Study of Air Velocity Adjustment to Maximise Spray Deposition in Peach Orchards

P. Marucco, M. Tamagnone, P. Balsari

DEIAFA – Università di Torino, Via L. Da Vinci 44, I 10095 Grugliasco (TO), Italy
paolo.marucco@unito.it

ABSTRACT

Air adjustment on air-assisted sprayers used for applying pesticides in orchard is very important to achieve an even spray deposition within the canopy. A set of tests were carried out in a peach orchard to investigate which combinations of air velocity measured on the target, sprayer forward speed and application rate are most suitable to get a high and even spray deposition within the whole canopy. Combinations of six different air velocities, ranging from 3.7 to 23.0 m s^{-1}, four different forward speeds (from 3.9 to 13.0 km h^{-1}) and four different volume rates (from 200 to 1000 l ha^{-1}) were examined. Test results pointed out that working at 7 km h^{-1} employing an air velocity of 14 m s^{-1} enabled to achieve the best compromise to get a uniform coverage of the canopy, especially when low volumes (up to 400 l ha^{-1}) were sprayed.

Keywords: Axial fan, orchard sprayer, canopy, air velocity, spray deposition, spray volume, driving speed, Italy

1. INTRODUCTION

Pesticide application in orchards is mostly carried out using axial fan air-assisted sprayers. These machines are often provided with few options for adjusting the air flow rate and the vertical spray liquid profile (Kaul *et al.*, 2004; Pergher, 2006). Typically, the air adjustment for conventional axial fan sprayers is based on the rotation speed of the fan for what concerns air velocity and on the regulation of air deflectors for what concerns air direction.

As the nozzles are mounted on semi-circular booms in the rear part of the sprayer, close to the fan output, especially the distance between nozzles and top of trees is often considerable (over 2 m, Figure 1).

The consequence is that large amounts of air are employed to convey the droplets from the sprayer to the top of the plants. The air flux generated by an axial fan strikes with the same magnitude the spray jets from all nozzles, therefore also the liquid addressed towards the lower parts of the canopies. Final result is that, on one hand, the air velocity which hits the leaves closer to the sprayer is very high, even excessive; this fact increases the risk that leaves are turned according to the air flux direction and a consistent fraction of spray overpasses the canopy and generates drift (Holownicki *et al.*, 2000; Cross *et al.*, 2003). On the other hand, the air velocity addressed towards the top of plants is generally not sufficient to guarantee an even coverage and an adequate spray penetration into the higher parts of tree canopy, especially when the latter is very dense (Vereecke *et al.*, 2000).

Spray deposition is however influenced not only by the air velocity addressed to the target but also by the volume of liquid applied and by the sprayer forward speed.

Figure 1. Example of typical orchard spray application carried out with an axial fan air-assisted sprayer: the distance between nozzles and top of trees is underlined.

With the aim to investigate the combination of sprayer forward speed, application volume rate and air velocity generated by the fan - measured in correspondence of the target - enabling to maximise spray deposition on the target, a set of tests were carried out in a peach orchard using an air-assisted sprayer equipped with a radial fan and adjustable air spouts (Marucco and Tamagnone, 2004).

2. MATERIALS AND METHODS

Tests were conducted in a Y trained peach orchard (cv. Nectaros), featured by a layout of 4.2 x 1.2 m, with an average tree height of about 3.8 m. Experiments were made when the vegetation was fully developed (BBCH 91) and Leaf Area Index, calculated as the ratio between the total foliar tree surface (taking into account only one leaf face) and the ground surface corresponding to the projection of the tree crown, ranged between 3.4 and 3.8. A Nobili Oktopus 45/1000T air-assisted sprayer, fitted with a radial fan (450 mm diameter, maximum air flow rate 14000 m^3 h^{-1}) and ten adjustable air spouts was employed, arranging all the spouts on one side of the sprayer, in order to obtain an even vertical air profile (Figure 2A and 2B). Air spouts were positioned at a distance of 95 cm from the sprayer centerline and at a distance ranging from 50 to 100 cm from the outside of the tree canopy. To achieve a wider range of air output velocities, wooden discs of different sizes (Figure 2C) were used to reduce the size of fan air suction.

