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Canopy density spraying in orchards in the Netherlands

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Abstract

Canopy Density Spraying (CDS) of a pear orchard was tested in commercial orchards to show - under practical conditions – that crop adapted spraying is possible and has its advantages. The benefits for the environment are shown by means of reduced use of plant protection products (PPP) in order to maintain comparable spray distributions as with standard application techniques and maintain good biological efficacy. Experiments were done to evaluate spray deposition in a spindle pear orchard at different growth stages. Spray deposition in tree canopy and on soil surface underneath the trees was assessed. Biological efficacy was similar for the CDS as for the reference sprayer. Spray deposition was changed based on nozzle settings and used decision algorithm of the CDS sprayer. CDS reduced spray volume during the growing season by 49% to 65%. Spray volume of the CDS sprayer was on average during the growing season 200 L ha^{-1} but increased from 170 L ha^{-1} to 240 L ha^{-1}. Spray volume reduction of the CDS sprayer was shown to be dependent on percentage of time nozzles were shut off because of gap detection and spray volume adaptation due to changes in canopy structure, size and density during the growing season.

Key words: Variable rate application, orchard spraying, spray deposition, use reduction

Introduction

Based on earlier developments of sensor guided precision spray technologies like canopy density spraying (CDS) (Zande *et al.,* 2008, 2010) in flower bulb growing, the CASA sprayer from the EU ISAfruit project in apple growing (Wenneker *et al.*, 2009), and the development of the SensiSpray in potato growing (Michielsen *et al.*, 2010) together with Dutch sprayer manufacturers (Homburg, Rometron, KWH) prototype sprayers were developed to be used under practical circumstances in strawberry, leek and pear crop growing. To demonstrate the potential options to fulfil the requirements of the EU Water Framework Directive a project was initiated to combine perspective crop protection developments amongst others CDS. Within this project named "Innovations[2]" (Hees *et al.*, 2012), integrated pest management solutions are introduced into strawberry production systems, leek production systems and pear production systems. The system innovations focus on soil management, fertilisation, and on pesticide application and efficacy. The developed spray technology aims at a reduction in spray drift, reduction in total amount of plant protection products used, and a spray deposition and efficacy at least at the same or an increased level as of conventional spraying. This paper presents the CDS variable rate spray application equipment introduced as one of the innovations in this project for pear production (Nieuwenhuizen & Zande, 2012; Sijbrandij *et al*., 2012).

Materials and Methods

The basal ideas for canopy density spraying in fruit orchards were founded and shaped from the CASA sprayer in the ISAfruit and PreciSpray EU-projects (Wenneker *et al*., 2009). The sprayer hardware is built upon a standard KWH D-1000 cross-flow fan orchard sprayer and was equipped with a variable air support system (VLOS) and a laser scanner (Hokuyo URG-04LX-UG01 LIDAR) measuring the size and density of the pear tree canopy and a variable dosing system based on Lechler VarioSelect nozzle bodies containing pneumatically switchable sets of four nozzles (Fig. 1). At the start of the project in 2011 four identical Albuz ATR lilac nozzles were chosen and in 2012 two standard hollow cone nozzles (Albuz ATR white, ATR lilac) and two spray drift reducing venturi hollow cone nozzles (TVI80-0050, TVI80-0075) were chosen (Table 1). The KWH-CDS sprayer can, at five height levels in the tree, adapt spray volume in four steps to the leaf development of the fruit crop. The laser scanner sensor was chosen as it outperforms earlier used ultrasonic sensors in terms of number of measurements per time unit and accuracy. The cross-flow fan sprayer consists of five sections left and right, 10 sections total. The total of 72 nozzles are distributed over the sections in groups of eight, eight, eight, eight and four nozzles from bottom to top of the cross-flow unit respectively. Each nozzle can be activated individually at an update rate of 3.5 Hz, as this results in a good building up of the spray cone and therefore spray result. The laser scanner is mounted at 1.5 m height and has a radial scanning distance of 4.0 m, large enough for conventional tree row spacing of 3–4 m. The spray nozzles are distributed at 0.3 m distance from 0.4 m height to 3.1 m height. The applied volume rates for each sprayer section could be adjusted by switching on or off either four identical nozzles (2011) or two sets of two nozzles of different sizes (2012), creating respectively five and three steps in spray volume (Fig. 2). The 90% drift reducing venturi nozzles were used within 20 m area alongside waterways and the standard hollow cone nozzles were used in the centre area of the orchard. Switching between drift reducing and standard nozzles was done automatically based on sprayer position within the orchard using GPS. The tailor made decision algorithm to adjust the spray volume based on tree row volume was specifically made within this project, taking into account previous research from e.g. Walklate *et al.* (2002). Canopy density based spraying in pear aims at: no spraying where gaps were detected in the crop foliage; reduced spray volume when minimal crop foliage was present, optimal spraying where large amounts of crop foliage was present.

