Set-up and verification of a segmented cross-flow CDS orchard sprayer equipped with a canopy contour guidance system

Proceedings of the VII Workshop on spray application techniques in fruit growing

van de Zande, J.C.; Michielsen, J.M.G.P.; Achten, V.T.J.M.; Porskamp, H.A.J.; Stallinga, H.

https://iris.unito.it/handle/2318/43874

Set-up and verification of a segmented cross-flow CDS orchard sprayer equipped with a canopy contour guidance system.

J.C. van de Zande, J.M.G.P. Michielsen, V.T.J.M. Achten, H.A.J. Porskamp & H. Stallinga

Institute of Agricultural and Environmental Engineering IMAG, P.O. Box 43, 6700AA Wageningen, The Netherlands

Summary

Matching spray volume to tree sizes and shapes can reduce chemical application, thus reducing operational costs and environmental pollution. A tree-specific variable volume precision orchard sprayer, guided by foliage shape and volume (canopy density sprayer; CDS) is developed. The spray and air volume is adjusted to tree variation of the foliage shapes and volumes of mapped trees. Tree mapping is done with stereoscopic aerial photography. Position of the sprayer in the orchard is linked to the mapped tree information from a GIS by RTK-DGPS. Spray deposition and distribution measurements with an artificial tree in the laboratory are used to set-up the prototype sprayer in an orchard situation.

Keywords: spray technique, spray deposition, orchards, fruit growing, canopy density sprayer

1. Introduction

In fruit crop spraying the goal is to come to an uniform spray deposition all over the leaves in the tree. Losses to the soil underneath the tree and outside of the orchard through spray drift are to be minimised. It is known that sprayer settings are important for spray distribution in tree canopy. Important parameters determined are: vertical liquid distribution (Jaeken *et al*., 2002), air settings (Moor *et al*., 2002; Svensson, 2002), and sprayer speed (Zande *et al*., 2001a). Spray distribution of orchard sprayers are measured in a vertical plane (Miralles *et al.*, 1996). Little is known on the relation between a spray distribution measured stationary in a vertical plane and that in a dynamic situation, when driving through an orchard, and the spray deposition on the leaves in the tree. Schmidt & Koch (1995) concluded that the requested distribution on a patternator depends on the type of sprayer and the shape and height of the trees to be sprayed. Koch *et al.* (1998) found that with a cross-flow fan sprayer a fixed nozzle distance in combination with a uniform distribution on the vertical patternator was preferred to obtain a homogeneous spray distribution on the leaves of the tree. Siegfried *et al*. (1995) prefer however a more canopy shaped spray distribution corresponding with leaf-mass and canopy-width in the tree. Canopy structure however varies a lot, because of plantation systems, plant varieties, pruning systems and in time during the season (Jaeken *et al*., 2001).

The research described in this paper is performed within a research project (PreciSpray EU-QLK5-1999-1630) aiming to develop a Canopy Density

Sprayer (CDS) using information on leaf canopy density and the structure of the trees (Meron *et al*., 2003; Zande *et al*., 2001b) to adapt spray volume and air settings (fig. 1). The PRECISPRAY project was initiated as part of the Precision Horticulture concept, to reduce pesticide use by tree shape and volume specific precise application of agrochemicals. Matching spray volume and direction to tree sizes and shapes can reduce chemical application, thus reducing operational costs and environmental pollution. Manual or sensors actuated orchard sprayers (Koch & Weisser, 2000; Molto et al., 2001; Solanelles et al., 2002) have shown reductions in agrochemical use of 30% and more. In the project a tree-specific variable volume precision orchard sprayer, guided by foliage shape and volume map (Canopy Density Spraying) is developed. Tree maps are obtained by a 3D-aerial survey method, converted from defence applications, and is imported as a layer into a plant protection and orchard management GIS database. The sprayer guidance module will control spray amount and direction according to the foliage structure map. The supporting GIS database will be capable to monitor infestation, utilise plant protection management and decision support systems and automatically recording spray applications from the guidance system feedback (Figure 1).

Using site-specific information of individual trees from an aerial survey (stereoscopic) enables to spray every tree as an individual and unique object using GPS. Knowledge of settings of a cross-flow sprayer on spray distribution for different heights is however very limited (Porskamp *et al*., 1993). Koch *et al.* (1998) showed the effect on spray deposition of individual spray elements on different heights of a cross-flow orchard sprayer in apple trees. More detailed information is needed to come to an algorithm to automate sprayer settings depending on tree structure and canopy density.

