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Evaluation of a single tree precision map- and sensor-based orchard sprayer

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Summary

A prototype site-specific sprayer was developed capable of task map-based spraying. The task map created contains on and off commands for spraying/thinning per individual tree. Chlorophyll sensors to indicate the presence of plant material added on the sprayer enable a more precise identification for present plant material at eight height bands and at sub-tree level in the driving direction addressing individual PWM nozzles. This resulted in a precise spraying action combining map-based and real time chlorophyll sensor-based spraying, only when a tree requires thinning, and only there where tree material is present. This paper describes the testing of the system in practice for spray distribution and spray drift spraying in an apple orchard. The precision is evaluated, as is the effect on spray deposition at leaves and canopy distribution in comparison with a reference sprayer. The effect on ground spray deposition is addressed as is potential reduction in plant protection product use. Results of spray drift measurements show the entrance in the Drift Reducing Technology (DRT) class of 99% drift reduction.

Key words: Precision spraying, fruit crop, apple, task map, chlorophyll sensor, PWM nozzle

Introduction

Apple trees tend to produce a great variation in the number of blossoms (20–300), resulting in a varying apple yield per tree (Dalfsen *et al*., 2018). A thinning operation is performed to ensure proper apple quality and is generally done in one homogeneous application for an entire orchard. The trees producing an overload of blossoms and apples require thinning, while the rest of the trees require a different strategy. Tree specific application of a thinning action would result in a more homogeneous fruit load and less variation in fruit yield over the years.

Within the Fruit4.0 project, the blossom load is measured through RGB images, captured with a separate mobile measurement unit driving along the tree rows (Hoog *et al*., 2019). A Blossom segmentation algorithm was applied, resulting in an estimated blossom number per individual tree and per tree section (top, middle, bottom). The obtained information is presented and processed through a web-based platform (Akkerweb/Farmmaps), producing application maps for automatic thinning based on a blossom threshold per tree algorithm (Dalfsen *et al*., 2020).

In 2019, a prototype site-specific sprayer was developed capable of task map-based spraying. The task map created (AgroManager) contains on and off commands for spraying/thinning per individual tree. Chlorophyll sensors to indicate the presence of plant material added on the sprayer enable a more precise identification for present plant material at eight height bands and at sub-tree level in the driving direction. This resulted in a precise spraying action combining map-based and real time chlorophyll sensor-based spraying, only when a tree requires thinning, and only there where tree material is present.

This paper describes the testing of the system in practice for spray distribution and spray drift. The precision is evaluated, as is the effect on spray deposition at leaves and canopy distribution in comparison with a reference sprayer. The effect on ground spray deposition is addressed as is the potential reduction in plant protection product use.

Materials and Methods

Spray technique

Spray deposition and spray drift measurements were carried out comparing a reference cross-flow fan orchard sprayer (Munckhof, Horst, The Netherlands) and a H.S.S. (Hol Spraying Systems, Geldermalsen, The Netherlands) precision cross-flow fan sprayer (Fig. 1). The measurements were performed in an apple (cv. Elstar) orchard (Randwijk, The Netherlands) in a full leaf situation (June–October 2019 and 2020). The reference sprayer was equipped with standard hollow cone nozzles (Albuz ATR lilac), operated at 7 bar spray pressure, a forward speed of 6.5 km h^{-1} applied during the experiments was in the high fan gear box setting of the sprayer. The H.S.S.-CF precision sprayer is on each side equipped with individual air spouts just behind the nozzles at eight height positions. With the H.S.S. CF orchard sprayer and Intelligent Spray Application (I.S.A.); a precision cross-flow fan orchard sprayer equipped with at each side three sensors for green leaf detection (Rometron) addressing eight channels and coupled to eight Pulse Width Modulation (PWM; Rometron) functioning nozzles for precise and variable dosing and a satellite navigation system (GNSS) to spray individual trees on a task-map was developed. Air settings of the H.S.S. sprayer used were reduced; 1400 rpm of the fan. Spray nozzles fitted to the HSS were Lechler IDK90015 flat-fan nozzles operated at 3 bar spray pressure. Forward speed was 8 km h^{-1}. Maximum spray volume was 240 L ha^{-1} at 8.5 km h^{-1}. The HSS precision sprayer used a task map for spraying individual trees and a task map + chlorophyll sensor for spraying only the green area of the identified trees to be sprayed.

