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Precision spraying in greenhouses

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Summary

In the NL-DE-InterregIV project Gezonde Kas (Healthy Greenhouse; 2011–2014) a plant protection system is developed taking into account building blocks consisting of equipment for DNA- and sensor- techniques and automated image processing, software tools, biological control strategies and precision spraying techniques. An important part in the Healthy Greenhouse system is monitoring on both macro and micro levels. Thanks to the early detection, application of biological agents or other alternative, environmental friendly measures become possible for the effective control of pests or diseases. If plant protection products (PPPs) then need to be applied, a reduction in the use of pesticide(s) is ensured by optimal precision spraying techniques. A spraying system was developed consisting of sensors, a precision sprayer and software that adapts spray volume and dose applied to the crop canopy. Spray dose is adapted to the crop canopy structure and spray distribution is optimised for maximum efficacy and minimal environmental impact and operator exposure. Results are presented for spray deposition on crop canopy, greenhouse ground surface, greenhouse cover, spray volume and reduction of pesticide use.

Key words: Tomato, cyclamen, crop sensor, nozzle type, precision spraying, greenhouse, use reduction

Introduction

In the NL-DE-InterregIV project Gezonde Kas (Healthy Greenhouse; 2011–2014) a plant protection system is developed taking into account building blocks consisting of equipment for DNA- and sensor- techniques and automated image processing, but also of software tools, biological control strategies and precision spraying techniques. By combining the products developed in the project they strengthen each other, resulting in the totally new concept of the Healthy Greenhouse system: innovative crop protection connecting to modern developments in the modern protected horticulture agribusiness. An important part in the Healthy Greenhouse system is monitoring on both macro and micro levels (Zijlstra *et al*., 2011). This enables detection of diseases before symptoms are visible by the naked eye. Thanks to this early detection, application of biological agents or other alternative, environmental friendly measures become possible for the effective control of pests or plant diseases. If chemical plant protection products are still required, then a reduction in the use of pesticides is ensured by optimal precision spraying techniques.

Therefore a spraying system was developed consisting of a precision sprayer and software that adapts spray volume and dose to crop canopy size, similar those used in to field crop situations (Zande *et al*., 2008). Spray dose is adapted to crop canopy structure and spray distribution is optimised for maximum efficacy and minimal environmental and operator exposure. The basis for the optimised dose is the information from sensors that detect plant structure and canopy volume. The system is optimised for high plant structures like tomatoes and for low plant structures like pot plants (cyclamen).

Materials & Methods

Spray techniques

The Crop Adapted Spraying (CAS) is an intelligent sensor-based sprayer which applies its spray onto the crop only when and where it is necessary. The CAS sprayer prevents losses to the ground, the greenhouse walls and roof, as potential emission to the environment. The CAS-sprayer for tomatoes was developed to control *Botrytis* ssp. in tomato stems and was built on a vertical spray mast (Fig. 1). The CAS-sprayer uses a sensor to detect the tomato stem (1 cm precision) and will spray it sideways when a disease is to be controlled. The spraying will be stem specific, with adapted spray dose according to the stem size, and saves spray liquid by not spraying the gaps in between the vertical tomato stems. In cyclamen the CAS-sprayer is directed downward, built on a horizontal spray boom and uses a sensor to detect if there is a green crop, the size and density of the crop canopy so only sprays when there is a plant present. Minimal distance between individual plants to trigger the sensor is 1 cm. The system is adapted from the Weedit (Rometron, Steenderen, NL) sprayer used to control weeds on pavements in the urban areas. The system uses Rometron PWM nozzles (50 Hz) to maintain spray volume adjusted to the forward speed and a Rometron chlorophyll sensor with five channels to identify 10 cm segments. Nozzle spacing on the vertical spray mast and the spray boom are therefore 10 cm also. Nozzles used at the tomato spray mast are TeeJet 400050 flat fan nozzles operated nominally at 2 bar spray pressure (flow rate 0.16 L min^{-1}). Walking speed for the tomato experiments in Straelen (DE) and Bleiswijk (NL) was 2 km h^{-1} (33 m min^{-1}) applying 500 L ha^{-1} in Straelen and 620 L ha^{-1} in Bleiswijk because of the difference in number of nozzles used, resp. 8 in Straelen and 10 in Bleiswijk. In Straelen conventional spraying in tomato was done with a spray mast equipped with Agrotop Airmix 11002 venturi flat fan nozzles operated at 2 bar spray pressure, with a forward speed of 2 km h^{-1} and 50 cm nozzle spacing applying 680 L ha^{-1} spray volume. Conventional tomato spraying in Bleiswijk was done using TeeJet 8002VK flat fan nozzles operating at 8 bar spray pressure (1.3 L min^{-1}) and 35 cm nozzle spacing applying around 2000 L ha^{-1}. All tomato treatments were done going through a single path and spraying in one direction towards a double row of plants over 15 m length.

