RHEA AIRBLAST SPRAYER: CALIBRATION INDEXES OF THE AIRJET VECTOR RELATED TO CANOPY AND FOLIAGE CHARACTERISTICS

Daniele SARRI[1], Riccardo LISCI[1], Marco RIMEDIOTTI[1], Marco VIERI[1]

[1]University of Florence Department Agricultural, Food Production and Forest Management
Piazzale delle Cascine 15, Firenze, 50144, Italy,

Abstract. The 2009/128/EC directive requires new management techniques of the pest control practices. In this respect, research is moving towards the definition of new solutions to optimize the pesticides use. In accordance with the European general guidelines, in the RHEA Project (Robot Fleets for Highly Effective Agriculture and Forestry Management NMP-CP-IP 245986-2 RHEA) the U.O. of Florence has developed a sprayer prototype that can vary the air flow rate and the spray mixture. This meets the purpose of spraying optimization because, the right practice, should include an adjustment of the variables of spraying in relation to the target features (Chen. This study was focused on the air flow management. In the Rhea air blast sprayer, to manage this variable a system made of butterfly valves located on the main inlet manifold and in the fan calotte collector, were designed. However, to fulfill this purpose, it is required the air flow characterization and its calibration. In this connection, a sensor that provides data related to the aerodynamic force that the air vector produces on an surface area, was developed. Furthermore, an instrumental procedure to measure the instantaneous force of the air flow produced by the fan and diffusers of the sprayer, was developed. The assessment involves the quantification of air jet momentum at a defined point at the outlet of the sprayer. Moreover, it seems possible to use the effect produced by the air jet momentum as measured by the reaction force on a standard surface during the time of sprayer passage. The integral of collected data, in the different infinitesimal times, during the treatments, can be assumed to be equivalent to the impulse of the air flow jet on the surface unit on the leaves. An apparatus that allows to measure the impulse and thus to estimate the air flow momentum in dynamic conditions (i.e., with sprayer moving in the orchard) and at different distances, with or without canopy interference, was built. Laboratory and field tests with a sprayer to validate the procedure were performed. Results showed a new possibility to compare sprayer features and operative parameters with the index impulse assessments. This permits the definition of the most appropriate set-up parameters to obtain an efficient spray application in different crop conditions.

Keywords: environmental sustainability, precision viticulture, recovery spraying Crop Protection Technologies, Airjet behaviour

1 Introduction

Precision farming is widely considered the way to reach efficiency, reduction of costs and emission safety (BAT best available techniques). Proposals on farm mechanization schemes are evolving towards integration systems and new advanced design are developing. This is the case of EU FP7 RHEA Project (Robot fleets Highly for Effective Agriculture and forestry management). RHEA focuses on the design, development, and testing of a new generation of automatic and robotic systems to perform field operations in sustainable crop management, using a fleet of small, heterogeneous robots –ground and aerial– equipped with advanced sensors, enhanced end effectors and improved decision control algorithms. RHEA can be considered a cooperative robotic system, falling within an emerging area of research and technology.

An objective is development of innovative equipment and advanced devices to precise spraying chemicals on tree canopy. The advances of the sensors, and actuators have facilitated the inclusion of electronics in sprayers for tree and bush crops. The first step was the interruption of liquid flow rate when no foliage it is detected, further developments were achieved with the control on the different vertical bands of the canopy. The next step was matching the spraying flow rate proportional to the canopy width using ultrasound sensors and, at a later stage, the laser LIDAR (Sarri *et al.*, 2013, Chen *et al.,* 2013a,b). The Rhea airblast sprayer introduces an important innovation in the studies concerning the pesticide variable rate treatment, i.e. the air flow management in site specific way and in real time in function to the target.