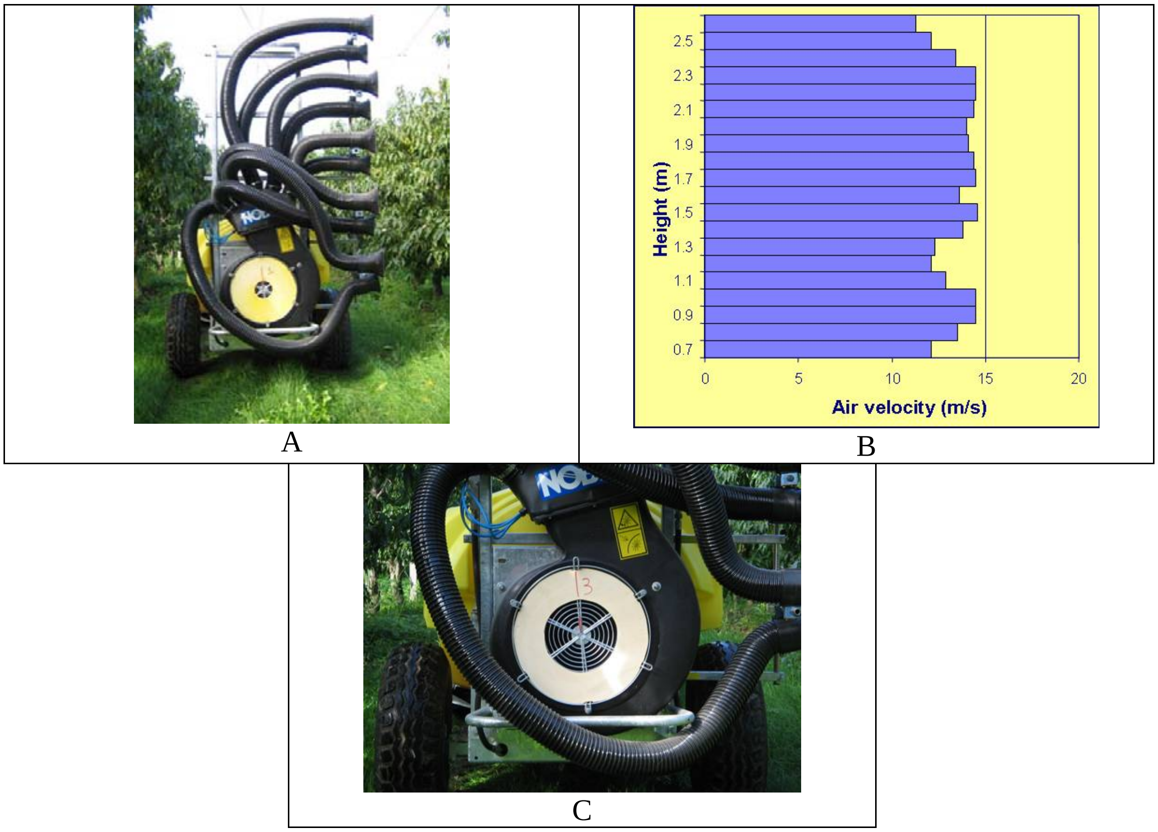

Figure 2. A) air-assisted sprayer employed in the test; B) vertical air velocity profile measured at 2 m distance from the centre of the sprayer; C) detail of the wooden discs used as diaphragms to reduce the size of fan air suction.

Six different air velocities, measured at 2 m distance from the centre of the sprayer (in correspondence of the outer part of the tree canopy), were then tested (Table 1). Air measurements were made using a sonic anemometer (Gill 2D1); at 0.1 m intervals between 0.7 and 2.6 m in height, corresponding to the zone where tree canopies were most expanded.

Table 1. Fan parameters adopted in order to obtain six different air velocities on the target

Fan rotation speed (r min^{-1})	Fan air suction diameter (mm)	Air velocity (m s^{-1})*
2000	120	3.7
2000	180	6.2
2000	240	10.3
2000	300	13.8
2000	440	17.0
2500	440	23.0

* average values measured at 2 m distance from the sprayer centre and between 0.7 and 2.6 m height.

A first group of tests, carried out in 2005, was made combining these six air velocities with four different forward speeds: 3.9, 6.8, 9.9 and 13.0 km h^{-1}. For all of the 24 treatments examined a volume rate of 200 l ha^{-1} was applied, acting on the size of 10 active hollow cone nozzles (Teejet TXB) and on the operating pressure (Tab. 2) to keep it constant. Attention was paid in order to maintain as far as possible the same spray quality for all treatments: VMD, measured in DEIAFA laboratory according to ISO 5682-1 methodology, ranged from 122 to 180 µm (Table 2).

Table 2. Operating parameters adopted in the tests carried out in 2005 in order to compare four different sprayer forward speeds combined with the six air velocities listed in Table 1, all applying a spray volume of 200 l ha^{-1}.

