows and in the paths in between the tree rows. Ground collectors (Technofil TF290; 100 cm × 10 cm) were laid out on both sides from the treated tree row, underneath the trees and in between the tree rows on the grass strips, up to 4.5 m in the upwind direction and to 7.5 m in the downwind direction. Vertical spray distribution going into the treated tree row was measured up till 3 m height using three collectors (Technofil TF290; 100 cm × 10 cm) on top of each other attached to a vertical pole in front of the treated row. Spray passing the trees and entering the next, second and the third tree row was measured downwind and upwind at collectors (Whatman no. 2; 300 cm × 2 cm) attached to vertical poles of 3 m height (resp. at 2 m, 5 m and 8 m from the treated row).

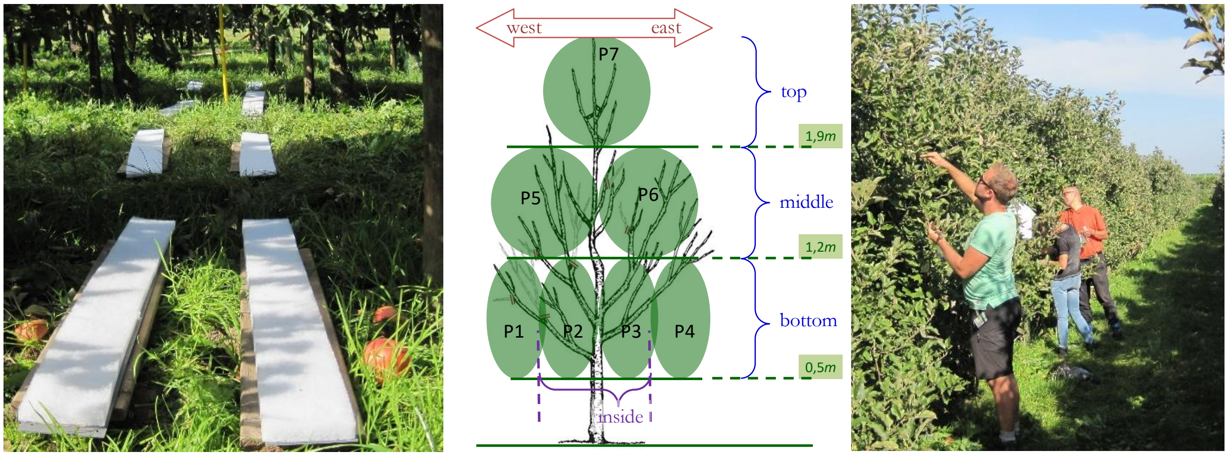

Fig. 1. Spray deposition measurement on collectors on the ground (left), leaf picking in the tree canopy (right) following the sampling scheme (centre).

Treatments

In this experiment different treatments were compared against a defined reference spray technique; the other techniques were evaluated in their standard setting for the full leaf development stage of the fruit trees, a standard sprayer setting using a 90% drift reducing nozzle (Zande *et al*., 2008) and one of the sprayer settings having the highest spray deposition in tree crop canopy at the full leaf stage from specific spray deposition optimisation research (Michielsen *et al*., 2019; Wenneker *et al*., 2014, 2018; Zande *et al*., 2018). The reference/standard technique was a conventional cross-flow fan sprayer (Munckhof); Albuz ATR lilac at 7 bar spray pressure (Very Fine spray quality; Southcombe *et al*., 1997), low gear air setting, 540 rpm PTO; 200 L ha^{-1}. Other techniques used were (Table 1)

Table 1. *Used application techniques in the spray deposition measurements in the period 2016–2018 at full leaf growth stage of the apple trees, set forward speed was 6.7 km h^{-1}*