The innovative devices developed and the wide versatility of the actuators designed, makes it possible to adapt the air flow in relation of the canopy thickness. Trials to characterize the air flow fluid dynamics and its relationship with changes of the power requirement of RHEA airblast sprayer, in the different operative scenarios, were conducted. The properly operational mode provides that the spray jet, the dose and air energy applied, shall be adequate to the morphological features of the treated canopy (Duga *et al.*, 2012). Implement a VRT (variable rate treatment) in tree crops spraying means to continuously adjust the parameters, i.e. the dose sprayed in the specific band and intensity of the air jet in realtion to the canopy features (Dekeyser *et al.*, 2012). In RHEA airblast sprayer a proportionality rule between nozzles flow rate and canopy thickness, spilt up in 4 settings (flow rate: 100%, 50%, <50% canopy thickness and absence of canopy) was set. Moreover, based on the needing of spraying, the opening or closing of the air flow rate in the different modules, was expected. However, it is necessary to refine the settings and deepen the relative studies, to gain a precise definition of the relationship between dose and airjet-vector energy in relation to the canopy features. This is the purpose of the preliminary experiments reported in this work.

2 Materials and methods

2.1 The RHEA Airblast Sprayer for tree crop treatment

The design of RHEA implement for the woody perennial crops treatment device system, was oriented toward a complete double side airblast sprayer made of eight separate spraying modules on four vertical bands of the canopy.

Fig. 1. The Rhea Robot equipped with the RHEA airblast sprayer

The equipment see Figure 1 presents the following main features:

- maximum height of the vertical boom 2.5 m;
- canopy band to be treated 2.7 m (3.0-3.5 m maximum crop height);
- total equipment weight (empty tank) 400 kg;
- mixture tank 300 L;
- hydraulic pump with maximum flow rate of 100 L min^{-1} at 25 bar and maximum 5 kW of power consumption at the power take off (p.t.o.)
- fan maximum 15 kW from the p.t.o.;
- the equipment is semi-loaded and coupled at the three hitch point lift but when it is working, floating and resting on its wheels.

In view of our aims and starting from the basic configuration of the Nobili Oktopus airblast sprayer the following changes, were designed:

- detection system made of eight ultrasonic sensors to reach data on canopy width of each vertical band;
- variable control of the liquid flow rate in each spray module to adapt dosage to the canopy thickness on each band with the following rules: 100% canopy thickness 100% dose; 50% canopy thickness → 70% dose; < 50% canopy thickness 30% dose, absence of canopy 0 dose;
- to control the liquid flow rate, double nozzles in each spray module were fitted. They were with 70% and 30% of needed flow rate on each band and in full canopy condition they are simultaneously opened
- to manage the airblast flow rate on each spray module butterfly valves (step motor controlled) located on each pipe of the eight fan calotte collector, were designed;
- the air flow rate control in the fan is actuated via a main butterfly valve (step motor controlled) sited on the fan inlet manifold;
- the variable inclination (step motor controlled) of the four terminal spray modules (top and bottom) to improve the deposition in these sensitive areas of the canopy.

The entire equipment, with the whole system of Devices (DS), it is controlled by the LLAS (Low Level Actuation System) that consist in a PLC (Programmable Logic Controllers) and related algorithms. All that is managed, in its turn, by the HLDMS (High Level Decision Make System) and upstream by the MM (Mission Manager) of the RHEA system. These solutions allow to the RHEA airblast sprayer the adapting of dose and air on each single vertical band in accordance with canopy thickness. The proper energy of air-jet vector to move correctly inside the canopy, shall to be evaluated taking into account the variable distance from the outlet and the width features of the foliage in the band.