In this paper we describe the results of the research on fan capacity and air outlet setting on spray distribution in free air, on leaf walls of defined density and in and through an artificial apple tree (Zande et al., 2001) in the laboratory. Results are evaluated for spray deposition and drift potential to prepare for use in a Canopy Density Sprayer controller.

The development of the full-sized prototype sprayer started with the testing of a sprayer segment in the laboratory on a spray track. One element of the segmented cross-flow orchard sprayer was moved on the laboratory spray track spraying an artificial apple tree placed inside the spray chamber. The effect of sprayer settings were measured spraying collectors placed in free air at different distances from the nozzle, behind a single and a double leaf wall and in and behind an artificial apple tree (Zande et al., 2002). Results showed that fan speed and air outlet setting define spray deposition in the tree and can be used to minimise spraying through tree canopy and therefore spray drift potential. The developed cross-flow sprayer was equipped with 5 segments of 0.50 m height on top of each other that can move perpendicular to the driving direction by means of electrically actuated side-shifts. Each section has an air outlet and three nozzles that can be switched on/off individually. The air speed of each outlet can be adjusted in four steps. The sprayer sections are controlled by three section microcontrollers that communicate with a sprayer controller in the tractor cab using an ISO11783 compatible CAN-bus system. Based on canopy contour information obtained from stereoscopic aerial photography (Shimborsky,

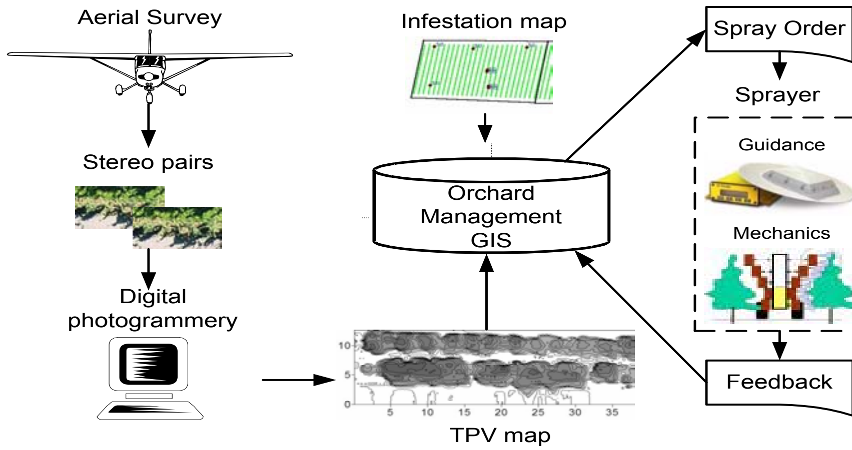

Figure 1. The PRECISPRAY tree size and foliage volume specific spray system

2003), also information in the spray computer is loaded about the place of individual trees and the canopy volume coinciding with the height of the vertical segments of the cross-flow elements next to the sprayer in the tree row. Canopy contour line information is used as input for the sprayer segment movements around the trees on different heights. Spray volume is adjusted according to canopy density information per segment height of individual trees (Van de Zande et al, 2002). Out of this information an application map that is prepared by the GIS database system (Hetzroni et al., 2003) is transferred to the sprayer controller by means of a data storage card. The sprayer position is determined using a RTK-DGPS receiver on the sprayer. On-line the sprayer controller calculates the section settings (section position, air speed and spray volume) based on the individual tree information obtained from the GIS and the actual position in the orchard and controls the sections accordingly(Achten et al., 2003). Switching the 3 nozzles for each segment on or off changes spray volume. Nozzles were switched on/off depending on the information input from the photographs and the actual position (the view in front of the segment) of the sprayer with RTK-DGPS. The optimal settings for different canopy densities were used for the full-size prototype sprayer to evaluate spray deposition. Outdoor measurements were performed on spray deposition with the RTK-DGPS guided segmented cross-flow orchard sprayer. Spray track was set up on a concrete track with additional position information of the place of the artificial tree. Canopy contour line information was input for the sprayer segment movements passing the trees on different heights. Spray volume was adjusted according to canopy density information per segment height. Results are presented for the spray deposition on different targets for the laboratory measurements as well as for the prototype sprayer in comparison with a standard cross-flow sprayer.

2. Materials and Methods

2.1 Sprayer segment in the laboratory

The development of the sprayer started with the testing of the sprayer segment in the laboratory on a spray track spraying an artificial apple tree (Van de Zande et al, 2001) placed inside a conditioned spray chamber. The effect of sprayer settings on the stationary air distribution and dynamically the spray distribution on different targets was assessed. The effect of sprayer settings on spray deposition was measured.

