15th Workshop on Spray Application and Precision Technology in Fruit Growing

Programme and Abstracts

July 16 - 18, 2019 • NIAB EMR, UK

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Welcome to the Workshop

This 15th Workshop on Spray Application and Precision techniology in Fruit Growing offers the floor for the presentation of scientific results and for discussion of the societal context of the application of plant protection products and the use of precision technology in orchards and vinyards. Suprofruit workshops have taken place biennially in Europe since 1991 with a primary focus on developments in spray application techniques in fruit and other three dimensional crops. The workshops offer a platform for scientists, researchers, technicians, advisors, manufacturers of spray equipment and industry from all over the world to present new ideas and developments, but also to discuss various topics in a three day workshop.

At this 15th Workshop at NIAB EMR, UK in July 2019, the scope of the conference has been widened to also cover PRECISION TECHNOLOGY. Precision technology encompasses techniques/tools/knowledge to target correct interventions of the correct magnitude according to need in time and space. In fruit and other horticultural crops, individual plants and parts of plants can be treated according to their individual needs. These technologies have been playing an increasingly important part in spray application and in horticulture in general. Contributions on all aspects of precision technology including for example remote sensing, the use of UAVs, Normalized Difference Vegetation Index mapping, image analysis, machine learning, Decision Support Systems and the utilisation big data and the Internet of Things, and especially where these relate to spray application, were sought.

This broadening of scope of Suprofruit into an exciting and developing area with so many possibilities yet to be realised and which will make a big contribution to the future sustainable development of fruit growing will add new dimensions to the workshop's focus on spray application. We hope you appreciate and enjoy!

Rob Saunders
H L Hutchinson Ltd, Chairman of the Tree Fruit Panel of the UK Agriculture and Horticulture Development Board
On behalf of the UK fruit industry

Dr Marcel Wenneker
Convenor of Suprofruit workshops

Prof Jerry Cross
Local Organiser
Science Group Leader, NIAB EMR

Convener

Dr Marcel Wenneker
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Local Committee

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Dr Charles Whitfield, NIAB EMR
James Shillitoe, FAST Llp

Scientific Committee

The scientific committee are responsible for ensuring the scientific quality and integrity of the Suprofruit 2019 workshop. They have invited plenary speakers and reviewed offered papers.

Paolo Balsari
Jerry Cross
Grzegorz Doruchowski
Jean-Paul Douzals
Emilio Gil
Kris Ruysen
Peter Triloff
Jan van de Zande
Marcel Wenneker (chairperson)
Charles Whitfield

Programme

Monday July 15th , 2019			
Anytime		Arrival at Hotels	
Tuesday July 16th, 2019			
Opening Session		Conference Centre, NIAB EMR, East Malling ME19 6BJ	
08:30-10:00		Registration	
10:00-10:15		Welcome to the Symposium On behalf of the UK fruit industry Convenor Local organiser	 Rob Saunders Marcel Wenneker Jerry Cross
Oral Session 1: Precision technologies in fruit growing **Session Chairs: Greg Doruchowski & Patricia Chueca**			**Tues July 16**
Time	**Abstract Number**	**Title**	**Presenter**
10:15-10:45 Plenary	1	Opportunities for precision technologies in fruit growing Jerry Cross, Eleftheria Stavridou, Bo Li, Charles Whitfield, Peter Walklate	Jerry Cross
10:45-11:00	2	Automated blossom detection for precision fruit farming Dirk de Hoog, Manya Afonso, Jan van de Zande	Dirk de Hoog
11:00-11:20		Coffee and snack break	
11:20-11:35	3	Canopy characterization with 2D Lidar in different French orchards Jean-Paul Douzals, Yoan Hudebine, Sophie Houee, Florence Verpont	Jean-Paul Douzals
11:35-11:50	4	Estimating vegetation volume of coffee crops using images from unmanned aerial vehicles João Paulo Arantes Rodrigues da Cunha, Matheus Aires Sirqueira Neto, Sandro Manuel Carmelino Hurtado	João Paulo Arantes Rodrigues da Cunha
11:50-12:05	5	Intelligent Fruit Vision – turning data into knowledge for apple growers Sam Dingle, Tony Harding, Megan McKerchar	Megan McKerchar
12:05-13:30		Lunch	
13:30-13:45	6	Precision yield management for UK vineyards: achieving fruit:canopy balance to increase fruit consistency and quality Julien Lecourt, Paul Tuteirihia	Julien Lecourt

Time	Abstract Number	Title	Presenter
13:45-14:00	7	Precision fertigation in soft fruit production Eleftheria Stavridou, Mark Else	Eleftheria Stavridou
14:00-14:15	8	Time series of chlorophyll degradation Manuela Zude-Sasse	Manuela Zude-Sasse
Oral Session 2: Precision spray application to fruit crops **Session Chairs: Peter Triloff**			**Tues July 16**
14:15-14:35	9	An update on the intelligent spraying system development for fruit and nursery crop applications Heping Zhu, Erdal Ozkan	Erdal Ozkan
14:35-14:50	10	Precision tree fruit dosing to optimise yield and quality: a new UK research project 2019-2021 Rob Saunders, Jerry Cross, Jim McDougall, Chris Elworthy, Oliver Hilbourne, Megan Mckerchar, Nick Seymour, Stan Stamper, Peter Walklate, Charles Whitfield	Rob Saunders
14:50-15:10		Coffee and snack break	
Oral Session 3: Spray cover and deposition **Session Chairs: Paolo Balsari & Andrew Landers**			**Tues July 16**
15:10-15:40 Plenary	11	A hand-held imaging fluorometer and attendant food-safe spray tracer for rapid quantification of spray deposits in the field Charles Whitfield, John Attridge, Jerry Cross	Charles Whitfield
15:40-15:55	12	Smartomizer – proactivity and traceability in orchard spraying Lars T. Berger, Paula Ortega, Emilio Gil	Lars T. Berger
15:55-16:10	13	Canopy adapted dosing and spray application: environment protection in crop protection Peter Triloff	Peter Triloff
16:10-16:25	14	Spray deposition of a cross-flow fan orchard sprayer with low air and low spray pressure settings Jean-Marie Michielsen, Hein Stallinga, Dirk de Hoog, Pieter van Dalfsen, Marcel Wenneker, Jan van de Zande	Jean-Marie Michielsen
16:25-16:40	15	Spray distribution in citrus canopies with different sprayers Cruz Garcerá, Alberto Fonte, Iván Carrillo, Patricia Chueca	Cruz Garcerá

Time	Abstract Number	Title	Presenter
16:40-16:55	16	Flat fan or cone nozzles for spray distribution in orchards and vineyard? Effect of nozzle type and row distance on the vertical distribution Emilio Gil, Jordi Biscamps, Jordi Llop, Marcel Valera, Robert Heinkel	Emilio Gil
16:55-17:10	17	Evaluation of sprayers used for regulatory efficacy assessment trials Carla Román, Jordi Llorens, Santiago Planas	Carla Román
17:10-17:25	18	Droplet size effect in a PWM system: first results to improve orchard spray application Jordi Llorens, Andrew Hewitt	Jordi Llorens
17:35		Bus transfer to hotels	
18:45		Bus transfer from Hotels to West Malling for free evening	
23:00		Bus transfer from West Malling to hotels	

Wednesday July 17th , 2019			
Oral Session 3 Spray cover and deposition continued: **Session Chairs: Emilio Gil & Paolo Marucco**			**Wed Jul 17**
08:30-09:00 Plenary	19	From direct injection to deposition indicator – a 45 year retrospective Andrew Landers	Andrew Landers
09:00-09:15	20	Improving spray deposition in apple orchards by multiple-row sprayers Marcel Wenneker, Jean-Marie Michielsen, Mostafa Snoussi, Hein Stallinga, Dirk de Hoog, Pieter van Dalfsen, Jan van de Zande	Marcel Wenneker
09:15-09:30	21	Drones for PPP distribution evaluation of spray deposits in orchards Changling Wang, Shiling Wang, Xiongkui He, Yajia Liu, Aijun Zeng, Jianli Song	Jianli Song
09:30-09:45	22	CitrusVol validation to control *Tetranychus urticae* Cruz Garcerá, Alberto Fonte, Enrique Moltó, Alejandro Tena, Patricia Chueca	Patricia Chueca

Time	Abstract Number	Title	Presenter
Oral Session 4: Pesticide dosing **Session Chairs: Jean Paul Douzals & Cruz Garcerá**			**Wed July 17**
09:45-10:00	23	Dose adjustment for pome fruit orchards in France: what canopy indicator options? Florence Verpont, Fanny Le Berre, Jean Le Maguet, Sébastien Ballion, Xavier Crete, Myriam Berud, Bruno Corroyer, Matthieu Benoit, Cécile Belleveaux	Fanny Le Berre
10:00-10:15	24	Dose adjustment in citrus and olive orchards: two-year validation of the DOSA3D system Santiago Planas, Joan Porta, José M Campos, José M Fibla, M Teresa Martínez-Ferrer	Santiago Planas
10:15-10:35		Coffee and snack break	
10:35-10:50	25	Evaluation of the MABO-dosing model as a cost-effective alternative to the conventional use of the Unrath tree-row-volume model in South Africa for applying pesticides sprays in high density apple orchards Philip Rebel, Johannes Gideon van Zyl, Adele Mcleod, Bekker Wessels	Johannes Gideon van Zyl
10:50-11:05	26	New developments to help farmers correctly dosing pesticides in olive orchards Antonio Miranda-Fuentes, Alberto Godoy-Nieto, Juan L. Gamarra-Diezma, Antonio Rodríguez-Lizana, Emilio J. González-Sánchez, Francisco Lara del Río, José M. Bejarano-Cabanás, Julio Román-Vázquez, Gregorio L. Blanco-Roldán, Jesús A. Gil-Ribes	Antonio Miranda-Fuentes
Oral Session 5: Spray atomisation, air support, new technologies for spray applications **Session Chairs: Kris Kruysen & Xiongkui He**			**Wed July 17**
11:05-11:20	27	Pneumatic nozzle droplets assessment: the effect of operative parameters Paolo Balsari, Marco Grella, Antonio Miranda-Fuentes, Paolo Marucco	Paolo Balsari
11:20-11:35	28	Automatic profiling precision orchard spray technique based on variable chemical flow rate and air volume with LiDAR Xiongkui He, Jianli Song, Yajia Liu, Aijun Zeng, Longlong Li	Xiongkui He

Time	Abstract Number	Title	Presenter
11:35-11:50	29	Solid Set Canopy System in France: the PULVEFIX project Florence Verpont, Fanny Le Berre, Sébastien Ballion, Damien Vincent	Fanny Le Berre
11:50-12:05	30	Solid Set Canopy Delivery System for modified vertical shoot position trained vineyards Rajeev Sinha, Rakesh Ranjan, Lav R. Khot, Gwen-Alyn Hoheisel, Matthew Grieshop	Lav R. Khot
12:05-13:00		Lunch	

Fruit Focus trade fair at NIAB EMR	**Wed Jul 17 13:00-17:00**

17:00	Bus transfer to hotels
18:10	Bus transfer from hotels to Bradbourne House, East Malling for conference dinner
18:30	Conference dinner & Ceilidh
23:30	Bus transfer from Bradbourne house to hotels

Thursday July 18th , 2019			
Oral Session 6: Spray drift: Session Chairs: Charles Whitfield & Erdal Ozkan			**Thur Jul 18**
09:15-09:30	31	Off-target deposition of a Solid Set Canopy Delivery System in high density apples Matthew J. Grieshop, Mark Ledebuhr, Keith Koonter, Ben Savage, Lav Khot	Matthew Grieshop
09:30-09:45	32	Direct and indirect methods for spray drift assessment in apple orchards Xavier Torrent, Eduard Gregorio, Jean-Paul Douzals, Joan R. Rosell-Polo, Santiago Planas	Santiago Planas
09:45-10:00	33	What are the best sprayer settings to spray avoid drift from apple orchards? Florence Verpont, Fanny Le Berre, Jean Le Maguet, Xavier Crete, Cécile Bellevaux	Fanny Le Berre
10:00-10:15	34	Reduction of spray drift by hail net over apple orchard Grzegorz Doruchowski, Waldemar Świechowski, Ryszard Hołownicki, Artur Godyń	Grzegorz Doruchowski

Time	Abstract Number	Title	Presenter
10:15-10:30	35	Spray drift of a two-row tunnel orchard sprayer Jan van de Zande, Jean-Marie Michielsen, Mostafa Snoussi, Hein Stallinga, Dirk de Hoog, Pieter van Dalfsen, Marcel Wenneker	Jan van de Zande
10:30-11:00		Coffee and snack break	
11:00-11:15	36	Practical implementation of drift-reducing nozzles in orchards Kris Ruysen	Kris Ruysen
11:15-11:30	37	Influence of canopy vineyard target presence in sprayer drift potential assessment using a test bench device. Marco Grella, Paolo Marucco, Paolo Balsari	Marco Grella
Oral Session 7: Knowledge exchange: **Session Chairs: Jan van de Zande & Santiago Planas**			**Thur Jul 18**
11:30-11:45	38	Gone with the wind – teaching fruit growers how to see the unseen Andrew Landers	Andrew Landers
11:45-12:00	39	INNOSETA - An H2020 European project to fill the gap between research and professional users in crop protection Emilio Gil, Montserrat Gallart, Paolo Balsari, Alex Koutsouris, Sebastien Codis, David Nuyttens, Spyros Fountas	Emilio Gil
12:00-12:15	40	OPTIMA EU project: main goal and first results of inventory of current spray practices in vineyards and orchards Paolo Marucco, Paolo Balsari, Marco Grella, Massimo Pugliese, Daniele Eberle, Emilio Gil Moya, Jordi Llop Casamada, Spyros Fountas, Nikos Mylonas, Dimitris Tsitsigiannis, Athanasios Balafoutis, Gerrit Polder, David Nuyttens, Luis Dias, Jean-Paul Douzals	Paolo Marucco
Poster	41	PERFECT LIFE PROJECT Pesticide reduction using friendly and environmentally controlled technologies Cruz Garcerá, Amalia Muñoz, Paolo Balsari, Clara Coscollá, Emilio Gil, Ana Cano, Daoíz Zamora, Sébastien Codis, Héctor Calvete-Sogo, Montse Gallart, Antonio López, Paolo Marucco, José Castro, Gonzalo Fernández, Xavier Delpuech, Patricia Chueca	Patricia Chueca

12:15-12:30	Thanks	Marcel Wenneker
12:30-13:30	Lunch	

Technical visit to a soft fruit then a tree fruit farm for demonstrations of precision technologies and specialist spraying equipment and operations (for full programme see overleaf)		**Thur Jul 18 13:30-18:00**
13:30	Technical visit to Hugh Lowe Farms (soft fruit spraying) then Bardsley Farms Ltd (tree fruit spraying) (see provisional programme overleaf)	
18:15	Bus transfer to Canterbury for free evening in city	
23:00	Bus transfer from Canterbury to Hotels	

Friday July 19th, 2019	
	Departure

Programme for technical visit
Thursday 18 July 2019

13:30 Depart NIAB EMR conference center (in 2 coaches)

13:45 HUGH LOWE FARMS MEREWORTH (HOST: DIRECTOR: TOM PEARSON)

Table top strawberries at Grove Farm, 15 Maidstone Road, Hadlow, Tonbridge TN11 0JL

Farm/Business introduction and challenges of strawberry spraying (Tom Pearson)

Divide into two groups

Demonstration of farms Wanner 6 row table top sprayer

Demonstration of N P Seymour table top sprayer (Nick Seymour, N P Seymour)

Demonstration of use of hand-held imaging fluorometer for quantifying spray deposits on table top strawberries from table top sprayer (Charles Whitfield)

Mobile bowser and mixing tank

Farm Knight air assisted boom sprayer for soil grown strawberry crops

Koppert Biocontrol applicator

14:45 **Primocane raspberries Orchard Place Farm, Comp lane, Wrotham Heath, Sevenoaks TN15 8LW (turning opposite Orchard Place Business Centre)**

Farm Wanner orchard sprayer used for raspberry spraying

Farm inter-row sprayer

15:15 Depart Hugh Low Farms

16:15 BARDSLEY FARMS LTD, HIGHLAND COURT FARM, BRIDGE, CANTERBURY, KENT CT4 5HN (HOST: MANAGER PAUL SMITH and FARM MANAGER WILL JARVIS)

Farm/Business introduction and challenges of apple spraying at Highland Court Farm (Paul Smith, Will Jarvis))

Divide into four groups for rotational 20 minute visits to each demo

1. Demonstration of farm Munckhof multi-row sprayer (in Jordans Gala apple orchard) (Farm and Han Smits, Munckhof)
2. Demonstration of Fede sprayer (In Careys Braeburn apple orchard) (Jhoanna Medina and colleagues, Pulverizadores Fede)

3. Demonstration of Birchmeier AS 1200 air-assisted knapsack sprayer (Jörg Lembachner, Birchmeier, Alin Borleanu, NIAB-TAG) and LiDAR crop scanning system (Charles Whitfield), NIAB EMR) (in Shepherds Close Gala orchard)
4. Demonstrations of Outfield UAV crop scanning (Jim McDougall, Oliver Hilbourne, Outfield); Euro Pulvé UAV crop spraying (Frederic Billard, Alexander Schmidt) and University of Southampton UAV support van (Robert Entwistle, University of Southampton) (In Badgers Braeburn apple orchard and adjacent Bunnies pumpkin field)

18:15 Depart Highland Court Farm, Bridge for Canterbury city

Opportunities for precision technologies in fruit growing

Jerry Cross[1], Eleftheria Stavridou[1], Bo Li[1], Charles Whitfield[1], Peter Walklate[2]

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PRECISION TECHNOLOGY TO MEET THE CHALLENGES OF MODERN FRUIT PRODUCTION

Modern fruit crops are highly productive and need to supply markets with near perfect produce. However, they require high investment, especially crops grown under protection, and have high labour requirements. The major challenges for fruit industries are 1) reducing labour inputs by mechanisation and increased efficiency; 2) increasing profitability by increasing yield and quality and/or reducing inputs, costs and losses; 3) targeting intervention to manage pest, disease and weed complexes including invasive aliens; 4) reducing environmental costs (e.g. pesticide contamination) (health, environment and cost aspects); 5) maximising the circular economy (recycling, reduce waste). Another feature of modern fruit growing is that operations/management are applied overall to the whole crop often on a routine (calendar) basis, the whole crop being treated the same with internal variability ignored. Precision technologies focussing on correct intervention of the correct magnitude according to need in time and space can make a big contribution to meeting the big challenges in fruit growing listed above. Crucially in fruit crops, unlike most arable and many other horticultural crops, individual plants and parts of plants can be treated according to their individual needs.

A vision of the future of fruit production is that crops and environment will be monitored continuously at the individual plant scale or better by remote sensing from satellites, UAVs, automatic weather stations, autonomous traps etc. Data will be collated and analysed and inputs to crops applied precisely in space and time according to need automatically, e.g. including from precision sprayers. Key components include remote sensing, image analysis, machine and deep learning, exploitation of the latest Internet of Things (Io T) and big data analysis. UAVs (drones) are likely to be important as they can be equipped with a wide range of remote sensing equipment to capture many images of a field that can be processed to create orthophotos and Normalized Difference Vegetation Index (NDVI) maps. Integration of disciplines where crop scientists, engineers, biometricians and programmers work together, will be vital. For a recent review of applications of precision technology in horticultural crops see Zude-Sasse et al. (2016).

EXAMPLES BEING DEVELOPED AT NIAB EMR

Three examples of new precision technologies for fruit crops being developed at NIAB EMR are as follows: 1) ***LiDAR to improve canopy management and optimise the yield and quality of pome fruits:*** Orchard-to-orchard performance is very variable. This is partly due to site, variety, planting system, orchard management, age, but lack of uniformity – tree-to-tree variation in yield within orchard is a major factor. We have found a >3 fold tree-to-tree variation in yield even in the most uniform productive orchards. The poorest orchards tend to be the least uniform. We have developed LiDAR hardware and software suitable for use by growers to quantify the canopy parameters (size, density, light interception…) for each tree (with GPS coordinates) and provide maps of orchard structure at the individual tree scale, which will allow growers to manage (prune, feed, growth regulate) each tree to optimise performance of each tree individually; 2) ***Identification of* Drosophila sp *by machine and deep learning techniques:*** Pest monitoring in crops often relies on manually serviced traps. Bait traps, e.g. for Spotted Wing Drosophila, are not species specific and require high entomological ID skills.

Identification of insects normally uses dichotomous key where identification is based on numerous agreed morphological characters presented in series of dichotomous choices. Very specialist obscure terminology is used and characters are often minute & difficult to see. We have developed machine and deep learning models to identify the UK common species of drosophila from single dorsal images giving >90% accuracy in identifying 7 species of Drosophila. These methods bypass recognised taxonomic characters. They are rapid and labour saving. Application in autonomous traps where real time data is collected is a huge opportunity for future development: 3) ***Non-destructive fruit quality measurements of plum fruits:*** We have developed a method of rapid, non-destructive measurement of fruit quality (firmness, sugar content, acidity etc.) on the tree or after harvest can be made using hyperspectral imaging. Hyperspectral images were used for initial system development with a hand held spectroradiometer used in field or post-harvest for final application (Li et al., 2018)

CHALLENGES OF USING PRECISION TECHNIQUES IN PRACTICE

There are many challenges in using precision technologies in practice. Important ones are 1) the need for robust, easy to use, cost effective technologies; 2) Adequate resolution is required for timely and location specific intervention; 3) Difficulty of linking the symptom to exact causes - Multiple causes could be present that require different interventions; 4) for many pests and diseases early detection at very low levels is essential and can't be achieved currently; 5) Techniques may be very production-system-specific; 6) Integrating data for each system from multiple sources and learning from it is key to getting the maximum win; 7) Integrating data for multiple systems for a crop.

OPPORTUNITIES FOR EARLY GAINS/EASY WINS

These include: 1) more automated production systems in glasshouses for monitoring crop growth to automate management; 2) Accurate, automated planting (putting individual plants in the right, known location); 3) Fruit yield prediction, marketing scheduling; 4) Post harvest grading for superficial and internal quality; 5) Precision spraying

CONCLUSIONS

Precision technologies are vital for addressing the challenges of modern horticulture. Remote sensing and image analysis are core sister approaches with huge potential. We are at the dawn of a new era but with much work to do! There are big wins from integration of multiple data sources. New multi-disciplinary expertise and investment are needed.

REFERENCES

Zude-Sasse, M., Fountas, S., Gemtos, T.A. and Abu-Khalaf, N. (2016). Applications of precision agriculture in horticultural crops. European Journal of Horticultural Science Volume 81, Issue 2, 78-90.

Li, B., Cobo-Medina, M., Lecourt, J., Harrison, R.J. and Cross, J.V. (2018). Application of hyperspectral imaging for non-destructive measurement of quality parameters for plum. Postharvest Biology and Technology 141 March 2018, 8-15.

Automated blossom detection for precision fruit farming

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INTRODUCTION

In arable farming, an ongoing trend is increased availability of data about crops that can be used in optimisation of different crop care practices. Our 'Fruit 4.0' project aims to apply similar technologies in orchard systems in order to optimise current farming practices. In this paper, we address the topic of blossom detection in apple trees.

Apple trees have the tendency to produce an overload of blossom, having a negative effect on fruit quality and yield. To overcome this effect, currently uniform chemical thinning is applied on orchard sections, although there is a great variation in the number of blossoms per tree within that orchard. To apply tree specific chemical thinning, a robust system is required that determines the blossom load on a tree. To determine blossom load on trees, a recording setup was realised, classification algorithms were developed, and field experiments were done to evaluate the practical performance.

MATERIALS AND METHODS

In order to reach a reliable method of determining the blossom load per individual tree, a measurement system was build and a classification method was tested. Both were first established in 2017 and adjusted according to the first findings in 2018. For the experiments, a single row of interest was selected in the experimental orchard of the Proeftuin Randwijk, this row contains 99 trees (Elstar), planted at a 1.10 m tree spacing (3 m row width), in a north-south orientation.

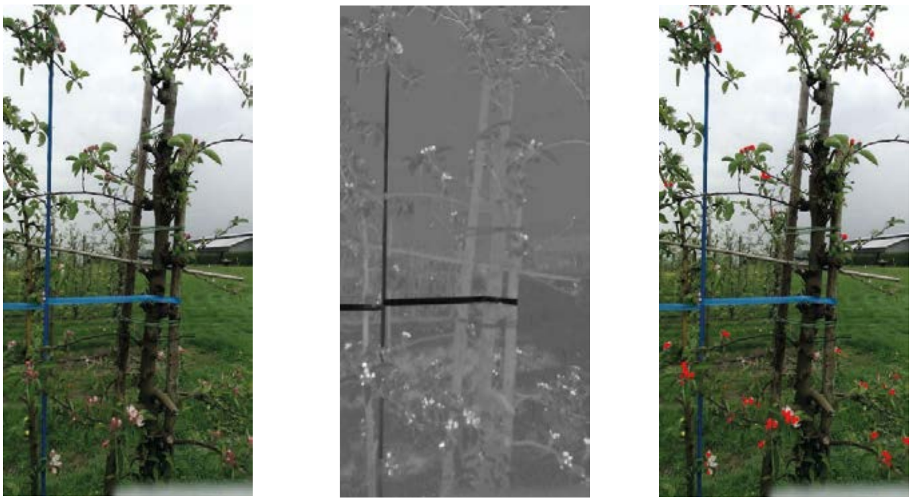

Figure 1 (left): colour image, (middle) Cr component of colour image, (right) colour image overlaid with segmented blobs.

We initiated experiments in 2017, before the blossoming period. The measurement setup consisted of a single Microsoft Kinect One camera, taking images at 2Hz, driving at about 2 km/h, RTK-GPS positions were logged at 10 Hz and in a later stage matched to the images by timestamp. For the 2017 dataset, a classic segmentation method was performed, in which a colourspace transformation was used to highlight the pink component of early apple blossom. The best colourspace transformation in which the early apple blossom stood out was the Cr component of the YCbCr transformation.

Figure 1 shows that in the Cr image, the regions where the flowers are present are noticeably brighter than the surrounding regions. We therefore apply an adaptive threshold to select those pixels which are at the 99th percentile, or the top 1% of the histogram of the Cr image. This pixelwise segmentation is shown overlaid on the colour image in figure 1. Figure 2. Detection performance developed bud detection system on 2 test images. Pink squares contain the detections.

In 2018, the measurement setup was improved according to the lessons learned in 2017. First of all, three Intel Realsense D435 cameras were installed to generate a higher resolution, capturing a section (top, middle, bottom) of the trees each and to ensure whole tree recording. So there was a higher pixel density for the blossom segmentation. Secondly, the recording frequency was increased to 6 Hz, to increase recording speed to 3.6 km/h. The 2018 dataset for classification algorithm development consisted of two measurement days. One at the pink bud stage (BBCH57) and one at stage where most of the blossom clusters are open BBCH 65. In accordance with the first findings of the research, the first dataset will be used for further analysis, since the pink outer leafs are better distinguishable.