Spray deposition measurements

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 Yellow (AY250; 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 2019 and 2020; 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 the H.S.S.-CF I.S.A. sprayer, and analysing leaves samples from four individual trees. Leaf samples were taken from the top (> 1.90 m), middle (1.20–1.90 m) and bottom (0.50–1.20 m) section of the trees by counting all leaves in six tree sections: Top West (TW), Top East (TE), Mid West (MW), Mid East (ME), Bottom West (BW), Bottom East (BE), 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 AY250. The leaf surface areas were determined (LiCor), and the spray specific deposition (µL cm^{-2}) was calculated. Spray deposition on ground surface was measured (Technofil TF290; 100 cm × 10 cm) underneath the tree rows and in the grass paths between the tree rows on both sides from the treated tree row, 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

Fig. 1. Reference cross-flow fan sprayer (right top) and H.S.S.-CF I.S.A. precision sprayer (right bottom) with detail of the Rometron green detection sensor (left top) and the Rometron PWM nozzle module (left bottom) switching of nozzles if a gap between trees is detected (centre).

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). In the laboratory these strips were cut into 10 cm parts to be analysed separately.

Precision measurements

The precision of the spray application was determined by attaching three chromatography paper strips (Whatman no. 2; 500 cm × 2 cm) at three heights in front of the tree leaf canopy (top, middle, bottom). A comparison was made for the H.S.S. precision sprayer in standard mode spraying all trees continuously, spraying individual trees yes/no using a task map, and spraying individual trees yes/no using a taskmap and Rometron green detection sensors. Two driving directions were tested, nozzles spraying either on the left or right side. After spraying these strips were taken to the laboratory and cut into 10 cm parts to be analysed separately. The results showed the accuracy of the on/off of the PWM nozzles spraying per detected leaf canopy part at the three heights and not spraying if no leaves were detected in between trees.

Task map

A task map with the changes in spray volume in forward trajectory distance was made in the GIS system (QGIS, Akkerweb, Farmmaps). The task map was transferred to the FarmManager terminal connected to the H.S.S. Controlbox GPS and the Rometron spray computers. Two versions of the task-map were uploaded; one indicating that all the trees in the orchard were to be sprayed, and the other indicating that the alternating consecutive individual trees in the tree rows to be sprayed (50%) and not to be sprayed, and the last row only to be sprayed from the outside inwards.

Spray drift measurements

With the H.S.S. CF orchard sprayer and Intelligent Spray Application (I.S.A.); a precision cross-flow fan orchard sprayer equipped with sensors for green leaf detection and Pulse Width Modulation (PWM) functioning nozzles for precise and variable dosing; WageningenUR performed spray drift experiments following the Dutch TCT (TCT, 2017) and ISO22866 protocols. Measurements were done in comparison with a reference spray technique (Munckhof cross-flow fan sprayer with Albuz ATR lilac nozzles at 7 bar spray pressure). Spray drift experiments were done in the 2019

(August–November) and 2020 (June–July) growing season spraying the downwind eight rows of an apple orchard. Applications were done in eight periods in the full leaf stage of the apples (BBCH 75–91). The H.S.S.-CF I.S.A. used a low air assistance setting (1400 rpm fan) and sprayed the outside tree row1-sided. Fan speed was controlled and recorded by the H.S.S. Drift Control box. For the same settings of the H.S.S.-CF I.S.A a comparison was made between spraying all trees and individual trees alternatingly sprayed or not sprayed, based on a defined task-map loaded in the spray computer.

Spray drift deposit measurements were made on a short cut grass strip downwind of the orchard at distances up to 25 m from the last tree row. The collectors used consisted of filter material (Technofil TF-290) of 0.50 m × 0.10 m arranged in a continuous line from 3 m up to 15 m and two single collectors of 1.00 m × 0.10 m at 20 m and 25 m. At 7.5 m distance from the last tree row a 10 m high measuring pole was placed with double lines of ball shaped collectors (Siebauer Abtrifftkollektoren) at 1 m intervals up to 10 m height.