In the IMAG spray laboratory experiments were performed on a spray track placed in a conditioned chamber (15mx5mx4m, lwh). On the spray track (free space to the floor 2m) a prototype spray element of a CDS cross-flow fan orchard sprayer was hanged. The spray element consists of a switchable three-nozzle element connected to a variable air-outlet of 0.50x0.06m. Direction of the nozzles is fixed to 20^{o} in the airflow. Individual nozzles were angled 10^{o} on top of each other to prevent spray fan disturbance. Nozzle type used was a Hardi ISO F8001 used at 5 bar pressure having a flow rate of 0.52 l/min. Only one nozzle was used in the experiments presented here. Fan speeds was variable and adjustable between 0 and 3000 rpm, having a maximum air flow of 7000 m^3/hr. Fan settings used in the experiments were 0, 1500 and 3000 rpm. The air-outlet was variable adjustable and used in the settings, full open, half open, ¼ open and closed. The spray element was moved on the spray track with a speed of 1 m/s.

Measurements performed were air distribution in the stationary situation to characterise the fan air-outlet combinations. Spray distribution was measured dynamically on different targets: poles on different distances to measure free flight spray distribution, leaf walls of known density, and an artificial apple tree.

Air distribution

Air distribution was measured with a vane anemometer (Lambrecht 1416 K). On distances 0, 0.25, 0.50, 0.75 and 1.00 m from the nozzle at nozzle height and 0.10, 0.20 m above and below nozzle height. A two-dimensional airflow pattern could be quantified. Measurements were repeated three times for a fan speed of 1500 rpm and 3000 rpm and the air-outlet settings: full, ½ open, and ¼ open.

Spray deposition

The quantification of the spray deposition on the collectors was performed by means of fluorimetry. Therefore a fluorescent tracer (Brilliant Sulfo Flavine BSF, 0.5g/l) was added to the tank mix.

Free air spray distribution

Spray distribution in free air was measured on chromatography paper (2.50x0.02m) fixed to vertical poles placed at 0.25, 0.50, 0.75, 1.00, 1.25, and 1.50m from the nozzle. Nozzle height was marked on the paper and after spraying the paper was cut into 0.10m pieces to be separately analysed on spray deposition.

Artficial tree

In order to evaluate spray distribution on the leaf in a tree, spray deposition measurements were performed passing an artificial apple tree. The tree was reconstructed from a semi-dwarf Elstar apple tree on M9 rootstock. Stem and main branches were reconstructed from stainless steel. Shoots were established with artificial Ficus Benjamina leaves. Height of the tree was 2.2m, crown diameter was 1.5m The tree had 3000 leaves and total leaf area was 6.8 m^2. With a tree density of 3m row spacing and 1.25m tree spacing in the row leaf area index (LAI) is 1.8. Number of leaves and leaf surface area are as measured from an orchard tree. On the trunk and behind the tree a chromatography paper strip was placed to measure vertical spray distribution.

Spray passing the tree is an indicator for the filtering capacity of the tree canopy and therefore indirectly for drift potential.

2.2 Prototype sprayer outdoor testing

The optimal settings for different canopy densities were used for the full-sized prototype sprayer to evaluate spray deposition in the orchard. Outdoor measurements were performed on spray deposition with the RTK-DGPS guided segmented cross-flow orchard sprayer. Spray track was set up on a concrete track with additional position information of the place of the free-air deposition rack and a row of three artificial trees. Spray deposition was measured on collectors (2m chromatography paper strips) placed 0.25m in front of the trunk, at the trunk position (1.50 m from the centre of the sprayer) and 0.25 m behind the trunk of the center tree. Collectors were also placed behind the center tree and at the same distance in between the center and third tree. A comparison was made for the PreciSpray prototype sprayer and a conventional Munckhof cross-flow orchard sprayer, both spraying 300 l/ha. The Munckhof sprayer was set up to produce an even spray distribution (Zande et al., 2001); average air speed was 30 m/s at air outlet. The PreciSpray sprayer (average air speed 20 m/s at air outlet) was compared as a cross-flow sprayer, all elements in a vertical position, and with the elements enabled to follow the tree contour lines, in both cases spraying with one nozzle per element. Another set-up of the Precispray sprayer compared was enabling both contour line following and switching of nozzles (Hardi ISO F8001; 5 bar pressure) depending on the distance of the canopy contour line from the trunk. Distances from the trunk to switch second and third nozzle were respectively 0.25m and 0.50m. When no leaf area was present in front of the element nozzles were closed.