In order to get the number of blossoms at high enough speeds for real time processing, the YOLOv3 convolutional neural network was selected to do the image segmentation. Metrics for evaluation of the system were the F1-score, precision, recall and the counting error, which is the error between ground-truth flower bud count and predicted flower bud count. In figure 2, an indication of classified apple blossoms can be observed.

Fig. 2. Detection performance developed bud detection system on 2 test images. Pink squares contain the detections.

RESULTS AND DISCUSSION

In the 2017 colourspace transformation method we were able to classify about 80 % of the visible blossom cluster pixels correctly. Even though this is a promising number, we found that the classification was too specific for this specific situation. The method would need to be re-developed before it could be applied to another situation.

The results for the 2018 YOLOv3 method show that the developed system is able to detect objects within the required processing time, 0.03 seconds. 50% of the flower bud count estimations per picture are within the required error range of 10 flower buds, for a range of 20 flower buds, 80 % of the images are classified in range. The F1-score, precision and recall were respectively 0.63, 0.65 and 0.61 which means that 65% of the detections was a flower bud and 61% of the annotated flower buds was detected.

The model was able to detect fower buds on unseen data, captured with another camera and in another year, with a maximum F1-score of 0.49, a precision of 0.45 and a recall of 0.53. These numbers are lower than the ones observed with the data of interest, however, they do show potential for when the model is trained for a more diverse dataset.

Canopy characterization with 2D Lidar in different French orchards

Jean-Paul Douzals[1], Yoan Hudebine[1], Sophie Houee[1], Florence Verpont[2]

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INTRODUCTION

The characterization of the orchard canopy is of great interest because it provides useful information in order i) to optimize the air and liquid flow settings of the sprayer (Cross et al., 2003) and ii) to define practical dosage of products and adapted application volume. Manual measurements are possible with limited measuring equipment but they appear time consuming and are restricted to external dimensions of the crop without consideration of the porosity, unless the use of photography.

2D LiDAR scanner is used in various European orchards since the late 1990 (Walklate et al., 2002) and showed capabilities to provide different levels of information on the canopy structure including density factors (Walklate PACE). Bastianelli et al, 2017 described the canopy structure in terms of both discretised Leaf Wall Area (called point-LWA) and Tree Row Volume (called TRV-area) at early stages were introduced earlier (Douzals et al., 2017) showing porosity factors of 30 to 50% according to the LWA and 10 to 60% according to the TRV. This paper introduces the results of study conducted in 43 different French orchards including pome fruits (24) and stone fruits (18) in 2018 where 3 to 4 LiDAR measurements were achieved during the growing season. The final aim of this study is to provide information on the canopy structure in terms of overall dimensions including porosity in order to adjust, after post processing, both sprayer settings in terms of air flow intensity and adapted application rate.

MATERIALS AND METHODS

A 2D Lidar (SICK LMS100, SICK, Germany) was used combined with a GPS RTK. This LiDAR used a waveband of 905 nm adapted to natural environment. The total scanning angle of the LiDAR is 270°, 0.5° resolution, with a blind area of 90° oriented downward (inter row area). The scanning frequency was 50Hz. Each second 27000 points are recorded. The system was mounted on a tractor travelling at 5 $km.h^{-1}$. Combining the angular resolution of the scanner, the scanning frequency and the forward speed, a spatial resolution of about 3 to 4.5cm^2 was obtained. Data were recorded on a data logger (Effidence, France) but are also visible realtime on a laptop connected through a Wifi link.

Data are analysed with a dedicated Matlab program with several steps. First, raw data from the LiDAR are converted from polar coordinates into a Cartesian mode taking into account the height of the LiDAR which was set at about 1.80m above ground. Second, a series of calculations are achieved on data in order to determine crop characteristics with different percentiles values on the crop height and depth. For better accuracy results, only the half row close to the scanner was investigated. Each sampled row was scanned both sides. Finally, an extract of a row was operated for visualization and further calculations under Excel. 43 orchards were selected from different experimental stations in horticulture located in South East, South West and Western part of France. Apple (axis), apricot (goblet), peach (wall or goblet) and prune (axis or goblet) were scanned at different crop stage from Dormant to full vegetation at least 3 to 4 time during the season 2018.

RESULTS AND DISCUSSION

Data from different orchards in terms of LWA and TRV were compared to manual measurements showing a quite good correlation for manual LWA with LWA 95th of the height. Comparison of Manual TRV with TRV 95th height/depth gave systematically no correspondence while manual measurements were overestimated. Then 2D and 3D porosity are determined through the comparison of overall dimensions (LWA and TRV) and discrete data (pLWA; TRVa). An example is given in Table 1.

Table 1: Example of results on an apple orchard – Golden – 9 years old - 3.3.m inter row.

date	BBCH	Plwa	LWA 95th p.	Porosity 2D	Trv95th	TRVa	Porosity 3D
28/02/2017	Dormant	7377	16665	55.7%	5598	1892	66.2%
19/04/2017	BBCH 67	9896	18999	47.9%	5884	3158	46.3%
31/05/2017	BBCH 74	10755	19478	44.8%	7392	4592	37.9%
24/07/2017	BBCH 76	11522	22925	49.7%	8766	5952	32.1%

The first calculations of the 2D porosity (Table 1) showed abnormally stable values with a parallel increase in overall dimensions and discretized data. The evolution of 3D porosity was more in line with the expected effect of the overlapping of the vegetation along the growing season. In order to confirm results, samples of 10m of each scanned row were directly analysed on an Excel spreadsheet where 2D porosity can be directly quantified. Similarly, the calculation of the 2D/3D porosity for goblet-trained crops did not show the expected results. The presentation will then focus on the modification of the analytical methodology to provide exploitable results.

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Estimating vegetation volume of coffee crops using images from unmanned aerial vehicles

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INTRODUCTION

Tree crops, such as Arabica coffee (*Coffea arabica* L.), present enormous technical challenges in terms of pesticide application. The correct deposition and distribution of the active ingredient throughout the aerial part of these plants depends on knowledge of the canopy volume, but manually determining this volume is time consuming and imprecise.

The objectives of this study were to develop a method to determine the vegetation volumes of coffee crops from digital images captured by unmanned aerial vehicles and to compare this approach with traditional vegetation volume estimation; the tree row volume (TRV) method.

MATERIALS AND METHODS

Field trials were carried out in the Coffee Growing Sector of the Federal University of Uberlândia in the city of Uberlândia, Minas Gerais, Brazil. Different coffee cultivation areas characterized by different crop stages under different management conditions (Fig. 1) were used to carry out this study.

The coffee canopy volume was estimated via two methods, (i) manually and (ii) using images collected by UAV. Four coffee plantation areas with TRVs ranging from 5,000 to 15,000 m^3 ha^{-1} were selected according to the year of planting and pruning management to verify the adequacy of the methods under different conditions. Spacing between rows was 3.5 m, and spacing between plants was 0.7 m. Each selected area was 50 m long and 7 m wide (2 rows).

Using the methodology adapted from Favarin et al. (2002), manual estimation was performed with 20 randomly selected individual plants from each orchard (four areas). The height (H) of the plants; the width of the lower (Li), middle (Lm), and upper (Lu) thirds of the canopy; and the spacing between planting (D) rows were measured.

The second estimation method was performed by digitally processing the aerial images. The UAV was a DJI Phantom 4 quadcopter (DJI, Shenzhen, China). Its camera system (model FC330, DJI, Shenzhen, China) features a 3-axis (x, y and z) image stabilizer, 4K video capture at 30 frames per second, full 1080p HD video capture at 120 frames per second, and an aspherical lens with a 94° field of view (FOV).

Initially, the obtained images were selected and aligned in the sequence in which they were captured and then subsequently calibrated. Subsequently, the volume of the targets in the selected areas in each plot was measured using the PIX4D Mapper software (version 3.2.23, Pix4D, Switzerland). All the plants inside the area were considered. The volume was computed using the DSM (Digital Surface Model).

To compare the adequacy of the TRV (vegetation volume) values measured using the aerial image of each plot and the values measured manually in the field, a one-sample t-test ($p \leq 0.05$) was performed.

RESULTS AND DISCUSSION

The tested statistical hypothesis was that the estimates of the coffee vegetation volume produced by the two methods would be the same. The results of the one-sample t-test were not significant (Table 1), indicating no significant difference between the two methods. The variation coefficients for manual estimation (n=20) were 16.6%, 24.4%, 25.9% and 21.3% for sample 1, 2, 3 and 4, respectively.

In coffee crops, no previous investigations have reported the assessment of vegetation volume from UAV-based crop surface models. Burkart et al. (2018) analysed a field trial with two barley cultivars using aerial images. They concluded that aerial images can be used to provide quantitative data in crop management and precision agriculture.

In coffee production areas, the canopy is not uniform and can even vary within a single field. Determining the vegetation volume with the manual method over extensive areas becomes costly, requiring a longer execution time and possibly generating inaccurate data. When one collects data manually in the field, plants are chosen randomly, and the number may not be representative of the dimensions of the plot. With the digital image processing method, the sample size can vary from some plants to all the plants in the plot.

We conclude that it is possible to determine coffee vegetation volume, which is a highly important variable used to determine practical and accurate pesticide application, by digitally processing images captured by UAVs. This method is fast and permits the assessment of large areas.

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Table 1. Results of the one-sample t-test (p≤0.05) comparing the vegetation volumes estimated manually and with digital image processing for each of the plots evaluated in the field.

Sample	Manual VV[a] (m^3 ha^{-1})	DIP VV[b] (m^3 ha^{-1})	t-test	Significance
1	9,653	9,767	-0.4250	0.6760
2	6,137	6,382	-1.1670	0.2578
3	6,394	6,700	-1.2990	0.2096
4	10,094	9,379	1.4850	0.1540

[a] Manual VV: Manual method of measuring the coffee vegetation volume in the field. [b] DIP VV: Method of measuring the coffee vegetation volume via digital image processing (DIP) of images obtained by UAV.

Figure 1. Aerial photo of the study site.

Intelligent Fruit Vision – turning data into knowledge for apple growers

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INTRODUCTION

Estimation of orchard yields and granular level orchard performance has been an ongoing challenge for commercial apple growers across the globe. Typically, calculations on yield are performed by counting a small sample of random trees from within an orchard and then extrapolating the values to estimate the total cropping potential of the area being assessed. Typically, within an orchard you find a range of performance on fruit counts and fruit size. Using only the naked eye it is very difficult to identify the areas where improvement is needed due to orchards often being large in scale and tree systems being complex in design. Prior to the development of the Intelligent Fruit Vision system there had been very limited work completed on a commercial scale to deal with these challenges. The development of an Intelligent Crop Scanning System for apples was developed to provide information for growers so could provide accurate, real time fruit yield estimates and to provide data to enable growers to implement improvement measures in areas of the orchard that underperform.

MATERIALS AND METHODS

The system consists of two HDR (5mp) cameras, a ruggedized PC/monitor and an on-board GPS. The vertically mounted cameras capture the image data and feeds this back via an Ethernet connection to the ruggedized processing unit. The image data is processed live in a ring-buffer, where the count and size information is reported at the GPS location which is recorded every second. Once the video analysis has taken place, and the useful information extracted, the video data is dumped by the system.

For fruit counting, the system captures image data at 20 frames per second, and tracks apples through consecutive frames to ensure the fruit is not counted twice. A machine-learning algorithm is in use, where characteristics such as the shape and texture of the target matter are used to identify the fruit against a leafy backdrop. Using these characteristics to identify the fruit means that red, green and bi-coloured varieties are within scope for the system.

For fruit sizing, the two cameras operate using stereoscopy to calculate the distance from camera to fruit, and then measure the pixels horizontally before grouping them to a size banding in mm (typically 5mm bandings). To allow sizing to operate at a commercially viable speed, we programme the distance from the camera to the mean visible apple, which acts as a line scan for any unobscured apples which intersect the line.

To estimate the crop load, the IFV system only scans one side of the tree. A manual calibration is therefore required to allow for the apples which cannot be seen by the system. The protocol we have adopted is to systematically count the apples on 10% or 10 trees within the first row (whichever value is higher), ensuring that the sample trees represent a cross-section of the row in its entirety. These figures are then input in to the system during set-up, and the first row of scanning allows the system to calibrate the percentage of apples detected based on the ground truth provided by the user. This obscuration factor is then applied to each subsequent row scanned.

By processing the data in real-time, the system is able to relay to the user the optimum scanning speed via a speed bar in the user interface. This indicates to the user whether they are travelling at an excessive speed and therefore missing fruit, or whether the processor isn't operating at near maximum capacity and can therefore allow for an increased speed. Also, if weather conditions change materially during scanning, the user has the opportunity to recalibrate the brightness settings using the automated function.

RESULTS AND DISCUSSION

The system has been in development for 6 years and is now in a Commercial Mark 3 format. The capability of the system is as follows:

- Can accurately count and size apples that are larger than 35mm in diameter when being grown on a 2D growing system or a formal production wall system up to a maximum height of 5.5 metres.
- The system reports to a GPS coordinate to enable accurate mapping of an orchard.
- A multifunctional reporting package is available to the user showing distribution of fruit counts and fruit sizing ratios for each scanning mission that is completed.
- There is a fully developed back office software tool that allows the preloading of orchard data information.
- The system travels at approximately 2-5km/h.

How does it Work?

1. The technology is mounted on a quad bike or small tractor and driven down the orchard rows at 2-5 Km/hr.
2. The system **captures the location of the fruit** and **records the count and diameter** as it passes through the orchard on the computer hard drive. The hard drive is capable of **storing several days' worth of scanning** before a download to a base station is required.
3. The system is **operated by one person** driving the vehicle. The operator should be able to operate the equipment after some simple training.

UK validation in an Envy and 3 Jazz apple orchards in 2018/19 showed that IFV estimates of fruit numbers were within 1.4% and 1.8% of actual numbers, respectively. Validation in New Zealand validation is in progress and is also showing good results.

Precision yield management for UK vineyards: achieving fruit:canopy balance to increase fruit consistency and quality

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INTRODUCTION

"Making good wines starts in the vineyard" is a common adage that reflects the importance of optimising growing practices to the local environment to obtain the highest yield possible of the quality expected by winemakers. Grapevine canopy management is one the most essential operation in the vineyard, comprising the choice of the training system and rootstock, pruning, shoot positioning and trimming vines at a chosen height. Canopy management does not only aim at optimising fruit microclimate but also balancing the vegetative growth with crop load. Indeed, the balance between the leaf and fruit compartments can be perturbed by too high vigour or crop load, leading to a decrease in the quality of the production and reduced vineyard performance over multiple years (Champagnol, 1984). The optimal leaf area (LA) per fruit mass (FM) ratio has been recently investigated only, showing its potential for the improvement of the quality, yield, wine characteristics and adaptation to climate change (Keller, 2010). Optimal values for the LA:FM ratio have been found to be between 0.8 and 2, depending on the variety, the vintage and the location of the experiment (Dufourcq 2005; Kliewer and Dokoozlian 2005). In practice, the balance between the LA:FM is managed through the modification of the canopy (trimming, leaf removal) and crop load (thinning) at the vineyard scale. This however does not consider the intra-vineyard variability for LA and FM, that reduces the quality of the production and overall vineyards performance. Modern imaging systems such as LiDAR systems have the ability to measure canopy parameters of individual plants at the vineyard scale. This enables the division of vineyards into zones of comparable vigour, allowing yield adjustment at pruning and thinning time, according to the plant canopy development.

MATERIALS AND METHODS

The experiment took place at the NIAB EMR research vineyard, in the United Kingdom (Latitude: 51.294208 | Longitude: 0.456294) in 2018. The vineyard has been planted in 2015 with multiple varieties including Chardonnay, Pinot noir, Pinot meunier and Bacchus. The vineyard was scanned with a LiDAR system at veraison and harvest. Vine leaf area, canopy volume and Leaf Area Index were measured as detailed in Walklate et al, 2002. At harvest, yield per vine and fruit quality at harvest were measured. The Nutritional Balance Index of the vines was measured using a Dualex scientific (Force A, France). The dataset was treated and the maps generated using the software R.

RESULTS AND DISCUSSIONS

The LiDAR scan highlighted a larger than expected variability in canopy development across the vineyard. At veraison, leaf area varied from 0.3 to 2 sq meters of leaves per plant. The use of interpolation method allowed the identification of 3 zones in the vineyard, according to their canopy development (figure 1). These zones were not determined by any of the nutrition indicators status of the vines, raising the question of the factor(s) responsible for the variations in canopy development. In order to manage crop load according to canopy development, we have used LA:FM values from the existing literature and therefore not necessarily the best suited for the United Kingdom. The combination of the LiDAR data and the LA:FM values allowed the adaptation of crop load to the canopy development, defining maximum crop load for an increased quality and consistency of the production. Optimal LA:FM values for the United Kingdom are being investigated in the frame of the NIAB EMR Viticulture R&D consortium and will be used to adapt further growing practices to the British climate and production goals. This study highlights the potential for applied research to significantly help growers improving their vineyard performance and profitability.

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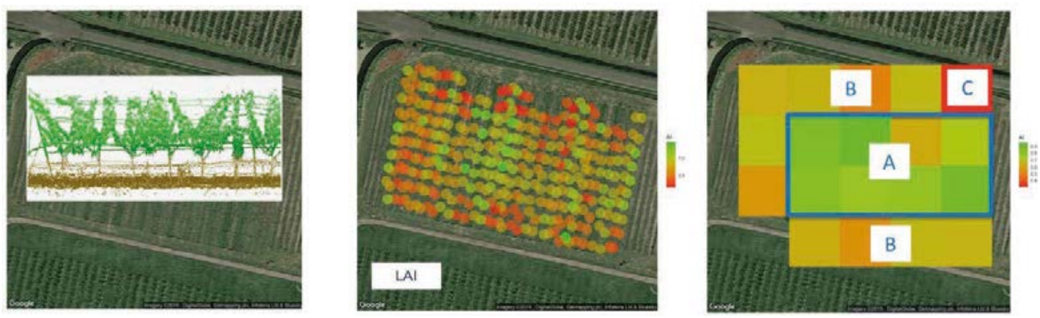
Fig. 1. Maps of the individual leaf area (middle) and after interpolation (right), allowing the identification of three management zones (A, B and C). The image obtained with the LiDAR is presented on the left picture.



Precision fertigation in soft fruit production

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INTRODUCTION

The UK soft fruit industry is a vital part of the UK's rural economy with an annual production of 169 Kt, worth c. £473M (Defra, 2018). The soft fruit sector has invested heavily in the development of new technology and higher-yielding varieties over the last 15 years, and strawberry Class 1 yields of 55+ t/ha are achievable if crop agronomy is optimised. Nevertheless, year-on-year variations in yields are common, due in part to changeable environmental factors within the polytunnels, and the operational decisions made by growers in response to these variables. Over-irrigation and high fertiliser inputs during changeable weather can increase disease susceptibility, lower marketable yields and reduce organoleptic quality. Consequently, up to 25% of harvested soft fruit is lost as waste, due to disorders such as rots, bruising and poor textural quality.

PRECISION FERTIGATION FOR SOFT FRUIT CROPS

Irrigation is essential in these intensive growing systems to ensure consistently high yields of flavoursome and phytonutritious fruit, and year-on-year growth for many soft fruit businesses has been possible because trickle irrigators have had unlimited access to water supplies. Consequently, the volume of water abstracted in the southeast for use in irrigation of crops has doubled in the last 10 years. However, since January 2018, all trickle irrigators must apply for an abstraction licence for their existing water supplies which cannot exceed historical abstraction levels. If growers wish to abstract more water to expand production, they will need to apply for a new licence which is likely to be more difficult to obtain and significantly more restrictive. Many growers are now considering reservoirs / water storage systems and rainwater harvesting to help to improve their local water security.

However, these interventions involve high capital costs and can be subject to planning constraints, and so in the short-term, a renewed emphasis on scheduling irrigation to high-value crops more effectively will help to match demand for water in the cropping season with existing supplies. In the soft fruit sector, the switch from soil to substrate growing over the last 10 years has highlighted the importance of effective and reliable irrigation systems and scheduling methods; crops now have a very limited substrate volume from which to extract water and nutrients, and even short-term restrictions in root water availability of just a few hours can lead to significant losses in Class 1 yields, berry quality and shelf-life. Many growers use at last one of several irrigation scheduling tools, including radiation sum, substrate moisture sensors and weighing balances, but most are not yet automated and so growers rely on daily measurements, calculations, and predictions to inform their decision making. The accumulation of “ballast ions” within the substrate to yield-limiting levels is also a concern and so many growers apply daily flushing events to reduce the build-up of ions, and run-off volumes of 15-30% are not uncommon.

RESEARCH AT NIAB EMR

Our research has focussed on developing tools to help soft fruit growers to improve the efficiency of water and fertiliser use. Recent advances in sensor and data-logging technologies, telemetry, cloud-based grower interfaces, and applied crop science have led to the development of automated irrigation systems that match crop demand for water with supply throughout the season, despite challenging and changeable weather, thereby ensuring a productive and efficient use of water and fertilisers. The automated precision irrigation system has been used successfully in commercial trials over the last 5 years, and by avoiding unplanned water deficits, even for short periods, yields of Class 1 fruit have been increased by between 4 and 10 % compared with conventional irrigation scheduling, whilst improving water use efficiency and reducing run-off volumes. This precision irrigation system is deployed at the Water Efficient Technologies (WET) Centre at NIAB EMR where, in collaboration with our partners, we are producing commercial yields of substrate-grown, high quality, phytonutritious strawberries using significantly less water and fertilisers than the industry average. In addition, added benefits of precision fertigation include greater consistency of flavour, an assured shelf-life, and crucially, less fruit waste.

Our on-going research is focussed on developing innovative virtual sensors to enable "real-time" estimates of coir concentrations of N, P, and K, and modelling approaches to understand plant nutrient requirements at different developmental stages; together these tools will help growers to target plant nutrition more precisely and avoid problems with fruit quality that are associated with over-feeding. The interactions of the plants with the wider environment is also under scrutiny and we are developing models and tools to monitor, manage and manipulate the aerial environment (the "phytoclimate") to optimise plant performance, productivity and quality, and to better estimate fruit ripening rates and Class 1 yields.

Time series of chlorophyll degradation in apple

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INTRODUCTION

The chlorophyll content of the fruit skin and first cell layers of parenchyma provides the green ground colour of fruit, which brightens when the chlorophyll content decreases. The decrease of chlorophyll can be measured non-destructively using spectral-optical analysis with miniaturized spectrophotometers (Zude and Herold, 2002). In more detail, the conversion of chlorophyll_b to chlorophyll_a, and from chlorophyll_a to pheophytins taking place during fruit development, was approached non-destructively by means of laboratory methods (Seifert et al., 2015). However, in practise the monitoring of the chlorophyll decrease at the tree would be most interesting for predicting the harvest date. In the present study, a new sensor was tested for in-situ fruit measurements by means of multi-spectral analysis.

MATERIALS AND METHODS

Trees of *Malus* x *domestica* Borkh. 'JonaPrince' on M9 rootstock grown in an experimental station located in Potsdam were equipped with a multispectral sensor system (FIORAMA, CP, Dallgow-Döberitz, Germany). The sensor consists of three probes each connected to one fruit on the tree by means of a elastic strip. The data are transferred via USB port or SIM card to local file or the data base of the company, respectively. The energy supply of the sensor is enabled by a solar panel. The multi-spectral fruit data were analysed as means over 3 fruits considering 6 readings taken in 1 hour interval during the night, when the signal to noise ratio was <0.5%. The water status of trees was monitored with three dendrometers, providing continuous data on the maximum daily shrinkage of the trunk. Temperature data were achieved from the weather station of the orchard and the growing degree-days were calculated applying 6°C as base temperature (Edey, 1989).

RESULTS AND DISCUSSION

The chlorophyll-related normalized difference vegetation index (NDVI [-1, 1]) showed low values compared to calibrated NDVI data [0; 1] published earlier (Zude, 2003) using handheld spectrophotometers. However, the double-sigmoid shape of curve considering the NDVI (Fig. 1), and corresponding content of chlorophyll appeared similar to earlier publications (Zude, 2003). The inflection point of the curve relating to the harvest date of the fruit, was found 121 dafb (29th August 2018), when 172 growing degree-days were reached (integral of 2035°C). The automated non-destructive sensor can support the acquisition of fruit data in the field to gain insight into the actual fruit development.

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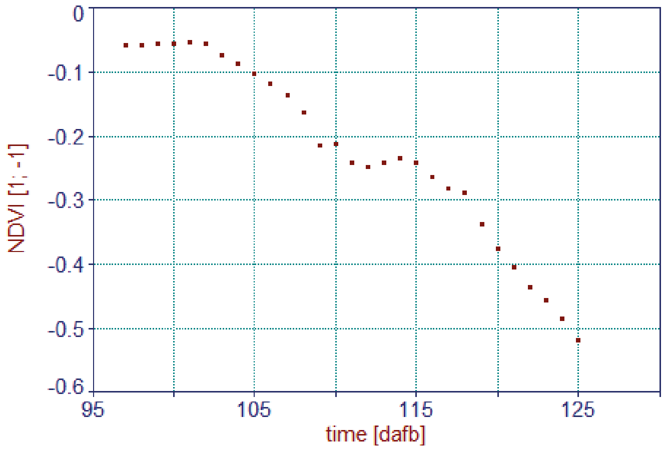

Fig. 1. Set-up of fruit sensor and normalized difference vegetation index (NDVI) of apple fruit measured by means of non-destructive, continuous measurements at the tree over time in days after full bloom (dafb).

An update on the intelligent spraying system development for fruit and nursery crop applications

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INTRODUCTION

To ensure high quality and maximize the yields of plants or products, pesticides will continue to be used to protect the majority of specialty crops in the foreseeable future. However, current pesticide spray technologies frequently result in over-application and excessive off-target losses and spray drift, primarily due to large variations in canopy size, leaf density, plant spacing, and constant application rate discharged by conventional air-blast sprayers (Fox et al., 2008). To address these problems, an air-assisted variable-rate intelligent sprayer was developed (Chen et al., 2012; Shen et al., 2017). This unique spraying system integrates a high speed laser scanning sensor to a custom-designed sensor-signal analyzer and variable-rate controller to manipulate variable-rate nozzles in a multi-channel delivery system. It detects plant presence, measures plant size, shape and foliage density, and then controls spray output of individual nozzles independently to match canopy volume and travel speed in real time. Field tests demonstrated that this sprayer technology could reduce airborne spray drift by up to 87%, spray loss onto the ground by 68% to 93%, spray volume by 47% to 73%, and an annual chemical cost savings of $345 to $690 per hectare while maintaining effective control of insects and diseases (Chen et al., 2013a, 2013b; Zhu et al., 2017). In order to have significant impact on the specialty crop industries, the current project is focusing on developing and testing a universal intelligent-decision spray control system that can be retrofitted onto existing conventional sprayers. In this way, it will allow growers to use their existing sprayers rather than relying on the purchase of a new sprayer with intelligent features built in. Also, manufacturers can add the system into their new sprayers without modifying sprayer designs.