2.2 Airblast behaviour

A lot of studies were focused to the characterization air-jet vector of the airblast sprayers (Dekeyser *et al.*,2013). As showed in Vieri and Venturi (2002) can refer to the simplified model of the free jet theory and through a simplified analysis is possible to predict the speed air jet decay compared to the distance see equation (1). Figure 2 shows that in the region of the diffusion the free jet speed V_x is expressed as a function of distance x from the exit point of the spray diffuser: where b_0 is the semi-width of the spray diffuser, r_0 the radius of the diffuser to the exit point, X_0 is the distance, with a negative sign, between the top of the virtual triangle facing the inside of the diffuser and the trailing edge of the latter, $X_0 = -0.52\ b_0$.

$$V(x) = 3{,}8\sqrt{\frac{b_0 r_0}{(x-x_0)(x+r_0)}}\,Vx_0 \quad (1)$$

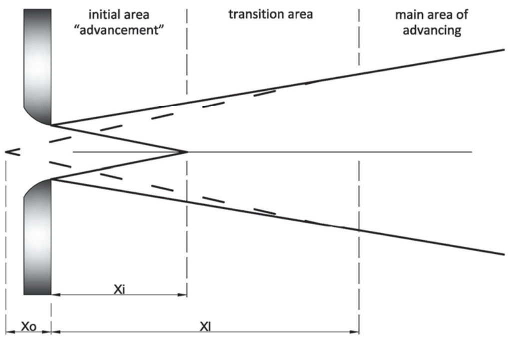

Fig. 2. Equation and representation of free airstream theory.

Figure 3 shows the decay curve in airblast speed. As illustrated in the figure 2 airjet vector need to reach the canopy with sufficient energy to pass it and to still have at the exit a speed of 2 m s^{-1}, that is considered the limit to get normal sprayed droplets (100 µm). The air flow speed at the outlet of each spray diffusors it takes on average of 58 m s^{-1} and decreases gradually as showed (green continuous line) in the figure 3. The orange line at 1.2 m from the outlet references indicate the tree position in the olive grove. Rectangles represent different levels of canopy development: green (dotted) 100%, red (dashed) 70%, blu 30%. Air stream speed inside the canopy decreases with a high magnitude as showed by the thin lines referred to the three scenarios.

Therefore, the air stream's momentun has to reach the canopy at different distances in accordance with development stages (30%, 70%, 100%) and to apply droplets up to the esternal limit of the canopy. To optimize the spraying in each spray modules, butterfly valves were setted. In particular, they were set in relation to the required air vector speed, such as to reach the appropriate momentum in the three different conditions of the impulse method (Vieri, 2003).

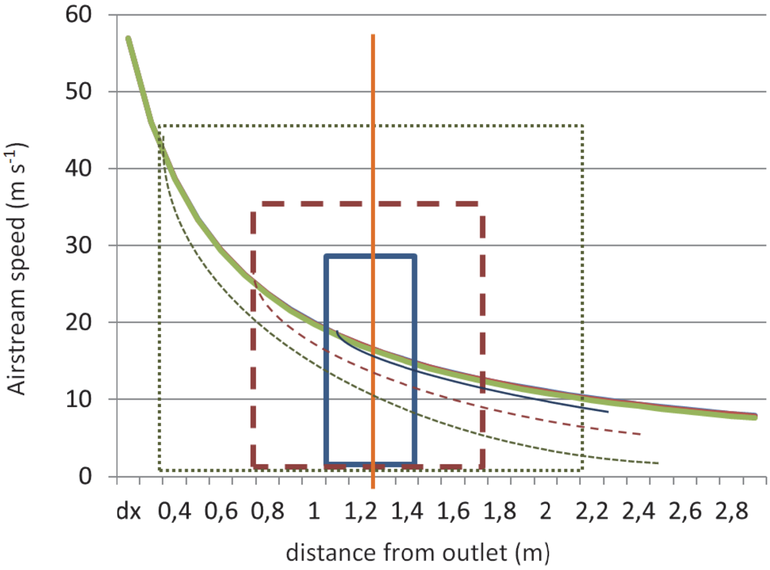

Fig. 3. Scheme of airstream behavior and scenarios of 2.0 m, 1.2 m, 0.6 m canopy thickness. Rectangles represent canopy section during the seasonal development: green (dotted) 100%, red (dotted) 70%, blu 30%.