Weather conditions during application were recorded with sensors at a measuring pole positioned 7.5 m downwind of the treated orchard. Average temperature during the experiments was 18.5°C, mean wind angle was 1° from rectangular to the tree row direction, mean wind speed at 2 m height was 1.6 m s^{-1} and 2.7 m s^{-1} at 4 m height (about 1 m above the top of the trees).

Tracer analysis

After spraying the collectors were picked up, bagged, coded and stored for analysis in the laboratory. In the laboratory the collectors were washed with deionised water and the solution measured with a fluorimeter (Perkin Elmer LS55; λ_{ex}=450 nm en λ_{em}=500 nm) to quantify AY250 concentration. From the quantified AY250 concentrations the deposition on collectors was calculated in µL cm^{-2} and as percentage of applied volume rate.

Data analysis

The results of the spray deposition measurements on leaves and collectors were described by different parameters characterising the height of spray deposition (µL cm^{-2} and % of nominal spray volume). Differences in spray drift deposition were statistically tested using Genstat procedure IRREML at specific evaluation zones and for airborne spray drift. Drift reduction of both settings of the H.S.S.-CF I.S.A. was calculated in comparison with the spray drift deposition of the reference spraying.

Results

Spray deposition

The results of the measured spray deposition in apple tree canopy (Table 1) show a higher spray deposition for both settings of the H.S.S. precision sprayer compared to the reference sprayer.

At the bottom and middle part of the tree canopy spray deposition of both settings of the H.S.S. precision sprayer are higher than of the reference sprayer. In the top of the tree spray deposition for the H.S.S. spraying on a task map is higher than of the reference whereas for the H.S.S. with taskmap + Rometron sensor spray deposition was lower than of the reference sprayer. Overall spray deposition of the H.S.S. precision sprayer was 18% to 34% higher than of the reference cross-flow fan sprayer. Spray deposition is determined based on measurements at four individual trees (Table 2). Leaf canopy structure and density can differ a lot per tree as measured leaf area per tree (m^2) and expressed as Leaf Area Index (LAI) based on a 3 m^2 ground area per tree varies between 1.4 and 3.0 with a mean LAI of all trees of 2.2 (m^2 m^{-2}). This variation in LAI per tree influences total spray recovery per tree. When calculating the total spray deposition at the total leaf area per tree the mean total recovered spray volume at leaf canopy are resp. 44, 59 and 60 L ha^{-1} for the reference sprayer and the two H.S.S. settings. At the individual trees spray deposition varies between 31 and 53 L ha^{-1} for the reference sprayer, between 46 and 71 L ha^{-1} for the H.S.S.

Table 1. *Spray deposition (% of sprayed volume) in tree sections Top (T), Middle (M) and Bottom (B) at the West (W) and the East side (E) of the sprayed tree row, after spraying with a reference sprayer and two settings of the H.S.S. precision sprayer (on taskmap and on taskmap + Rometron sensors); mean spray deposition and relative (%) to the reference sprayer*

	Spray deposition in tree sections (% sprayed volume)							
	Mean	Relative to ref (%)	TW	TE	MW	ME	BW	BE
Reference	11.1	100	14.6	11.7	10.6	10.5	10.9	8.5
H.S.S. taskmap	14.9	134	13.9	15.0	17.0	20.0	12.2	11.3
H.S.S. taskmap + Rom	13.1	118	10.1	10.6	17.4	14.0	14.0	12.6

Table 2. *Leaf Area Index (LAI) of the four sampled trees (T1, T2, T3, T4), spray deposition (L) per tree and mean (L ha^{-1}) and as percentage of applied spray volume (%) per tree and mean relative to the reference sprayer for two settings of the H.S.S. precision sprayer* (*on taskmap and on taskmap + Rometron sensors*)

			T1			T2			T3			T4		
	Mean L ha^{-1}	Rel to ref (%)	LAI	L	%	LAI	L	%	LAI	L	%	LAI	L	%
Reference	44	100	2.2	41	21	1.6	31	15	3.0	53	26	2.6	50	25
H.S.S. taskmap	59	120	2.3	71	31	2.1	62	27	1.4	46	20	2.2	59	26
H.S.S. task + Rom	60	120	1.6	38	17	2.0	38	17	2.8	83	37	2.2	80	35

sprayer operated at a taskmap and between 38 and 83 L ha^{-1} for the H.S.S. sprayer operated at a taskmap and using the Rometron sensors for green detection. Normalised for applied spray volumes of the two sprayers (resp. 226 L ha^{-1} and 200 L ha^{-1}) the spray deposition of the H.S.S. sprayers are 20% higher than of the reference sprayer.