MATERIALS AND METHODS

Major components of the intelligent spray control system were a high speed laser scanning sensor, a Doppler speed sensor, a computer program, an automatic nozzle flow rate controller, pulse width modulated spray flow control valves, and an embedded computer with touch screen. The control system was retrofitted on a conventional radial air-assisted sprayer for field experiments (Fig. 1). The sprayer also consisted of a hydraulic pump, a seven-blade fan, a fiber glass spray tank, and nine hollow cone nozzles on each side of the sprayer. Two volumetric flow meters were installed on two liquid lines to measure the amount of spray outputs discharged from the sprayer.

During the sprayer operation, the laser-scanning sensor was able to detect objects within 270˚ and 30 m of radial and linear range with a 0.25° angular resolution. After the sensor detected the objects, it immediately transmitted distance signals to the embedded computer through USB interface. Simultaneously, the Doppler speed sensor measured the real-time speed and transmitted it to the embedded computer. After processing the distance and speed signals, the embedded computer calculated the tree canopy volume and then translated the tree volume to the flow rate of each spray nozzle to discharge variable-rate outputs in real time. The control system allowed operators to choose either variable-rate mode (VRM) or constant-rate mode (CRM) during spray applications.

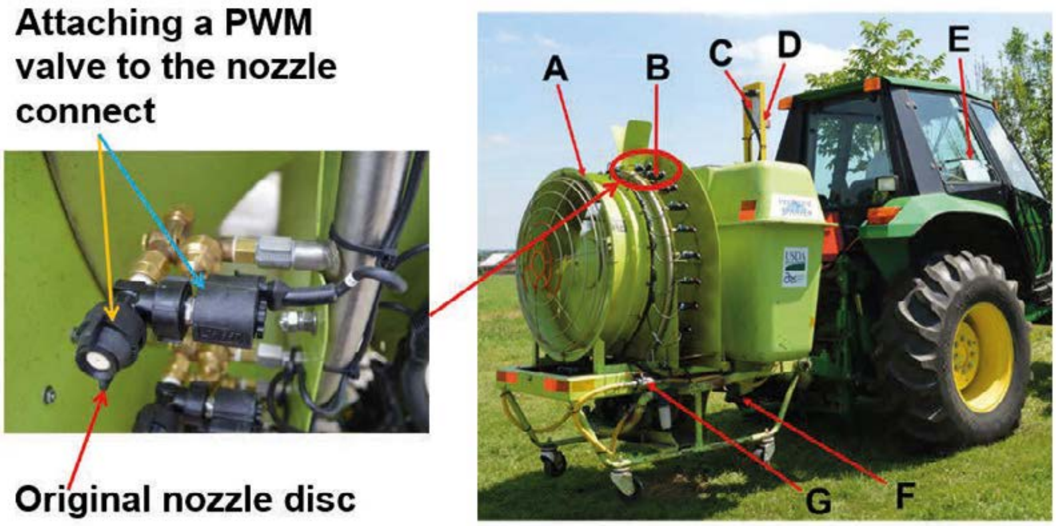

Figure 1. A conventional radial air-assisted sprayer retrofitted with intelligent spray control system to achieve variable-rate applications: A - seven-blade fan, B - nine PWM-coupled hollow cone nozzles, C – flow rate controller, D - laser scanning sensor, E - embedded computer, F - Doppler speed sensor, and G – flow meter.

RESULTS AND DISCUSSION

Field experiments were conducted in an ornamental nursery, an apple orchard and a vineyard to compare spray deposition quantity between VRM and CRM in 2018 growing season. Test results from the ornamental nursery showed that VRM used 42.4% to 51.2% less spray volume than CRM while foliar deposits and coverage at most positions of tree canopies from the two modes were comparable. However, the amount of spray deposits on the ground with VRM were 52% to 59% lower than those with CRM (Fig. 2). Similar results were also obtained from the comparison tests in the apple orchard and in the vineyard that VRM provided similar or more amounts of spray deposition inside canopies with much less airborne drift and ground losses, and consumed less than half of spray volume than CRM.

In addition, efficacy of growers' conventional air-assisted sprayers retrofitted with the intelligent spray control systems was also tested in commercial nurseries, and apple and peach orchards. VRM used less than half of pesticides in average while insect and disease controls were comparable compared with CRM. Therefore, the laser-guided variable-rate intelligent sprayers would have great potentials to significantly reduce pesticide use and reduce pesticide inputs to non-target areas while maintaining effective pest insect and disease controls. Smart Guided Systems LLC in Indiana has commercialized the intelligent spray product (https://www.smartguided.com/intelligent-sprayer).

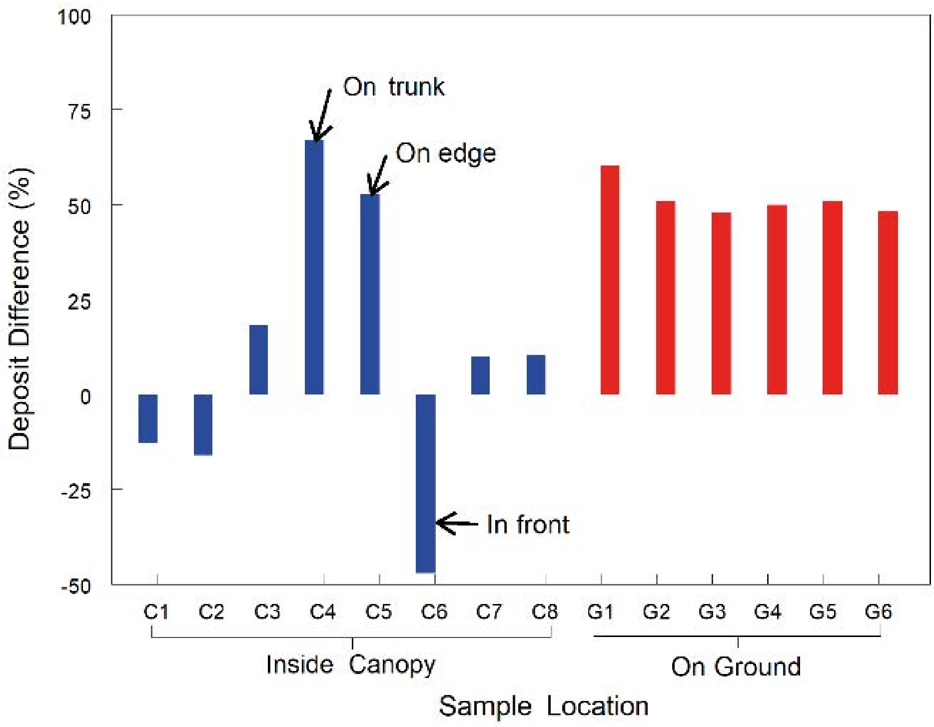

Figure 2. Percentage of spray deposit differences between VRM and CRM treatments at different sample locations. (Positive difference represents CRM produced greater spray deposits than VRM).

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Precision tree fruit dosing to optimise yield and quality: a new UK research project 2019-2021

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INTRODUCTION

There is substantive tree-to-tree variability in tree structure and crop load and quality in tree fruit orchards which are the major causes of less than optimal, often poor, overall yield and quality. In previous work funded by Innovate UK (project 101405, 2013-2016) tree-to-tree variability in yield ranged from 2-3 fold in the six most productive and uniform apple orchards in the UK, with much greater variability in poorer orchards. Larger scale within-orchard variability and bienniality also contribute to poor performance. In the project we developed the LiDAR system for quantifying tree structure parameters and crucially showed that tree-to-tree variability in yield and quality caused by variability in crop load, tree size and density to be a major cause of poor orchard performance. If the performance of poor trees could be brought up to that of the best, the productivity of orchards would be greatly increased, which would transform the profitability and competitiveness of fruit tree production. Here we report the start of a new 3 year project to develop a precision tree fruit dosing system to optimise yield and quality in orchards. The technological challenge is to develop an automated precision dosing orchard foliar spraying system that applies precise doses of agrochemicals to sections of canopy on individual fruit trees according to 3D spatial distribution maps of blossom density, crop load and tree structure to optimise performance of individual trees.

CURRENT STATE OF THE ART

In commercial practice currently, orchard treatments are usually applied at a fixed rate to the whole orchard, over-dosing some trees and under-dosing others. Our proposed system will allow treatments to be targeted at appropriate scales (canopy sections of individual trees) according to their pre-determined specific needs. Variable Rate Application has been in development in agricultural crops for several decades targeting the differences between relatively large field zones. In tree fruit growing there is opportunity to tailor application to individual trees and canopy sections (3D precision spraying). Existing precision tree fruit sprayers (e.g. CASA sprayer) use real-time sensors (optical, ultrasonic, LiDAR) to switch nozzles on/off in relation to the presence of the canopy and are costly in relation to their benefits (pesticide savings). This approach does not allow pre-planning for other important factors that occur at different times in the season. Satellite imaging does not have adequate resolution.

NEW RESEARCH PROJECT

In the new project, we shall develop a precision dosing orchard foliar spraying system to improve the uniformity of pome fruit orchards and greatly increase their economic performance. This will be achieved through the use of differential doses of fruit thinners and growth regulators, appropriate to individual trees (or parts of trees if greater precision is required). Current practice is to spray whole orchards at the same dose, regardless of tree structure variation or crop load. The equipment will apply precision doses according to need providing optimised delivery of foliar spray, based on precision GPS maps of tree size and canopy density provided by LiDAR (developed in previous Innovate UK project 101405) and blossom cluster density maps to be developed in this project from analysis of images taken by UAV mounted cameras during blossom using state-of-the-art image analysis combined with deep machine learning methods. The performance of poorer performing trees will be increased towards that of the best and the tendency for out-of-sync tree-to-tree biennial bearing minimised. The main focus of the innovation will be the development of software algorithms to determine appropriate treatment doses, tailored using high resolution, precision RTK-GPS aerial imaging of blossom cluster density (using deep and machine learning) and LiDAR quantification of tree size and canopy density, to generate 3D maps of crop treatment to control the Precision Spray Control System (PSCS), the precision spray equipment. All scanning, imaging and software processing will be carried out in advance of spray application, the precision control spray system will be adjust dose according to its mapped, precise location within the orchard. This innovation will provide a more cost effective alternative to existing orchard management practices including hand thinning and canopy pruning.

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A hand-held imaging fluorometer and attendant food-safe spray tracer for rapid quantification of spray deposits in the field

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INTRODUCTION

Crop sprayers throughout the world are used to make spray applications of pesticides and other agrochemicals. However, although sprayer operators are provided with instructions on the dose and sometimes guidance on the spray volume and quality to be applied and sprayer manufacturers provide standard methods for setting up sprayers, spray operators have hitherto had no ready means of measuring the results of their spray applications in the field in terms of the amount, cover and distribution of spray deposit achieved, nor compare them against best practice. Guidance on the spray deposits needed for satisfactory biological efficacy have not hitherto been provided because widely available rapid means of assessment have not been developed. The results of spray applications are variable because they are greatly affected by the method of spray application (sprayer type and set up), crop growth stage and architecture and meteorological conditions at the time of application. If spray deposits could be easily measured in the field, spray applications could be optimised, achieving better, more consistent results and avoiding wastage. Measurements of deposits by spray operators for particular sprayers/crops/applications will enable them to adjust sprayers for individual applications and verify and quality assure them. Here we make our first report of a new hand held instrument and attendant spray tracer we have developed to fill this void for the first time, which we offer as a useful and valuable invention of world-wide benefit and application in crop spraying.

CURRENT METHODS

Current methods for spray operators to assess spray deposits in the field (water sensitive papers (WSPs), visual inspection) are qualitative, unsatisfactory and seldom implemented. Though WSPs are cheap, readily available, and can be visually assessed, the deposition seen on them is a poor representation of crop deposition because the characteristics of plant surfaces are very different from WSPs. The current methods used by researchers for studying deposit amounts, cover and their distributions vary considerably. Direct measurements of deposits of pesticides are seldom made as they are too time consuming and costly. Soluble and recoverable tracer materials, usually colourants, are used. Fluorescent tracers are favoured because they provide high sensitivity and ease of analysis with fluorescence spectroscopy or photography. Fluorescent colourants are expensive, usually require crop destruction as they are not edible, and may exclusion of extraneous light. None of these methods are commonly used by spray operators due to costs, complexities, and restrictions required. To study deposit distribution, large numbers of samples of plant material are taken from the field after spraying and deposits are extracted and analysed by fluorometry in the laboratory. Spray cover is measured by image analysis of photographs. Such studies require laboratory facilities and staff and are time consuming and costly. They are not suitable for on-the-spot measurements by spray operators. Investigations by researchers are generic, only providing general information about sprayer set up and adjustment. They do not cover the plethora of different sprayers and the wide range of ways they are used in practice nor inform on adjustment for individual applications nor provide verification and quality assurance.

HAND HELD IMAGING FLUORIMETER

We have developed a small, portable, hand-held imaging fluorometer that can readily and quickly be used by sprayer operators to take direct measurements of surface spray deposits of an attendant food-safe spray tracer (see below) as soon as they have dried in the field. Each measurement is derived from an image of a circa 1 cm^2 area of plant surface, multiple (typically 20-30) measurements being used to build up a statistically valid evaluation of spray deposit distribution in a particular zone. An image analysis algorithm is used to determine the percentage spray cover, number and size of deposits etc. The deposit amount per unit area, normalised by the amount of spray applied per unit ground area (expressed as a percentage), is calculated from the fluorescence intensity. An overall statistical analysis of the measurements taken in the whole job, including SE and CV values, is automatically provided. Target surfaces and non-target surfaces can be sampled to check for drift and sprayer efficiency. Immediate results from the imaging device guide spray operators to adjust their sprayer setup to optimise spraying. The sampling can take 5 to 30 min depending on the level of detail required.

ATTENDANT FOOD-SAFE SPRAY TRACER

We have developed an attendant food safe spray tracer for which a patent application has been filed. The fluorometer is only likely to function when used in conjunction with this tracer. As the tracer is food safe, crop destruction should not be required. The tracer can be put in spray tank alone or with agrochemicals, or through direct injection equipment. The tracer formulation contains stabilisers to greatly reduce photodegradation and crucially an agent that greatly enhances the fluorescence of deposits when they have dried. However, it is recommended that measurements are taken as soon as possible after the spray deposit has dried and within 60 minutes in very bright conditions.

APPLICATIONS

The instrument and tracer have many important applications, including the following: 1) to assess the results of spraying at start of a spray job and compare with best practice; 2) to adjust sprayer and spraying method to increase deposits and cover and reduce losses as necessary; 3) to check deposits and cover during the spraying process; 4) to measure precisely, analyse, and keep records of their spray application and use this data to inform how to improve future applications and provide farm staff with knowledge on the most appropriate spray equipment, settings, and methods for the application of sprayed products for specific crops and conditions.

BENEFITS

This new technology has numerous important benefits, including the following: 1) improvement of spray deposits and cover so improving efficacy of control of pests, disease and weeds; 2) reduction in crop losses; 3) reduction in pesticide waste and environmental contamination; 4) increased efficiency of agrochemical use; 5) to provide proof of correct practice; 6) afford multiple cost savings.

Smartomizer – proactivity and traceability in orchard spraying

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INTRODUCTION

Spraying of Plant Protection Products (PPP) accounts for 30% of costs in specialty crop production and has a direct impact on harvest quality and market selling price. With conventional application equipment, approximately 80% of the treatment failures are consequences of an incorrect human use. Errors may entail an excessive release of products that enter the food chain, pollute the environment, or both. Furthermore, it causes dangerous pest resistances, as in many cases over 50% of pesticides are not reaching the target organisms but contaminate the environment with considerable negative effects for biodiversity, bee life, bystanders, and the ecosystem as a whole (Cunha *et al.*, 2012). Thus, the $H_3O^{®}$, a holistic system of elements (Fig.1), is presented to combat the application error problem.

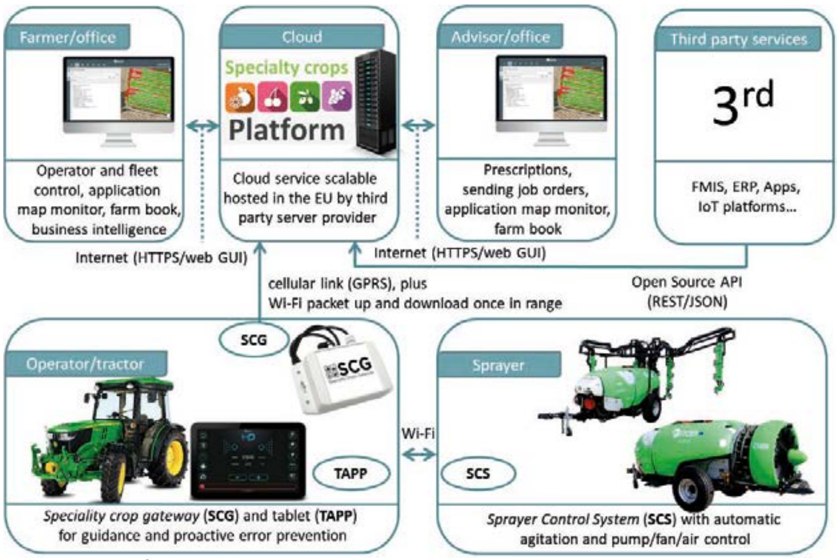

Fig. 1. Conceptual $H_3O^{®}$ system technology deployment view.

The proactive $H_3O^{®}$ system connects physical IoT (*Internet of Things*) devices on the implement side - in this case a *sprayer control system* (SCS) (Fig.1 bottom right) with a control tablet (TAPP) and a *speciality crop gateway* (SCG) in the tractor's cab (Fig.1 bottom left). The SCG contains a global satellite system receiver to guide the operator in real time and to log positioning data during operations for back-office analysis and treatment traceability. Apart, the SCG constitutes a node on the edge network that connects via a cellular link and the Internet to a private Cloud marked *Speciality Crops Platform* (SCP) (Fig.1 top left). By this way, farm managers and/or advisors connected to the SCP via web GUI (*graphical user interface*) can perform actions like sending prescriptions and job orders to the tractor operators and machines in the field, as well as monitoring results and post processing data, for example, to automatically produce the farm book that records all plant protection product treatments. The tractor mounted SCG also enables limited control and traceability of non-data capable sprayers or other implements like simple fertilizer spreader, pre-pruners, disc mowers, *etc.*, which are hooked up to the tractor's *power take off* (PTO). If on the other hand, the implement is a high-end intelligent sprayer, a so called *Smartomizer*, with an embedded *sprayer control system* (SCS), the work order contains sprayer configuration data that allows the sprayer's actuators to adjust the sprayer to field and crop dimensions. Moreover, interoperability of the SCP with third parties, *e.g.* with *farm management information systems* (FMIS), is assured through APIs on the basis of REST/JSON (Fig.1 top right).

RESULTS AND DISCUSSION

During spraying application, the tablet in the tractor's cab (TAPP) allows real-time job control through both visualization of the application and by receiving warnings in case any critical parameter differs from its expected value (*e.g.* tractor forward speed, *revolutions per minute* (PTO RPM), agitation, spray pressure). Relaying the machinery and treatment data to the farm management back office allows treatment analysis afterwards, while data are additionally securely stored in SCP database to allow for full treatment traceability. Fig. 2. (b) shows a typical treatment result map as accessible from the back-office GUI.

(a) (b)

Fig. 2. (a) In cab display with proactive operator guidance system (TAPP). (b) Traceability data of completed treatment in the *Speciality Crops Platform* (SCP).

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Canopy adapted dosing and spray application: environment protection in crop protection

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INTRODUCTION

The public's perception of pesticides is increasingly negative, demanding a reduction in pesticide use. Negative effects on non-target organisms and the environment has resulted in demands for re-registration of products, but also for new molecules, problems especially acute for pome fruit with its large pest and disease complex including invasive species. The availability of products has been reduced to a threatening extent, reducing options for resistance management, and making sustainable control increasingly difficult.

Spray drift reduction has proven to be an effective tool and is addressing an important fraction but only a minor quantity of the amount of pesticides released into the environment. It does also not reduce consumption per unit area as it just moves a small quantity of deposit from the surroundings of the orchard onto the treated area. A reduction of the consumption is only possible by an improvement of the application itself and the dosing rules, as both components determine the amount of a pesticide per unit area released into the environment before spray drift reduction comes into play. Especially the high sediment on the orchard floor from high water volumes serves as a long-term source for a direct contamination of surface waters and leakage into drainage systems and ground water.

After the introduction of a low volume spray application technique with reduced dose rates in the late 1980ies at Lake Constance, the idea of reducing pesticide use by improving spray application has been augmented by further components over the past 25 years, resulting in a highly resource efficient crop protection in 3D crops.

MATERIALS AND METHODS

The core of the concept are fan types with cross flow characteristics that have passed the AirCheck® fan type certification for a rectangular air distribution on a "Herbst WP 5000" air distribution test bench as the basis for its sophisticated use, spraying any canopy width at a canopy adapted fan speed, avoiding spray mist to significantly exit into the neighbouring alley way. As a primary effect, small droplets are kept inside the canopy, increasing spray deposition rate up to 35% and enabling the adaptation of the pesticide dose to the canopy (Triloff, 2011, Triloff et. al., 2013). As secondary effects, adaptation of fan speed to canopy width results in an enormous reduction of fuel consumption and noise emission. As canopy width and row distance decrease, forward speed can be increased up to approximately 12 km h^{-1}. The combination with reduced fillings per spray trip through low water volumes results in an enormous increase of work rate. When a grower orders a sprayer with a certified fan type, it is officially inspected, followed by successful adjustments of air and liquid vertical distributions to farm specific demands as prerequisites for ensuring the purchase of a fully functioning and individually adjusted sprayer.

For controlling the adaptation of dosing and spray application to canopy and orchard characteristics, the AOS43 dosing model (former MABO-model) is used which adapts the four parameters (dose rate, water rate, forward speed and fan speed) required for applying pesticides in three dimensional crops to the canopy. With this model, water volume, dose rate and fan speed decrease and forward speed increases as canopy width decreases, whereas liquid pressure is kept constant (Triloff, 2005).

With the use of a cross flow fan and the adaptation of fan speed to canopy width despite the use of hollow cone nozzles, spray drift is already reduced by approx. 95% compared to an axial fan at full fan speed. Further - official - drift reduction of >75% is obtained by replacing the two top most hollow cone nozzles by two "01"-ISO anti-drift nozzles (Triloff, 2011). For >90% drift reduction additionally only an upwind application in the first three tree rows may be required. The concept is completed by the training of operators and a close cooperation with innovative sprayer manufacturers through their membership in the AirCheck®-initiative with an annual workshop.

RESULTS AND DISCUSSION

The enforcement of spray drift reduction decreases spray drift in practise but will not reduce leakage of pesticides into surface waters, draining systems and ground water because drift reduction even increases the soil deposit on the treated area. Since soil deposit is linked to dose rate, water volume, droplet size and quality of spray application and may even be higher than the spray cover at the target, a reduction of the contamination of the orchard floor as a non-target area can only be realized by improving spray application and dosing in order to reduce dose rates applied. This however requires a system change with an optimization of the spray application with hollow cone nozzles and a suitable dosing model in a first step, completed by a drift reduction method in a second step that does not kill the first step. Canopy adapted dosing and spray application with AirCheck®-certified cross flow fans and small droplet nozzles fulfils these demands since canopy adapted spray application already reduces spray drift. The remaining spray drift requires just two small anti-drift nozzles at the two top most nozzle positions and eventually the first three tree rows to be sprayed upwind only to reduce spray drift as much as with classical drift reduction.

Depending on the status quo of a fruit farm, canopy adapted dosing and spray application may affect crop protection in 3D crops in various parameters with great importance in commercial fruit growing and environment protection in crop protection: overall pesticide use may be reduced in the range of 50%, fuel consumption and noise emission up to approx. 80%, labour time and crop protection cost up to approx. 40%.

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Spray deposition of a cross-flow fan orchard sprayer with low air and low spray pressure settings

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INTRODUCTION

To improve the current practice of spray application in fruit crops a research programme was setup assessing spray and liquid distribution of nowadays often used single- and multiple-row orchard sprayers and spray deposition and distribution in orchard trees. Potential pathways of improvement are; air amount, nozzle type and spray pressure. Improved spray deposition can lead to reduced use of agrochemical and therefor reduced emission to the environment while maintaining high levels of spray drift reduction and biological efficacy. This paper presents results of a single row cross-flow fan sprayer.

MATERIALS AND METHODS

Spray deposition measurements compared a reference cross-flow fan orchard sprayer (Munckhof, Horst, The Netherlands) and a HSS (Hol Spraying Systems, Meteren, The Netherlands) cross-flow fan sprayer following the ISO-22522 protocol. The measurements were performed in an apple orchard (Randwijk, The Netherlands) in full leaf (June-October 2017). 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 applying a spray volume of 200 l/ha (Table 1). Air setting during the experiments was in the high fan gear box setting of the sprayer. The HSS sprayer is equipped with individual air spouts just behind the nozzles at 8 height positions. Air settings of the HSS sprayer used were maximum and reduced; resp. 2100 rpm and 1800 rpm of the fan. Spray nozzles fitted to the HSS were Albuz TVI8001 hollow cone venturi nozzles operated at 7 bar spray pressure, and the Lechler IDK 9001 and IDK90015 flat-fan nozzles both operated at 3 bar spray pressure. Forward speed was varied between 6.5 km/h and 8 km/h (Table 1). Spray volume varied therefore between 138 L/ha and 263 L/ha.

To measure the spray deposition in the apple tree both sprayers sprayed the tree rows with a fluorescent tracer (BSF 0.3 g/l). A single row was sprayed from both sides over a 25 m length spraying consecutively from the left and right hand side of the sprayer (same driving direction). Four individual trees were sampled and leaf samples were taken by counting all leaves in seven tree sections: Top, Middle East side, Middle West side, Bottom Inside West, Bottom Outside West, Bottom Inside East, Bottom Outside East and putting every 10th leaf in a bag. The picked leaves were analysed in the laboratory for spray deposition of the sprayed fluorescent tracer BSF. The leaf areas were determined, and the spray deposition was calculated and expressed as $\mu l/cm^2$ and % of applied spray volume per tree compartment and for the whole tree leaf canopy.