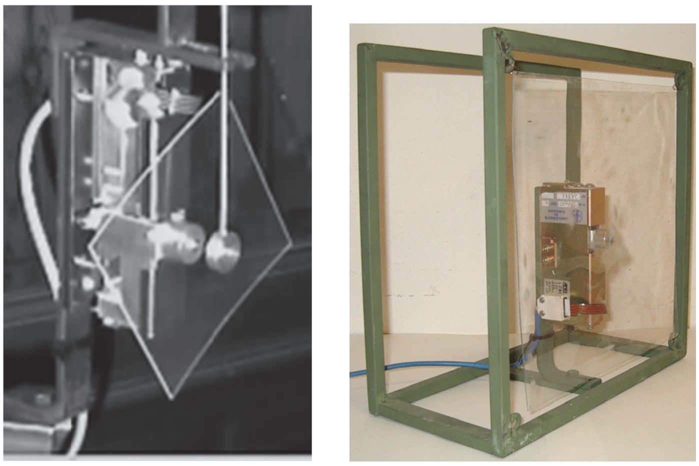

Fig. 4. Sensor and test frame for impulse measurement.

For the tests a specific tool made of three modular sensor units, placed perpendicular to the air flow and positioned close the row and beyond it was used. Each module is made of a sheet of polycarbonate (200 mm L; 200 mm W ; 0,8 m H) (Figure 4) and by a pressure transducer located in the center of thereof.

The sheet, pushed by the air flow, acts the load cell (Single Point Units Beam Load Cell - LC4001 - 1.2 N FC - sens.0, 4mV / v - err. ± 0.0015%) that generates a signal acquired by MCDR-M-128. Multichannel Data Recover produced by Leane. All data were acquired in real time by a PC that elaborated diagrams every time the sprayer passed in front of the device. Through the charts peaks, were highlighted. These represent the maximum impulse at the passage of the sprayer. The overall impulse value was determined as the integral of the curve. In the figures 5 and 6, the sensors' values correlation between pressure (N/m2) and acquisition time (s) with a frequency of 5 Hz, were plotted. So for each trials and for the three sensors the impulse values, were observed. These were averaged for three series of measurements. The final score represent the impulse value expressed in Nm / s for every test and the canopy bands. The tests were carried out with Nobili Oktopus that has similar features to RHEA Airblast sprayer. These ones were made using a single module sprayer horizontally sited to the ground and at a distance of 1.2 m from the row corresponding to the greatest thickness canopy point. The sensors were placed in the following manner: 0.7 m from the outlet, on the row (1.2 m from outlet), beyond the row (1.8 m from outlet). The tests were carried out in a three years olive grove, similar to the RHEA field where will be performed the final test, setting two forward speed 1 m s^{-1} and 2 m s^{-1}.

2.3 Sprayed chemical deposit on leaves assessment

Further tests, to assess the sprayed deposit with a tracer solution, were conducted. The spray mixture was prepared containing water and tracer Tartrazine (concentration 10 g/l) and a spraying set-up of 200 L/ha (conventional treatments). To evaluate the foliar deposits, before spraying, collectors were placed on the canopy. After the spraying 150 leaves per experimental treatment were collected for bands evaluation and placed in petri dishes. The leaves collected were weighted to define the foliar surface of the sample. After that the correlation surface versus weight was defined. Deionized water is added in each sample leaves. The folders sample are manually shaken for some second, allowed to stand for 24 h, and then shaken again. A 5 ml of solution is taken from each container and optical absorbance of this one was measured. A spectrophotometer Savetec 6300 was used for measurements. Tracer concentration is determined via calibration curve. The total amount of spray applied per unit ground (for deposits on the ground) ,or in µg cm^{-2} of the target (for foliar deposits), expresses the deposit.