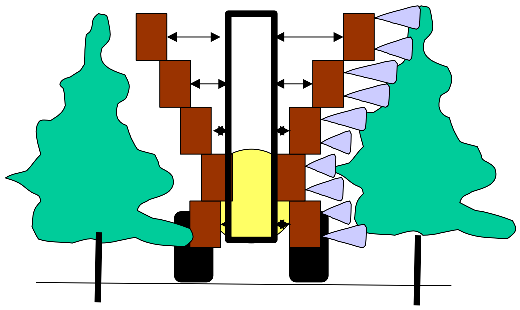

Figure 2. Schematic layout of the PreciSpray prototype orchard sprayer

3. Results

3.1 Segment measurements

Air distribution

Measured air speeds at the center line of the air outlet for the high (3000 rpm) and low (1500 rpm) fan capacities and the air-outlet setting: full open, ½ open and ¼ open are presented in Figure 3. The smaller the opening the higher is the air speed coming out of the air-outlet. For both fan capacities the narrower air-outlet showed air speed to be more uniform over the total height of the air-outlet. On nozzle height air speed is for both fan capacities higher for the smaller opening of the air-outlet. For the ¼ open air-outlet air speed decreases however in such a fast way that already after 0.50m from the nozzle air speed is lower than for the other settings. After 0.50m little difference exists in centerline air speed for the ½ open, ¾ open and full open air outlet settings.

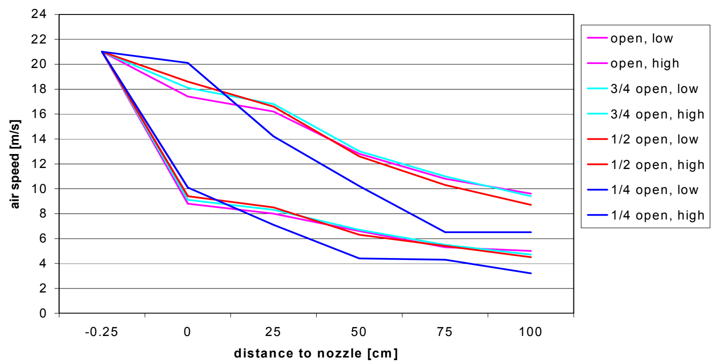

Figure 3. Air speed at the center line of the air outlet for different settings of the air-outlet and with a high (3000 rpm) and a low (1500 rpm) fan capacity.

Spray distribution in free air

The spray distribution in the free air for the high fan capacity (3000 rpm) is shown for the different air-outlet settings in figure 4. Averaged spray deposition in front of the spray element (0.60m height) on different distances

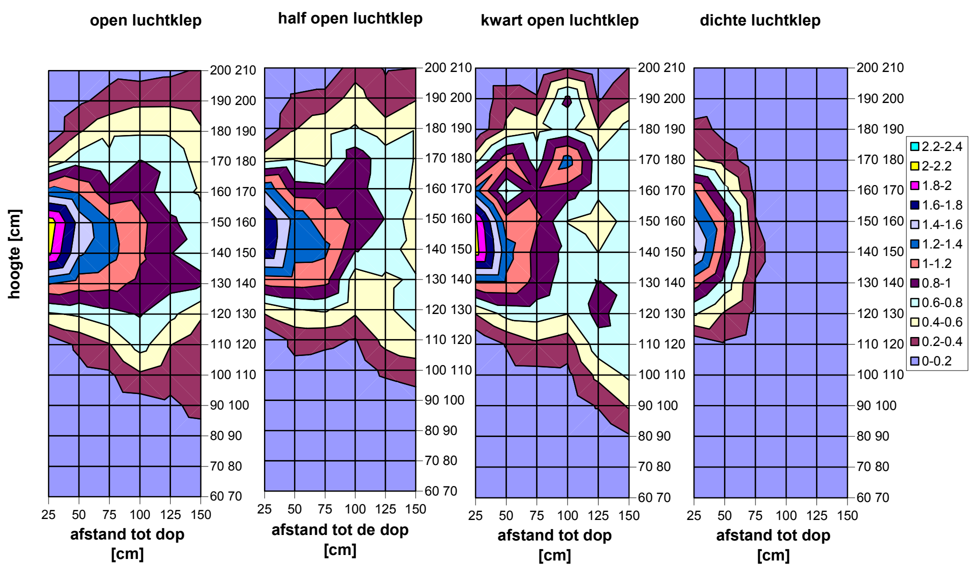

Figure 4. Effect of air-outlet settings on the spray distribution ($\mu l/cm^2$) in the free air. Presented from right to left for the full open, ½ open, ¼ open and closed air-outlet setting. Nozzle position is at left side on 1.50m height.