Precision

To check the precision of spray application and its accuracy measurements were done at three heights (Top, Middle, Bottom) in the tree canopy for the H.S.S. sprayer spraying in a continuous spray mode, based on a taskmap spraying only 50% of the consecutive individual trees in the tree row, and on a task map spraying 50% of the trees in the row including the use of the Rometron sensors (Fig. 2). The task map mode of the H.S.S. sprayer clearly is capable of spraying the individual trees as spray deposition on the horizontal lines at the three tree levels show no deposition in between the trees to be sprayed. The additional use of the Rometron sensors makes the on/off switching more precise than of the taskmap alone and leads to higher spray deposition values of the to be sprayed trees.

Spray drift

Results of the spray drift experiments are used to quantify spray drift reduction of the H.S.S. CF I.S.A. precision cross-flow fan orchard sprayer equipped with PWM modules at the nozzle bodies, Lechler IDK 90-015 C flat fan venturi nozzles (3 bar spray pressure), low air setting (1400 rpm fan) and green leaf detection sensors and single-sided spraying of the outside tree row spraying (Fig. 3).

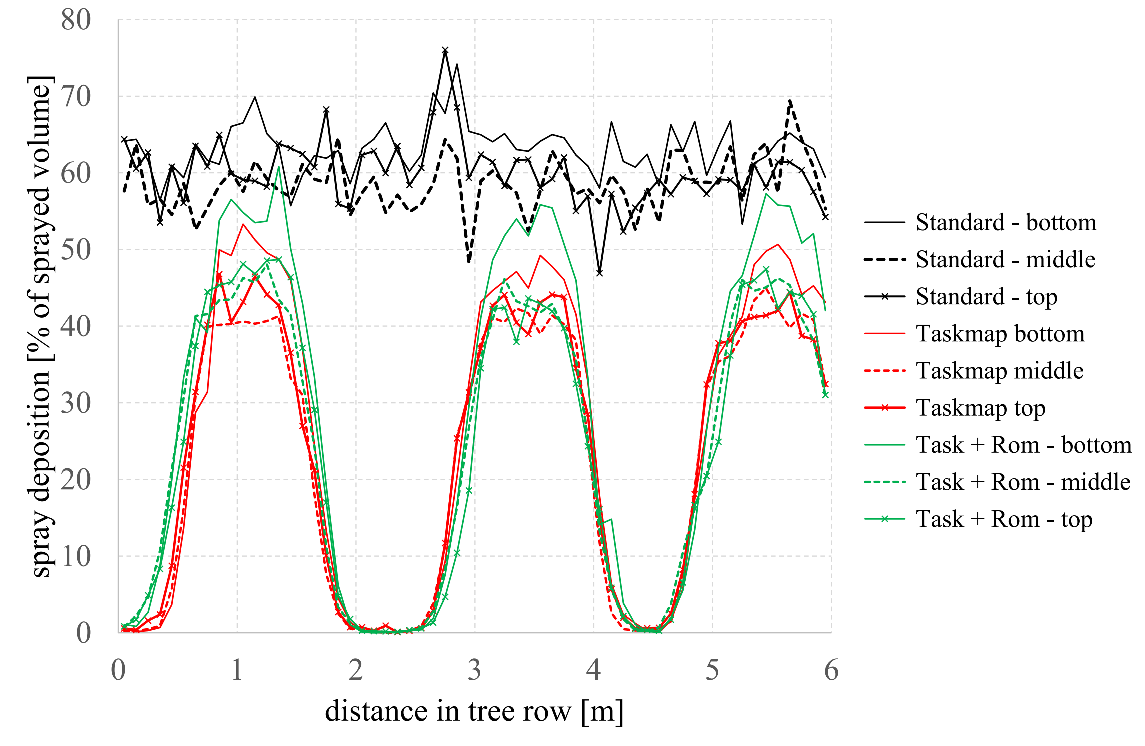

Fig. 2. Spray deposition (% of sprayed volume) over 6 m tree row length at the top, middle and bottom part of the tree for the H.S.S. precision sprayer spraying at constant flow rate in standard mode (Standard), spraying individual trees yes/no using a task map (Taskmap) and spraying individual trees yes/no using a taskmap and Rometron green detection sensors (Task+Rom).