RESULTS AND DISCUSSION

Total spray deposition in the leaf canopy of the apple trees for the reference sprayer was only 13% of total applied spray volume. This could be increased by as much as 67% depending on nozzle type, air setting and forward speed of the HSS sprayer (Table 1). Low air setting, using low spray pressures of 3 bar and flat fan nozzles (IDK9001, IDK90015) seems to be good alternatives for increasing spray deposition in tree canopy compared to high pressure (7 bar), full air setting and TVI8001 hollow cone nozzles.

Table 1. Spray deposition in full-leaf situation of apple trees presented as µL/cm² at leaves, % of sprayed volume in tree canopy and in tree canopy deposition of the different objects of the HSS sprayer (1-8) relative to that of the reference sprayer (9)

object		Nozzle	bar	Speed (km/h)	Air setting	Spray volume (L/ha)	LAI tree	Spray deposition (µL/cm²)	% of sprayed volume	relative to reference
	1	TVI 01	7	6.5	Low	251	1.97	0.46	18%	145
	2	TVI 01	7	6.5	Full	263	2.14	0.37	14%	111
	3	TVI 01	7	8	Low	211	1.88	0.44	23%	167
	4	TVI 01	7	8	Full	211	1.67	0.33	16%	123
	5	IDK 01	3	6.5	Low	165	1.73	0.31	18%	150
	6	IDK 01	3	6.5	Full	172	1.66	0.22	14%	104
	7	IDK 015	3	8	Low	207	1.72	0.37	18%	141
	8	IDK 015	3	8	Full	207	1.88	0.29	14%	113
Ref	9	atr lilac	7	6.5	Full	201	1.81	0.25	13%	100

Not only is spray deposition at total leaf canopy influenced by sprayer settings but also in-tree distribution. Differentiation in spray deposition for the top, middle and bottom section of the apple tree shows large variations (Fig. 1) between sprayer settings. Low air setting increases spray deposition mainly in the middle and top part of the tree whereas 8 km/h forward speed increased spray deposition mainly in the bottom part of the tree. For the HSS sprayer increased spray deposition in total leaf canopy (50%) seems most homogeneously distributed over tree sections with the IDK9001 at 3 bar, low air setting and 6,5 km/h forward speed (object 5).

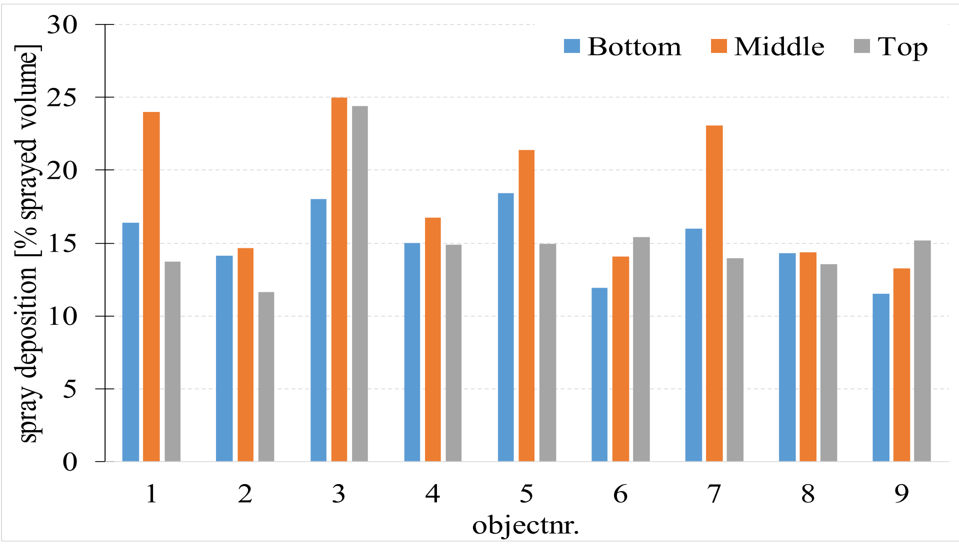

Fig. 1. Spray deposition (% of sprayed volume) of the different techniques (9=ref) in the Top, Middle and Bottom section of the apple trees.

Spray distribution in citrus canopies with different sprayers

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INTRODUCTION

Coverage and deposition uniformity have a practical significance for biological efficacy (Ebert and Downer, 2006; Garcerá et al., 2011), and these depend on the type of sprayer used and its setup parameters (Salyani and McCoy, 1989; Whitney et al., 1989; Hoffmann and Salyani, 1996), so the application methodology influences the efficacy of pesticides. The objective of this work was to determine the influence of the sprayer on the spray distribution on citrus canopies.

MATERIALS AND METHODS

The assays were carried out in a commercial Clementine cv Clemenules orchard located in Chiva (Valencia, Spain) (39°26'21.1"N, 0°32'49.7"W). It had 3x6 m tree- and row-spacing. Trees averaged 3.4 m in height, 2.7 m in width along the row and 4.0 m in width across the row, with a mean canopy volume of 14.44 m^3, considered as an ellipsoid.

All the sprayers were configured to release around 3500 L/ha, with a forward speed between 1.4-1.6 km/h (Table 1). In the airblast sprayers, low drift nozzles Albuz TVI-80 (Solcera, Évreux, France) were used. Only water was sprayed.

Table 1. Sprayers and set up tested.

Sprayer		Description	Airflow (m^3/h)	Waterflow (L/min)	Forward speed (km/h)	Volume rate (L/ha)
	1	Pneumatic with 14 outlets	38479	55.45	1.56	3562
	2	Airblast with air deflector and 2 nozzle manifolds	106081	51.76	1.41	3671
	3	Airblast with triangular fan outlet	86692	49.78	1.40	3556
	4	Airblast with double vertical fan in a tower	82846	51.48	1.38	3730
	5	Airblast with three nozzle manifolds	100332	57.06	1.62	3515

To study the distribution of the spray in the canopy, the coverage (%) was determined in half of the sprayed canopy. For this, 24 water sensitive papers (WSP) (76 × 26 mm, Syngenta Crop Protection AG, Basel, Switzerland) were distributed in 6 zones, result of dividing the half of the canopy into 3 heights (top, middle and bottom) and 2 depths (outer and inner). In each zone, 4 WSP were randomly placed: 2 on each side of the leaf (abaxial/adaxial), three repetitions were carried out. WSP were digitized and analyzed with custom-made software for image analysis (Food-Color Inspector, http://www.cofilab.com). To study the effect of the sprayer (S) on the coverage, and the side of the leaf (L), height (H) and depth (D), a multifactor ANOVA (MANOVA) was performed. Tukey's range test was used to compare means at P =0.05.

RESULTS AND DISCUSSION

The results showed that despite the different design of the tested sprayers, in general the spray distribution in the citrus canopy was similar between them (Fig. 1), and coverage was not significantly different between the sprayers (F_S= 2.14; df_S= 4, 357; P_S= 0.0759), with a mean coverage of 57-68%. Outer canopy got significantly higher coverage than inner in all cases (F_D= 37.41; df_D= 1, 357; P_D<0.0001). In general, coverage decreased inversely to height, but differences between heights depended on the sprayer (F_{HxS}= 3.82; df_{HxS}= 8, 357; P_{HxS}= 0.0003).

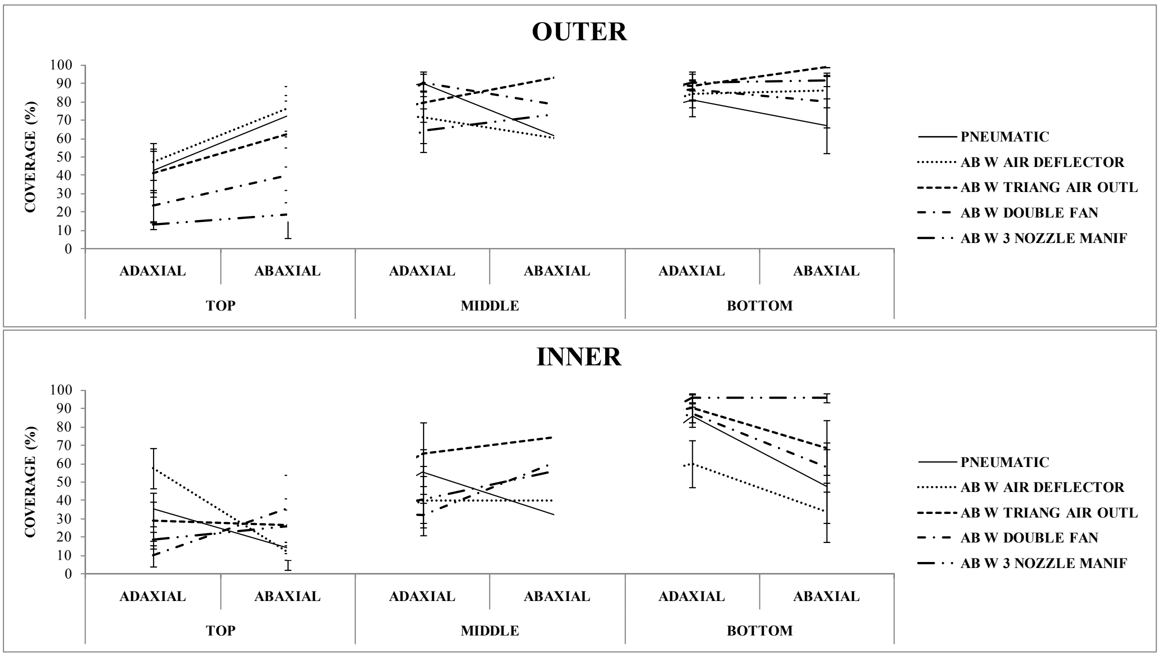

Fig. 1. Coverage (%) (mean±Standard Error) from each sprayer (AB= Airblast).

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Flat fan or cone nozzles for spray distribution in orchards and vineyards? Effect of nozzle type and row distance on the vertical distribution

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INTRODUCTION

Vertical distribution matching the canopy distribution is one of the most important aspects for a good pesticide distribution over the three-dimensional crops. Historically, air assisted sprayers for orchard and vineyard pesticide application have been provided with hollow cone nozzles in order to guarantee a good coverage. However, vertical distribution obtained with hollow cone nozzles does not always follow the canopy distribution in a proper way.

The main objective of this research was to evaluate the effect of different nozzle's spray patterns on vertical distribution of liquid during spray application in orchards and vineyards. Additionally, several specific objectives were defined: a) determine the effect of droplet size of flat fan nozzles (conventional vs air injection) on the obtained spray pattern; b) determine the influence of every single nozzle on the sprayer on the total vertical distribution of liquid; and c) quantify the effect of the distance to the target on the vertical profile.

MATERIAL AND METHODS

Vertical distribution of the liquid was obtained using an AAMS vertical test bench (AAMS-Salvarani, Maldegem, Belgium). This test bench had a total height of 4.5 m and it was provided with 40 individual collectors placed at a uniform distance of 0.10 m. The amount of collected liquid at every single collector was recovered on 40 individuals graduated cylinders. The amount of liquid recovered on every single cylinder was determined by dedicated ultrasonic sensors placed on the head lecture unit, allowing to automatically storage the data.

A conventional mistblower sprayer Inverter Qi 9.0 Ecoteq (Pulverizadores Fede, S.A.) with 2000 L tank capacity and 900 mm diameter axial fan was used for all the trials. The sprayer was provided with 14 nozzle's seats (7 left + 7 right). Transmission power to the sprayer was provided by a Landini Rex 90F (90 CV).

Three different nozzle types were selected, including hollow cone nozzle (Albuz ATI 80-03), air injection flat fan nozzle (Lechler IDK 90-03) and conventional flat fan nozzle with 30º (Lechler series 652.402). The three selected nozzles were tested at 1.0 m, 2.5 m and 5 m distance from the vertical test bench. During the trials, weather data (temperature, relative humidity, wind speed and wind direction) were automatically collected using a WatchDog weather station model 250.

RESULTS

Results indicated a good adaptation of flat fan nozzles, especially the air injection one, for the uniform distribution over the entire canopy. Values of coefficient of variation generated by hollow cone nozzle, air injection flat fan nozzle and conventional flat fan nozzles for 1 m distance from the sprayer to the vertical test bench were 38.5%, 28.1% and 34.7%, respectively (Fig. 1).

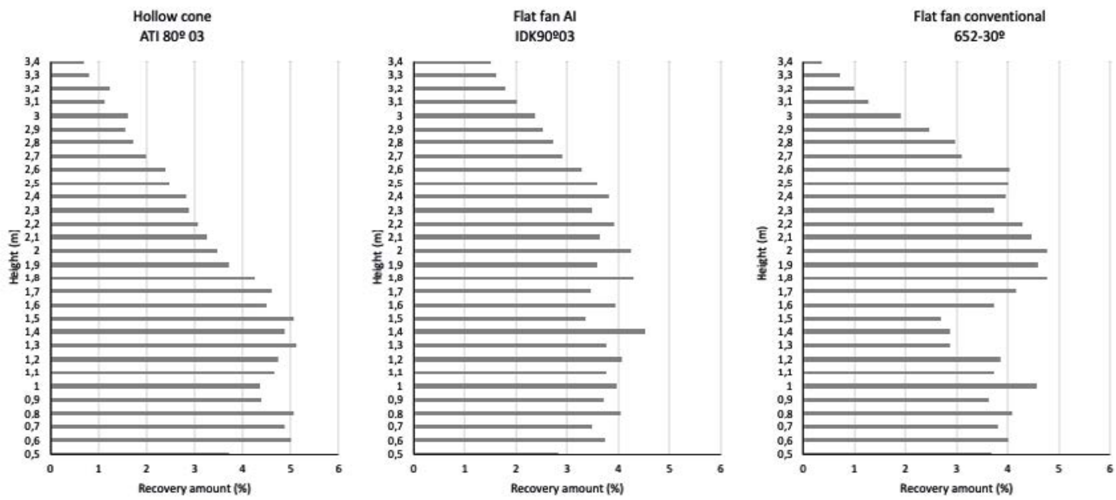

Fig. 1. Vertical distribution obtained with hollow cone nozzles (left), air injection flat fan nozzles (center) and conventional flat fan nozzles (right).

Evaluation of sprayers used for regulatory efficacy assessment trials

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INTRODUCTION

Regulation (EC)1107/2009 establishes a legislative framework for the evaluation and authorization of plant protection products (PPP). It includes the concept of zonal evaluation of PPP and promotes the mutual recognition of authorizations in each of the 3 European zones that have been defined. To carry this out, the European Plant Protection Organization developed quality standards for efficacy trials (EPPO Standards PP 1/181(4) and PP 1/214(4)) in which the good use of the application equipment is included within the good experimental practices (GEP) to achieve an acceptable efficacy.

However, in the efficacy trials submitted for PPP authorization, commercial sprayers are not commonly used. In addition, the application volumes rates do not correspond to those used at farm level, these being 800l/ha in apple orchards and less than 500 l/ha in vineyards at full leaf stage. Therefore, the hypothesis of this work is that the equipment used for these tests does not represent the real conditions.

This study presents a comparison between two sprayers used for efficacy evaluation for the Biological Assessment Dossiers (BAD) and two sprayers used by farmers.

MATERIALS AND METHODS

Trials were conducted in an established apple orchard and a vineyard in Lleida at IRTA (Gimenells) and Codorníu SA (Raïmat), respectively, in July 2018 (Table 1).

Table 1. Crop characterization. A) Apple orchard. B) Vineyard

	Apple Orchard	Vineyard
Crop stage (BBCH)	75-77	73-75
Row distance (m)	4,00	3,00
Tree distance (m)	1,40	2,10
Canopy height (m)	4,00	1,87
Canopy mid-width (m)	1,88	0,83
Canopy porosity (%)	20	20
LAI estimated (DOSA3D methodology)	3,31	1,78

For each crop, a gun sprayer and a motorized knapsack sprayer (Fig. 1) were compared to the sprayers used at farm level, an air-blast sprayer (apple orchard) and a vertical booms sprayer (vineyard). The intended volume rates were 1000 L/ha for apple trees and 500 L/ha for grapevines (Table 2).

The spray distribution assessment was done according to ISO 22522:2007 in three replicates per treatment randomly distributed in one row of each crop. Food dye tartrazine E-102 was used as tracer. Leaf deposition was measured in 3-4 leaves picked in each sampling zone and soil deposition in artificial collectors (filter paper).

Leaf deposition was normalized by the tracer concentration of the tank and it was related to the collector surface (µL/cm^2). For each crop, one-way ANOVA on square root transformed data with sprayer as the factor was performed.

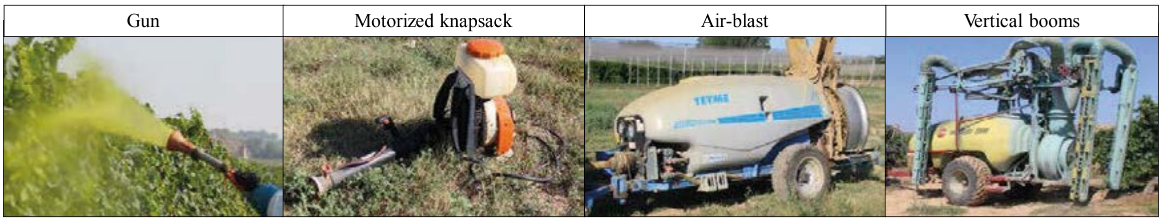

Figure 3. Sprayers used in the trials

RESULTS AND DISCUSSION

In the case of apple orchard, there were no significant differences between treatments in terms of leaf deposition but the air-blast was the most homogenous treatment.
In the vineyard, the vertical booms sprayer was the most efficient with significant higher leaf deposition and similar homogeneity.

Table 2. Application settings and results

	Apple Orchard			Vineyard		
Sprayer type	Gun	Motorized knapsack	Air-blast	Gun	Motorized knapsack	Vertical booms
Volume rate (L/ha)	1116	952	1000	439	590	532
Tartrazine dose (g/ha)	5924	4894	3793	2295	3115	2786
Mean leaf deposition (µL/cm^2)*	1,71a	1,14a	1,48a	1,2a	0,93a	2,08b
Variation coefficient (%)	103,9	84,0	63,3	78,8	65,7	84,8
Efficiency (leaf recovery)	50,9%	39,8%	49,1%	48,9%	28,2%	70,0%
Soil losses	13,2%	6,0%	6,4%	30,9%	9,5%	19,3%

**Mean differences in HSD test. Different letters in each crop mean significant differences*

The differences between treatments may affect the efficacy assessment process for the BAD and provide non-realistic dose values. Therefore, it would be suitable to carry out more work in this line to try to harmonize the methodology of efficacy trials.

ACKNOWLEDGMENTS

This work was partly funded by the *Department d'Agricultura, Ramaderia i Pesca* (contract S18053) and the *Secretaria d'Universitats i Recerca del Departament d'Empresa i Coneixement* (Grant 2017 SGR 646) of *Generalitat de Catalunya*. The work of Jordi Llorens was supported by Juan de la Cierva Incorporación (JDCI-2016-29464 N18003) from Spanish Ministry of Economy, Industry and Competitiveness. Authors also would like to thank the staff from IRTA and Codorníu SA.

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Droplet size effect in a PWM system: first results to improve orchard spray application

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INTRODUCTION

Spray application in an orchard must be improved using technologies to adjust exactly the amount of liquid needed at each point of the field. Currently most variable rate sprayers, use a system that adjusts the total amount of liquid to be applied for all the nozzles on the sprayer at the same time. To improve spray application in orchards is necessary to use a system to apply variable rate for each nozzle mounted on the sprayer. The flow rate control for each nozzle, through a previous calculation of the amount of liquid needed at each side of the sprayer, can be done using a Pulse Wave Modulated (PWM) system, this system is commonly used in variable rate boom sprayers. If it is necessary to adopt this system in an orchard sprayer is necessary to know its effect in droplet size to be conscientious of possible problems that can occur by the in droplet size changes. Drift, soil deposit or poor deposition are the most problematic situations. This PWM system has been already mounted in a prototype described by Silva, et al. (2018). The objective of this work was to evaluate the changes in droplet size distribution caused by the effect of pulse wave modulation system in three conic nozzles.

MATERIALS AND METHODS

In this study 3 nozzles (Albuz ATR 80 Red, Teejet TXB 8001 and Teejet AITX 8001) were mounted in a conventional Teejet body nozzle (QJT8360-NYB) equipped with the electric solenoid shut-off valve (Ref. num. 55295-1-12-15, Teejet). The place where the solenoid valve is mounted is in the diaphragm check valve position. To energize the electric solenoid using a PWM signal an Arduino Mega board with a specific electronic circuitry was connected. The working frequency of the generated signal is 10 Hz. Six different duty cycles were tested, but to better understand the results, only the results of three (20, 60 and 100 %) are presented in this paper. When a duty cycle of 100% is used, the valve is always open, that means no flow rate reduction. Experiments were conducted in a wind tunnel (University of Queensland, Gatton Campus) with a wind speed of 9 m/s. The different nozzles and PWM values were tested with water at two different pressures, 4 and 6 bar. The droplet size distribution was measured using HELOS laser diffraction equipment (Sympatech Inc, Clausthal, Germany). The measurements were done inside the wind tunnel in a downwind position. Each measurement was compared with BCPC (British Crop Protection Council) nozzle classification schema allowing classification of each nozzle into these droplet categories: Very Fine, Fine, Medium, Coarse, Very coarse, Extremely coarse.

A minimum of four replicate measurements were made for each combination of nozzle and PWM. Each replicate was a complete traverse of the nozzle vertically through the laser. The average of each measurement was analysed and the maximum of standard deviation of all curve points was calculated.

RESULTS AND DISCUSSION

Figure 1 presents the results of droplet size measurement at every duty cycle tested, for each nozzle analysed and for two pressures studied. On each graph, we can see the droplet size classification following BCPC classification. Conventional (no low drift) nozzles present bigger differences in droplet sizes (see grey lines in Figure 1 and Volume Medium Diameter values in Table 1) compared to low drift nozzles. We can see big differences between duty-cycle with the ATR nozzle. Specifically, these differences make that the droplet size classification changes from Fine to Medium when the PWM system changes from 100 to 20 % of the duty cycle. For TXB nozzle happen the same change but between VF and F classes. No big changes in droplet sizes are appreciated in AITX nozzle.

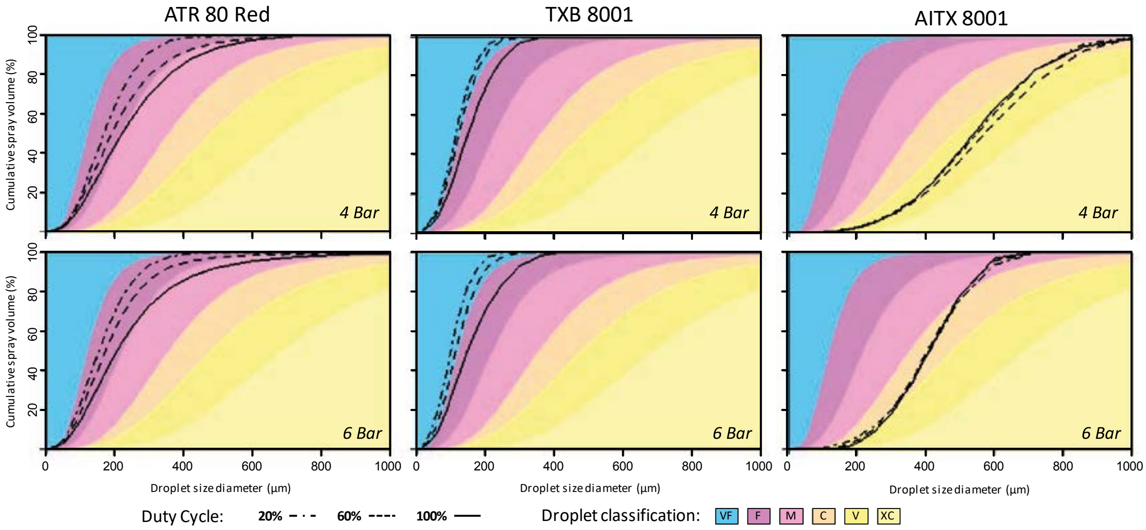

Fig. 1. Cumulative volumetric spray curves for each situation tested. Background colours represent droplet BCPC classification. Black and gray lines define the results at each duty cycle tested.

Table 1. Basic parameters of the thesis tested. Number of replications (n), maximum standard deviation between points on the curve and Volume Medium Diameter in µm.

			ATR			TXB			AITX		
		PWM	*n*	*max sd.*	*VMD*	*n*	*max sd.*	*VMD*	*n*	*max sd.*	*VMD*
Pressure	4	20	4	2.21	224	6	4.02	146	8	16.91	550
		60	4	0.78	191	5	2.33	120	5	13.38	562
		100	4	2.62	164	4	3.83	109	8	10.82	550
	6	20	7	2.69	210	4	1.79	150	6	6.88	409
		60	7	4.15	175	4	1.70	114	6	8.74	405
		100	5	0.62	154	4	5.27	96	5	5.03	409

FUNDING

Gatton work (Queensland, Australia) wind tunnel was supported by GRDC (Grains Research and Development Corporation) and Wine Australia. The work of Jordi Llorens was supported by the Spanish Ministry of Economy, Industry and Competitiveness through a postdoctoral position named Juan de la Cierva Incorporación (JDCI-2016-29464 N18003).

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From direct injection to deposition indicator – a 45 year retrospective

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INTRODUCTION

Applying pesticides to crops is one of the great engineering challenges, not only because pesticides are potentially hazard to the operator but also to the environment. The application equipment needs to be accurate but also easy for the operator to understand and operate. Spray drift, whilst inevitable in most circumstances, must be minimised. The onward march of progress leads us towards automation and the use of electronics in the form of sensors and controls. The cascading of research findings to the end-user completes the research package. For the past 45 years the author has spent many research hours developing various systems to provide a more efficient sprayer. This paper provides a retrospective journey through applied agricultural engineering in application technology.

THE FIRST HALF - EUROPE 1972-1998

Protecting the operator and the environment is the cri de coeur of anyone involved in spraying research. The development of the Dose 2000, a direct injection sprayer was my first significant project. Mixing pesticide with water in an in-line mixer allows spray to be applied as and when necessary (patch spraying) and results in a tank of water with no rinsing/disposal concerns. Automation allows precise application via field scouts and GPS. My first major project was the development of an injection system using a piston pump with a stepper motor controller, from concept to market place. Further developments included a compressed air injection system. The need to attach or decant concentrated pesticide containers to the system resulted in the parallel development of a closed transfer device, the CTS (Landers 1992). The CTS allowed the operator to connect a "male unit" to the shipping container and invert it into a "female receptor". Empty pesticide container disposal was a problem and still remains so to this day. A chipping machine was developed to reduce plastic containers, labels, carboard boxes into small chips which reduced bulk considerably.

Decision making in sprayer management was addressed by the development of an ExcelTM spreadsheet. Farmers could look at the effect on sprayer output by changing operating inputs such as tank size, refill time, travel distance and application volume with a user-friendly interface. Plenty of student projects to validate the models.