Object	Sprayer	Nozzle	Pressure [bar]	Air assistance	Spray volume [L ha^{-1}]
1	Munckhof cross-flow	Lilac[1)]	7	High gear fan, 540 rpm PTO	200
2		TVI8001		High gear fan, 540 rpm PTO	300
3		TVI8001		Low gear fan, 300 rpm PTO	300
4	HSS cross-flow	Lilac		High; 2100 rpm fan	200
5		TVI8001		High; 2100 rpm fan	300
6		IDK9001	3	Low; 1800 rpm fan	200
7	Lochmann 2-row tunnel	Lilac	7	High, 540 rpm PTO	200
8		TVI8001		Low, 400 rpm PTO	300
9		TVI8001		Low, 330 rpm PTO	300
10	Munckhof 2-row cross-flow	Lilac		High, 540 rpm PTO	200
11				Low, 400 rpm PTO	200
12		TVI8001		Low, 400 rpm PTO	300
13	KWH 2-row cross-flow	Lilac		High, 540 rpm PTO	200
14		TVI8001		High, 540 rpm PTO	300
15		TVI8001		Low, 400 rpm PTO	300

[1)] Reference sprayer.

Fig. 2. Sprayers used for assessing spray deposition in the full leaf stage of the apple trees: Munckhof cross-flow (top left), H.S.S. cross-flow (top centre), KWH multiple-row cross-flow (top right), Lochmann 2-row tunnel (bottom right), Munckhof multiple-row cross-flow (bottom left).

the Munckhof cross-flow fan sprayer at high and low air setting and 90% drift reducing nozzles (Albuz TVI 8001 at 7 bar); HSS cross-flow fan sprayer at high (Albuz ATR Lilac and TVI8001 at 7 bar) and low air (IDK9001 at 3 bar); Lochmann two row tunnel sprayer at high and low air (ATR and TVI nozzles); Munckhof 2-row cross-flow sprayer at high and low air (ATR and TVI nozzles) and the KWH 2-row cross-flow sprayer at high and low air (ATR and TVI nozzles). Spray volume for the ATR were 200 L ha^{-1}, for the ID nozzles 250 L $ha^{-1}$and for the TVI nozzles 300 L ha^{-1}.

Results

In Tables 2–4 the results of the different experiments in the period 2016–2018 are summarized. The results are presented for the measured spray deposition on the leaves in the tree canopy and the ground underneath the trees. Results of the spray deposition on vertical poles in front of the target tree row, representing the spray entering the target and the spray deposition on vertical poles in front of the next rows of trees, representing spray drift potential, are not presented.

The spray deposition on the leaves in the tree canopy and on the ground is in Table 2 presented for the standard sprayer (obj 1) over the period 2016–2018, as a reference in the comparison with the other spray techniques in this study. This shows that the measured spray deposition on the leaves, either expressed as µL cm^{-2} or as % of applied spray volume (%dos) varies a lot between the individual dates over the full leaf period. On average the spray deposition on the leaves at full leaf development stage was 0.33 µL cm^{-2} and 16%. Lower and upper limits per measuring day in the period 2016–2018 were respectively 0.20 µL cm^{-2} and 10% (17 July 2018) and 0.53 µL cm^{-2} and 27% (31 August 2016). Taking into account the variation of the leaf area of the trees on which spray deposition was measured in the orchard per measuring day, which was on average a LAI of 1.5 and varied between 0.8 and 3.1, then spray deposition in the trees as presented as the total volume of applied spray in the total leaf canopy varied was on average 43 L ha^{-1} and varied between 33 L ha^{-1} (9 June 2018 and 29 September 2018) and 58 L ha^{-1} (20 September 2018). This means that when calculated taking in account the total leaf volume on which the measured average spray deposition is deposited (in L ha^{-1}) the values differ from those of the measured spray deposition (µL cm^{-2} and % dos). This means we must agree on the results presented in order to be able to compare data from different studies. Another remarkable result from the measured spray deposition on the leaves is from two following dates 28 and 29 September 2018, as other trees were sampled in the comparative measurements it is obvious that the variability in trees can affect the results very much, resp. 47 and 33 L ha^{-1} whereas the difference in measured values is only 0.36 and 0.32 µL cm^{-2}.