Fig. 1. Spray techniques used in tomato spraying; CAS-sprayer (left) with sensors and PWM nozzles (centre), standard spray mast (right).

In cyclamen pot plants a comparison was made between a knapsack sprayer (Gloria 2001) with handheld lance equipped with a single G-H49-55 full cone nozzle producing a flow rate of 0.75 L min^{-1} applying 1000 L ha^{-1}, and a spray boom equipped with Lechler LU12003flat fan nozzles operated at 3 bar spray pressure and a forward speed of 1.0 m s^{-1} applying 1000 L ha^{-1} (Fig. 2). The CAS sprayer was equipped with TeeJet 400050E even spray nozzles operated at 3 bar spray pressure at 0.5 m s^{-1} and 1.0 m s^{-1} forward speed realising a spray volume of resp. 500 L ha^{-1} and 1000 L ha^{-1}. All treatments sprayed cyclamen planted in 10 cm pots placed at a 7.90 m × 1.80 m table. Pots were placed in 60 rows and 17 pots wide positioned against each other in a diagonal placement (not square).

Fig. 2. Spray techniques used in cyclamen pot plant spraying; hand held lance (left), spray boom (center) and CAS-sprayer with sensors to detect individual plants (right).

Spray deposition

Spray deposition measurements were performed by spraying a tank mix of the fluorescent tracer Brilliant Sulpho Flavine (0.5 g L^{-1}) and Agral Gold (0.075 mL L^{-1}) to mimic a standard spray solution. Collectors (Technofil TF-290; 10 cm × 100 cm) were placed on the ground in between the tomato rows and the cyclamen tables to quantify potential leaching, on the glass wall to quantify emission potential towards condensation water and above the treated area to measure upward spray that potentially could escape through ventilation windows in the green house roof. For the tomato crop, on the gutter underneath the plants, collectors were placed on top of the substrate slabs to measure the potential route into the recirculation water of the water system (Fig. 3). The spray deposition on the tomato stems was determined on two series of four of the upward leafless stems (front and back positioned on the gutter) of the hanging tomato plants was measured in 50 cm long pieces; one piece laying on the gutter, one transition piece, and two more or less vertical stem parts.