THE SECOND HALF-NORTH AMERICA AND AUSTRALIA 1998-2019

Tunnel or recycling sprayers have been around since the late 1940's but there is always the challenge in inventing a better "mousetrap". A tunnel sprayer was developed for the Tasmanian grape growers in an attempt to reduce drift and pesticide use.

Every manufacturer of spraying machines claims their machine is better than the competition, for twenty years we have conducted independent field trials, working in conjunction with biologists, to verify the claims made. Not everyone is happy with results obtained!

Adjustments to dose is a continuing concern, rigorous field trials of the Catalonian system "Dosavina" in New York State led to substantial reductions (up to30%) in pesticide use for competent growers.

Tractors and sprayers travelling along every row has been of concern. We have studied single-sided spraying with suitably adjustable fan systems such as small individual SARDI fans with great success. The progress made with narrow spindle canopies has resulted in a great requirement for airflow adjustment. Fixed-line orchard sprayers where the tractor and sprayer are eliminated in favour of a pumped spray-line mounted within the canopy has potential but as of yet 100% success remains elusive.

Airflow continues to be a great area of development. The use of retro-fit systems to provide adjustable airflow, such as the “Cornell doughnut” and the “Landers louvre” provided simple yet effective solutions.

The ever-present desire to move the subject onwards has seen the introduction of electronics on the grand scale. The simple electronics we used on the direct injection sprayer of the mid-eighties has developed into the use of Lidar canopy detectors on the autonomous sprayer (complete with on-the-move adjustments to air and liquid flow) we developed for the Florida citrus growers.

Precision spraying at a lower cost resulted in the development of infra-red, and then ultrasonic canopy detection sensors coupled with off-the-shelf Lechler VarioSelect and airflow adjustment.

The field trial remains the proving ground of all engineering developments. The organization of field trials, the encouragement of the labour involved and the endless hours of repetitiveness, all under the name of scientific rigour resulted in the commercial development of a deposition indicator. Electronic sensors that can determine real-time spray deposition and penetration, without the need for the traditional army of summer students and technicians, has been a tremendous boon.

During a 45-year career I have taught students, farmers and growers in many countries. I have concentrated my research and teaching efforts at two first-class institutions, one in the UK and one in the USA. I have seen many methods of teaching and examination come into fashion only to disappear just as fast. I am still amazed as to how a group of growers can spend a whole day on an applied spraying workshop without any degree of examination being provided. There are many facets to education, teaching does go hand in hand with examination. Research funding, based upon the model of government matching funds provided by growers has been highly successful for me. I have been the lucky recipient of millions of research dollars over my career. I believe that grants should contain an extension component to ensure that information doesn’t languish in academic journals but is cascaded out to the stake-holder.

During my long career I have met many first-class people, from mentors to students and colleagues, I wish to thank them for their enthusiasm for their subjects and enthusiasm for life!

Improving spray deposition in apple orchards by multiple-row sprayers

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INTRODUCTION

It is proven that multiple-row sprayers reduce spray drift significantly (Wenneker et al., 2014, 2016). This is due to the spraying system that sprays tree rows from both sides at the same time, in contrast to standard orchard sprayers that spray the tree row only from one side. It is assumed that spray depositions are improved when spraying with multiple row sprayers and dose can therefore be reduced accordingly, without reducing biological efficacy. 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 e.g. Munckhof and KWH, were compared to conventional cross-flow fan sprayers (Munckhof). Previous experiments showed that spray deposition varied significantly, depending on nozzle spray quality, fan setting and sprayer type. Further research is carried out to adjusted sprayer configurations for a further improvement of spray deposition in the tree canopy for multiple and single-row orchard sprayers. The objective is to find the optimum combination of application parameters for different stages of canopy development to improving spray deposition. In the experiments multiple-row orchard sprayers of two manufacturers (Munckhof and KWH), were compared to a conventional cross-flow fan sprayer (Munckhof).

MATERIALS AND METHODS

The spray deposition measurements were performed in an apple orchard (Randwijk, The Netherlands) to quantify the effect of a reference cross-flow fan orchard sprayer (Munckhof) and multiple-row sprayers in a full leaf situation (June-October 2016 and 2017). The reference sprayer was equipped with a standard hollow cone nozzle (Albuz ATR lilac), operated at 7 bar spray pressure and a forward speed of 6.7 km/h. Eight nozzles were used on both sides of the sprayer resulting in a spray volume of 200 l/ha. Air setting during the experiments was in the high the fan gear box setting of the sprayer. Also, for the multiple row orchard sprayers (used as 2-row sprayers) the spray pressure was 7 bar, 4 x eight nozzles (Albuz ATR lilac) were used, and a spray volume of 200 l/ha. Air assistance of the multiple row sprayers was set to high (540 rpm PTO) and to low (400 rpm PTO).

To measure the spray deposition in the apple tree a single row and two rows were sprayed with a fluorescent tracer (BSF 0.3 g/l) from both sides for resp. the cross-flow and the multiple-row sprayers. Spraying was consecutively done from the left and right hand side of the sprayer (same driving direction) for the cross-flow fan sprayer. Four repetitions were made, i.e. spraying 30 m of tree row from both sides, and analysing leaves samples from four individual trees. Leaf samples were taken by counting all leaves and putting every 10th leaf in a bag in seven tree sections: Top, Middle East, Middle West, Bottom Inside West, Bottom Outside West, Bottom Inside East, Bottom Outside East. The leaf areas were determined, and the spray deposition was analysed, calculated and expressed as $\mu l/cm^2$ and % of applied spray volume per tree compartment and for the total leaf canopy of the whole tree.

RESULTS AND DISCUSSION

Total spray deposition in the leaf canopy of the apple trees was for the reference sprayer only 20% of total applied spray volume. This could be increased by as much as 64% depending on nozzle type and air setting of the Munckhof multiple-row sprayer (Fig. 1). In general spray deposition in tree leaf canopy is increased through the use of the multiple row sprayers. Relative large differences per year occur per year as well as for the KWH for both the low and high air setting and for the Munckhof in the low air setting.

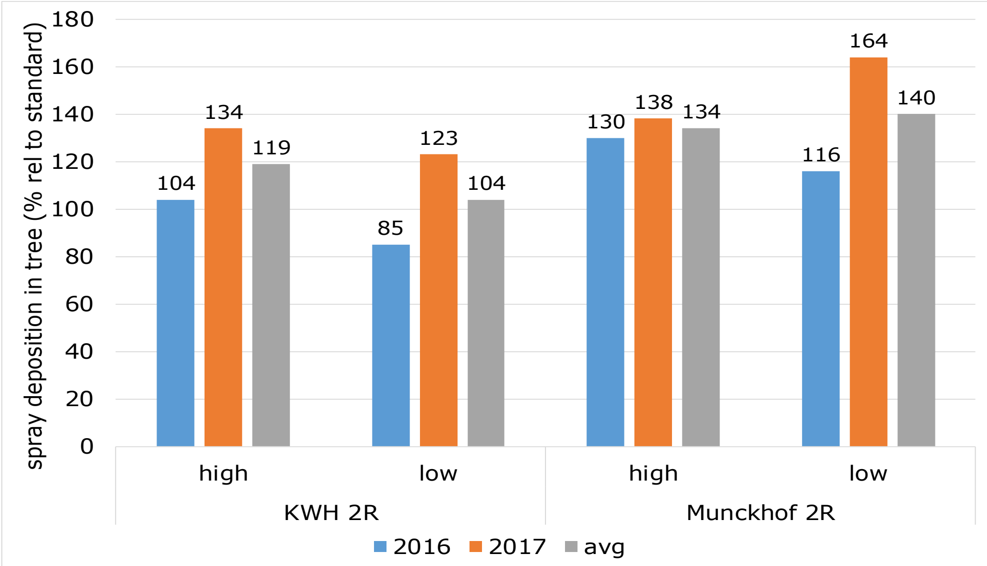

Fig. 1. Spray deposition in the tree leaf canopy of the KWH and Munckhof multiple-row orchard sprayers (2R) using Albuz ATR lilac nozzles (7 bar) and high (540 rpm PTO) and low (400 rpm PTO) air settings relative to that of the reference spray system (set to 100%).

Average increase in spray deposition in tree leaf canopy is for the KWH in the high air setting 19% and in the low air setting 4% whereas for the Munckhof multiple-row sprayer equipped with Albuz ATR lilac nozzles was 34% in the high air setting and 40% for the low air setting. For the KWH multiple-row sprayer the best results in the increased spray deposition in the tree were obtained with high air setting in 2017 (34%), and for the Munckhof multiple-row sprayer with the low air setting in the same year (64%).

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Drones for PPP distribution evaluation of spray deposits in orchards

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INTRODUCTION

In recent years, spray application by drones has become increasingly common in China and is being applied to a wider variety of crops. The wide range of crop applications provides the potential for development in areas where large ground sprayers are difficult to operate such as rice paddies, middle and late-stage corn fields, and crops on steep slopes. A variety of plant protection drones have been developed in China to cope with the increasingly severe pest control tasks (He et al., 2017). In comparison with traditional manual knapsack sprayers, plant protection drones for low-altitude and low-volume spray applications are characterized by high operational efficiency and low labour intensity.

Different types of plant protection drones have been studied to control pests and diseases on rice, wheat, and corn since 2012 (Xue et al., 2013; Gao et al., 2013; Qin et al., 2014; Zhang et al., 2012). Drone spraying applications are becoming more sophisticated as applied in various field crops such as paddy rice, wheat, corn, and other crops, and thus can essentially meet pest control requirements for such crops.

Unfortunately, this technology as used on orchards has been rarely reported. Less than 20% of orchards are suitable for mechanized operations in China. The main spraying equipment in most orchards is spraying guns with long tubes and pumps driven by engines at the edges of the orchards because of the high degree of canopy closure and topography problems such as steep slopes. Plant protection drones could be a good alternative for spraying plant protection products in orchards where productivity of manual application is much lower.

In this study, remote control helicopters (RCH) and multi-rotor drones were chosen to spray orchards, and the distribution of droplets deposition in the canopy were evaluated. The objective was to verity the feasibility of plant protection drones in fruit tree pest control and to study the effects of different parameters on droplet deposition distribution.

MATERIALS AND METHODS

An engine-driven RCH and 3 types of 4 multi-rotor drones were used to spray in peach orchards, apple orchards, and citrus orchards having different tree training systems. Spraying was done with pure tap water. Water sensitive papers were fixed on the upper sides and undersides of the leaves in top, middle, and bottom positions of the canopy to measure droplet distribution. Measurements were conducted from July to August, 2018. The temperature was 25~30℃, and the wind speed was less than 2m/s.

Table 1. Drone and Application Parameters

Test	Drone	Fruit/training system	Flight altitude/m	Speed/$m \cdot s^{-1}$	Flight route	Spray volume/$L \cdot ha^{-1}$
1	4 multi-rotor drone	Peach/open-centre	0.5/1.0/1.5/1.0/1.0	3.0/3.0/3.0/4.0/5.0	Middle of the tree top	40.35/40.35/40.35/30.3/24.3
2	4 multi-rotor drone	Apple/spindle	1.5	2	Middle of the tree top	60.6

3	4 multi-rotor drone	Citrus/ open-centre	1.5	2.0	Middle of the tree top	55.05
4	4 multi-rotor drone	Citrus/ open-centre	1.2	1.5	Middle of the tree top	55.5
5	RCH	Peach/V shape	1	2/4	Middle of the tree top/ Middle of the row	45.9

RESULTS AND DISCUSSION

Droplets can be deposited effectively at different parts in the canopy, and the deposition density of droplets on the upper and underside of leaves is more than 10 per square centimetre. The deposition of droplets on the upper side of leaves was significantly higher than that on the underside of leaves, however, in some tests, the deposition of droplets on the underside of leaves was higher than that on the upper side of leaves in some positons of the canopy.

The flight routes of drones relative to the fruit tree canopy can significantly affect the deposition and distribution of droplets. Flight altitude, flight speed and droplet size are all factors that can significantly affect droplet deposition. Increasing the downwash air flow of drones is not sure to increase the deposition on the underside of the leaves. It is necessary to consider the downwash airflow, branch and leaf swing and droplet deposition track to improve the deposition distribution of droplets.

In the control of pests and diseases in orchards, for drone pesticide efficiency, it is necessary to select reasonable parameters such as flight route, flight speed, altitude, and droplet size according to the positon of pests and diseases in canopy.

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CitrusVol validation to control *Tetranychus urticae*

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INTRODUCTION

CitrusVol is a Decision Support System (DSS) developed by IVIA to calculate the optimal volume rate for plant protection product (PPP) applications with airblast sprayers in adult citrus orchards (Garcerá et al., 2017). This DSS allows adjusting the spray volume to the characteristics of the vegetation (canopy volume, tree and row spacing, foliar density and pruning level), the type of pest or disease and the type of PPP. The objective of this work was to validate CitrusVol for the control of the red spider mite, *Tetranychus urticae* Koch (Acari: Tetranychidae) in clementine mandarin trees (*C. clementina* Hort. *ex* Tan.), since it is one of the main pests for this crop.

MATERIALS AND METHODS

The assays were carried out in a commercial Clementine cv Clemenules orchard located in Chiva (Valencia, Spain) (39°26'32"N, 0°33'23"W). It had 6- by 3-m row and tree spacing. Canopy of the trees averaged 2.55 m in treated height, 3.07 m in width along the row and 4.15 m in width across the row, with a mean canopy volume of 17.13 m^3, considered as an ellipsoid (mean values of ten random trees). The 1.6-ha orchard was divided in two blocks with similar size; in one block the adjusted spray volume recommended by Citrusvol (V_A) was applied and in the other block the conventional spray volume used by the farm (V_C) was applied. During 2016 and 2017 seasons, 6 spray applications against *T. urticae* were carried out with airblast sprayer (Table 1). Application dates and applied PPP were decided by the technician of the farm. PPP concentration was kept constant for both volumes, so different doses were applied with the different volumes.

Table 1. PPP application data.

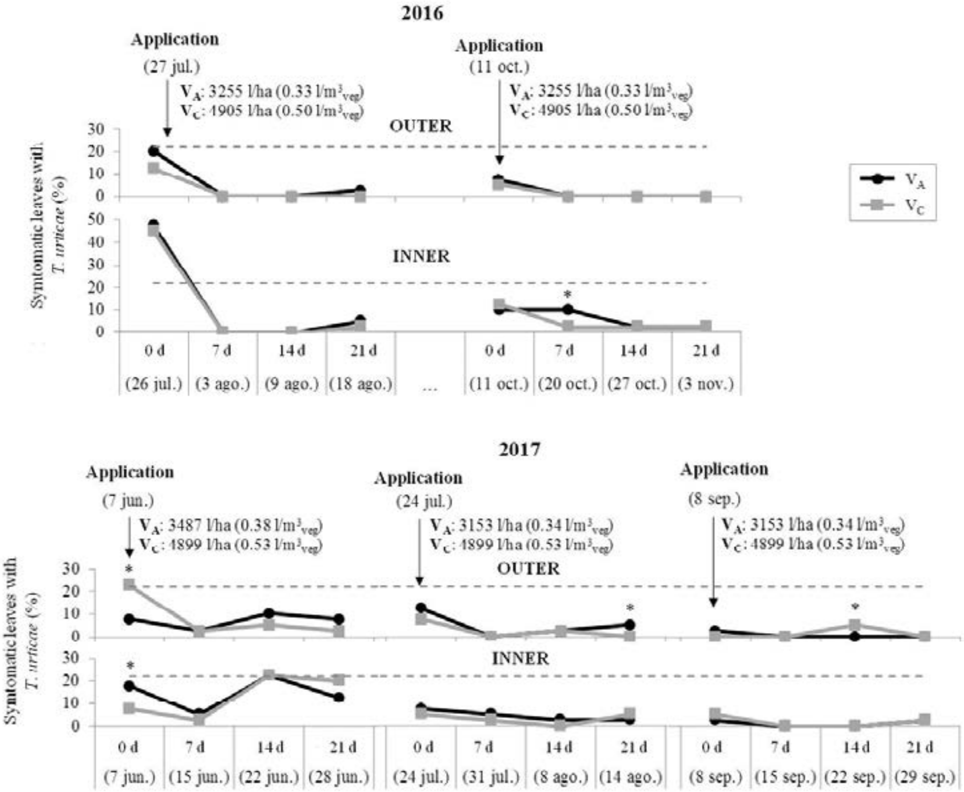
Date	Spray volume			Mixture		
	V_C (l/ha)	V_A (l/ha)	Reduction (%)	PPP	Active ingredient	PPP concentration (%)
27/07/2016	4905	3255	33.64	Cal-Ex	Abamectine	0.100
				Movento 150 O-Teq	Spirotetramat	0.040
				Envidor	Spirodiclofen	0.023
11/10/2016	4905	3255	33.64	Cal-Ex	Abamectine	0.100
07/06/2017	4899	3487	28.82	Dursban 48	Chlorpyrifos	0.267
				Stygma	Abamectine	0.100
24/07/2017	4899	3153	35.64	Abasi EC	Abamectine	0.100
				Envidor	Spirodiclofen	0.023
08/09/2017	4899	3153	35.64	Reldan E	Chlorpyrifos-methyl	0.400
				Dauparex	Abamectine	0.100
				Envidor	Spirodiclofen	0.023

To assess the efficacy of both spray volumes against *T. urticae*, 4 samplings were done: before spray application and at 7, 14 and 21 days after spray applications. In each sampling, 2 random leaves with symptoms of red spider mite attack per tree, one from the outer canopy and one from the inner, in a total of 40 random trees per block were inspected to evaluate if they were or not occupied by red spider mite (with ≥2 alive mites per leave). The percentage of symptomatic leaves occupied by *T. urticae* was calculated.

To study the effect of the spray volume on control of *T. urticae* a Chi-square test with P= 0.05 was performed per each sampling of each application date.

RESULTS AND DISCUSSION

In the majority of samplings for each application, significant differences in the percentage of symptomatic leaves occupied by red spider mite between V_A and V_C were not found (Fig. 1). This allows concluding that CitrusVol recommended a spray volume around 33.5% lower than the one used conventionally in the farm, but control efficacy was not reduced. Therefore, the spray volume recommended by CitrusVol resulted adequate for the control of *T. urticae* in clementines in the case of study.



*Significant differences between volumes (Chi-square test; P= 0.05)

Fig. 1. Symptomatic leaves occupied by *T. urticae* (%) depending on the location of the leave (outer/inner) for each sampling of each application. Dashed lines represent the treatment threshold (22%).

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Dose adjustment for pome fruit orchards in France: what canopy indicator options?

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INTRODUCTION

In France the applied dose of plant protection products (PPP) in fruit growing is a real concern. Orchards have a high diversity of canopy structures (e.g. fruit hedge for pome fruits, goblet for stone fruits, and large volume for nuts), and also for each structure there is a significant change in the vegetation density between bud break and harvesting. Currently, the French dose expression used for the registration of PPP's is a fixed dose / ha. This expression leads to variable deposits per unit of foliage area depending of the vegetation. Dose adjustment to crop growth is clearly aimed at reducing inputs that are identified by the parliamentary mission and re-transcribed in the National Ecophyto II plan.

MATERIALS AND METHODS

This article presents the work carried out and the first results obtained within the PulvArbo project, led by the Ctifl, in partnership with the IRSTEA, the experimental stations (Invenio, SudExpé, La Morinière, La Pugère, Cefel), and the cider sector (IFPC, CRA Normandie, Agrial, Cidres de Loire) and conducted in close collaboration with the Agriculture Ministry.

The creation of a dose adjustment tool for orchards necessitates several steps :

-The first step is to characterize canopy development using simplified indicators (treated high, width of canopy, distance between rows, Leaf Wall Area, Tree Row Volume…), both measured manually and by LiDAR.

-The second step is to define various scenarios of dose adjustment based on the vegetation indicators collected in the first step. In our set of trials we chose to adapt according to the LWA and a personal grid based on BBCH stage.

-The final step is to evaluate the impact of the different dose adjustment scenarios on biological efficacy during a complete growing season. For this, shoots and fruits are observed regularly for all the pests and diseases of interest.

RESULTS AND DISCUSSION

Three hundred orchards have been characterized at different growth stages: 78% pome fruits, 20% stone fruits, and 2% nuts. A data base has been created. For each specific tree crop it is possible to link the crop parameters and the description of the orchards (training, age, variety and location) and for each orchard it is possible to establish vegetation evolution curves during the season. The LiDAR also provides information on the porosity of the canopy. Based on these data it is possible to define a value of standard orchard for each crop expressed as LWA or TRV. Different scenarios of dose adjustment taking into account several parameters have been tested in apple orchards since 2016 on 9 experimental sites located in the different regions of apple production in France. Three of these scenarios are based on the LWA for different values of "standard apple orchard" LWA: 15000 m²/ha, 17000 m²/ha and 21000 m²/ha. The fourth scenario is based on a grid taking into account BBCH stages, treated height and width canopy classes. A first assessment of the interests and constraints of each method has been done. The Index of Treatment Frequency (ITF) has been decreased from 1% to 30% (depending on the orchards and the scenarios) compared to the reference treated at the full dose. The phytosanitary status of the trees is very dependent on the location of the orchard and the local pressure of pests and diseases. In most of the cases a dose reduction of 15% doesn't affect the quality of the harvest.

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Dose adjustment in citrus and olive orchards: two-year validation of the DOSA3D system

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INTRODUCTION

Citrus and olive orchards, respectively, represent 5% and 29% of the total area of 3D crops grown in the EU (Eurostat, 2018). All of these orchards are located in the Southern Zone for the registration of pesticides (Reg. EC 1107/2009). Every year, the number of treatments ranges from 4-10 for citrus fruits and 2-6 for olives. For the majority of the PPP currently applied to these crops, the label-recommended dose is expressed as a concentration (%), and only occasionally with relation to ground surface (kg or L/ha). The majority of new citrus orchards are managed very intensively, with mature trees forming a near continuous-row canopy which can have a crosswise mid-width of up to, or over, 3.0 m. The sprayers work at a constant flow rate. In contrast, olives are traditionally grown as isolated trees, with canopies up to 4.0 m high and 6.0 m wide (Fig. 1). In this case, the liquid flow between trees tends to be, either manually or automatically, turned off. In compliance with the SUD Directive (2009/128/EC), when applying chemical treatments to 3D crops, experts (Cruz et al., 2017; Miranda et al., 2016; Planas et al., 2015) and authorities recommend adjusting the dose applied in line with crop dimensions, to ensure that a minimal (safe) but sufficient (efficient) quantity of chemicals is sprayed,

Fig. 1 Geometric figures showing the shape of the citrus (left) and olive canopies (right)

MATERIALS AND METHODS

The DOSA3D system (www.dosa3d.cat), which is currently used for fruit and grape orchards, but also for citrus and olive orchards, establishes the optimal dosage based on the required spray volume according to the canopy volume. The volume application rate (V) ($L \cdot ha^{-1}$) is decided by the following expressions:

$$\boldsymbol{V} = \boldsymbol{TRV} \cdot \boldsymbol{I_c} \text{ (citrus)} \qquad \text{and} \qquad \boldsymbol{V} = \boldsymbol{TCV} \cdot \boldsymbol{I_c} \text{ (olives)}$$

Where ***TRV*** is the apparent tree row volume (m^3/ha) in citrus orchards, ***TCV*** is the apparent canopy volume (m^3/tree) for isolated olive trees and ***Ic*** is the liquid index, which is equivalent to the volume to be sprayed per unit of canopy volume (L/m^3). This varies according to the canopy density (HD/LD) and the position of the pest to be controlled (Table 1).

Table 1. Liquid index ***Ic*** (L/m3) values for citrus orchards and isolated olive trees

	citrus		**olives**	
Pest, position on the canopies	HD(1)	LD(2)	HD(1)	LD(2)
Internal and external (red scale, mites, peacock spot)	**0.30**	**0.20**	**0.07**	**0.05**
External (aphids)	**0.20**	**0.10**		

(1) high vigor and not pruned for more than two years; (2) low vigor or last pruned in less than two years

The DOSA3D system was validated in commercial orchards in the southern part of Catalonia over a two-year period (2017-18). Eleven field tests were carried out in citrus orchards with the objective of assessing the efficacy of chemical treatments for controlling California red scale (*Aonidiella aurantii*), two-spotted spider mite *(Tetranychus urticae)* and aphids *(Aphis gossypii, Aphis citricola, Toxoptera aurantii and Myzus persicae*) and a further two field tests were conducted in olive orchards to control peacock spot *(Cycloconium oleaginum)*.

RESULTS AND CONCLUSIONS

DOSA3D provided adjusted doses which permitted pesticide savings of up to 30% in citrus orchards and 50% in olive groves with respect to the standard doses normally applied by farmers. No significant differences in efficacy were noted between the adjusted and standard doses. DOSA3D could therefore prove very helpful for harmonizing the doses applied in citrus and olive orchards and for taking action to reduce the use of pesticides, as advocated by the SUD Directive.

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Evaluation of the MABO-dosing model as a cost-effective alternative to the conventional use of the Unrath tree-row-volume model in South Africa for applying pesticides sprays in high density apple orchards

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INTRODUCTION

In South Africa, the current pesticide dosing model used in apple orchards is the Tree row volume (TRV) model (Sutton and Unrath, 1984). The model has some practical drawbacks; spray machine setup and the pesticide spray tank concentration must constantly be changed between orchards differing in canopy size and volume leading to longer orchard spray times on a farm and the need for more spray machines to reduce spray time. Due to rapid emergence and development of new leaves, timely application is very important to ensure adequate coverage of new plant material to prevent infection by apple scab (*Venturia inaequalis*). Thus, growers must be able to spray a farm in 2-days to an impending infection period.

The Marktgemeinschaft Bodenseeobst (MABO) dosing model is an extended and modelled form of the TRV dosing model. Dose adjustments between different orchard areas are conducted by only adjusting tractor speed, which is correlated with the tree canopy width and spray time per hectare, while a constant liquid flow rate is used for a whole farm (Triloff, 2005). Modernization of apple orchards has led to a higher tree density per hectare and lower tree canopy volumes (m^3/ha), in which the MABO dosing model has the potential to improve the economy and efficiency of spray applications.

The aim of the study was to evaluate the MABO model versus the conventional TRV model in South African high-density apple orchards as influenced by volumetric air flow rates using a previously developed spray deposition assessment protocol that evaluates deposition parameters through the use of fluorometry, photomacrography and digital image analysis.