One of the main challenges was to gather sensor data of different crop growth stages to develop decision algorithms (Kempenaar *et al*., 2012). These decision algorithms are crucial in canopy density based spraying systems, as they dictate the volume rate to be applied and automate a task conventionally performed by the sprayer operator. For pear and apple, laser scanner data was gathered during spring, summer, and autumn in different training systems of orchards to gather data for decision algorithm development. GPS data was included in the sensor data, such that plots of fields could be easily made. Applied volume rates were measured in pear and apple and compared with standard farmers practice. Based on the GPS data files, the decision algorithm was adjusted to reach acceptable application rates. Spray deposition trials were made in pear to validate the practical value of the decision algorithms.

Experiments performed

To show where differences exist between a CDS-sprayer and a standard application technique spray deposition measurements were done in spindle apple trees, spindle and V-shaped pear trees in 2011 (BBCH 91–92) and in one crop growth stage of spindle pear trees in 2012 (BBCH 71). Leaf

Fig. 1. Canopy Density Spraying system in pear orchards consisting of a laser scanner (middle) in combination with Lechler Varioselect pneumatic actuated nozzle bodies (right).

Area Index of the pear trees was respectively 1.33 in 2011 and 0.84 in 2012. Row spacing of the tree rows was 3.5 m in 2011 and 3.25 m in 2012 with three heights of 3.0–3.2 m resulting in Tree Row Volume values of respectively 10714 and 7384. A comparison was made between the KWH-CDS sprayer, the KWH sprayer without CDS operational and a Munckhof standard cross-flow fan orchard sprayer (Table 1). The spray deposition measurements were done spraying one row of trees in the orchard from both sides with the fluorescent tracer Brilliant Sulpho Flavine (BSF). With the spray deposition measurements the distribution of the spray in different segments in the tree; top, middle, bottom, and on the soil surface underneath the tree row and in the paths between the tree rows is quantified (Fig. 2). Spray deposition on the tree leaves was measured by sampling three trees in a row and picking every tenth leaf from a tree segment to analyse on amount of BSF. In the laboratory the leaves were washed, leaf area measured and the spray deposition per cm^2 leaf area determined. Spray deposition on soil surface was measured using filter collectors (Technofil TF-290) and were analysed in a similar way in the laboratory.

Table 1. *Machine settings of the sprayers used in the spray deposition measurements Spray pressure was 7 bar and air assistance was used in full setting*

	Standard	KWH2011	CDS2011	KWH 2012		CDS 2012	
nozzle	fine	fine	fine	fine	coarse	fine	coarse
manufacturer	Albuz	Albuz	Albuz	Albuz	Albuz	Albuz	Albuz
Type	ATR lila	ATR lila	ATR lila	ATR lila	TVI 80-0075	ATR wit and ATR- lila	TVI 80-0050 and TVI 80-0075
Flow rate [L min^{-1}]	0,42	0,42	0,42		0,46	0,32 / 0,42 and 0,74	0,31 / 0,46 and 0,77
Nr nozzles	2 × 8	2 × 8	switching	2 × 9	2 × 9	switching	switching
Speed [km h^{-1}]	6,7	6,7	5	6,6	6,7	6,5	6,7
Spray volume [L ha^{-1}]	174	185	436 max=922	242	203	126 max=325	129 max=340