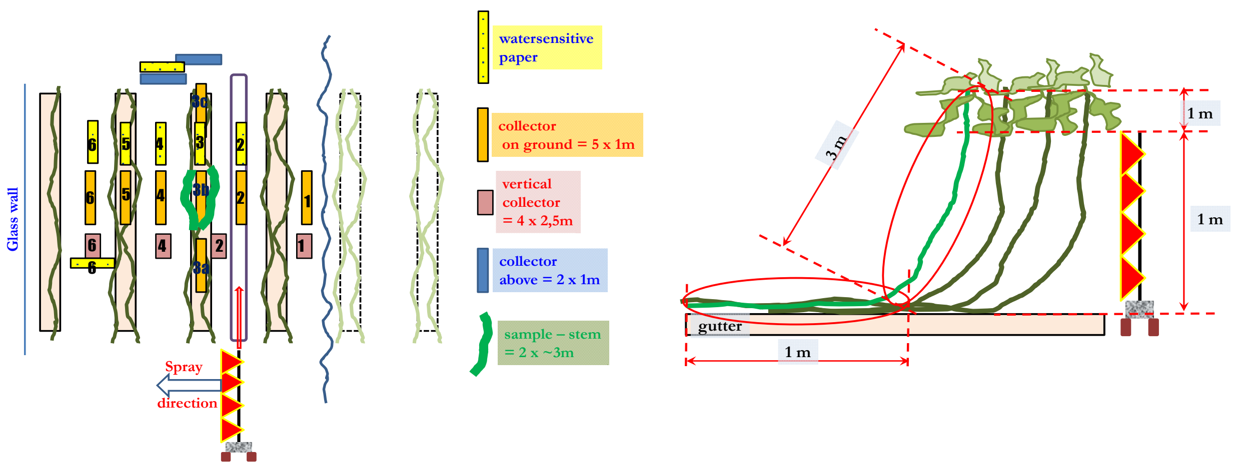

Fig. 3. Schematic presentation of sampling positions of different collectors, spray direction and path sprayed in between tomato rows (left) and sampled hanging two rows of four tomato stems of 4 m length with effective 1 m height sprayed and laying on gutter (1 m length).

Spray deposition on the cyclamen was determined on collectors (Technofil TF-290; 10 cm × 100 cm) above the crop (Fig. 2), and underneath the crop (Whatman no.2 chromatography paper strips 10 cm × 2 cm) and on the cyclamen plant tissue. Leaf area was measured using a surface area meter (Licor LI3000). Collectors and plant samples were washed with demineralised water and concentration of the BSF tracer measured using a fluorimeter (Perkin Elmer LS-55). Spray deposition was calculated as µL cm^{-2} and as percentage of applied spray volume.

Results

Cyclamen pot plants

Depending on plant distribution and growth stage of the cyclamen the CAS-sprayer saved 20–35% of spray liquid, after transplanting to wider pot distances when the plants are grown this can increase to up to 55% (Fig. 4). With the CAS-sprayer the in-crop spray deposition was higher or comparable than with a standard spray boom. The variation in spray deposition was lower using the CAS-sprayer. The CAS-sprayer reduced spray deposition on the ground between the tables by 80–90% compared to the conventional spray boom. The CAS-sprayer reduced spray deposition at the greenhouse wall by 50–80% compared to a horizontal spray boom. Spray deposition on the greenhouse roof was similar for both sprayers.