Forward speed (km h^{-1})	Nozzle size	Operating pressure (MPa)	VMD (µm)
3.9	01	0.60	122
6.8	015	0.90	135
9.9	02	1.00	154
13.0	03	0.80	180

A second set of trials, carried out in 2006, was conducted combining the same six air velocities listed in Table 1 with four different volume application rates: 200, 400, 700 and 1000 l ha^{-1}. In this case, for all the 24 treatments examined, the same forward speed of 6.8 km h^{-1} was adopted. To obtain different volume application rates, the number and size of active hollow cone nozzles and the operating pressure were conveniently adjusted (Table 3) trying to keep, as far as possible, similar droplets sizes (VMD was measured in DEIAFA laboratory according to ISO 5682-1 methodology). Spray deposit values were normalised to the volume of 200 l ha^{-1} according to the following expression:

$D_n = D_a \times V_n / V_a$

where

D_n is the normalised spray deposit (µl cm^{-2})

D_a is the measured spray deposit (µl cm^{-2})

V_n is the reference volume (200 l ha^{-1})

V_a is the volume applied (l ha^{-1})

Table 3. Operating parameters adopted in the tests carried out in 2006 in order to compare four different volume application rates combined with the six air velocities listed in Table1 applied at a sprayer forward speed of 6.8 km h^{-1}.

Volume rate (l ha^{-1})	Nozzle size	Number of active nozzles	Operating pressure (MPa)	VMD (µm)
200	015	10	0.90	135
400	015	20	0.90	135
700	04	10	1.40	185
1000	04	20	0.80	200

All tests were made spraying plots of the orchard rows with a test solution of water and yellow Tartrazine E102 (5% v/v). Leaf samples were picked up at 2 m height from the external and internal part of the canopy (Fig. 3): from each sampling position (internal canopy and external canopy), 5 samples, each made of 5 leaves picked up randomly in the sampling area, were taken. Sprayed leaves were then analysed in laboratory and amounts of spray deposits were determined through spectrophotometric analysis (Biochrom LybraS11). Spray deposits were expressed in µl cm^{-2}.

Results were statistically processed by ANOVA ($\alpha = 0.05$), using SPSS 9 package and applying Ryan-Einot-Gabriel-Welsch (REGW) test post-hoc.

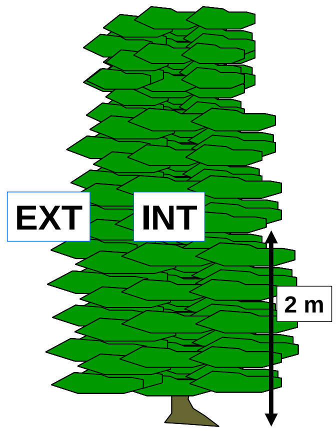

Figure 3. Sampling positions of sprayed leaves in the canopy.

3. RESULTS

Tests carried out in 2005 pointed out that air velocity and position of the leaves (external/internal) within the canopy significantly affected the amount of spray deposits while forward speed did not (Table 4).

Table 4. Significance of operating parameters examined in the tests carried out in 2005 (ANOVA, $\alpha = 0.05$)
ns = not significant; * = poorly significant; ** = significant; *** very significant.

Parameter	Degrees of freedom (df)	F	p-level
Forward speed	3	2169.799	0.442^{ns}
Air velocity	5	4.779	0.000^{***}
Leaf position	1	161.742	0.000^{***}
Forward speed X air velocity	15	2.620	0.001^{***}
Forward speed X leaf position	3	0.340	0.797^{ns}
Air velocity X leaf position	5	18.308	0.000^{***}
Forward speed X air velocity X leaf position	15	1.919	0.023^{**}
Error	192		

Use of high air velocities led to a decrease of average spray deposits on the leaves in the external part of the canopy, independently of the forward speed adopted (Fig. 4 and Fig. 5).