MATERIALS AND METHODS

Two replicated trials were conducted in 3.5 & 4 m row-width apple orchards with the following four treatments: (i & ii) MABO & TRV at a high volumetric airflow rate (VAR) = 36000 m^3/h (iii & iv) MABO & TRV at low VAR= 28000 m^3/h. For TRV sprays an industry norm speed of 4.2 km/h and spray volume of ±750 l/ha was used. MABO dosing and calibrations were done as described by Triloff (2005) with slight modifications to allow for adaptation to SA conditions and regulatory rules. A filter area (FA) of 5750 and 6000 m^2/ha was calculated and used separately for trial one: 3.5 m rows = 6.5 km/h & 439 l/ha; 4 m rows = 4.5 km & 526 l/ha and two: 3.5 m rows = 6 km/h & 458 L/h and 4 m rows = 4.5 km/h & 573 l/ha. Speed was influenced by gear selection at 540 RPM PTO speed, thus the nearest gear to the MABO speed indicated was used. A net spray time of 33 min per FA was used. A high-profile axial fan spray machine with a blade pitch of 28.5° (ROVIC LEERS EVENFLOW® sprayer, ROVIC LEERS (Pty) Ltd) was used for all treatments.

Ten trees were sprayed per application of which three trees were sampled from. 12 leaves were randomly sampled from the inner and outer canopy at the top, middle and bottom positions per tree. Digital images were taken of sampled leaves illuminated by UV-A ≈ 365 nm light source and the following deposition parameters determined by means of image analyses: Deposition quantity, measured as percent of total leaf area covered by pigment particles (percentage fluorescent particle coverage; %FPC); deposition uniformity, measured as the coefficient of variation (CV%) of deposition quantity between leaves at various positions in the tree; and deposition quality, measured as the interquartile coefficient of dispersion (%ICD) of deposition quantity measured in each 100×100 pixel square of each leaf image (van Zyl *et al*., 2013). An FPC benchmark model was developed for mancozeb to evaluate the effectiveness of deposition quantity in relation to theoretical disease control using thermal infrared imaging disease quantification with *Venturia inaequalis* used as model pathogen.

RESULTS AND DISCUSSION

The study showed that the MABO model resulted in spray deposition parameters (quantity, uniformity and quality) that were comparable to those of the TRV model in high density apple orchards in South Africa. In the 4 m orchards the MABO model did not differ significantly from the TRV model. The use of two different volumetric airflow rates (VAR, 28000 m^3/h [low] and 36000 m^3/h [high]) in the 4 & 3.5 m orchards furthermore yielded similar deposition parameters for both models. In the 3.5 m orchards, the MABO model yielded a significantly higher deposition quantity than the TRV model; either on top canopy leaves or for the whole canopy. No clear trends were seen in model performance with regards to deposition uniformity and quality. The MABO model on average resulted in a 40 to 28.5% spray cost saving relative to TRV, depending on the spray volume used.

The deposition quantities achieved with the MABO and TRV models in apple orchards were above (0.70- 4.7 FPC%) those required for controlling apple scab with mancozeb, based on a benchmark laboratory model developed in the current study. The benchmark model, developed using thermal infrared imaging (TIRI) disease quantification, showed that 0.40%, 0.79% and 1.35 FPC% corresponded to 50, 75 and 90% control respectively. The benchmark model showed that mancozeb yielded high levels of disease control at very low concentrations. The MABO model can be used as a cost effective and grower friendly dosing model in high density apple orchards in South Africa. The mancozeb deposition benchmark values established in this study will be valuable for assessing the efficacy of spray applications made in future research trials and grower applications. Due to the low benchmark values identified for mancozeb, future studies should also investigate benchmark values for other contact fungicides as well as for mesosystemic and systemic fungicides used for controlling apple scab world-wide.

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New developments to help farmers correctly dosing pesticides in olive orchards

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INTRODUCTION

Different efforts have been undertaken to improve pesticide dosing in 3D crops over the last years. Thus, different authors have developed dosing approaches for their respective crops, like stone fruits (Walklate et al., 2003), vineyards (Gil and Escolà, 2009), citrus (http://dosacitric.webs.upv.es/) and olives (Miranda-Fuentes et al., 2016). These strategies have been shown to achieve important liquid savings without compromising the biological efficacy of treatments, so they are a powerful tool to implement in the field. Nevertheless, an additional effort should be done to bring these systems to farmers in a way they can understand and use. In this sense, phone apps seem to be a good solution, as nearly every farmer has a smartphone with which to use these apps. Thus, some of these systems, like DOSAVIÑA, have been taken into an app format, with successful results in terms of spread and acceptance (https://uma.deab.upc.edu/es/dosavina). This work presents the scientific work behind DOSAOLIVAR, a double system for both dosing and regulating the sprayer operation in olive orchards.

MATERIALS AND METHODS

Data collection

The project began with a study of the olive tree characteristics in commercial orchards. The app development required a data collection process to include the most of the variability inherent to this crop. Two data bases were developed for the purpose: an olive tree geometry database and a commercial nozzle database. The tree geometry database was necessary to give orientations to farmers who are unable to use the characterization method included in the app for their own trees. The data collected included the olive cultivation system (extensive and intensive ones), the trunk diameter, the tree crown height and two diameters, to generate the ellipsoid tree volume (Zaman and Schumann, 2005), the eight necessary vectors to calculate the mean vector to correlate with the crown volume (Miranda-Fuentes et al., 2015), and the canopy density(Miranda-Fuentes et al., 2016). The nozzle database included most of the commercial hollow-cone nozzle available on the market. The final purpose of this database was to make it possible for the farmer to select their nozzle and let the regulation system to automatically set the correct pressure for the advised application and the given nozzle.

Field trials

The field trials aimed establish the most adequate dose for every single combination of the selected variables in every cultivation system. The experimental fields were set in commercial farms in the Cordoba province, and every application was performed with a commercial airblast sprayer (Eolojet 2200, Osuna-Sevillano S.L., Jauja, Spain). The first step was to establish the basic spray volume to be sprayed according to the cultivation system. This is known for intensive trees (0.12 $L \cdot m^{-3}$), but some of our previous trials indicated that it could be reduced in traditional orchards, so values of 0.12, 0.11 and 0.10 $L \cdot m^{-3}$ were tested in a field test replicating the one reported in Miranda-Fuentes et al. (2016) for the intensive systems. Afterwards, several trials were conducted to determine the combined effect of tree size and leaf density on the spray deposit distribution. Thus, packs of 30 trees were selected in different orchards of the two cultivation systems to develop models to be integrated in the app.

The main independent variables considered were: the cultivation system (CS), the tree crown volume (CV) and the leaf density (LD). The dependent variables were the mean deposition (d), the mean leaf coverage (SC), the deposition homogeneity (DH) and the spray penetration (SP). The trees were sprayed with food dye E─102 (Tartrazine) and the spray deposition was sampled with filter paper and WSP.

RESULTS AND DISCUSSION

The database of canopy characteristics included a total of more than 400 trees (340 TV data and 60 LD data), whilst the nozzle database included 473 nozzles belonging to different manufacturers. The field trials gave as result an optimal specific spray volume of 0.11 $L{\cdot}m^{-3}$, which gave the highest mean deposition with a top mean coverage. The d was significantly influenced by the CV ($p<0.05$) but it was not significantly affected by the LD, so the final model did not include this factor in this CS. In the case of the traditional trees there is a significant influence of both factors, with 3 different volumes for 3 LD levels.

The final developments include the aforementioned dosing app for iOS and Android and a sensor kit that enables the sprayer monitoring and the auto-regulation of the operating pressure. Both instruments can communicate with each other to make absolutely automatic the application process. At this moment, the developments are finished and they are involved in an exhaustive testing process. It is expected that they will be released by the end of the year.

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Pneumatic nozzle droplets assessment: the effect of operative parameters

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INTRODUCTION

Pneumatic spraying is known to produce very fine droplets, usually below 100 µm in diameter which are very drift-prone. In pneumatic spraying, the most important parameters affecting droplet size are the liquid flow rate –LFR- and the fan air speed –AS- (Balsari et al., 2019). Under practical conditions there are two options to increase the dimension of the generated droplets. The first one is to reduce the AS and the second option is to increase the LFR. The objective of this work was to evaluate the changes produced in the droplet size spectra, homogeneity and driftability by varying the LFR and AS in two types of spouts usually mounted on the multiple-row pneumatic sprayer.

MATERIALS AND METHODS

An *ad hoc* developed test bench able to simulate the operating conditions of a real pneumatic sprayer was used (Miranda-Fuentes et al., 2018). The droplet size was measured with a laser-based instrument (SprayTec ®, Malvern Instruments Ltd, Worcestershire, UK) equipped with a 300 mm lens. A cannon-type and a hand-type spout, respectively mounted on the top and at the bottom of a spray head TC.2M2C of the multiple-row Cima pneumatic sprayer (Cima S.p.a., Pavia, Italy) were used. For each type of spout two configurations, derived from the combination of two liquid flow rates –LFR- and two air speeds –AS- at the spout outlet (Tab. 1) were tested. The studied variables were D50 (VMD), D10 and D90, as a measurement of the droplet size. The Relative Span Factor (RSF) was then calculated as a measurement of the droplet size homogeneity. The volume fraction smaller than 100 µm (V_{100}) was also calculated, and used as a spray drift indicator. The results were analysed with a T-test (α=0.05).

RESULTS AND DISCUSSION

The T-test showed a clear difference between the configurations tested, both in cannon-type and hand-type spouts, derived from the combination of low LFR combined with max AS –C1- and max LFR combined with min AS –C2- for all the parameters measured D50, D10, D90, RSF and V100 ($p < 0.001$) (Fig. 1). In particular, the configuration C2 is able to double the D50 value and halve the V100 indicator irrespective of spout type, showing to be less-drift prone than the C1 configuration. In general, the droplet homogeneity (RSF) showed to be higher for the hand-type spout. The cumulative sprayed volume curves, obtained in both types of spouts compared with ASABE nozzles classifications (ASABE S572.1, 2009) showed that an appropriate selection of pneumatic sprayer operational parameters, namely LFR and AS, allows to move from a very fine (VF) to a fine (F) spray quality (Fig. 2). Despite the possibility to increase VMD by two times acting on LFR and AS, and therefore to reduce driftability, the spray quality only changed from VF to F.

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Table 1. Parameters of configurations examined (drift prone & drift low-prone) using cannon-type and hand type spouts.

Config. ID	Config. type	Spout type	Spray pressure (Mpa)	Tot. Flow rate (L min^{-1})	Air speed (m s^{-1})
C1	Dift prone	Cannon	0.1	1.00	97.6
C2	Low-drift prone	Cannon	0.1	2.67	72.8
C1	Dift prone	Hand	0.1	0.84	84.2
C2	Low-drift prone	Hand	0.1	2.07	57.9

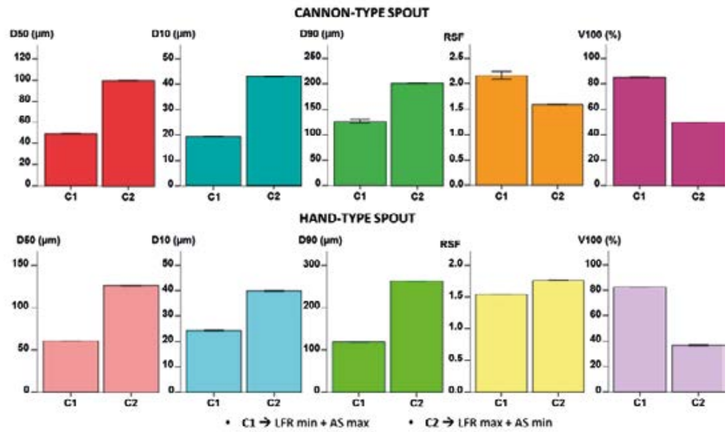

Fig. 1. Droplet size parameters D50, D10, D90, RSF and V_{100}, measured for different combinations of LFR and AS in cannon-type and hand-type spouts.

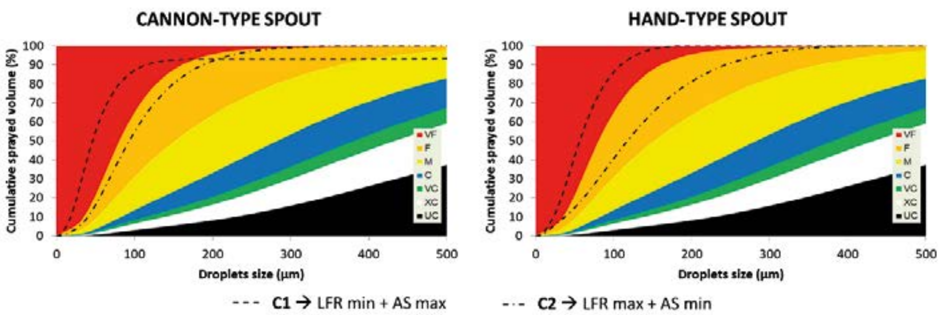

Fig. 2. Cumulative sprayed volume curves (%) as a function of droplet size (µm) measured in cannon-type and hand-type spouts. The curves are shown for the different combination of LFR and AS.

Automatic profiling precision orchard spray technique based on variable chemical flow rate and air volume with LiDAR

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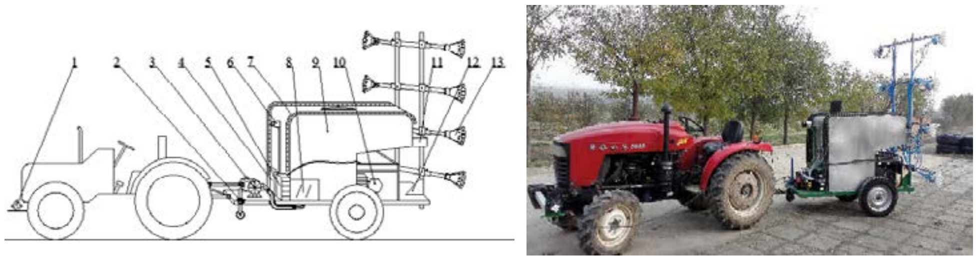
INTRODUCTION

As a powerful and effective plant-protection approach to achieve high yield and better quality produce, pesticide spraying is widely adopted in nurseries and orchards (He et al., 2003; Qiu et al., 2015). Tree shapes, sizes and canopy density vary greatly in different growth periods and different locations. This variability requires adjusting flow and blow rate to match trees with different shapes, heights, canopy volume and density, from location to location. Flow rate and air volume were changed in real-time according to the canopy parameters of fruit tree acquired by laser scanning sensor. Big air flow and flow rate for big and dense tree, on the contrary small air flow and flow rate for small and sparse tree, no-spraying in the gap between trees were realized. The technique improves the uniformity of the deposit and reduces drift. VARS spray deposition is 1.26 fold greater compared to CABS and 1.12 fold greater than DAJS. Off-target loss on the ground in the 3 neighbouring rows is 2.5 μL/cm^2 with VARS, 6.8μL/cm^2 with DAJS and 8.6μL/cm^2 with CABS.

MATERIALS AND METHODS

Prototype: The structure of the prototype is shown in Fig. 1. The sprayer was traction type, which forms a complete set of 22kW-power tractor. For the convenience of realizing the function of automatic control, the system power was provided by a gasoline generator. The main working parameters of prototype sprayer are shown in Table 1.



a. Schematic view   b. Photograph of prototype

1.Speed sensor 2.Screw return roller 3.Hydraulic pump 4.Transformer 5.Microprogrammed control unit 6.LIDAR 7.Cable drag chain 8.Drive system 9.Sprayer tank 10.Electric generator 11.Solenoid valve1s 12.Boom frame 13.Five-finger atomizer

Fig.1. Overall structure of automatic variable rate orchard sprayer based on laser scanner

Table 1 Main working parameters of prototype sprayer

Parameter	Value
Size（Length×Width×Height）/mm	2200×1200×3400
Generator power/kW, Sprayer driving speed (km/h)	8, 3.6
Pump flow rate/(L·min^{-1}), Tank volume /L	107.9, 1000
Number of brushless fan, Fan flow rate/（m^3·s^{-1}）,	8, 0～2.96
Nozzle type, Nozzle number（one side）	HVV-L-8004 flat fan nozzle, 20
Rated spray pressure/MPa , Spray flow rate/（L·min^{-1}）	0.3, 0～48.32
Air velocity of fan outlet (m/s)	0～50 adjustable

Working principle: The prototype was installed with a LiDAR scanning sensor with a 270° working angle, to detect canopies on both sides of a row. When the sprayer was working, the laser scanner scanned the target and transfer the data to PC, PC calculated the air flow and flow rate based on algorithm and the speed information collected by MCU from speed sensor. Then the results were sent to the signal-chip microcomputer control module to transform into PWM signal. Electromagnetic valve actuations (40 ways) and brushless motor drivers (8 ways) adjusted duty cycle individually after receiving signals.

Air volume and flow rate: To achieve the uniform spraying and variable air volume control, the five-finger atomizer was designed. The atomizer consists of shell, brushless fan, nozzle and liquid inlet piping system, Brushless fan connects atomizer shell through duct and the diameter of back-end cylinder is 75mm, each outlet finger is 30mm.

Each nozzle was connected with one solenoid valve. The output of the prototype's 40 nozzles were adjusted individually based on the solenoid valves' PWM signals. The relationship between nozzle flow rate and duty cycle is shown in the following equation (25 Hz, 0.3 MPa): Q=1.25x-0.042, Q is the flow rate per nozzle, L/min; x is the solenoid valve's duty cycle, %. Brushless DC fan was selected as airflow actuator to partly achieve variable air volume function, while the control system regulated rotation speed by changing the fan's PWM duty cycle. The fan impeller's diameter is 85 mm, while its maximum rotating speed is 28 000 rpm. The fan's duty cycle is converted into outlet air velocity based on the following equation according to regression analysis results: V=15.625ln(r)+53.426 (R^2=0.9891), V is outlet air velocity, m/s; r is fan's duty cycle, %.

Field test: With 3.6 km/h working speed in the apple orchard, two classical orchard sprayers with a central big fan were considered for this paper. The first type was a conventional air blast sprayer (CABS: 4 Lechler ST11003 nozzles from one side, 0.3KPa spray pressure, 3.6 km/h working forward speed, 25000m^3/h fan flow rate with 22m/s air velocity of fan outlet), the second reference equipment was a directed air-jet sprayer (DAJS: 5 Lechler ST11004 nozzles from one side, 0.3KPa spray pressure, 3.6 km/h working forward speed, 5500m^3/h fan flow rate with 25m/s air velocity of fan outlet) equipped with a centrifugal fan and 4 individual air spouts on each side, connected to the air outlet by flexible ducts. The tree row was 5×2m and the average height was 4.1m. Tests concludes chemical consuming, deposit on the canopy, penetration, Loss to the air and loss to ground.

RESULTS AND DISCUSSION

The test showed that on average, 46% less spraying solution was applied compared to conventional applications, while penetration rate was similar to DAJS. Normalized deposition in the canopy with variable application was higher than that of conventional applications, indicating that electronic sprayers are more efficient than conventional sprayers. It was also observed that VARS could significantly reduce off-target loss.

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Solid Set Canopy System in France: the PULVEFIX project

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INTRODUCTION

Apple is the first fruit production in France and plays a major role in the economy of the fruit market. Apple trees are sprayed 36 times per year on average to control different pests and diseases and to guarantee a good fruit quality. Even if the main aim of the experimental stations is to decrease the use of pesticides in agriculture, spraying is still the final step of most of the new plant products. Moreover growers are often confronted with problems with neighbours because of the noise of the spraying device and environmental problems because of the drift generated by airblast sprayers. Upon this knowledge, a reflexion to build a new Solid Set Canopy System has started. It is based on the first prototype of the Ctifl and La Morinière and well inspired by the US investigations in Michigan. Using this technique, the aim is to spray very quickly and thus avoid useless preventive sprays, to save on fuel and workforce, to decrease noise pollution, to ensure better safety of workers and to reduce airborne drift.

MATERIALS AND METHODS

The first step was to study the already existing prototypes and analyse their drawbacks and advantages in order to build our new Solid Set Canopy System (SSCS). Then the optimized prototype has been implemented at 3 experimental sites in 3 apple growing regions in France. In the last year this system will be set up in one commercial orchard or more. The second step is to spray all year long (fungicides and insecticides) using this prototype and study its efficacy on pest and diseases compared to a reference plot sprayed with an airblast sprayer. For this, shoots and fruits are being assessed on the variety Pink Lady® every month in the untreated plot, the reference and the SSCS and fruits kept in cold storage after harvest. The yield and the residues at harvest are also recorded. The third step is to evaluate the spraying quality of the SSCS compared to a reference airblast sprayer. For this, we clip plastic collectors onto the leaves and a spray mix solution of food dye is sprayed on the trees. The airblast sprayer is used at 400 L/ha, 540 PTO and a mix of ATR nozzles. The volume of the SSCS depends on the location and varies between 570 and 690 L/ha. After a run of spectrophotometry analyses we can map the quantity of the deposits according to the area of the trees. The prototype that has been selected uses pipes and reservoirs that are attached to the structure of the orchard (at the top of the hailnet posts). A pump is used to fill these reservoirs with the spray mix. Once the hydraulic pipes and reservoirs are full, pressurized air is sent through the system to push the water out through the sprayers. The sprayers are provided on every tree at the top of the canopy.

RESULTS AND DISCUSSION`

Until now the biological efficacy on apple scab is quite good on shoots: 58% of scabbed shoots in the reference and 62% in the SSCS on average at the 3 locations and at the end of the first season 2018. On the fruits, 9% of the fruits had scab lesions in the reference and 18% in the SSCS on average at the 3 locations at harvest. We had very poor control of powdery mildew that tends to develop under the leaves and the efficacy on *Dysaphis plantaginea* is less with SSCS. Indeed, looking at the spraying quality, most of the treatment is localized on the upper surface of the leaves and at the top of the canopy (more than 60% of the treatment). The airborne drift is almost zero but the deposits on the floor of the orchard are greater than the reference.

There are no differences in the chemical residues on the fruits at harvest whatever the height in the canopy, and these residues stay beyond the legal threshold.

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SOLID SET CANOPY DELIVERY SYSTEM for modified vertical shoot position trained vineyards

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INTRODUCTION

A solid set canopy delivery system (SSCDS), a variant of fixed spray system, offers several advantages over a conventional airblast sprayer in terms of applying chemicals in perennial specialty crops (Grieshop et al., 2018). To translate the SSCDS technology to the Washington State, our team has been optimizing configurations for a modified vertical shoot position (VSP) vineyards (Ranjan et al., 2019; Sinha et al., 2019) and high-density apple orchards. We have tested 91 m systems with focus on the identification of the emitter types and within canopy placement for optimal spray deposition and coverage. This article shares pertinent results and associated comparison with airblast sprayer applications in vineyards.

MATERIALS AND METHODS

Two configurations (91 m set length), SSCDS 1-tier and SSCDS 2-tier (Fig. 1a, b), were installed in the modified VSP vineyard near Prosser, WA, USA. It has 2.4 m row and 1.7 m vine spacing. SSCDS 1-tier had a pair of microemitters (N1, Table 1) at 76 cm above the cordon. SSCDS 2-tier had two hollow cone nozzles (N2, Table 1) in combination with emitters as in SSCDS 1-tier. Respective systems were operated for 12 s and 8 s at 310 kPa to achieve 468 l ha^{-1} application rate. Airblast sprayer had 12 hollow cone nozzles (N3, Table 1) on either side. Sprayer was operated at 1 ms^{-1} forward speed with only 4 active nozzles on either side to achieve 468 l ha^{-1}. Grapevines were sprayed with a fluorescent tracer (Pyranine 10G, Keystone Inc., Chicago, IL, USA) at 500 ppm in water. Six grapevines were selected from each treatment to quantify spray deposition at either (adaxial and abaxial) side of leaf surfaces and two (top and bottom) canopy zones. The mylar cards were used as samplers. Also, quantified was the ground (samplers at 0.9 m, 2.7 m and 4.5 m downwind) and aerial drift (samplers on drift pole at 1.8 m and 3.6 m downwind). Fluorometry analysis, details are in Sinha et al. (2019), was done in the laboratory to quantify deposition.

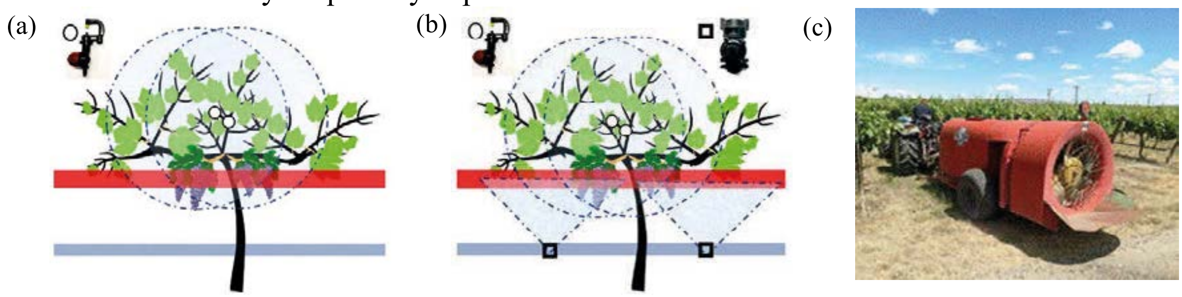

Fig. 1. SSCDS a) 1-tier and b) 2-tier configurations, and c) an airblast sprayer system.

RESULTS AND DISCUSSION

The SSCDS 1-tier provided statistically similar deposition in different canopy zones compared to the airblast sprayer. The SSCDS 2-tier had highest deposition in the bottom canopy zone; however, it resulted in significantly lower spray deposition in the top canopy zones when compared to other two spray systems (Fig. 2a). Also, three systems provided statistically similar deposition on adaxial and abaxial leaf surfaces (Fig. 2b). However, the uniformity of spray distribution, calculated through coefficient of variation (CV, %) was better in airblast sprayer compared to SSCDS configurations. The airblast sprayer also resulted in significantly higher, at 5% level, ground and aerial drift compared to SSCDS (Table 2). The airblast air-assist, absent in SSCDS, could have aided in the transport of the spray particles to off-target locations. Overall, optimized SSCDS may be viable technique for vineyard spraying as it has comparable within canopy deposition to airblast sprayer and reduced off-target drift.

Table 1. Specifications of emitters used in the study (source: manufacturer datasheets).