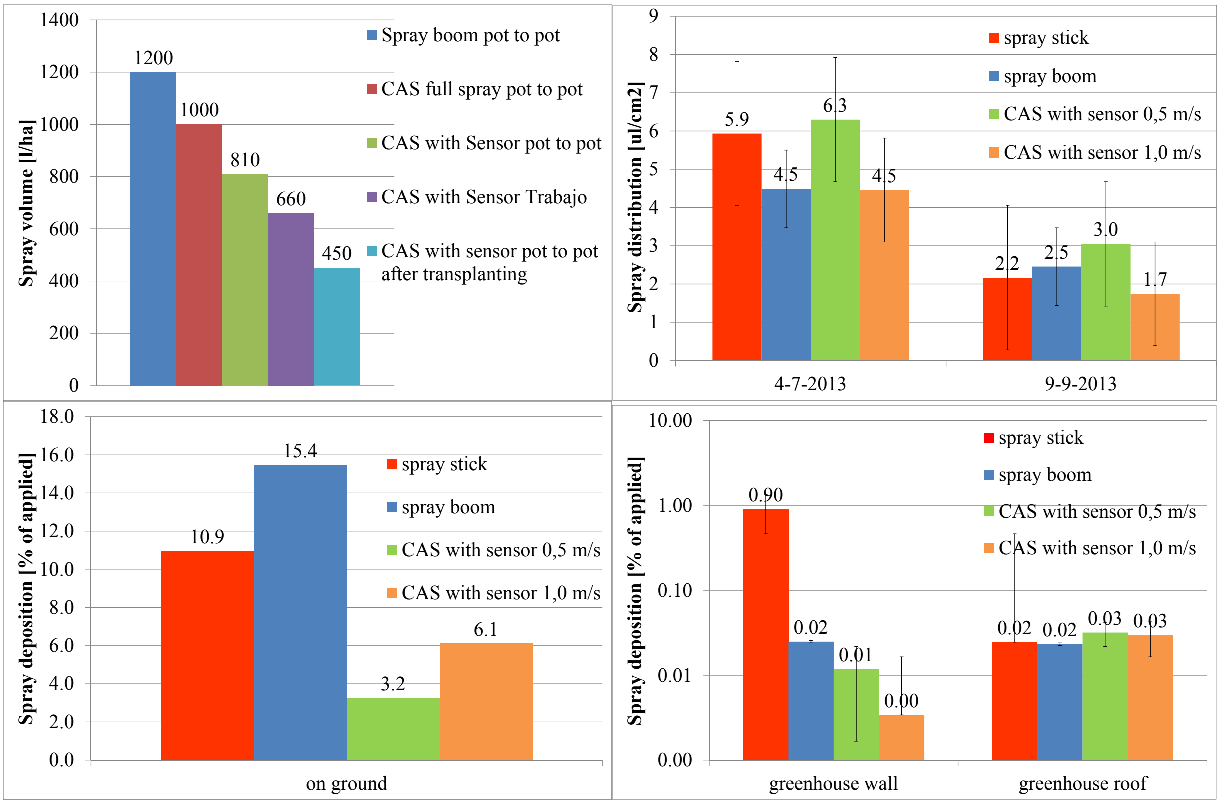

Fig. 4. Effect of spray techniques (spray lance, spray boom, Canopy Adapted Spraying at two speeds) on spray volume used (L ha^{-1}; top left) for different plant spacing, spray deposition on cyclamen leaf area (µL cm^{-2}; top right) on ground surface in the greenhouse (% applied dose; bottom left) and greenhouse wall and roof (% applied dose; bottom right); means and standard deviation.

Tomato stems

Straelen

Spraying only the stems of the tomato plants the CAS-sprayer saved 50% of the spray volume because of the use of the sensor and 65% compared to the standard spray mast and therefore similar amounts of PPP. Spraying only 250 L ha^{-1} the CAS-sprayer with sensors in use gave a similar spray deposition on the tomato stems (four pieces of 50 cm in height) as a vertical spray mast applying

700 L ha^{-1}. The CAS-sprayer with sensors in use reduced spray deposition at the substrate by 85% compared to a vertical spray mast and by 45% at the ground in the greenhouse when spraying tomatoes. The CAS-sprayer reduced spray deposition on the greenhouse wall by 60% compared to a vertical spray mast. Spray deposition on the greenhouse roof was similar for both types of sprayers.