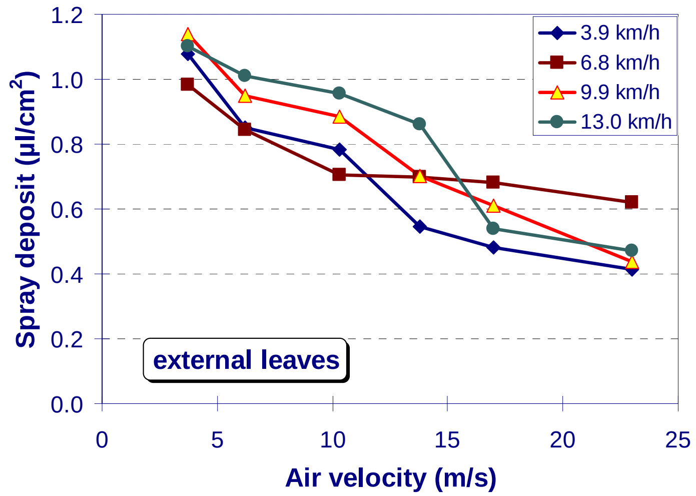

Figure 4. Average spray deposits registered on the leaves of the external part of the canopy in function of the air velocity adopted and working at different forward speeds.

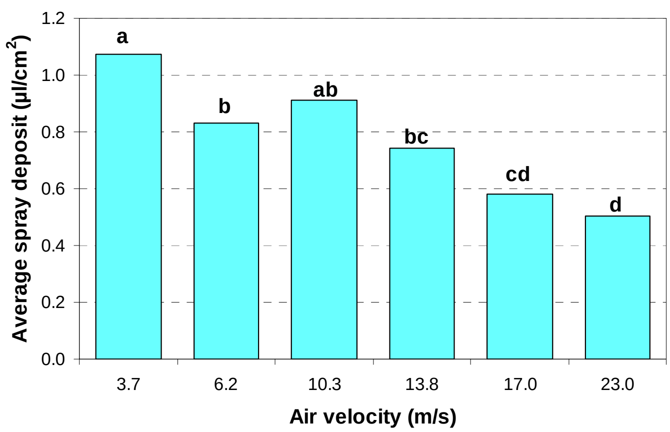

Figure 5. Average spray deposits measured on the leaves of the external part of the canopy in function of the air velocity adopted averaged for all sprayer speeds (REGW test, $\alpha = 0.05$; different letters mean significant differences).

On the outer leaves of the canopy best results in terms of spray deposition were achieved adopting the highest forward speed (13.0 km h^{-1}) for air velocities up to 15 m s^{-1}, and working at 6.8 km h^{-1} forward speed when higher air velocities were employed (Figure 6). The use of the lowest forward speed (3.9 km h^{-1}) generally provided the worst results in terms of spray deposits. Nevertheless, changing the forward speed no statistically significant differences, in terms of spray deposits on the leaves, were observed (Table 4).

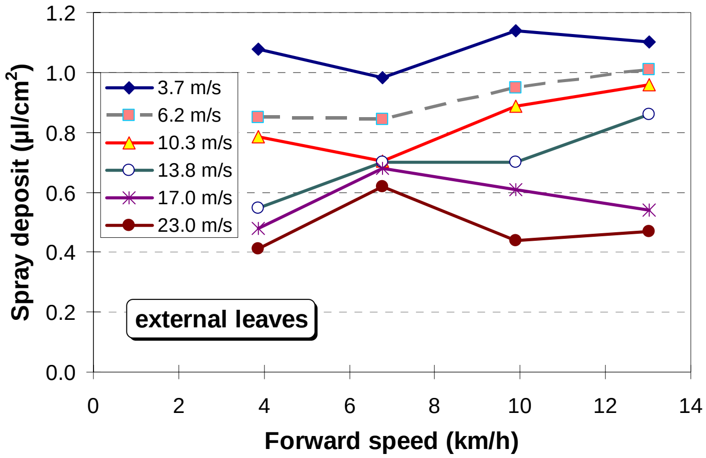

Figure 6. Average spray deposits measured on the leaves of the external part of the canopy in function of the forward speed adopted and working with different air velocities.

Concerning the leaves in the inner canopy, for all the forward speeds taken into account, best results were obtained employing an air velocity around 14 m s^{-1}; lower air velocities were insufficient to enable a good penetration of sprayed droplets into the canopy and higher air velocities made the spray pass through the canopies over the rows, blowing away from the leaves a lot of droplets (Fig. 7 and Fig. 8).