Emitter	Type	Model	Manufacturer	Flow rate @ 310 kPa (lpm)*	Size (°)
N1	Full-circle	Full-circle	Jain® Irrigation Inc.	0.7	NA
N2	Hollow cone	D2/DC13	TeeJet® Technologies	0.3	80
N3	Hollow cone	TX-VK12	TeeJet® Technologies	0.8	80

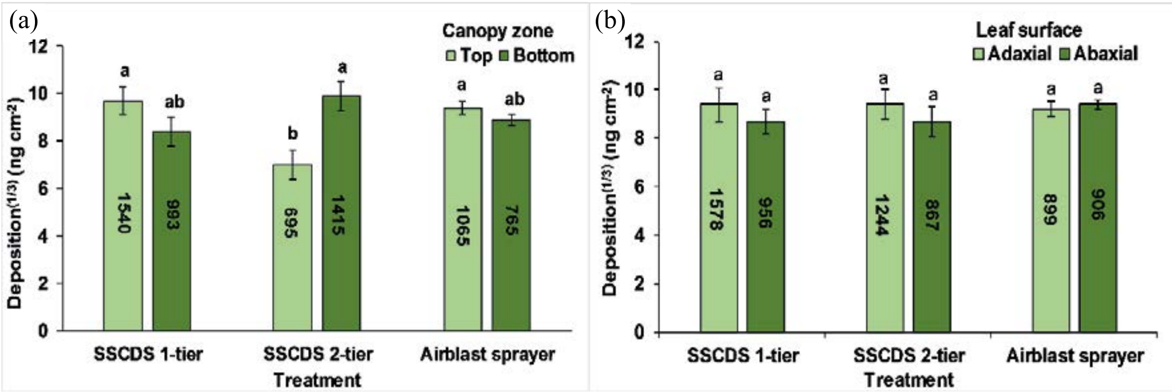

Fig. 2. Spray deposition (transformed data) at a) different canopy zones and b) leaf surfaces in grapevines (Error bars show std. error of mean; significantly different means are shown with different letters; non-transformed means are shown in individual bar graphs).

Table 2. Mean off-target spray drift at different downwind distances from the spray row†.

Sprayer system	Off-target spray drift, ng cm^{-2}				
	Ground			Aerial	
	Downwind distance, m			Downwind distance, m	
	0.9	2.7	4.5	1.8	3.6
SSCDS 1-tier	11^{c}	1^{cd}	1^{d}	0.2^{C}	0.1^{C}
SSCDS 2-tier	12^{c}	0.3^{d}	0.4^{d}	0.3^{C}	0.2^{C}
Airblast sprayer	129^{a}	59^{ab}	59^{b}	272^{A}	79^{B}

†Shown is the non-transformed data whereas statistical analysis was performed on the cube-root transformed data; different lowercase and uppercase letters represent significant differences at 5% significance level.

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Off-target deposition of a Solid Set Canopy Delivery System in high density apples

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INTRODUCTION

Apple orchards have been transforming from low density, freestanding tree systems comprised of tall spheres to high-density, trellised tree systems comprised of continuous narrow "fruiting walls" (Robinson, 2007). Narrower row spacing in this cropping system have reduced the productive capacity of tractor-pulled airblast sprayers designed for large, broad canopies and increased the risk of crop damage from contact of the crop by the tractor and sprayer. Ongoing Solid Set Canopy Delivery Systems (SSCDS) research has demonstrated that this technology is capable of at least matching the pest management performance of a typical radial air blast sprayer (Agnello and Landers, 2006, Owen-Smith, 2017; Owen Smith et al., 2019). The objective of this two-year study was to identify and quantify the non-target losses of SSCDS and radial airblast sprayers in a high density apple orchard. To this end, in-orchard spray losses to ground, immediate downwind vertical flux, and classical downwind spray drift sedimentation were measured.

MATERIALS AND METHODS

Study Site Description: Our study was conducted in the summer months of 2017 and 2018 in a mature high-density, single-trellised four-row block of HoneyCrisp apple trees located at the MSU Clarksville Research Center (MSU AGBioResearch, Clarksville, MI USA). The area immediately downwind of the orchard was an open level field of mowed soybeans or corn, in 2017 and 2018, respectively. This site was selected in concordance with the ISO 22866 or ASABE S561.1 standard.

***Experimental Design*:** In 2017, two treatments were investigated in a 4-row orchard block: 1) A "control spray" applied with a Rears PB533N radial airblast sprayer equipped T-Jet hollow cone nozzles with DC23 whirlplates D4 discs and operated at 180 psi (0.69 bar) calibrated to 70 gallons/acre (650 L/Ha) with 10 nozzles on at an operating speed of 3.8 Miles per hour (6.1 km/h) we turned 3 nozzles off to best target this particular canopy, resulting in a net application rate of 49 gallons per acre (460 L/Ha). The sprayer was operated at 0.69 bar using and 2) a prior tested SSCDS design (Owen-Smith 2019) utilizing Jain Irrigation Modular Group 7000 series micro-sprinklers with violet nozzles and yellow flat spreaders and 32 psi stop drip device (NanJain Irrigation, Fresno, CA). The experiment was repeated in 2018 with the addition of an SSCDS system utilizing Jain GreenSpin rotary atomizer type nozzles. Spray volume for SSCDS treatments was maintained at 70 gallons/acre (650 L/Ha) and spray solutions consisted of water and a 0.1% volume/volume non-ionic surfactant and 0.1% mass/volume Pyranine dye. Wind speed and GPS rectified wind direction, Relative Humidity, and Temperature were monitored for each trial and treatments were replicated 3-4 times in each study year.

Measurements Taken: In-orchard losses to ground were quantitatively measured, along with downwind sedimentation typical to drift studies. Horizontal Downwind Drift Sedimentation was measured quantitatively using 3 parallel rows of 102 mm square Mylar targets spaced 0,1, 2, 4, 8, 16, 32 and 64 m downwind of the orchard, as described in ISO standard 22866 and ASABE S561.1. Vertical flux was measured using 3, 8m tall drift poles at the downwind edge of the orchard using 1.8 mm braided polypropylene string that was exposed to the duration of each replication's spray application. String was separated into 1 meter segments harvested in individual bags for quantitative analysis. Ground deposition was collected using 15 cm Petri dishes placed in 4 rows perpendicular to the 3rd easternmost sprayed row of the 4. They were placed in the same location for all replications and treatments, at 0 meters, +/- 50 cm (drip edge of tree) then +/- 1.3 and +/- 1.8 meters (the drive middle center). Fluorometry was done using a Plate Fluorimeter (BioTek Synergy HT Winooski, VT).

RESULTS AND DISCUSSION

Vertical Mass Flux measurement: In 2017, mean SSCDS and airblast Vertical Flux at 1 m to 8 m ranged from 4.0% to 0.7% and 20.21% to 3.66% , respectively. In 2018 mean SSCDS Hadar, SSCDS Greenspin and airblast Vertical Flux at 1m to 8m ranged from 7.58%-0.34%, 11.07%-0.21%, and 49.34%-3.86%, respectively. These data suggest that somewhere between 5 and 10 times more of the material delivered by the airblast sprayer compared with either SSCDS configuration was released and lost above the tree canopy.

Downwind Deposition: In 2017, mean SSCDS and airblast downwind deposition at 0 m to 64 m ranged from 9.03% to 0.29%, 14.23% to 0.61%, respectively with a total collection at distances beyond 4 m 1.94% and 17.05%, respectively. In 2018, mean SSCDS Hadar, SSCDS GreenSpin and airblast downwind deposition at 0 m to 64 m ranged from 20.16% to 0.06%, 45.26% to 0.01%, and 54.85% to 0.42% respectively with a total collection at distances beyond 4 m of 2.02%, 0.74%, and 39.1%, respectively. Thus, SSCDS configurations generate considerably less horizontal drift then the airblast sprayer.

Ground Deposition: In 2017, overall mean ground deposition was 6.13% and 14.81% for the SSCDS and Airblast treatments respectively. In 2018 overall mean ground deposition for SSCDS Hadar, SSCDS GreenSpin and airblast were 38.54%, 70.35%, and 22.74%, respectively. These results suggest that the Hadar nozzles provide comparable or lower losses to ground compared to the airblast sprayer but GreenSpin nozzles loose an appreciable portion of spray to ground loss.

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Direct and indirect methods for spray drift assessment in apple orchards

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INTRODUCTION

The spray drift assessment in field conditions is a complex and laborious task (ISO 22866:2005). Because of this, the indirect drift assessment methods like Phase Doppler Particle Analyser (PDPA) (ISO 25358:2018) and wind tunnel (ISO 22856:2008) have taken a relevant role (Torrent et al., 2019). However, most of these studies have been carried out with flat-fan nozzles (Nuyttens et al., 2010). Moreover, an interesting methodology to consider is the LiDAR technique (Gregorio et al., 2019), which allows a real-time monitoring of spray drift, providing range-resolved measurements, and requires reduced time and labour consumption. This work compares the spray drift potential reduction (DPR) values determined from three indirect methods (PDPA, wind tunnel and LiDAR technique) and one direct method (field measurements) for two different types, standard and drift reduction hollow-cone nozzles.

MATERIALS AND METHODS

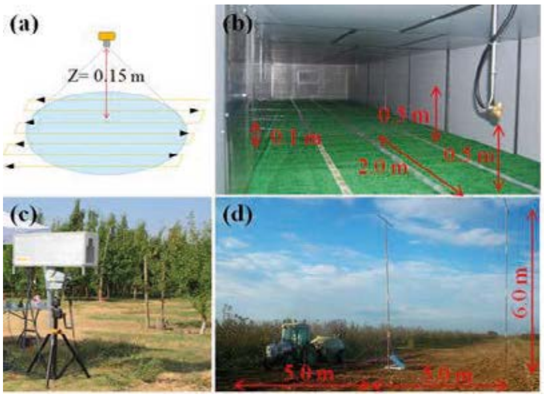
The hollow-cone nozzles tested were: Albuz ATR 80 Grey (standard nozzle, STN) and Albuz TVI 8003 Blue (drift reduction nozzle, DRN) at 1 MPa, with flow rates of 2.08 $l \cdot min^{-1}$ and 2.19 $l \cdot min^{-1}$, respectively. A comparison between the following drift assessment methodologies was carried out (Fig. 1):

- PDPA (Dantec Dynamics A/S. Skovlunde, DK). The following droplet size parameters were determined: Dv_{50}, V_{100} and V_{200}.
- Wind tunnel (ISO22856:2008). The sedimenting (WT_H) and the airborne deposition (WT_V) were measured.
- *Ad hoc* LiDAR system. Drift potential tests were carried out using an airblast sprayer (Teyme Eolo Star 2090). The LiDAR was at 50 m from the sprayer, which remained in a static position. The LiDAR signal (S_{lidar}) was measured.
- Field tests according to the ISO 22866:2005. The tests were conducted in an intensive apple orchard, using the same airblast sprayer applying 810 and 860 $l \cdot ha^{-1}$ for the STN and DRN, respectively. Sedimenting deposition (F_H), airborne deposition at 5 m and 10 m ($F_{V\text{-}10M}$ and $F_{V\text{-}5M}$, respectively) from the last tree row, were determined.

DPR for each methodology was calculated according to:

$$DPR = \left(1 - (DP_D / DP_S)\right) \cdot 100 \qquad (1)$$

where: DP_D is the drift potential of the DRN (%) and DP_S is the drift potential of the STN (%).



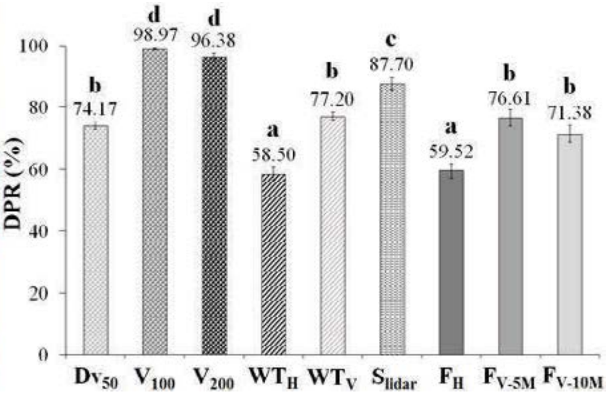


Fig. 1. Drift assessment methodologies compared in this study: (a) PDPA; (b) ISO wind tunnel; (c) Ad hoc LiDAR system; (d) ISO field tests.

Fig. 2. DPR values (mean±SE) based on different parameters when comparing DRN and STN nozzles. Different letters indicate statistically significant differences (Tukey's HSD test, $p<0.05$).

RESULTS AND DISCUSSION

Fig. 2 shows the DPR determined with each methodology, presenting values higher than 50% in all cases. It is observed that the DPR values with the ISO wind tunnel present no significant differences to those obtained in field measurements, for both airborne (WT_V, $F_{V\text{-}10M}$ and $F_{V\text{-}5M}$,) and sedimenting (WT_H and F_H) depositions, while the PDPA (V_{100} and V_{200}) tended to overestimate the drift reduction. DPR based on LiDAR (S_{lidar}) took intermediate values between the PDPA and the field. These results suggest that the LiDAR and the ISO tunnel are promising methodologies for the assessment of spray drift generated by hollow-cone nozzles, although it is necessary to extend this methodological comparison to a wider range of nozzle types and sizes.

ACKNOWLEDGEMENTS

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What are the best sprayer settings to avoid spray drift from apple orchards?

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INTRODUCTION

France the application of chemical plant protection products (PPP) in fruit growing is of increasing concern. With more than 36 spray treatments per year and a strict regulation in order to protect the environment and especially for the preservation of water quality, drift reduction is a major concern. To spray tall fruit tree crops a fan is needed to spray the top of the canopy in an adequate way, however, this often results in spray drift. The aim of this research was to evaluate airdrift losses and to quantify the deposition and the distribution of different sprayers in order to better understand the influence of sprayer settings on spraying quality.

MATERIALS AND METHODS

Four rows were used for each modality; i.e. a combination of one sprayer and its settings.

We sampled the middle row in order to collect both the spray deposits from the right side of the sprayer and from the left side of the sprayer. On the middle row, 4 trees were selected, each one being at least 10 meters away from the next one. The deposition on these trees is the total of what is sprayed directly on the trees and what is over sprayed from the other rows.

The canopy of the observation trees was divided in 7 sections: top, middle east/centre/west and bottom east/centre/west. In each section, 10 plastic collectors were clipped on 5 leaves: one on the upper side of the leaf and one on the lower side of the leaf. In addition, 10 plastic collectors were placed on the ground on each side of the sampled trees. A solution of Tartrazine (5g/L) was prepared for all treatments. The plastic collectors are collected once the droplets had dried. All the collectors from one area of one side of a leaf were placed in the same plastic jar. All the jars are well labelled with the number of the tree (replicate one to 4), the side of the sprayer (right, centre or left), the position in the canopy (top, middle or bottom) and the treatment. The day after, 20 mL is poured in each pot to wash the collectors.

Knowing the LWA of our trees and the area of the collectors we then have a quantity of Tartazine per cm^2 of leaf area for each treatment and each section of the tree or the ground.

RESULTS AND DISCUSSION

Five different types of sprayers were tested: (i) a radial atomizer with a simple fan (reference sprayer), (ii) an atomizer with double fan, (iii) an atomizer with simple fan and tower (partly tangential), (iv) an atomizer with a double fan and a tower (partly tangential) and (v) a tangential pneumatic sprayer. The modalities we studied are: type of nozzles, fan speed, PTO speed, forward speed, flow rate, and alternate row spraying.

Results showed that it is possible to spray with a low fan speed and reduced PTO speed (up to 430 rpm) whatever the time of the year (first stage of leaf development until full leaf development). Under 370 rpm PTO speed and with the fan in first gear, reduced amounts of deposition in the trees were observed. No differences were observed between anti-drift nozzles and normal nozzles whatever the atomizer (simple/double fan and with or without tour) and the position of the nozzles (only at the top or over the entire height of the sprayer). Spraying every two rows resulted in reduced amount of dye on the "unsprayed" side of the canopy, even at the early stages of leaf development. Spraying quality and distribution was very good even at low spray volumes such as 200 L/ha and increasing forward speed also increased the deposition in the trees but only until June (middle stage of canopy development).

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Reduction of spray drift by hail net over apple orchard

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INTRODUCTION

Despite technological progress and innovative legal solutions of the last decade spray drift generated during applications of plant protection products in fruit growing remains a serious challenge of environmental, economic and social nature. Among the spray drift mitigation measures, apart from the direct ones, reducing the drift at source (e.g. liquid atomisation methods and spray application techniques) there are also indirect measures, such as windbreaks or hail nets, which capture the drifting spray particles. The latter ones are nowadays used increasingly by fruit growers to protect their crops not only from hail but also from sunburn, wind, birds, insects and other pests (Caruso at al., 2015).

The reported drift reduction potential of hail nets amounts to 50% (Herbst et al., 2012) or 65% (Schweizer et al, 2013), and in combination with other direct drift reduction measures to 75% (Herbst et al., 2012), or even more than 90% (Triloff and Knoll, 2014). In Germany a hail net installed over the orchard sprayed with properly adjusted sprayer is a classified spray drift reduction technology (SDRT) registered in drift reduction class 50%, and for applications with a number of defined drift reducing nozzles operated at 4-5 bar in class 75% (JKI, 2019). Hail nets are also considered drift mitigation measures (50% drift reduction) in the web-based applications such as Drift Evaluation Tool (ECPA-TOPPS PROWADIS - http://www.topps-drift.org/) (Doruchowski et al. 2013) and Drift Mitigation Measures (ICPS-ASST - https://www.icps.it/test/Mitigation2.asp) that support growers' decisions on pesticide application methods in fruit growing,.

The sources referred to do not report on how the drift reduction potential of hail nets is affected by growth stage of the sprayed crop or mesh size and installation layout of the net. However, these factors may affect spray drift reduction by hail nets. The objective of this study was to determine the drift reduction potential of hail nets as they are set up in Poland in different growth stages of apples.

MATERIALS AND METHODS

Over the apple orchard cv. Gala/M9, with slim, dwarf trees 3 m tall and spaced 3.5 x 1.0 m, the hail net was installed with the edge stretching next to the last row, at the height 1 m above ground. The HDPE net was of leno (cross) weave type with rectangular mesh 3.4 x 8.8 mm, being greater than mesh used in southern regions of Europe. The orchard was sprayed with a conventional orchard sprayer fitted with standard hollow cone nozzles TR 80-01 producing fine spray. The spray liquid being 0.25% solution of fluorescent tracer BF7G was applied on five outer rows of orchard at volume rate 200 l ha^{-1} and at the sprayer driving speed 6 km h^{-1}. A ground deposition of sedimentation drift was collected on Petri dishes located next to the orchard, in 10 lines 1,0 m apart, oriented perpendicularly to the rows of trees. In each line the samplers were placed at 7 distances from the edge of the hail net: 1 - 3 - 5 - 10 - 15 - 20 - 25 m. During the trial drift was measured in the presence (NET ON) and in the absence (NET OFF) of the hail net. For each situation measurements were repeated 3 times. The trials were made in 2017 and 2018 at three growth stages: pre-blossom (April), post-blossom (May) and at full-leaf stage (July-August).

RESULTS

The results of spray drift reduction potential due to hail net installed over the orchard in different growth stages relative to wind speed measured during the trials are presented in table 1. The values of drift reduction in each case were calculated based on the relationship between drift data in NET ON and NET OFF situations on the day of trial, so the latter one was always considered a reference. The results show clear influence of growth stage on drift reduction potential. The lack of data consistency between the seasons of 2017 and 2018 was most likely due to big differences in wind speed during the trials, even though they were carried out in the best existing conditions for each growth stage. The low wind evidently promoted drift reduction which likely influenced the spray drift catch efficiency of the net depending on the velocity of spray particles.

Table 1. Spray drift reduction for hail net, obtained in different apple growth stages.

Growth stage	2017		2018	
	Wind speed $m\ s^{-1}$	Drift reduction %	Wind speed $m\ s^{-1}$	Drift reduction %
Pre-blossom	5.2	7.5	2.0	26.0
Post-blossom	2.2	10.1	1.5	46.1
Full-leaf	0.8	74.2	2.0	59.3

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Spray drift of a two-row tunnel orchard sprayer

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INTRODUCTION

Earlier spray drift experiments showed that orchard tunnel sprayers equipped with standard nozzles achieved a spray drift reduction of 85% (Huijsmans et al., 1993). Spraying and blowing from both sides at the same time towards the tree canopy captures higher levels of spray in canopy and by shielding the spray process with a tunnel less spray can blow away. It is therefore expected that also the Lochmann two-row tunnel orchard sprayer may achieve high levels of spray drift reduction. To assess and underpin this expectation WUR performed spray drift field experiments spraying an apple orchard in the full leaf stage comparing the two-row tunnel sprayer equipped with 90% drift reducing nozzles (DRN90; Zande et al., 2008) against a reference cross-flow fan sprayer equipped with Very Fine spray quality nozzles.

MATERIALS AND METHODS

Spray drift experiments were setup to fulfil the requirements of and to provide proper data for the authorisation procedure of Plant Protection Products (Ctgb), the Environmental Decree (TCT protocol) in the Netherlands and international protocols on spray drift measurements and its classification (ISO22866, ISO22369). In the spray drift field experiments a comparison was made between the Lochmann two-row tunnel orchard sprayer (Van der Linden, Dreumel, Netherlands; Lochmann Plantatec, Nals Italy; tunnel -Lipco GmbH, Sasbach Germany) fitted with Albuz TVI8001 venturi hollow cone nozzles (7 bar spray pressure, DRN90) and a standard cross-flow fan orchard sprayer; Munckhof with Albuz ATR Lilac nozzles (7 bar spray pressure). Average tree height was 2.75 m. Highest operating nozzle was for both sprayers set at 2.5 m. Air setting of the reference sprayer was; high fan gear box at 540 rpm PTO, having an air outlet speed of 21 m/s. Air setting of the tangential fans of the tunnel sprayer was 1570 rpm producing on average an outlet air speed of 10 m/s.

During the spray drift experiments the downwind outside 24 m of an apple orchard (Elstar; tree row spacing 3.0 m; Proeftuin Randwijk, Netherlands) was sprayed at the full leaf stage (BBCH 90/92) using the fluorescent tracer Acid Yellow 250. Spray drift deposition was collected downwind on a mowed grass area up to 25 m distance from the last tree row. Filter collectors (Technofil TF-290) were used on ground surface of sizes 0.50x0.10 m in a continuous row from 3 m to 15 m and of 1.00x0.10 m at 1,5 m, 20 m and 25 m distance from the last tree row. Airborne spray drift was measured at 7.5 m distance from the last tree row on a pole at which two lines with collectors (Siral Abdriftkollektoren) were attached at 1 m spacing up to 10 m height. For ground deposition spray drift reduction was evaluated at 4.5-5.5 m from the last tree row, position of surface water in a standardised ditch in the authorisation procedure for fruit crops in the Netherlands (Zande et al., 2000).

RESULTS AND DISCUSSION

The spray drift experiments showed that spraying an apple orchard at the full leaf stage (BBCH 90/92) with a Lochmann two-row tunnel orchard sprayer fitted with 90% drift reducing nozzles (Albuz TVI8001; 7 bar spray pressure, DRN90) spray drift was clearly lower than of the reference sprayer (Fig. 1). Spray drift reduction at 4.5-5.5 m distance from the last tree row was 99.4% in comparison with the reference spray application. Based on these results this combination was classified as a spray Drift Reducing Technique (DRT) in the 99% drift reduction class in the Netherlands.

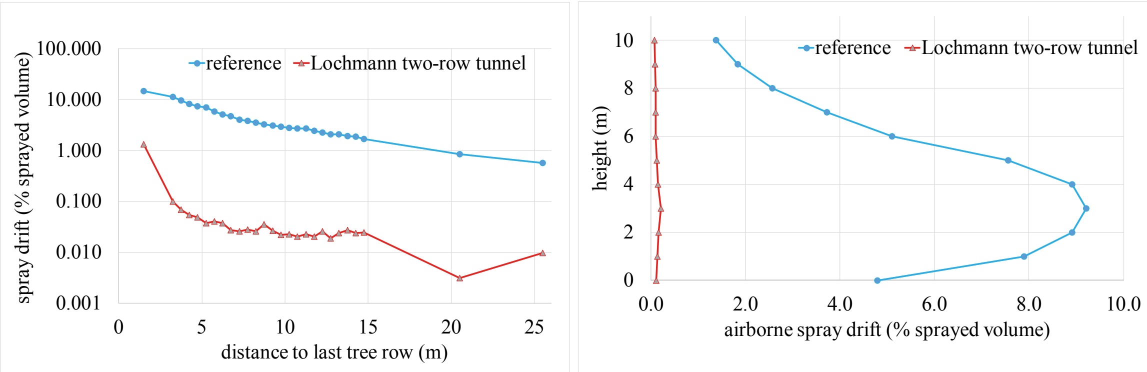

Fig. 1. Spray drift deposition (left) and airborne spray drift (right) at 7.5 m from last tree row (% sprayed volume) downwind of sprayed apple orchard in full-leaf situation (BBCH90-92) with a cross-flow fan sprayer (reference) and a Lochmann two-row tunnel sprayer equipped with 90% drift reducing nozzles.

Airborne spray drift at 7.5 m distance from the last tree row was for the Lochmann two-row tunnel orchard sprayer fitted with 90% drift reducing nozzles also much lower than of the reference spray system. Averaged over 10 m height airborne spray drift reduction of the Lochmann two-row tunnel orchard sprayer fitted with DRN90 nozzles was 97.8%.

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Practical implementation of drift-reducing nozzles in orchard spraying

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INTRODUCTION

Spray drift has a high ecological, economic and social cost. The use of drift-reducing nozzles will reduce spray drift significantly, while functioning as well as classic nozzles. This was demonstrated in an earlier research project (Ruysen et al., 2015), in which on the one hand the importance of the type of sprayer used was shown, and on the other hand the settings of the sprayer.

However, because of practical obstacles, the implementation of drift-reducing nozzles in practice was difficult after the research project ended in 2014. (At that time, drift-reducing nozzles were not mandatory). Fruit growers mentioned several reasons why they did not want to switch to drift-reducing nozzles, amongst others:

- Increased risk for clogging of drift-reducing nozzles;
- Reduced efficacy in terms of crop protection;
- The adjustment of the sprayer is not suited to work with drift-reducing nozzles;
- Drift-reducing nozzles result in more visible residue on the fruits;
- When using drift-reducing nozzles, it is difficult to see if the nozzles are working properly.

To eliminate these bottlenecks, we wanted to show the fruit growers during a demonstration project (January 2017 - June 2019) how drift-reducing nozzles can be used without disadvantages in order to reduce the impact on the environment.

MATERIALS AND METHODS

First, the current process of spraying from the growers' point of view had been analysed using a Failure Mode and Effects Analysis method (FMEA). Possible failure modes were mapped and ranked by severity of the end effect, the frequency of the occurrence of the failure cause and likelihood of a failure being detected. These rankings were merged into a risk priority number (RPN) for each failure mode. In this way, the highest risks were identified and improvement proposals to reduce these risks were generated. Improvement proposals were then re-evaluated and translated into recommendations for growers, with regard to modifications of the sprayer, as well as the procedure to apply these modifications. The recommendations will result in the highest degree of effectiveness and robustness of the sprayer. The proposed recommendations were applied on 10 pilot companies (fruit growers) during two years.