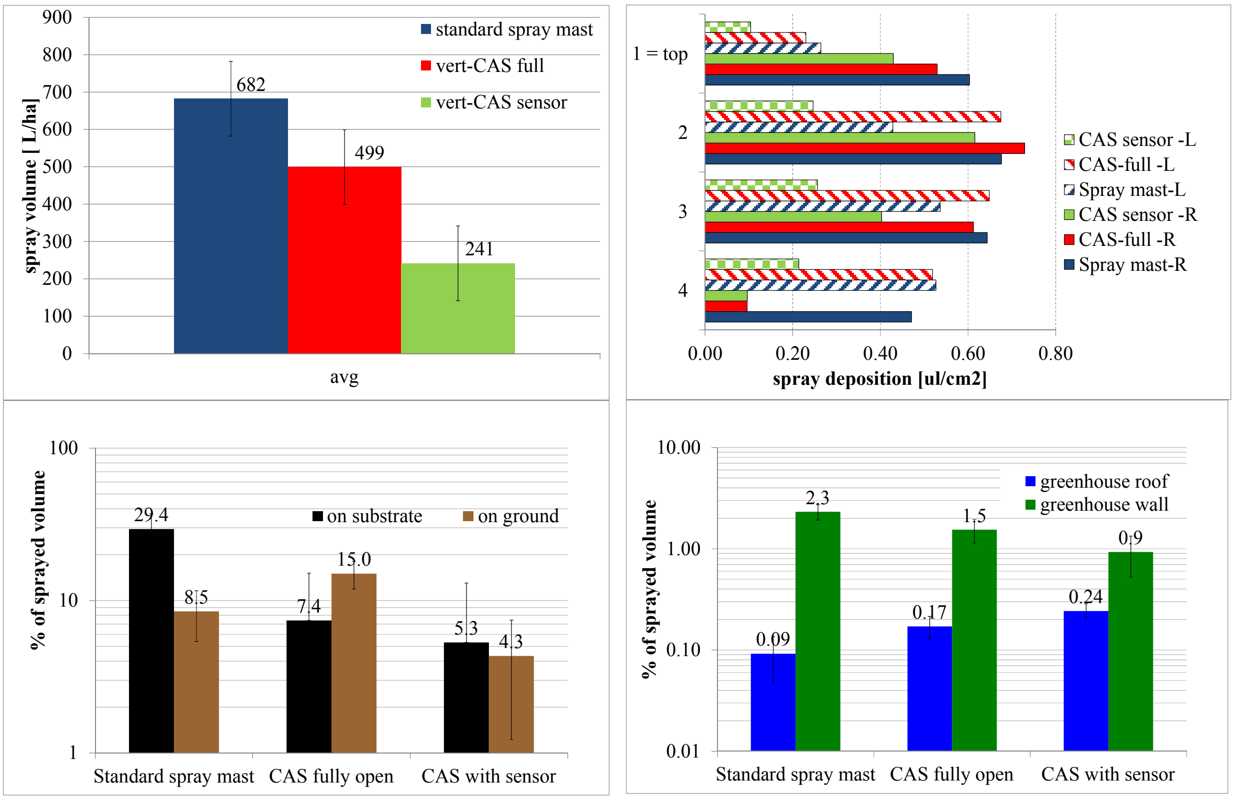

Fig. 5. Effect of spray techniques (standard spray mast, Canopy Adapted Spraying full spray and with sensor operational) on used spray volume (L ha^{-1}; top left) spraying tomato stems (Straelen, 2013), spray deposition on four parts of 50 cm of the tomato stems (µL cm^{-2}; top right) on substrate and ground surface in the greenhouse (% applied dose; bottom left) and greenhouse wall and roof (% applied dose; bottom right); means and standard deviation.

Table 1. *Spray deposition (µL cm^{-2} and % of sprayed volume) for three spray techniques on two rows of tomato stems (L is further away, R is direct next to sprayer) and average on a plant bed;Straelen experiments*

	Spray deposition uL cm^{-2}			% sprayed volume		
	L	R	avg	L	R	avg
Spray mast	0.44 a	0.60 a	0.52 a	6.5 a	8.8 a	7.6 a
CAS-full	0.52 b	0.49 b	0.50 b	10.4 c*	9.8 a	10.1 b
CAS sensor	0.21 c	0.39 c	0.30 c	8.6 b*	16.1 b	12.3 c

[a)]different letters per column means significant difference between means (a<0.05; a*<0.10).

Table 1 shows that absolute spray deposition (µL cm^{-2}) decreases from spray mast to CAS sprayer without sensor in use to CAS-sprayer with sensor in use. However the efficiency of the deposited spray on the tomato stems related to the applied spray volume increases from mast sprayer to CAS-sprayer with sensors in use.

Bleiswijk

Spraying only the stems of the tomato plants the CAS-sprayer saved 50% of spray volume and therefore PPP. Spraying only 250 L ha^{-1} the CAS-sprayer with sensors in use gave a similar spray deposition on the tomato stems (four pieces of 50 cm in height) as a vertical spray mast applying 2000 L ha^{-1}. The CAS-sprayer with sensors in use reduced spray deposition at the substrate by 45% compared to a vertical spray mast and by 40% at the ground in the greenhouse when spraying tomatoes. The CAS-sprayer reduced spray deposition at the greenhouse wall by more than 90% compared to a vertical spray mast. Spray deposition at the greenhouse roof was in these experiments more than 90% lower for the CAS-sprayer.