is for the high fan capacity presented in Figures 4 and 5 respectively. From both figures 4 and 5 it is obvious what the effect of air assistance is in spray transport and deposition. Spray deposition is for the full open air-outlet setting higher than for the ½ open setting for a distance up to 1.0m from the nozzle (α<0.05). The level of spray deposition of the high and low fan capacities do not differ for the full open and ½ open air-outlet setting.

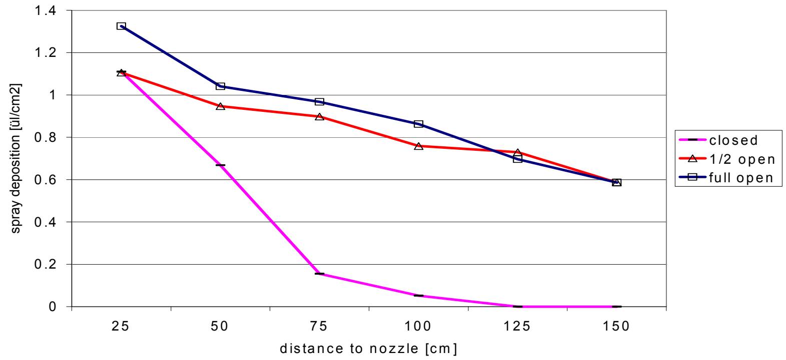

Figure 5. Averaged spray deposition ($\mu l/cm^2$) in front of the spray element for the high fan capacity and the air-outlet settings full open, ½ open, and closed.

Spray distribution in an artificial tree

The spray deposition on the tree trunk within the tree and passing through the artificial tree is presented in table 1 for the high and low fan capacities. Spray deposition behind the tree is lower than inside the tree at trunk level. The backside of the tree still acts as a filter for the spray. It is obvious that no air assistance gives poor penetration. However, the spray deposition on the stem inside the tree is remarkable and must be related to the variation in tree canopy structure compared to the more homogenous distributed leaves in the leaf walls.

Table 1. Spray deposition ($\mu l/cm^2$) inside an artificial tree on trunk level and behind the tree for different settings of the air-outlet and fan capacities

Air-outlet	Low fan capacity		High fan capacity	
	Trunk	Behind tree	Trunk	Behind tree
closed	0.023	0.000	0.164	0.000
¼ open	0.020	0.014	not measured	
½ open	0.022	0.006	0.113	0.012
Full open	0.031	0.006	0.158	0.046

Sed: Low fan: air-outlet = 0.008, place = 0.009, air-outlet*place = 0.018
High fan: air-outlet = 0.027, place = 0.035, air-outlet*place = 0.061

In general spray deposition decreases with narrowing the air-outlet, except with the ¼ open high fan capacity setting that has highest values behind the tree.

3.2 Prototype measurements

Spray distribution in free air

The spray distribution in free air ($\mu l/cm^2$) of the PreciSpray prototype sprayer operating all segments vertical at the same distance to the distribution rack – like a cross-flow sprayer- is presented in figure 6. The sprayer operated at a speed of 1 m/s and 1 nozzle per segment spraying. Spray deposition decreases with increasing distance from the nozzles. Output levels measured at 25 cm distance of 2 to 4 $\mu l/cm^2$ decrease in general to levels of lower than 1 μl/cm^2 at 150 cm distance. On 80-120cm height deposition levels of up to 3 μl/cm^2 however do reach the 150cm distance from the nozzle.