In order to advise growers which nozzle to use, we made a selection of nozzles according to practical criteria like pressure range, durability, risk of breakage and risk of clogging. The selected nozzles were subjected to further trials. Different nozzles were tested on different sprayers with regard to liquid distribution using a vertical patternator (developed by Aams Salvarani). We focused on an optimal nozzle position relative to the airstream. To achieve a higher degree of drift reduction, trials were carried out at lower spray pressures, while ensuring a good liquid distribution. In this way the limits of spray pressure were explored.

Furthermore, we looked into the problem of visible residue in a trial setup, in which the fruits were treated different times using different nozzles.

RESULTS AND DICUSSION

Practical recommendations for modification of the sprayer were developed and distributed among fruit growers using brochures. To avoid clogging it is recommended (i) to use a pressure filter of 80 to 100 mesh, (ii) to use long nozzle filters that are a bit coarser (40 mesh) and (iii) to avoid rotatable nozzle holders. A step-by-step plan was developed to remove historical pollutions present in the sprayer.

To get a good efficacy, we recommend calibrating the machine using a minimum of 300 litres water per hectare leaf wall area (LWA) and to use a pressure range as recommended by the nozzle manufacturer. Related to the pressure, deviations in the pressure gauge and loss of pressure into the pipes have to be taken into account. After calibration an adjustment of the sprayer with the vertical patternator is necessary.

By detailed tests with the vertical patternator, we are able to demonstrate the difference between hollow cone nozzles and flat fan nozzles. We demonstrated the spray pattern, vertical distribution, and stability of the pattern at different pressures. In summary, flat fan nozzles result mostly in a more even vertical distribution. Thanks to the design of this nozzle, it is easier to position the nozzle to reach the top of the trees.

With this knowledge the 10 pilot companies were able to run two seasons without clogging of the nozzles and with a good biological efficacy. Due to the benefits of the flat fan nozzles demonstrated during the project, farmers are now using more and more this type of nozzles for orchard sprayers. In the course of this project drift-reducing nozzles became mandatory, but growers now know how to deal with it.

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Influence of canopy vineyard target presence in sprayer drift potential assessment using a test bench device

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INTRODUCTION

Spray drift reduction measures are essential to avoid the risk of environmental contamination, which is directly related to the spray application technology. Therefore, a strong need has emerged for an objective method of spray drift evaluation of different pesticide application techniques and for the consequent sprayer's classification according to this parameter. This study aims at validating the proposed test bench method for the evaluation of potential spray drift generated by airblast sprayers (Grella et al., 2017), through the comparison of results obtained in trials conducted in absence and with the presence of the vineyard target canopy.

MATERIALS AND METHODS

An *ad hoc* test bench designed to measure the potential spray drift generated by bush and tree crop sprayers was used applying the methodology detailed by Grella et al. (2019). To validate the test bench method, the effect of the presence of the target crop on spray drift potential was assessed by comparing DPVs obtained from test bench trials conducted without target crop, as originally designed and proposed by Grella et al. (2017), as well as in the presence of a vineyard canopy target. Furthermore, to evaluate the consistence of the proposed methodology and its applicability in sprayer drift classification process, three types of sprayers characterized by different liquid atomization, type of fan air-assistance, and passes management between rows were tested in two configurations ("drift prone" & "drift low-prone"). A mounted airblast sprayer Dragone k2 500 with a tower shaped air conveyor, a trailed sprayer Nobili Octopus 45-1001 010T with six individual air spout outlets, and a mounted pneumatic sprayer Cima 50 Plus 400L with different spray head/spouts were used. The configurations tested are listed and detailed in the Table 1. The Dragone sprayer in ATR6H configuration was chosen as "reference" and the other sprayers and configurations were considered the "candidates" (Tab. 1). For both trial types (absence or presence of canopy target) Drift Reduction potential –DRP- (%) achieved by each candidate configuration, versus the reference one, was calculated. The DRP values obtained from the two trial types were then compared.

RESULTS AND DISCUSSION

Irrespective of canopy target presence or absence, the results achieved using the proposed test bench drift measurement methodology showed that in all the tested sprayer types, the "drift low-prone" spray application techniques effectively reduced the spray drift (Fig. 1). Even if some slightly differences due to the canopies were found comparing pair by pair the DPVs obtained from trials conducted in presence and in absence of target, the comparison of DRP values obtained from drift classification process results in an identical final classification of the tested sprayers/configurations. Only the configuration Cima MC6S (Tab.1) results in different final DRP according to the trials type –absence and presence of target- (Fig. 1). These results suggest that the target absence has negligible effect when test bench is used for comparative measurements aimed at determining the DRP of a given vineyard sprayer/configuration.

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Table 1. Parameters of sprayers' configurations examined (drift prone & drift low-prone) in trials conducted in absence and presence of canopy vineyard target: reference and candidates.

Test	Config. ID §	Sprayer	Nozzles/spouts Type	Spray pressure (Mpa)	Active nozzles (n°)	Tot. Flow rate (L min^{-1})	Applied volume (L ha^{-1}) †	Fan air flow rate (m^3 h^{-1})
Reference	ATR6H	Dragone k2 500	ATR80 orange	1.0	6	16.32	583	20000
Candidate	TVI6L	Dragone k2 500	TVI8002	1.0	6	17.52	626	11000
Candidate	ATR6L	Nobili Octopus	ATR80 orange	1.0	6	16.32	583	12000
Candidate	TVI6L	Nobili Octopus	TVI8002	1.0	6	17.52	626	12000
Candidate	MC6S	Cima 50 Plus	TC.2M2C ††	0.1	-	10.8	193	7750
Candidate	M6S	Cima 50 Plus	T.4+4 †††	0.1	-	5.4	193	7750

† 2.8m inter-row distance considered; †† multiple-row pneumatic spray head equipped with two hand-spouts type at the bottom and two cannon-spout type at the top of spray head; ††† single-row pneumatic spray head equipped with two hand-spouts type; § light yellow rows identify the configurations defined "a priori" as drift low-prone, in contrast to the one defined as drift prone

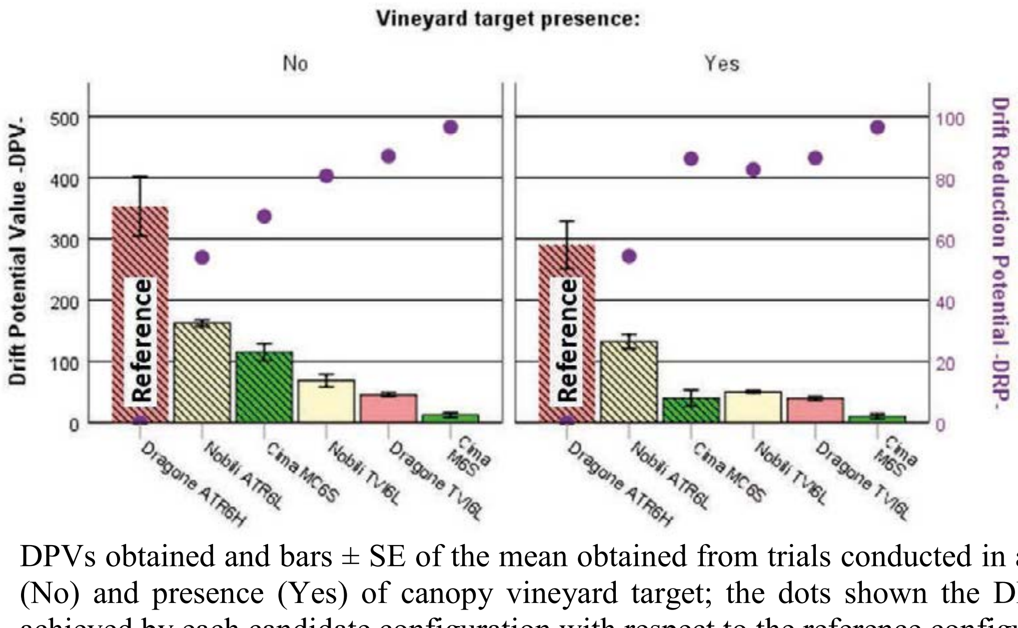

Fig. 1. DPVs obtained and bars ± SE of the mean obtained from trials conducted in absence (No) and presence (Yes) of canopy vineyard target; the dots shown the DRP (%) achieved by each candidate configuration with respect to the reference configuration.

Gone with the wind – teaching fruit growers how to see the unseen

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INTRODUCTION

Many millions of dollars have been spent on pesticide application research throughout the world, most of it languishes in the academic journals in which it was published. It is a sad fact that many proposals for research grants do not contain a clause requesting publication in the farming or extension press.

As the trend towards narrower, smaller and manicured canopies continues so there is a need to encourage growers to become more aware of the airflow characteristics of their sprayer. Encouraging a greater understanding of air flow in an environment of old-fashioned sprayers where "bigger is best" is a challenge.

How can researchers cascade their valuable research information regarding airflow characteristics to the end-user with a degree of impact?

MATERIALS AND METHODS

Outdoor demonstrations

Where the air goes, the droplets will surely follow. For many years teachers have relied on safe tracers such as kaolin clay or brightly-coloured dyes to demonstrate deposition and penetration to show where the droplets have traveled.

Water or oil sensitive cards (WS) remain an excellent visual indicator of droplets within the canopy, the drawbacks being the installation, collection and the effect of inclement weather. Drift may also be observed by either placing the WS cards on collecting trays located on the top of the canopy of each row or mounting long strips of WS cards on the leading edge of wooden boards.

To provide a visual comparison of a number of sprayers, water sensitive cards can be fixed to large display boards. To provide quantitative results cards can be collected post application. A number of image analysis programmes can be used to quantify the % area covered on the cards by the droplets.

The recent development of electronic deposition indicators (Palleja et al., 2016) can be an excellent replacement for WS cards as they allow an instantaneous display of deposition and penetration.

To demonstrate airflow at grower meetings, an airflow indicator, the "Jeanmachine", was developed, (J. Langenakens, pers. comm., 1999). The unit comprises a 300mm grid pattern made from mono filament nylon fitted with 300mm cotton ribbons mounted at each corner of the grids fitted within a plastic frame. The ribbons hang downwards in still air and flutter in the direction of the airflow. The units can be located at row ends to demonstrate how far the air is blowing and its direction.

Artificial targets can be used to produce a standard, uniform demonstration unit, (G. Backer, pers. comm., 2001). A novel standard penetration device for use in vineyards comprises a series of 100mm plastic pipes are arranged 100mm apart, in frames set 100mm apart. On the front and rear of each vertical pipe WS cards are placed to detect water droplets emitting from the canopy sprayer and penetrating the unit. The water sensitive strips can be removed to show growers the degree of penetration at various depths. This unit can be very useful in early season when very little canopy is present.

Vertical patternators, (Landers et al., 2012) can demonstrate airflow direction and show growers how to make simple adjustments to their sprayer nozzle orientation.

Indoor demonstrations

The winter months are when most fruit grower meetings are held, the lecture presentation seems to be the norm, but using a booth in the exhibition hall provides an excellent opportunity to show the application of science to a wider audience. A series of display panels were created using two perspex sheets, with a 100mm electric fan that mimic an airblast sprayer fan, hanging cotton threads show the resulting air movement. 3 panels were made to demonstrate airflow patterns from sprayers with no deflectors, manufacturers small deflectors and the adoption of a tower outlet. A small rheostat is used to control the fan speed and show the effects of reducing airflow to match the canopy. The panels are mounted on large frames. Videos can be made of specific airflow characteristics in the field. Drones are particularly useful for this purpose.

Helium-filled soap bubbles can demonstrate airflow around the fruit and show the effect of airspeed. Bubble generators can produce 400 neutrally buoyant bubbles per minute. With appropriate lighting these bubbles can be filmed, and put into a Microsoft PowerPoint presentation as a video clip. The moving image has long been regarded as a successful instruction medium.

DISCUSSION

There are a number of novel techniques and educational units which can be used by teachers to demonstrate some of the more complex aspects of airflow and how the growers can make adjustments to their canopy sprayers.

Applied research needs to be applied! Judging by the state of many sprayers and spraying practices throughout the world, it is fairly obvious that research results aren't cascading to farm level. A need exists for better education of all concerned with regards to pesticide application. Researchers should be encouraged, as part of their grants, to publish their findings in the farming press.

Researchers should attend grower meetings to help disseminate and receive information, it is a two-way street where researchers can then find out which major application problems exist. Novel techniques should be used to make research results more applicable to the audience. Many growers prefer to see practical applications of theory rather than hear how equations were derived!

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INNOSETA - An H2020 European project to fill the gap between research and professional users in crop protection

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INTRODUCTION

INNOSETA - Innovative practices for Spraying Equipment, Training and Advising in European agriculture through the mobilization of Agricultural Knowledge and Innovation Systems (www.innoseta.eu) is an EU project financed under the H2020 (RUR-2016-2017) program coordinated by the Universitat Politècnica de Catalunya (Spain). The consortium consists of 15 international partners representing all the stakeholders (research and academy, farmer's associations, sprayer's manufactures, pesticide companies, advisors). The main goal of INNOSETA is to establish a self-sustaining and innovative thematic network on the sustainable use of plant protection products (spray equipment, training and advice) to help close the gap between research, and the use and exploitation of all this by the farmer. The project promotes the effective exchange of new ideas and information between research, industry, extension and the agricultural community so that existing commercial and research solutions can be widely disseminated and applied. The aim is to reduce/eliminate the existing gap between research and the agricultural sector, allowing a great improvement of the training skills of the involved stakeholders. The main objectives of INNOSETA can be described as follows:

a) Create an inventory of directly applicable spraying equipment and technologies, training materials and advisory tools available from the large stock of research results and commercial applications.
b) Assess end-user needs and interests, and identify factors influencing adoption considering regional specificities.
c) Generate interactive multi-actor, innovation-based collaborations among different stakeholders.

Set up an ICT tool for the on-line assessment of the Spraying Equipment, Training and Advising (SETA) and the crowdsourcing of grassroots-level ideas.

COLLECTION OF SETA MATERIAL

Since the beginning of the project, an intense searching for useful material has been arranged. SETAs have been organized into four different typologies: a) research projects; b) research and technical articles; c) industrial solutions; and d) training material. Figure 1 shows the results obtained.

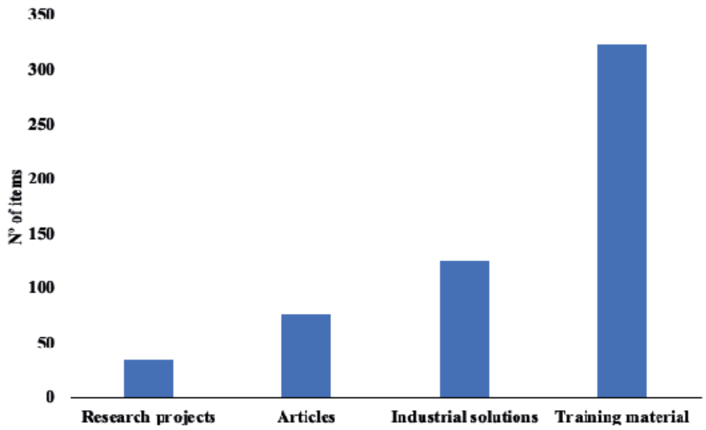

Figure 1. Collected SETAs to implement INNOSETA Platform

INNOSETA PLATFORM AND WEBSITE

The INNOSETA platform allows the running of a specific search of available materials, searching by language, type of crop, technology or topic. Detailed detained information of the selected SETA is then displayed as it is shown in Fig. 2.

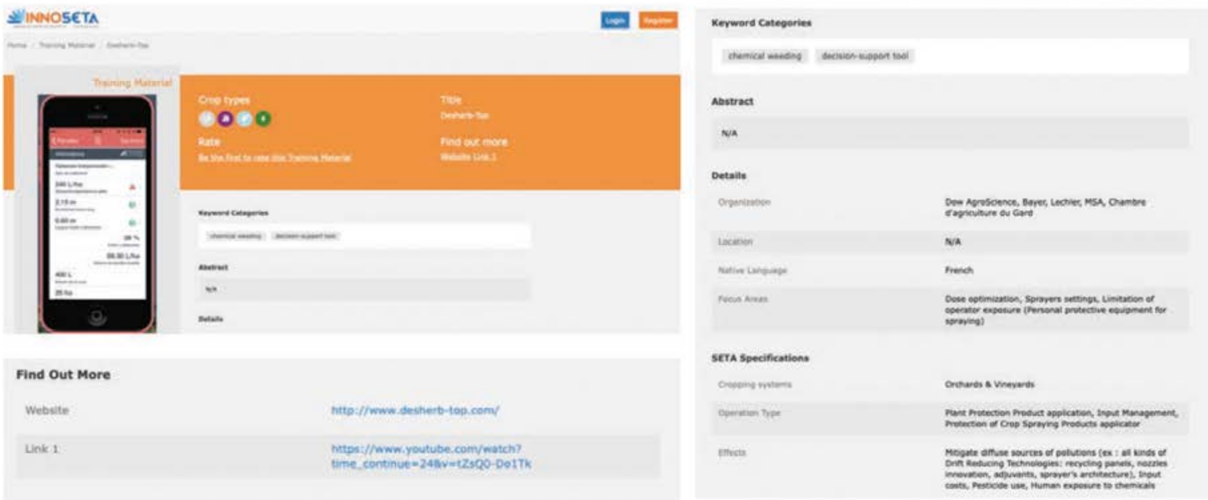

Figure 2. Example of detailed information available on INNOSETA platform for a selected material

The INNOSETA platform is available at INNOSETA website (www.innoseta.eu)

OPTIMA EU project: main goal and first results of inventory of current spray practices in vineyards and orchards

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INTRODUCTION

The Horizon 2020 EU Project "Optimised Pest Integrated Management to precisely detect and control plant diseases in perennial crops and open-field vegetables" (OPTIMA), a 40 month long project started in September 2018, is aimed at developing an environmentally friendly IPM framework for vineyards, apple orchards and carrots by providing a holistic integrated approach which includes all critical aspects related to integrated disease management, such as i) use of novel bio-PPPs, ii) disease prediction models, iii) spectral early disease detection systems and iv) precision spraying techniques. Three pilot areas have been chosen to assess the applicability and the efficacy of the OPTIMA IPM strategy: 1) Nouvelle Aquitaine in France (focusing on Alternaria in carrots), 2) Aragon in Spain (focusing on apple scab) and 3) Piemonte in Italy (focusing on vine downy mildew). In order to actively involve farmers and advisers of the pilot areas in the development of the project activities, a questionnaire was prepared and submitted to them so to have a preliminary feedback about their current practices for crop protection management and about their expectations and remarks on the OPTIMA proposed activities.

In the present work the results obtained in Spain (apple orchards growers) and in Italy (vineyards growers) are reported and commented.

MATERIALS AND METHODS

In each pilot area farmers and advisers were informed about the objectives and planned activities within OPTIMA Project through a brochure translated into local languages. A questionnaire containing 20 questions in total, divided in three sections: a) general information about the interviewed person; b) information about current practices adopted for crop protection (open field carrots in France, apple orchards in Spain and vineyards in Italy); c) needs and expectations from OPTIMA project, was submitted to farmers, contractors and advisers in the three pilot areas via face to face or phone interviews. For most of the questions, guided answers to select were provided.

Among the questions addressed about current crop protection practices, some concerned the crop disease detection method commonly adopted, the plant protection strategy followed, the sprayer type used for PPP application, the average volume rate applied along the season, the operating pressure adopted, the number of treatments made per year and the technologies available on the sprayers (e.g. anti-drift nozzles, sprayer control units, GPS, etc.). One question was specifically addressed to rate which of the OPTIMA activities was considered more promising to provide concrete results applicable in the farms on a large scale. In each pilot area the answers collected were examined within a focus group composed by representatives of the Project Consortium and representatives of the interviewed persons in order to issue a final report on the indications obtained.

RESULTS AND DISCUSSION

In Spain 54 farmers and 16 field technicians were interviewed. The majority of them declared to rely on extension service bulletins to detect crop diseases while few of them declared to trust on their own personal expertise or to directly use disease prediction models. The majority of farmers (69%) applied IPM voluntary protocols, generally using basic conventional axial fan sprayers (72%, see Fig. 1). Volume application rates ranged from 500 up to 1200 L/ha, resulting on average around 900 L/ha. Operating pressure ranged from 8 to 30 bar (14 bar on average). 56% of interviewed farmers declared to mount anti-drift nozzles on their sprayers and 6% declared to have a DPA control unit installed on the sprayer. The majority of the interviewed farmers (64%) and field technicians (75%) considered the development of disease early detection instruments and refined disease prediction models as the most promising activity within OPTIMA project. In Italy 82 farmers, 11 field technicians and 9 contractors were interviewed. The majority of farmers (62%) declared to rely on extension service bulletins to detect crop diseases but a not negligible 37% relied on his own expertise. Nearly 80% of farmers followed IPM voluntary crop protection protocols, using conventional axial fan sprayers (58% of cases) or pneumatic sprayers (27% of cases, see Fig. 1). Average volume application rate resulted 360 L/ha operating at 15 bar pressure when using conventional axial fan sprayers and about 250 L/ha operating at 2 bar pressure with pneumatic sprayers. Nearly all farmers (98%) declared to have not anti-drift nozzles or computers for spray control installed on their machines. Concerning the most promising OPTIMA activity, farmers indicated the assessment of the impacts of the proposed IPM system on human health, the environment, the society and the economy (30% of interviewees). In conclusion, the feedback received in the pilot areas from the submission of the questionnaires and the discussions made in the focus groups, pointed out that the general architecture of OPTIMA project is suitable to match expectations of farmers and technicians in order to improve the IPM of their crops but some refinements can be considered to achieve a better success and applicability of whole OPTIMA IPM strategy on a wide scale.

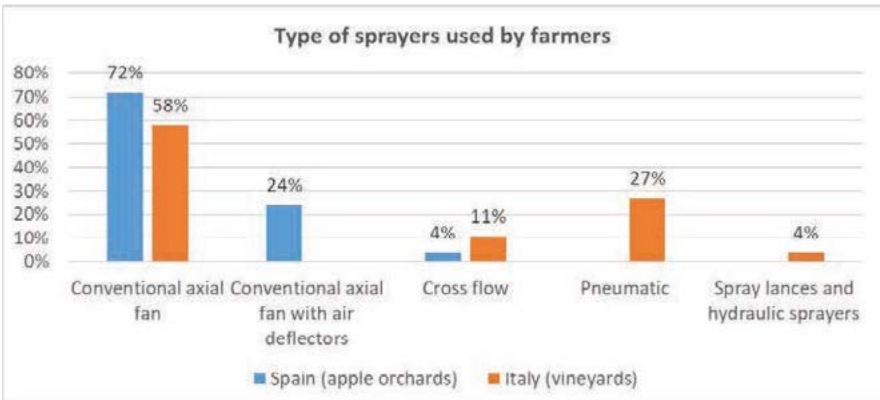

Fig. 1. Type of sprayers used by the farmers in the pilot areas selected in OPTIMA Project.

PERFECT LIFE PROJECT
Pesticide reduction using friendly and environmentally controlled technologies

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INTRODUCTION

Control of pests and diseases in commercial crops is a permanent concern for farmers because they cause important yield and economic losses. Nowadays, the main method of control is based on pesticide spray application. In fact, crop production in the EU without pesticides currently is not realistic (Keulemans et al., 2019). The problem is that spray volume rate commonly used by growers use to be very high, without adjustment to the real needs, in terms of quantity of vegetation to be protected, pest/disease to be controlled, and type of product to be applied. In this sense, two tools for the optimal volume rate adjustment have already been developed: "Dosaviña" for pesticide applications in trellised vineyards with hydraulic sprayers, and "CitrusVol" for pesticide applications in adult citrus with airblast sprayers. Besides, only a portion of the spray volume applied is deposited on the target, and the rest is lost in the environment as drift or to the soil, and may affect biodiversity and people (sprayer operators, bystanders and residents). There are some tools and techniques already available to growers to prevent and reduce drift, such as low drift nozzles, air deflectors, the Drift Evaluation Tool software developed in the ambit of LIFE TOPPS project (available at www.topps-drift.org), and the VErtical SPray Pattern (VESPA) software developed by DiSAFA (available at www.laboratorio-cpt.to.it).

PERFECT LIFE PROJECT

The PERFECT project (http://perfectlifeproject.eu/) is a European project funded by the Life call of the European Commission that runs from September 2018 to September 2022. It is developed in Spain, Italy and France and its working team consists of 8 partners including universities, research centers, agricultural cooperatives and a private company.

It is a demonstration project, so the general objective of PERFECT is to demonstrate the reduction in environmental contamination of pesticides and their metabolites in air using Optimal Volume Rate Adjustment (OVRA) tools, CitrusVol and Dosaviña for citrus and vineyards, respectively, and Spray Drift Reducing Techniques and Tools (SDRTs), low drift nozzles, deflectors, TOPPS Drift Evaluation Tool, and VESPA software, which will decrease the pesticide exposure risk for fauna, flora and humans. PERFECT targets applications performed with hydraulic sprayers assisted with air in Mediterranean citrus and vineyards (Fig. 1). Current work in PERFECT is directed to selection and characterization of farms where demonstrations will be carried out, and the design of protocols to follow in these demonstrations, and also to widen the applicability of the proposed tools, i.e. translate CitrusVol

OVRA tool, to languages of countries where citrus is an important crop (Italian, Greek, etc), and extend the use of the Dosaviña OVRA tool to vineyard systems (different to trellis, etc.)

Fig. 4. General objective of PERFECT project

Besides, a new ultra-fast, sensitive and time resolved technology for analysis of pesticides will be developed to assess the application of pesticides from a health standpoint, in real agricultural conditions. This tool will sample pesticides in the air in real-time and lately will analyse the sample in the laboratory. In this way pesticide concentration over an area around the treated area with high resolution, both in space and time, will be characterized. After PERFECT it is expected to be directly offered to the farmers as a service, together with all the other tools proposed in PERFECT, in such a way they could demand the assessment of their pesticide applications to know their efficiency and demonstrate their "eco-use" of pesticides, which would include the use of minimum quantity of pesticide and reduction of drift.

Demonstration studies will be conducted in Valencia and Catalonia (Spain), Piemonte region (Italy), and the Occitanie region (France) and the results will be used to support the advantage of the proposed tools. As a result, PERFECT expects to obtain a general procedure for pesticide application with low emissions to the atmosphere and hence low impact over people with less: pesticide consumption, diesel consumption, atmospheric pollution, water footprint, non-target crop deposition, etc. Due to the proper selection of the spray volume rate, it is expected that a 20% reduction of pesticides released to the environment in the experimental areas of PERFECT will be achieved. As a priority action, the project is focused on the dissemination of knowledge and techniques among different French, Italian and Spanish stakeholders (farmers, researchers, municipalities, governments, etc.) through training courses and field demonstrations to encourage PERFECT practices to reduce pesticide impacts.

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Notes

Notes

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