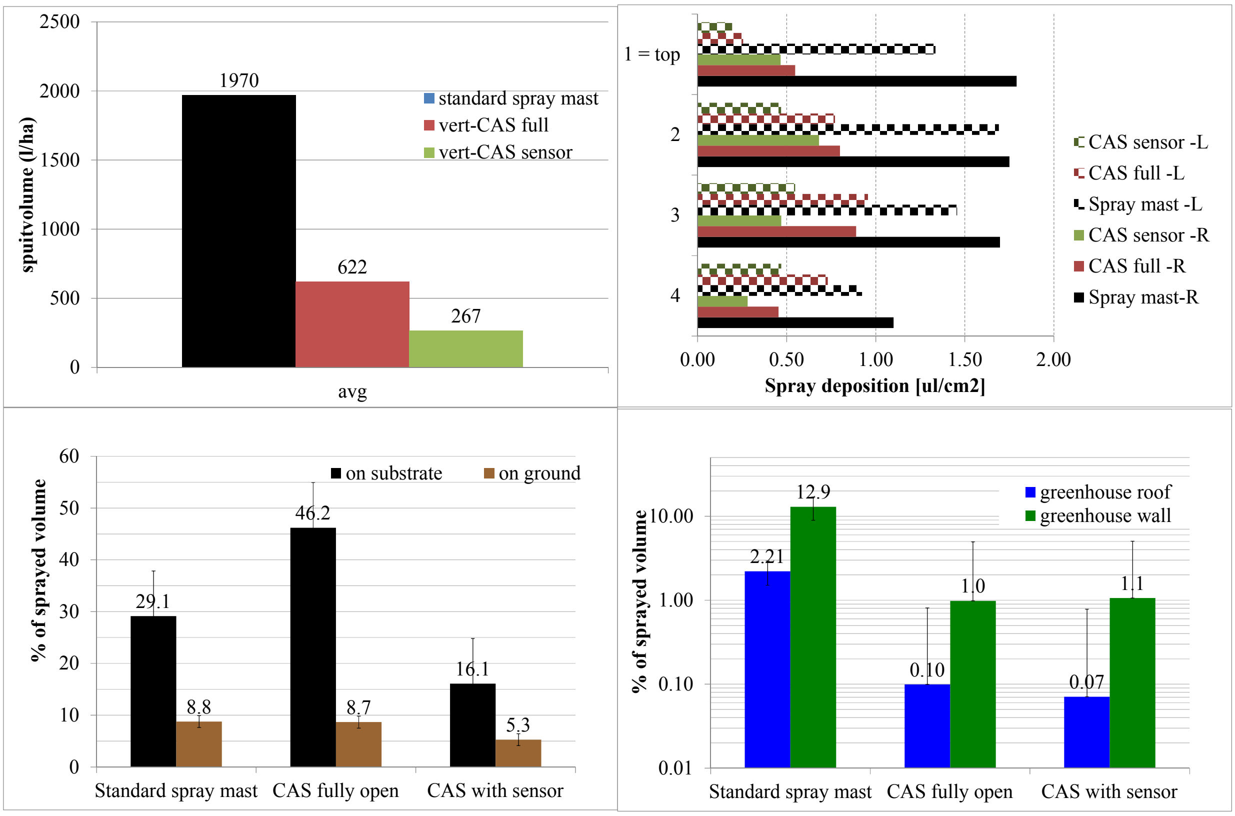

Fig. 6. Effect of spray techniques (standard spray mast, Canopy Adapted Spraying full spray and with sensor operational) on spray volume used (L ha^{-1}; top left) spraying tomato stems (Bleiswijk, 2014), spray deposition on our pieces of 50 cm tomato stems (µL cm^{-2}; top right) on substrate and ground surface in the greenhouse (% applied dose; bottom left) and greenhouse wall and roof (% applied dose; bottom right); means and standard deviation.