Table 2. *Spray deposition at the leaves in the fruit tree canopy and the ground (row underneath the trees and path in between tree rows) for the reference spray technique (obj 1; Munckhof cross-flow, ATR lilac, high air) at different measuring dates (2016–2018) in different parameters*

		2016			2017					2018		
	date	9/6	31/8/	27/10/	5/7/	23/8/	28/9/	29/9/	17/10/	17/7/	20/9/	avg
leaf	µL/cm^2	0.31	0.53	0.35	0.27	0.25	0.36	0.32	0.43	0.20	0.28	0.33
	%dos	16	27	18	14	13	18	16	22	10	14	17
	LAI	1.2	1.0	1.1	1.7	1.8	1.8	1.4	1.2	3.1	1.8	1.6
	L/ha	34	40	49	32	42	42	47	33	54	58	43
	% appl.vol	17	20	25	16	21	21	24	17	27	29	22
ground	row	*	19.0	32.6	50.8	17.9	57.9	24.1	30.0	44.7	29.5	32.9
	path	*	20.6	30.8	44.0	15.4	52.1	35.8	20.0	26.0	29.0	31.5
	mean	*	20	32	47	17	55	30	25	35	29	32
	L/ha	*	40	63	95	33	110	60	50	71	59	64
total recovered [%]		*	40	56	63	38	76	53	42	62	58	59

* not measured.

In a similar way the spray deposition at ground surface is presented (Table 2) for the standard (obj 1, reference) sprayer. Mean spray deposition on ground surface is 32% of applied spray volume with a differentiation in underneath the trees in the tree row of 32.9% and in between the tree rows on the grass covered paths of 31.5%. Variation between lowest and highest mean spray deposition on ground surface is resp. 17% (23 August 2017) and 55% (28 September 2017). This means that of the applied volume on average 64 L ha^{-1} is measured on the ground. The amount that is recovered in the tree canopy and on the ground was 108 L ha^{-1}, being 59% of the applied 200 L ha^{-1} spray volume. Part of the gap in recovery will be on the stem and branches of the tree, on the fruits and be deposited in the next tree row as spray passes the target row because of the high level of air assistance.

Because of the occurrence in variation in spray deposition of the reference spray application (obj 1) at the tree canopy between individual measuring dates, spray deposition data of the other techniques are presented as percentage deposition on the leaves relative to that of the reference technique (obj 1) for that specific measuring date (set to 100% deposition). Results for the measurements in the period 2016-–2018 of the 14 other application techniques are presented (Table 3) for the individual years and as mean for the period. Differences in spray deposition on the leaves in the tree canopy between the reference technique and the individual techniques in comparison (Michielsen *et al*., 2019; Wenneker *et al*., 2014, 2016, 2018) showed that in general a level of 10% in spray deposition was statistically significant (P 0.05). Results show that over the three years only spray technique 4 produces on average a lower spray deposition at leaves in the tree canopy this is a result of predominantly the remarkable low value (75%) in 2018. The other application techniques result in a 13–51% higher spray deposition at leaves in the tree canopy. The highest increase did remarkably occur for the standard sprayer with the 90% drift reducing nozzle and the low air assistance setting of the sprayer (300 rpm PTO). In general, it can be said that the use of a 90% drift reducing nozzle increased spray deposition in tree canopy and this was further increased using lower levels of air assistance (except for technique 12.

Table 3. *Total spray deposition at leaves in tree canopy relative to deposition of the standard sprayer (obj 1; set to 100) for the different spray techniques over 2016–2018 in the full leaf development stage*

Obj	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
2016	100	84	*	111	110	*	113	145	*	130	110	101	104	105	110
2017	100	117	146	*	124	136	*	132	144	138	142	94	134	122	127
2018	100	*	156	75	*	113	120	129	*	70	*	99	119	*	137
mean	100	100	151	93	117	125	117	135	144	113	126	98	143	114	125

* not measured

Spray deposition at ground surface (Table 4) shows a difference in spray deposition underneath the tree rows (row) and in between the tree rows at the grass strips (path). Mean spray deposition on the ground for all used spray techniques was 32% which is equal to that of the reference spray technique (obj 1). Underneath the tree rows the lowest spray deposition was 8.8% (obj 9) and the highest was 62.5% (obj 2). On the path in between the tree rows the lowest and highest spray deposition was resp. 16.6% (obj 4) and 54.7% (obj 2). Total ground deposition was lowest (20% of applied volume) for techniques 4, 7 and 13 being 39% lower than of the reference technique and highest ground spray deposition (59% of sprayed volume) was for technique 2 being 82% higher than of the reference spray technique.