Spray distribution in an artificial tree

Incoming spray distribution and spray deposition in the tree at the trunk level are for the conventional sprayer and the different settings of the PreciSpray sprayer presented in figure 7. Spray distributions in the free air (fig. 6) at 25 cm distance of the individual measurements are taken as potential input to the artificial tree. The comparison of the cross-flow set-up and the contour following set-up, both with 1 nozzle spraying, show that spray deposition at the trunk level increases because of the segment movements. Especially the movement of the top sprayer-segments towards the tree canopy results in higher deposits at the top of the tree. Spray deposition at the trunk level reaches the output level of 3-4 μl/cm^2. A peak in the spray deposition at the trunk level occurs at 100 cm height. This coincides with the higher values at that height for the free-air distribution (fig. 6). However this can also be a resultant of the tree canopy structure at that height, being less dense. In general spray deposition at the trunk level of the PreciSpray sprayer is higher than of the reference sprayer. This can both mean that the deposition in tree canopy is higher but also that penetration through canopy is higher. The area defined as the difference between potential input distribution and measured deposition at the trunk level can be seen as the potential spray deposit in the near to the sprayer part of the tree canopy. This area is for the Precispray sprayer settings cross-flow with 1 nozzle operating, contour following with one nozzle operating and for contour following with all nozzles switching respectively; 275, 290, and 1186 μl/cm canopy length. The very high value for the contour-following and nozzles switchable set-up of the PreciSpray sprayer is because of the more nozzles spraying at the lower segments of the sprayer depending on the width of the tree canopy contours. For the reference sprayer this value is 190 μl/cm canopy length, showing that for the PreciSpray sprayer the spray deposit is higher in the near to the sprayer part of the tree canopy. A further evaluation of spray penetration through this canopy is still to be done based on the spray deposit measurements behind the tree, as is a full-scale test in an orchard.

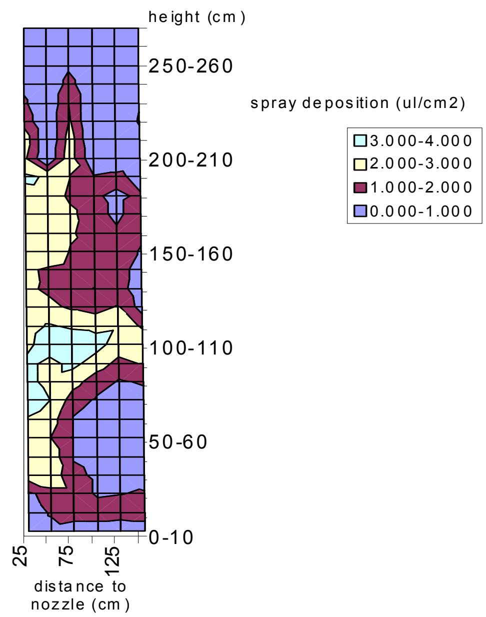

Figure 6 Spray distribution in free air (μl/cm^2) – sprayer speed 1 m/s

4.Discussion

From the laboratory measurements it was concluded that fan speed and air outlet settings define spray deposition in the tree to the most and can be used to minimise spraying through tree canopy and therefore spray drift potential. Commonly used air speeds of orchard sprayers can be lowered to maximise spray deposition in canopy and to reduce spray passing through canopy. A full range of sprayer settings exists to control spray flow depending on canopy structure and density. These data are used to develop the control algorithm used in the Canopy Density Sprayer. Especially the low fan speed fits the low-drift demand independent of the three air-outlet settings. When within this group of settings also spray deposition in tree canopy (front-side of the trunk) is maximised the full open air-outlet setting gave the best result and is therefore used in the first outdoor full-scale prototype tests.

As found by Moor et al (2002), Jaeken et al (2002) and Svensson et al (2002) this study also shows that fan capacity and air outlet shape are of importance to characterise the air assistance of an orchard sprayer. It is however also shown that minimal changes in air-outlet dimensions can alter the airflow to a great extend. The used methodology of measuring air speed in a stationary situation cannot be used in a dynamic situation, as reaction time of vane-anemometers is to slow. High frequency measuring equipment like ultrasonic or hot wire anemometers are then needed. A need for the dynamic measurements of spray and airflow with different driving speeds and air settings is still needed, as well in as outside a canopy structure.

The use of standardized targets like an artificial tree is a good tool to develop a sprayer and can be used in the laboratory as well as outside. Both elemental designs of e.g. air outlets, nozzle spacing and optimisations can be evaluated as ell as full-scale prototypes and its settings on a standardized track.

For the orchard situation, as mimicked on a standardized track, results are also presented for the spray deposition and distribution of the prototype PreciSpray sprayer in comparison with a standard cross-flow sprayer. From the amount of spray passing through an identical canopy structure (artificial tree) shown it can be concluded that the movement of the nozzles towards the tree canopy and the switching of nozzles increases the control of spray flow from sprayer to the target. Further measurements are still to be done in a real orchard, testing both the position and guidance aspects of the sprayer as the spray distribution and biological efficacy aspects.

Acknowledgement

This research was sponsored by the Dutch Ministry of Agriculture, Nature Management and Fisheries and the EU project PRECISPRAY (EU-QLK5-1999-1630).