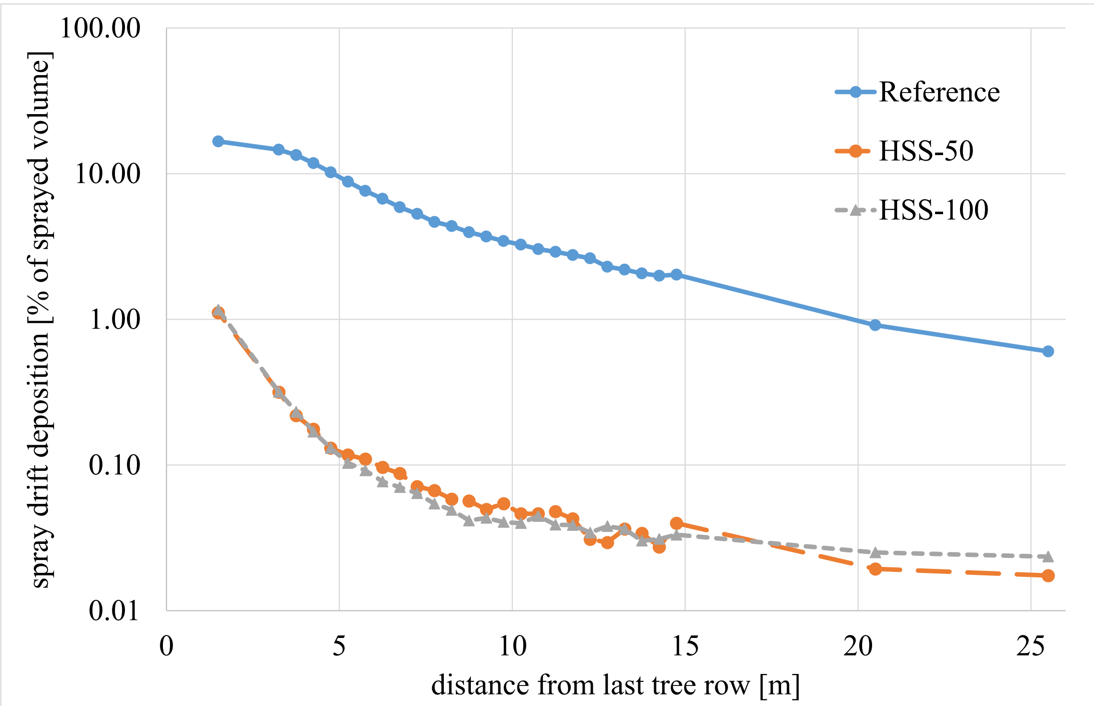

Fig. 3. Spray drift deposition (log % of sprayed volume) at different distances from the last tree row for the reference sprayer and the H.S.S.-CF I.S.A. with GNSS/task-map spraying all the trees in the orchard (HSS-100) and only 50% of the individual trees in the tree row (HSS-50).

To quantify the spray drift reduction the spray drift deposition at 4.5–5.5 m from the last tree row of the H.S.S-CF I.S.A. and its settings, spraying all trees in the orchard or spraying only 50% of the consecutive individual trees in the tree row, is evaluated against the spray drift deposition