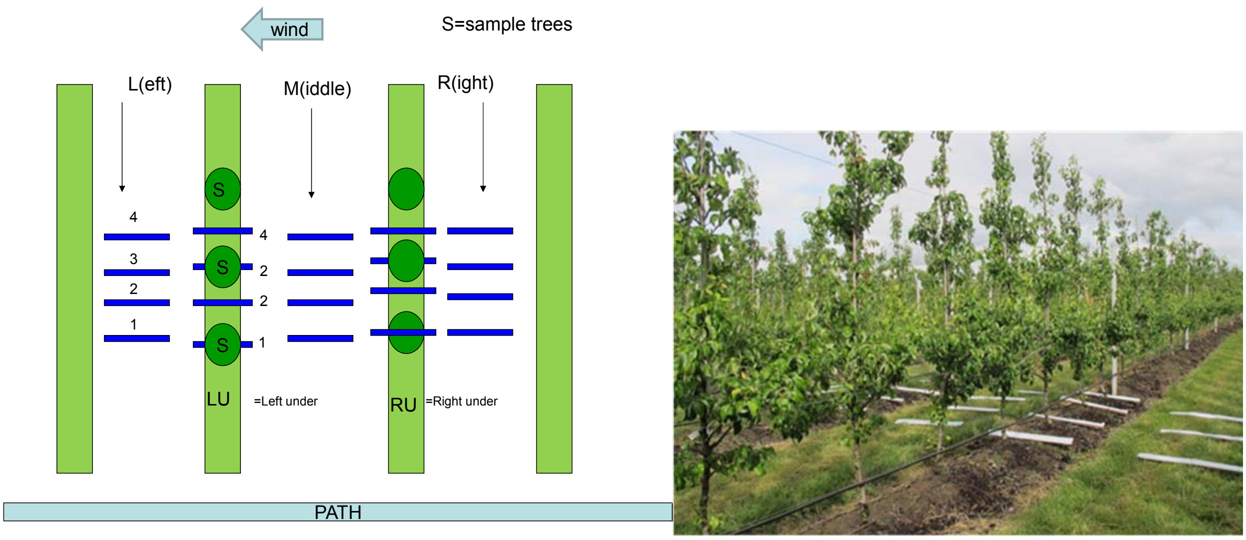

Fig. 2. Schematic lay-out of sample trees and collectors on soil surface underneath trees (left) and in the orchard (right).

Results

2011 experiments

Results of the 2011 spray deposition measurements for the three sprayer types in spindle pear canopy are presented in Fig. 3. Spray deposition of the KWH cross-flow fan sprayer is in the top of the tree higher than of the standard cross-flow fan sprayer. In the middle compartment of the tree and the inside part at the bottom of the tree spray deposition of the KWH cross-flow fan sprayer is lower than of the standard sprayer. In all compartments spray deposition of the CDS sprayer is higher than of both the other standard cross-flow fan sprayers. Average spray deposition over all compartments of the tree was 0.33 µL cm^{-2} for the standard cross-flow fan sprayer (CV= 37%), for the KWH cross-flow fan sprayer 0.30 µL cm^{-2} (CV = 90%) and for the CDS sprayer 0.88 µL cm^{-2} (CV = 45%).