RESULTS

The Figure 5 shows an example of the tracings impulse achieved in the tests. In the tests performed, for each set of adjustments (fan speed and distance from the detection device), average values for each impulse and deposit in each canopy bands, were obtained. Impulse provides a very interesting index for the qualitative evaluation of the treatments. This index can be used to characterize the operating conditions as the air flow rate and the forward speed. The results showed that for a maximum flow rate of 3.0 m3 / s on the row and with canopy interference, impulse varies from about 30 Ns/m2 with forward speed of 1 m / s, to 15 Ns/m2 with forward speed of 1.5 m / s. It is reduced up to 10 Ns/m2 with a forward speed of 2 m / s. With the half of air flow rate 1.5 m3 / s, the impulse varies from 11 Ns/m2 with forward speed of 1 m / s, to 8 Ns/m2 with forward speed of 1.5 m / s, and decreases further at 3 Ns/m2 with forward speed of 2 m / s.

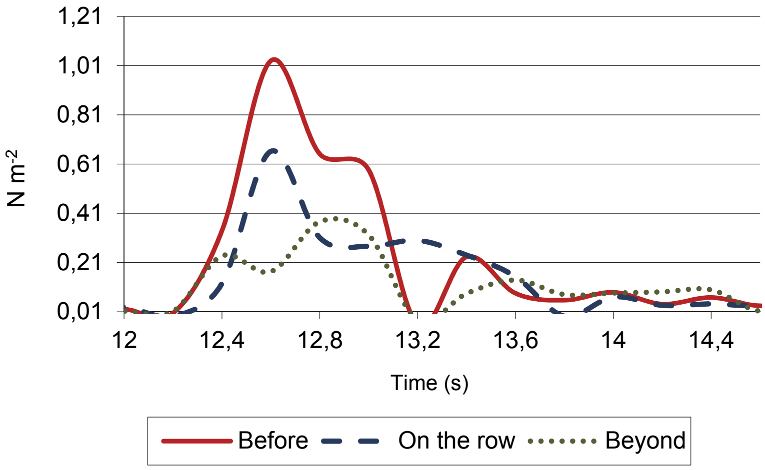

Fig. 5. Example of a impulse test carried out with fan setting in first gear speed

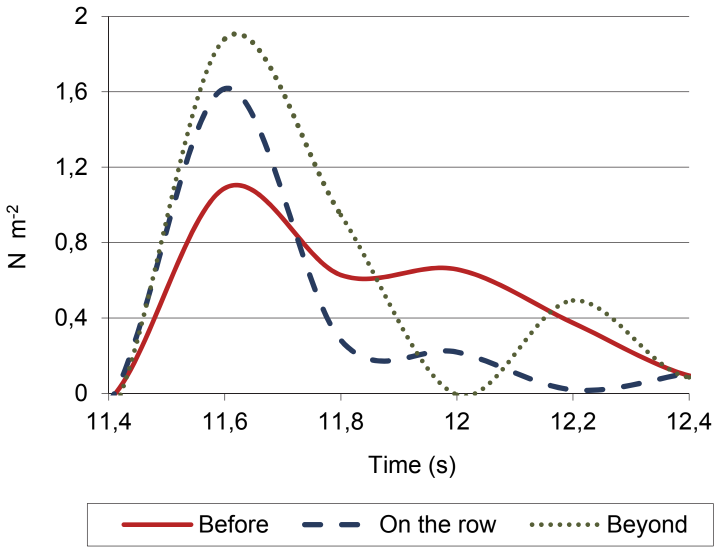

Fig. 6. Example of a impulse test carried out with fan setting in second gear speed