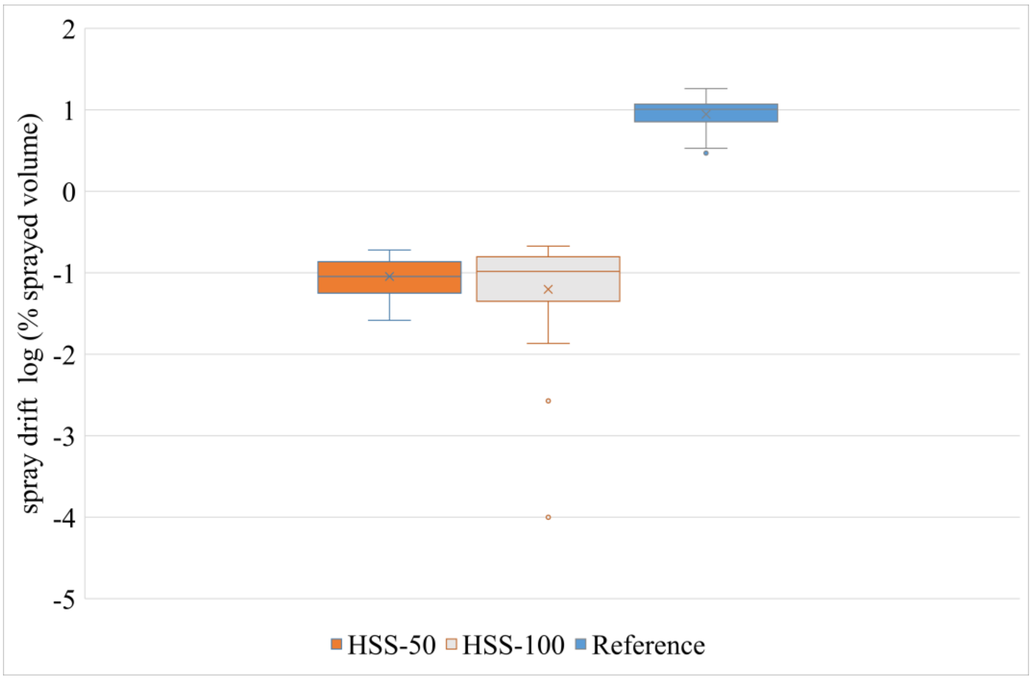

Fig. 4. Spray drift deposition (log % of sprayed volume) at 4.5–5.5 m from the last tree row for the reference sprayer and the H.S.S.-CF I.S.A. with GNSS/task-map spraying all the trees in the orchard (HSS-100) and only 50% of the individual trees in the tree row (HSS-50).

of the reference spray technique, being resp. 0.100%, 0.102% and 9.8% (Fig. 4); showing spray drift reduction for both settings was 99% (DRT99) with no significant difference between the two H.S.S.-CF I.S.A settings.

Measurement of airborne spray drift averaged over 0–10 m height at 7.5 m distance from the last tree row resulted in a spray drift reduction of 97.6% when spraying with the H.S.S.-CF I.S.A. and both settings.

Discussion

Results are described of an innovative process bringing together spray technology from fruit crop spraying and arable crop spot spraying. This led to the design and construction of a precision orchard sprayer by H.S.S. and Rometron together. A process with challenges and stress, especially for research institute being asked to underpin the thoughts of what would be the best solution for nozzles, spray pressure, nozzle position and orientation, spout direction and timing of on/off switching of the PWM nozzles to spray the tree canopy at the right position and the wished dose. In this process it was obvious that pace of research at institutional organisations does not fit in the pace of manufacturers development scheme and bringing first (prototype) sprayers to the market. We together learned a lot of this and showed that new spray technology developments, like precision spraying in fruit crops, needs the research evaluation and quantification and therefore funding to make these innovations happen, available for the market and robust for use in practice. Not only for sales and marketing of the manufacturer, the growers for knowing and fact-checking the potential use suggested, but also to provide quantified proof for crop protection industry and regulatory authorities to be able to advise and use Best Available Techniques in crop protection.

The developed H.S.S. I.S.A. precision orchard sprayer increases spray deposition at leaf canopy with about 20% compared to that of the reference sprayer. The accuracy and precision of the H.S.S. sprayer showed a 10 cm precision is possible when spraying on a task map which is improved when using Rometron green detection sensors additionally to detect the target within the mapped application window of the individual tree. The fast-switching Rometron PWM nozzle modules makes this possible. Use reduction from grower's experience in practise mention savings of on average 20% for all spray application done during the whole growing season, whereas individual thinning operations showed reductions of up to 80% less trees sprayed. In our experiments we measured reductions in spray volume use of 15% using the taskmap mode and of 30% using both the taskmap mode and the Rometron sensors in full leaf growth situations of a spindle apple tree orchard. Ground deposition underneath the trees reduced by 50% using the precision orchard sprayer in taskmap + Rometron operation modus. Spray drift reduction was 99% for both operation options of the H.S.S.-CF I.S.A. precision orchard sprayer.

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