Table 2. *Spray deposition (µL cm^{-2} and % of sprayed volume) for three spray techniques on two rows of tomato stems (L is further away, R is direct next to sprayer) and average on a plant bed; Bleiswijk experiments*

	Spray deposition uL cm^{-2}			% sprayed volume		
	L	R	avg	L	R	avg
Spray mast	1.35	1.58	1.47	6.9	8.0	7.5
CAS-full	0.68	0.54	0.61	10.9	8.6	9.8
CAS sensor	0.42	0.47	0.45	15.7	17.8	16.7

Table 2 shows also for the Bleiswijk experiments that absolute spray deposition (µL cm^{-2}) decreases from spray mast to CAS sprayer without sensor in use to CAS-sprayer with sensor in use. However the efficiency of the deposited spray on the tomato stems related to the applied spray volume increases from mast sprayer to CAS-sprayer with sensors in use.

Biological efficacy

Cyclamen pot plants

Biological efficacy in cyclamen was evaluated by counting defined aphid population before and 1, 7, 14 days after a single treatment with an insecticide (Karate Zeon) comparing the handheld sprayer (T3) and the CAS-sprayer applying 100 mL m^{-2} with (T5) and without (T4) sensors, and controls with (T2) and without (T1) aphids. The aphid numbers decreased dramatically one day after spraying (Fig. 7). For all treatments a lighter decrease in aphid numbers could be seen one week after spraying. In week 2 after spraying the aphid numbers increased again. Unfortunately the standard deviation is so high that we can hardly find any statistical differences between the treatments. However handheld spraying looked a little better than the CAS-sprayer, likely due to the spray direction which is more horizontal for the handheld and therefore reached more of the underside of the leaves than with the vertical downward spraying of the CAS-sprayer. The switching of the nozzles of the CAS-sprayer used with sensors in operation had no negative effect on biological efficacy.

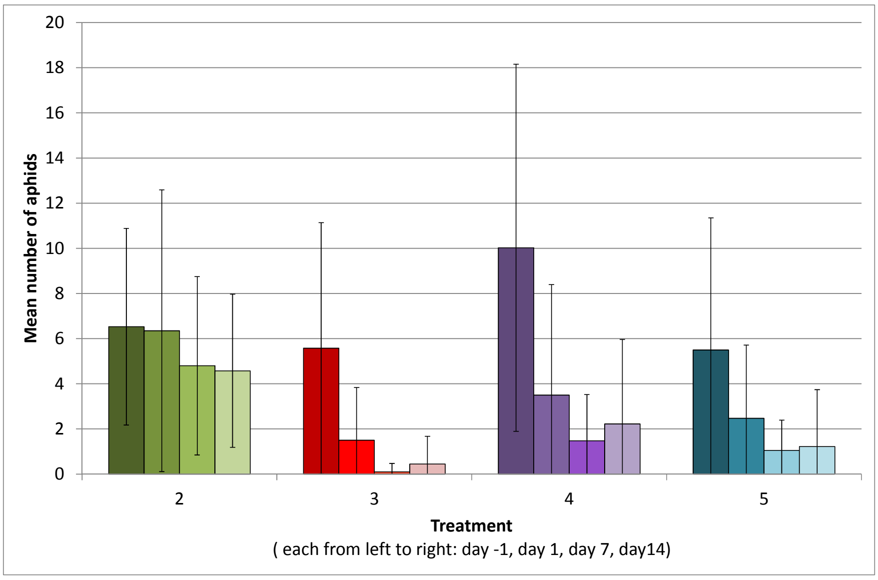

Fig. 7. Mean number of aphids in cyclamen on day -1, day 1, day 7 and day 14 after treatment. Means and Standard Deviation of four replications each with 10 cyclamen plants for untreated T2 and treatments; handheld T3, CAS-sprayer without sensor T4 and with sensor T5.