References

Achten, V.T.J.M., R.P. van Zuydam, J.C. van de Zande & P.G. Andersen, 2003. Development of a canopy density adjusted segmented cross-flow orchard sprayer equipped with a canopy contour guidance system (PreciSpray). Proceedings of the 4th European Conference on Precision Agriculture, Berlin.

Jaeken, P., 2001. Dose calculation in fruit crops. *Parasitica* **57**(1-2-3)

Jaeken, P., J. Vercammen, A. de Moor & J. Langenakens, 2002. Impact of vertical liquid distribution profiles of orchard sprayers on within-tree deposit gradients. International advances in pesticide application. Aspects of Applied Biology 66: 267-275

Hetzroni et al., 2003. Proceedings of the 4th European Conference on Precision Agriculture, Berlin.

Koch, H. & P. Weisser, 2000.Sensor equipped orchard spraying – efficacy, savings and drift reduction. Pesticide application. Aspects of Applied Biology 57: 357-362

Koch, H., P. Weisser, H. Funke & H. Knewitz, 1998. Untersuchungen zur Verteilungscharakteristik einzelner Düsen bei Applikation von Pflanzenschutzmitteln mit Gebläsesprühgeräten. *Nachrichtenblad Deutsche Pflanzenschutzdienst,* ***50****: 30-36.*

Meron, M., J.C. van de Zande, R.P. van Zuydam, B. Heijne, M. Shragai, J. Liberman, A. Hetzroni, P.G. Andersen & E. Shimborsky, 2003. Tree shape and foliage volume guided precision orchard sprayer - the PreciSpray FP5 project. Proceedings of the 4th European Conference on Precision Agriculture, Berlin.

Miralles, A., N. Goretta, L. Dusserre-Bresson, F. Sevila, P.C.H. Miller, P. Walklate, R.P. Van Zuydam, H.A.J. Porskamp, H. Ganzelmeier, S. Rietz, G. Ade, P. Balsari, D. Vannucci & S. Planas, 1996. Results of a European programme to compare methods used to test orchard sprayers. Bulletin OEPP/EPPO Bulletin **26**: 59-68.

Molto, M., B. Martin & A. Gutierrez, 2001. Pesticide loss reduction by automatic adaptation of spraying on globular trees. *Journal of Agricultural Engineering Research*, 78(2001)1:35-41

Moor, A. de, & J. Langenakens, 2002. Dynamic air velocity measurements of air-assisted sprayers in relation to static measurements. International advances in pesticide application. Aspects of Applied Biology 66:309-322

Payne et al., 1993. Genstat 5 Release 3 Reference Manual. Oxford: Clarendon Press.

Porskamp, H.A.J., Michielsen, J.M.G.P., Hujsmans, J.F.M., 1993. Emission reducing spray techniques in fruit growing. Spray deposition and spray drift. Institute of Agricultural and Environmental Engineering, IMAG-DLO report 94-19. 45p..

Schmidt, K. & H. Koch, 1995. Einstellung von Sprühgeräten und Verteilung von Pflanzenschutzmittelbelägen in Obstanlagen. *Nachrichtenblad Deutsche Pflanzenschutzdienst,* ***47****:161-165.*

Shimborsky, E., 2003. Digital tree shape mapping and its applications. Proceedings of the 4th European Conference on Precision Agriculture, Berlin.

Siegfried, W.,E. Hollinger & U. Raisigl, 1995. Eine neue Methode zur Bestimmung der Brühe und Präparatmengen im Obstbau. *Schweizerische Zeitschrift für Obst- und Weinbau, 131,* ***6****: 144-147*.

Solanelles, F., S. Planas, A. Escola & J.R. Rosell, 2002. Spray application efficiency of an electronic control system for proportional application to the canopy. International advances in pesticide application. Aspects of Applied Biology 66:139-146

Svensson, S.A., 2001. Converging Air Jets in Orchard Spraying – influence on deposition, air velocities and forces on trees. PhD Thesis Swedish Agricultural University, Uppsala, Sweden.

Zande, J.C. van de, H.A.J. Porskamp & J.M.G.P. Michielsen, 2001. Effect of the spray distribution set-up of a cross-flow fan orchard sprayer on the spray deposition in a flat surface and in a tree. *Parasitica* **57**(1-2-3): 87-97

Zande, J.C. van de, M. Meron, E. Shimborsky, S. Meir, H. Koch, B. Heijne, 2001. the PriciSpray project. VIth Workshop on spray application techniques in fruit growing, Leuven Belgium, January 2001.Abstracts.