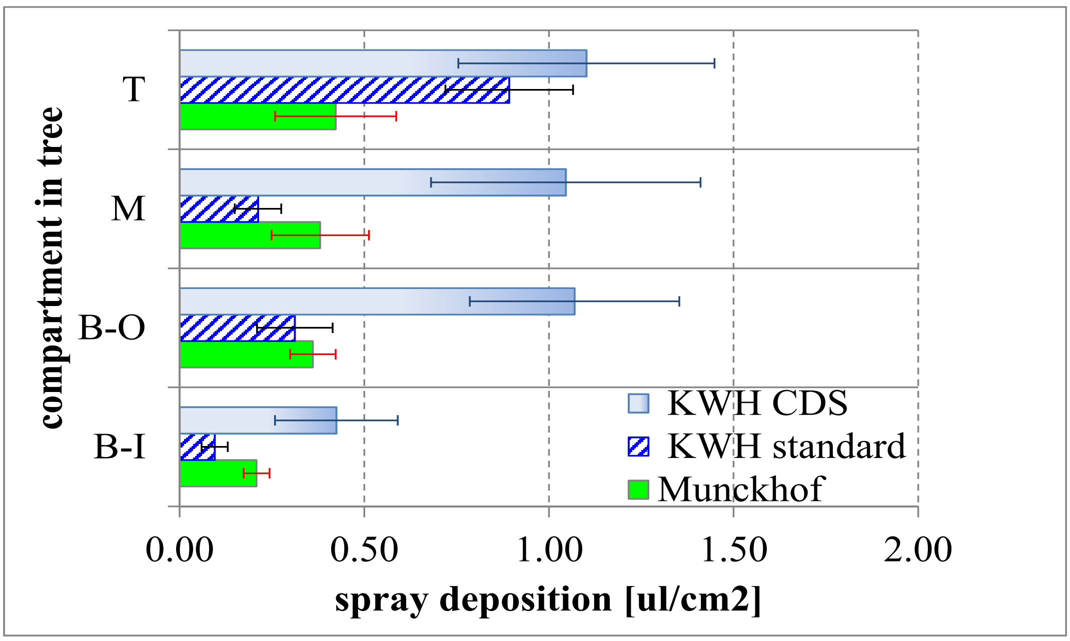

Fig. 3. Spray deposition (µL cm^{-2}) in different compartments (Top, Middle, Bottom-outside, Bottom-inside) of pear spindle trees for a standard cross-flow fan sprayer (Munckhof) and a KWH cross-flow fan sprayer without (KWH) and with spray volume adaptation to the canopy volume and position (Canopy Density Spraying; CDS) (after Sijbrandij *et al.*, 2012).

Spray deposition underneath the tree rows and the paths in between relative to the treated row is highest for the CDS sprayer and lowest for the KWH sprayer (Table 2). Related to the sprayed volume of the three sprayer types the average spray deposition is 16% for the standard sprayer, 12% for the KWH sprayer and 13% for the CDS sprayer. Potential spray volume reduction of the CDS sprayer was 53% as sprayed volume during spray deposition measurements was 436 L ha^{-1} of the maximum of 922 L ha^{-1} when all nozzles were open.

Table 2. *Spray deposition (µL cm^{-2}) at different positions under treated tree row (pear, BBCH92) for a standard cross-flow fan sprayer (Munckhof) and a KWH cross-flow fan sprayer without (KWH) and with spray volume adaptation to the canopy volume and position (Canopy Density Spraying; CDS)*

Machine	Position to treated row				
	-1,5	0	1,5	3	4,5
	path	treated tree row	path	tree row	path
Standard	0.151	0.193	0.206	0.059	0.057
KWH	0.060	0.149	0.211	0.037	0.076
CDS	0.311	0.389	0.338	0.060	0.204

2012 experiments

In 2012 a comparison was made between the KWH cross-flow fan sprayer and the CDS system on the sprayer in a pear orchard at growth stage BBCH 72 (Fig. 4). The spray volume of the standard spray technique spraying the pear trees was 240 L ha^{-1} and of the KWH-CDS sprayer 125 L ha^{-1} using the standard hollow cone nozzle types and 130 L ha^{-1} using the drift reducing venturi hollow