Table 4. *Spray deposition (% of sprayed volume) at ground surface underneath the trees (row) and at the grass strips in between the tree rows (path) after spraying apple trees in the full leaf development stage for the standard sprayer (1) and for the different spray techniques and settings over 2016–2018 in the full leaf development stage*

Obj	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Avg
Row	32.9	62.5	39.0	23.8	30.9	25.3	20.9	38.9	8.8	24.2	27.1	39.9	20.9	29.6	32.9	30.9
Path	31.5	54.7	47.2	16.6	31.3	45.1	18.1	27.6	36.9	27.8	37.4	36.7	18.1	24.5	27.3	32.2
Mean	32	59	43	20	31	35	20	33	23	26	32	38	20	27	30	32
Rel to ref		82	34	-39	-4	9	-39	3	-29	-19	0	19	-39	-16	-7	-2

Discussion

Based on the presented results of increased spray deposition in tree leaf canopy it can be concluded that for some sprayer types and settings also an increase of the biological efficacy of the used PPP could be expected . When using PPP with already good levels of efficacy the higher levels of spray deposition could also mean that the tank concentration of the PPP can be similarly reduced as the spray deposition is increased as effective active ingredient on plant tissue will remain the same. In this view increased spray deposition is to be evaluated also in perspective of MRL of the PPP used, that no thresholds will be passed. Results presented show that an increase of spray deposition on the target of more than 50% is possible. This is even obtained in this comparison with a standard cross-flow fan orchard sprayer (the reference sprayer), equipped with 90% drift reducing nozzles and adjusted at a low level of air assistance (300 rpm PTO). As with this technique spray deposition on the ground is higher than of the refence spray technique (34%) other spray techniques with lower high levels of spray deposition on the leaves in the tree canopy but lower levels of spray at the ground can be more in favour.

In order to be able to easy evaluate these changes a classification system is suggested. . Similar as to energy reducing technology classification using a colour card (red standard – the greener the higher the levels of lower energy use) for the stepwise increase per 10% of spray deposition could be taken to better visualise the increased spray deposition (Fig. 3).

colour coding for increased spray deposition (%)	
standard	E
0-10	D
10-20	C
20-30	B
30-40	A
40-50	A+
50-60	A++

Fig. 3. Suggested steps (% of applied spray volume) and colour coding for increased spray deposition.

The results for the spray deposition measurements at the leaves in the tree canopy (Table 3) can using this classification methodology be presented as done in Table 6. Following the classes presented in Table 3 the ranking of the presented spray techniques for spray deposition at leaves in tree canopy vary between E (being similar to the reference) up to class A++ having an increase in spray deposition of 50%-60% compared to the reference technique.

Table 6. *Presentation of the increased spray deposition at the leaves in the tree canopy relative to the standard application technique (1) for the different techniques tested following the suggested colour coding and classes (Fig. 3) as a label*

Technique	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Label	E	E	A++	E	C	B	C	A	A+	C	B	E	A+	C	B

Such a classification as presented in Table 6 can also be used for a decrease in spray deposition at ground level. Another opportunity could be the use for precision spray applications applying only to a certain part of the field depending on, for example, sensor values or task maps and as such spraying a reduced spray volume. Reduction in PPP volume could be added up in that way in a simple manner and be used in, for example, the authorisation procedure of plant PPP.

The measured lower levels of spray deposition on the ground mean that potentially leaching of PPP decreases at similar levels, and therefore the exposure of soil organisms, ground water and surface water. Results show that the choice of spray technique, nozzle and lower levels of air assistance can lead to higher levels of efficiency of the used PPP, can lead to PPP savings, reduced risk of PPP use and thus a safer use.

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