Zande, J.C. van de, A. Barendregt, J.M.G.P. Michielsen & H. Stallinga, 2002. Effect of sprayer settings on spray distribution and drift potential when spraying dwarf apple trees. Paper presented at the 2002 ASAE Annual International meeting/ CIGR XVth World Congress, Chicago, ASAE-Paper No. 2002-1036. 10pp.

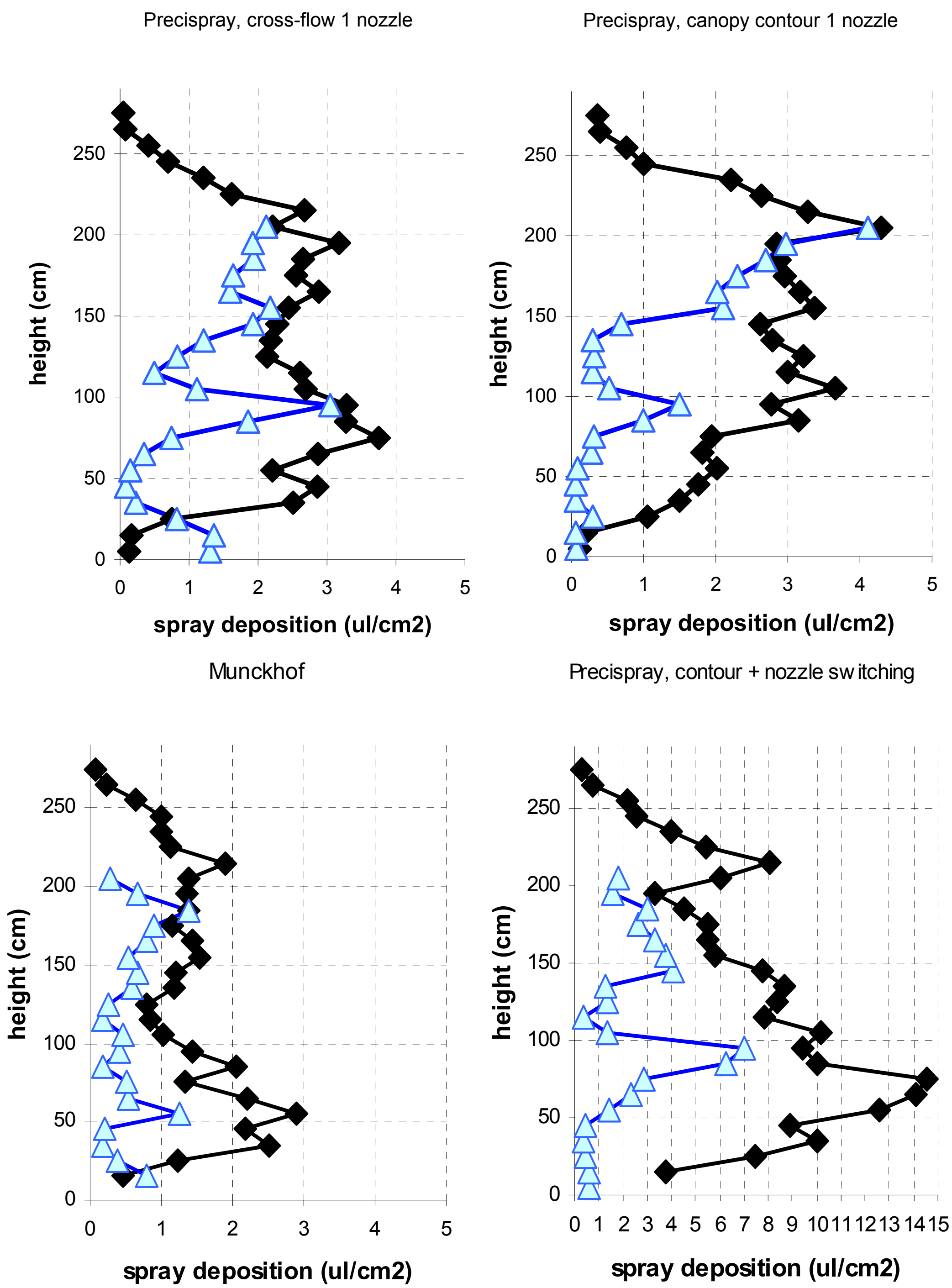

Figure 7. Spray distribution in front of the tree and at trunk level inside an artificial tree for different settings of the PreciSpray prototype sprayer and a reference sprayer (Munckhof)