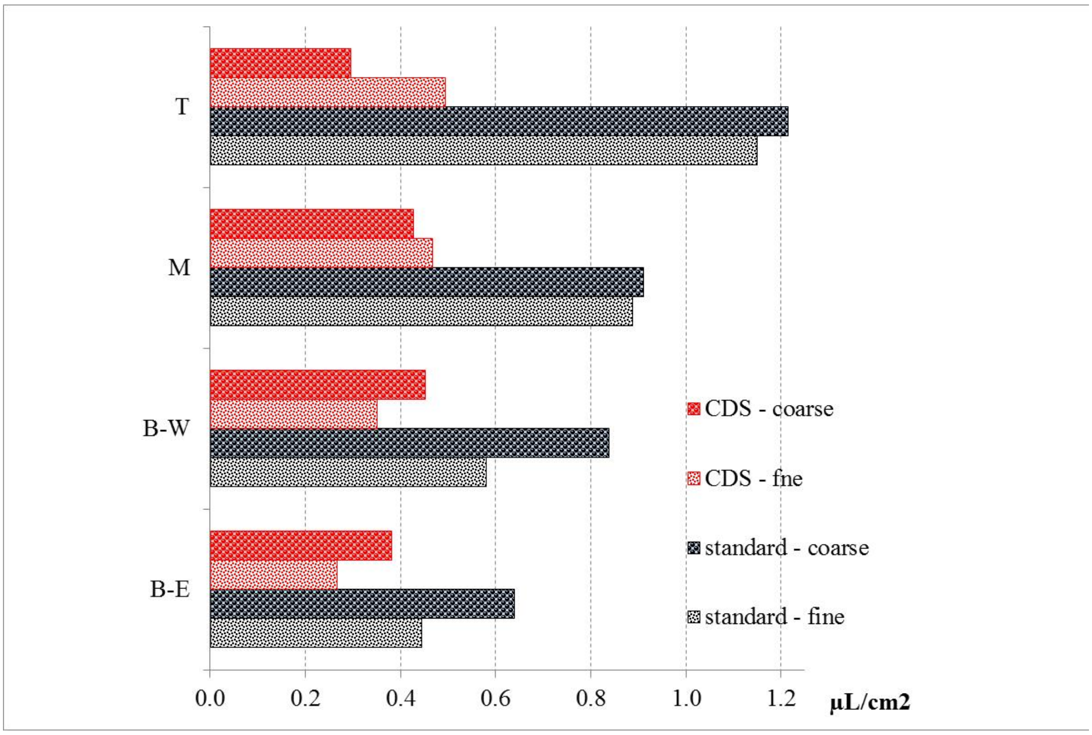

Fig. 4. Spray deposition (µL cm^{-2}) in different compartments (Top, Middle, Bottom-westside, Bottom-eastside) of pear spindle trees for a KWH cross-flow fan sprayer without (KWH) and with spray volume adaptation to the canopy volume and position (Canopy Density Spraying; CDS) and two nozzle types (fine, coarse).

cone nozzle types. The level of spray deposition in the different segments of the pear trees was for the KWH-CDS comparable to that of the Munckhof standard cross-flow fan sprayer (0.4 μL cm^{-2}) but lower as of the KWH cross-flow fan sprayer (0.8 μL cm^{-2}). Spray distribution over the segments in the tree was for the KWH-CDS more homogeneous than of the KWH cross-flow fan sprayer and the Munckhof standard cross-flow fan sprayer. Taking into account the leaf volume in the pear orchard 35 L ha^{-1} (27%) of the applied 130 L ha^{-1} is found in leaf canopy for the KWH-CDS sprayer. For the KWH cross-flow fan sprayer 60 L ha^{-1} (25%) of the applied 240 L ha^{-1} was found back in tree canopy.

On soil surface underneath the row of trees and in the paths between the tree rows (Table 3) spray deposition is on average for the KWH-CDS sprayer and the KWH cross-flow fan sprayer 45 L ha^{-1} using standard hollow cone nozzle types (respectively 36% and 19% of applied spray volume). Using drift reducing venturi hollow cone nozzle types spray deposition on soil surface is 210 L ha^{-1} for the KWH cross-flow fan sprayer (77% of applied spray volume) and 128 L ha^{-1} for the KWH-CDS sprayer (71% of applied spray volume). The use of drift reducing venturi type nozzles results in higher spray deposits on soil surface in the orchard than of the standard hollow cone nozzle types and is therefore of higher risk to leaching to soil water and drainage to the surface water.

Table 3. *Spray deposition (μL cm^{-2}) at different positions under treated tree row (pear, BBCH72) for a KWH cross-flow fan sprayer without (KWH) and with spray volume adaptation to the canopy volume and position (Canopy Density Spraying; CDS) and two nozzle types (fine, coarse)*

Row		1	2	3	4	5
Technique	Nozzle	Path	Treated row	Path	Under tree	Path
KWH	fine	0.04	0.25	0.30	0.22	0.10
	coarse	0.06	1.89	0.62	0.33	0.24
CDS	fine	0.10	0.40	0.23	0.10	0.08
	coarse	0.11	1.31	0.31	0.07	0.04

Potential spray volume reduction of the CDS sprayer was 46% which is predominantly realised by not spraying the gaps in between the trees. And although the KWH-CDS sprayer applies 46% less spray volume a similar amount as of the standard Munckhof cross-flow fan sprayer is found in tree canopy (2011 experiment).

Spray volume adaptation during the season

During the growing season spray volume and switching on/off nozzles varies because of the growth stages of the trees. In Fig. 5 the percentage time the nozzles are spraying of total spray time is presented at different heights in canopy spraying a commercial pear orchard. At the bottom part of the tree nozzles are spraying on average for 83% of the time, in the middle part for 42% and in the top of the trees only for 13%. On average for all heights nozzles are spraying for 53% of time. Spray volume related to canopy density is presented in Fig. 6. Spray volume during the growing season increases in the bottom part and the middle part and is constant in the top of the trees.

Average spray volume during the growing season was in the bottom part of the tree 330 L ha^{-1}, in the middle part 155 L ha^{-1} and in the top of the tree 17 L ha^{-1}. On average for the whole tree canopy spray volume increased from 170 L ha^{-1} to 240 L ha^{-1} and was on average 200 L ha^{-1}. Depending on the place in the orchard and tree shapes and time during the season spray volume reductions were obtained in commercial fields of 49–65% because of gap detection and Canopy Density Spraying.