Table. summary of the results obtained

Air flow rate [A]	Forward speed [V]	A / V index	Average air speed on the row (static conditions)	**IMPULSE** spray side	on the canopy	opposite spray side	**DEPOSITS** (normalized 350 l/ha) frontal leaves [a]	rear leaves[b]
($m^3 s^{-1}$)	(m s^{-1})		(m s^{-1})	(Ns m^{-2})			(µl cm^{-2})	
3.0	1.0	3.3	16.0	29	25	12	0.6	0.5
	1.5	2.0		15	12	10	0.7	0.2
	2.0	1.5		10	9	7	0.6	0.3
1.5	1.0	1.5	7	11	9	2	0.6	0.2
	1.5	1.0		8	4	1	0.6	0.3
	2.0	0.7		3	2	0.5	0.7	0.3

The preliminary results showed an almost equality of the deposits in the two canopy zones (spray side and opposite spray side); we need to take into account that in symmetrical way the treatment of the adjacent rows the deposit, was added. Further tests shall be conducted to assess the scenarios of full and minimal canopy

CONCLUSION

The impulse measurement allows to characterize the treatment through the air flow rate and forward speed factors. This characterization takes into account that the energy on the leaves is proportional to the air flow rate that reaches the canopy and viceversa inversely proportional to the forward speed. The jet vector energy must be such as to allow at the drops to cross the entire of the canopy thickness, avoiding disperse elsewhere. The impulse can be considered as a useful index to indicate clearly when you aren't properly working. In that case, if the impulse is too low, the average deposition increases significantly and viceversa, if the impulse is too high there is an opposite trend . Further tests shall be conducted to assess the scenarios of full and minimal canopy

Acknowledgments

The authors wish to thank the NOBILI Agricultural Equipment of Molinella (Bo) for the technical support. And also to our colleague Mr. Giancarlo Cosi for the special commitment and passion to develop the RHEA air sprayer prototype devices.

References

Chen Y., Zhu H., Ozkan H. E., Derksen R. C., Krause C. R. Spray drift and off-target loss reductions with a precision air-assisted sprayer . Transactions of the ASABE

Vol. 56(6): 1273-1281 2013 American Society of Agricultural and Biological Engineers ISSN 2151-0032 DOI 10.13031/trans.56.10173 (2013a)

Chen Y., Ozkan H. E., Zhu H., Derksen R. C., Krause C. R. .Spray deposition inside tree canopies from a newly developed variable-rate air-assisted sprayer . Transactions of the ASABE Vol. 56(6): 1263-1272 2013 American Society of Agricultural and Biological Engineers ISSN 2151-0032 DOI 10.13031/trans.56.9839 (2013b)

Dekeyser D., Duga A.T., Verboven P., Endalew A. M., Hendrickx N., Nuyttens D. Assessment of orchard sprayers using laboratory experiments and computational fluid dynamics modelling Biosystems Engineering n°114 pp 157 e 169 (2013)

Dekeyser D., Foque D., Endalew A M, Verboven P., Goossens T., Hendrickx N., Nuyttens D. Assessment of orchard sprayers using laboratory trials . Aspects of Applied Biology 114, 2012 International Advances in Pesticide Application 395-404 (2012)

Duga A.T., Endalew A.M., Hendrickx N., Goossens T., Dekeyser D., Nuyttens D., Nicola B., Verboven P. . Computational fluid dynamics modelling of orchard sprayer performance: machine type and operational parameters characterization (2012) Proceedings CIGR-AGENG 2012 Valencia Spain - International Conference of Agricultural Engineering (2012)

Sarri D., Rimediotti M., Lisci R., Vieri M. The RHEA-project robot for tree crops pesticide application. Proceedings 9th European Conference on Precision Agriculture, Lleida, 7-11 July 2013, Catalonia (SPAIN) (2013).

Vieri M., Venturi A. Una procedura informatica per il controllo del comportamento delle gocce nella irrorazione con atomizzatori. A software procedure to forecast dropplets bewhaviour in Rivista di Ingegneria Agraria, XXXII, 4/2001 (2001)

Vieri M. . Spray airjet characterisation by impulse measurement. 7th Workshop on “Spray application techniques in fruit growing”. Cuneo 25-27 june 2003. 149-156 (2003)