Tomato stems

To evaluate biological efficacy against *Botrytis* in tomato (variety Komeett) two experiments were setup in two different greenhouses and in two different periods (144 m^2 in July 2014 and 500 m^2 in October–November 2014). The tomato crop was grown in a high-wire system with a plant stem length of more than 10 m of which the top is attached to a high wire and maintaining growing with about a 1.5 m length with leaves and the rest of the stem without (picked). The stem hangs on the wire for a height of about 1.5 m and the rest lies in a gutter next to the substrate plant blocks. The tomato stems were wounded (knife cuts as if leafs were picked from the stem) at two spots and treated with a spray solution of Switch (40 g/100 L; 50% of advised dose). Treatments were untreated T1, standard spray mast (2000 L ha^{-1}) T2, CAS-sprayer without (600 L ha^{-1}) T3 and with sensor active (300 L ha^{-1}) T4. After treatments the wounds at the stems were inoculated with a solution of 10^5 botrytis spores mL^{-1}. In July two rows of eight plants were wounded and treatments were performed in three repetitions spraying the rows from both sides. In October two rows of 12 plants were wounded and sprayed form both sides in three repetitions. The wounds infected with Botrytis were calculated in the weeks after treatment (resp. 3 and 5 weeks) and for the October treatment also the size (cm length) of the infected area.

Despite the higher spray volume of the standard spray mast (2000 L ha^{-1}) compared to that of the CAS-sprayer without sensor in use (600 L ha^{-1}) the number of infected wounds in the July experiments were both comparable (Fig. 8). The number of infected wounds of the CAS-sprayer with sensor in use was also comparable and slightly better as time after treatment increased, despite only being applied in a spray volume of 300 L ha^{-1}. Therefore a lower amount of agrochemical was applied as applications were with identical tank mixture concentrations. For the October treatment infection rates after treatment were high and decreased slightly in time after treatment; this was probably due more to the climate in the greenhouse than due to treatment. Which means however that the CAS-sprayer, despite its low volume rate and even with the sensors in use, produced similar or better results than the standard spray mast with lower amounts of agrochemical (similar tank concentrations were used).

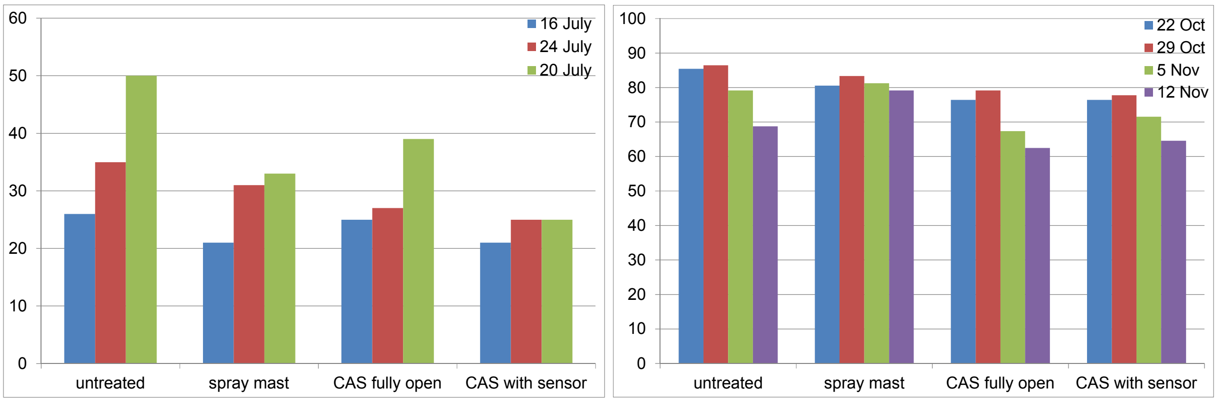

Fig. 8. Percentage of tomato stem wounds infected with *Botrytis* for the July 2014 (left) and October 2014 (right) experiments for untreated, standard spray mast and CAS-sprayer without and with sensor active.

Discussion

Biological efficacy was evaluated for aphids in cyclamen and botrytis infection on the tomato stems. In the cyclamen there were some problems in control of aphids on the underside of the leaves. Efficacy of the CAS sprayer was similar, without or with using the sensor, e.g. continuous spraying, to the standard horizontal spray boom but lower than the handheld spray lance. In the tomatoes the botrytis on the tomato stems was equally or better controlled with the CAS-sprayer compared to without using the sensors and the standard vertical spray mast despite the 50–60% lower applied amounts of plant protection products.

Precision spraying equipment as developed for outdoor crops can, with typical adaptations, be transferred to greenhouse crop situations and save on PPP use and reduce the potential emission from the greenhouse.

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