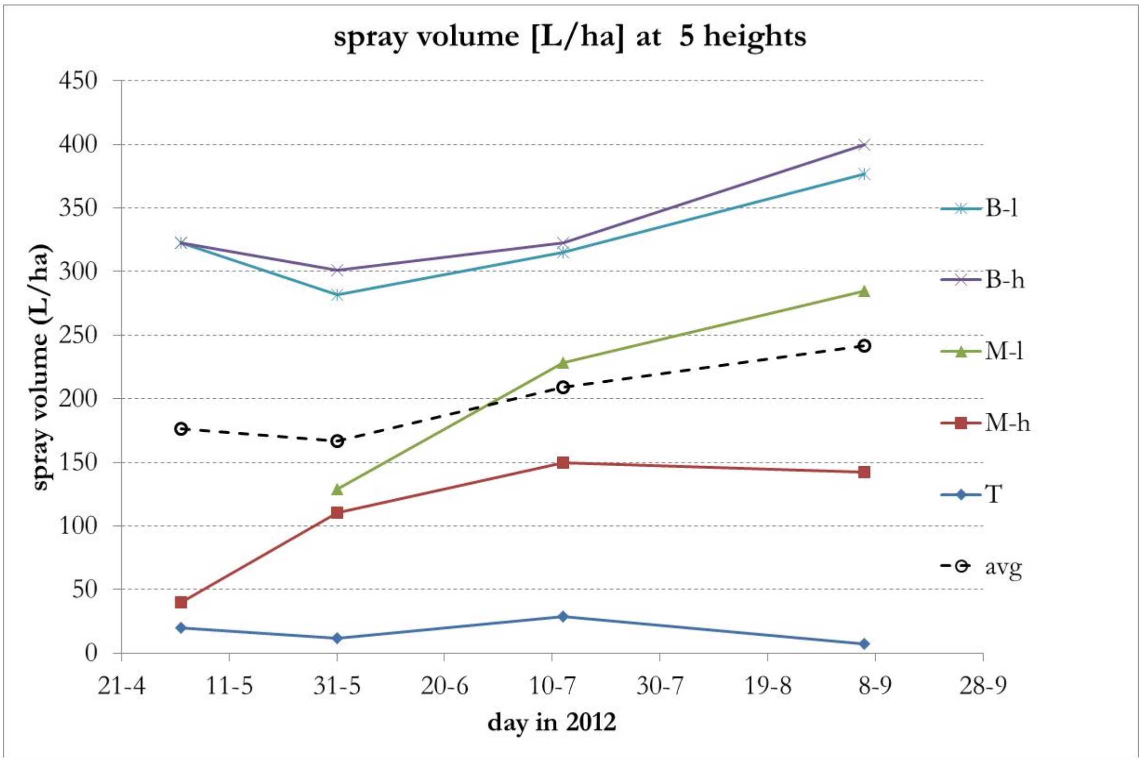

Fig. 6. Spray volume (L ha^{-1}) during the growing season at different heights of tree canopy (Top, Middle high/low, Bottom high/low and average) using a CDS sprayer in a commercial pear orchard.

Discussion

First results of the 2011 spray deposition measurements show that in pear canopy the spray deposit for the CDS sprayer was higher than of the conventional sprayers. As these higher spray deposits could lead to higher risks of too high residue levels on the fruits the dose algorithms were adjusted in 2012. On average the CDS variable rate spray technologies in practice resulted in a spray volume reduction of 30%.

The CDS sprayers were introduced at practical farms where it showed that knowledge is lacking on how to translate sensor signals measuring crop growth stage to spray volume rates to be applied. Especially, to generalise the decision algorithms concept to different crops is an on-going process in communication with farmers, advisors and researchers.

Starting with sensor guided spraying farmers do not know on beforehand the amount of spray liquid that will be used on their fields. It would be good to help them predict from previous applications what they should put in their sprayers. Direct chemical injection systems could be of help as well, as the spray liquid is then mixed at the time of application.

Knowledge is lacking on the process of spray deposition within a crop canopy. Large differences exist between the spray deposition in the flat surface beneath the sprayer and the spray deposition on the plant surface of the crop. This causes difficulties in the development of decision algorithms, where relations have to be made between sensor signals and volume rates to be applied on the crop.

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