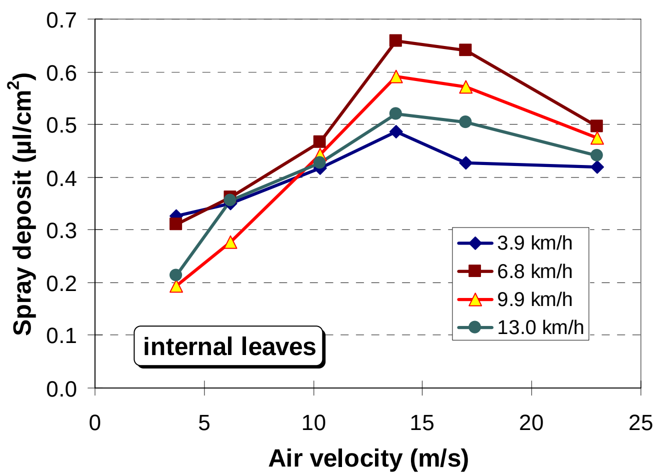

Figure 7. Average spray deposits measured on the leaves of the internal part of the canopy in function of the air velocity adopted and working at different forward speeds.

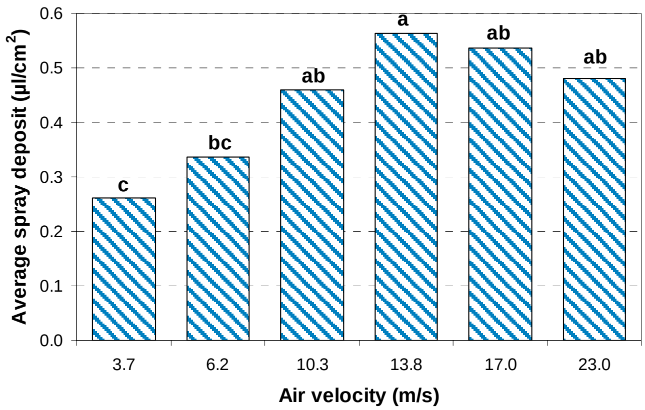

Figure 8. Average spray deposits measured on the leaves of the internal part of the canopy in function of the air velocity adopted averaged for all sprayer speeds (REGW test, $\alpha = 0.05$; different letters mean significant differences).

Highest values of the average spray deposit on the internal leaves were reached working at about 7 km h^{-1} and adopting an air velocity between 14 and 17 m s^{-1} (Fig. 9). Differences in spray deposits due to different forward speeds were not statistically significant.

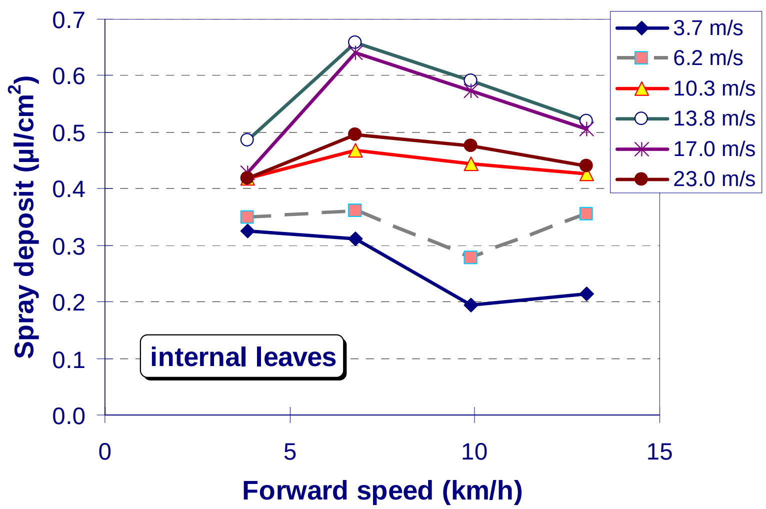

Figure 9. Average spray deposits measured on the leaves of the internal part of the canopy in function of the forward speed adopted and working with different air velocities

Tests carried out in 2006 confirmed that air velocity significantly affected the amount of spray deposits on the leaves while volume application rate was not significant (Table 5).

Table 5. Significance of operating parameters examined in the tests carried out in 2006 (ANOVA, $\alpha = 0.05$).
ns = not significant; * = poorly significant; ** = significant; *** very significant.

Parameter	Degrees of freedom (df)	F	Sig.
Volume application rate	3	1.819	0.143^{ns}
Air velocity	5	6.342	0.000^{***}
Leaf position	1	46.197	0.000^{***}
Volume application rate X air velocity	15	0.736	0.748^{ns}
Volume application rate X leaf position	3	0.903	0.479^{ns}
Air velocity X leaf position	5	0.969	0.453^{ns}
Volume application rate X air velocity X leaf position	15	0.770	0.729^{ns}
Error	453		

Spray deposits on the leaves measured in the trials conducted in 2006 generally resulted in higher deposits than those achieved in 2005, because of a less dense tree canopy surface that was a consequence of the very hot and dry season. Nevertheless, the results obtained confirmed the tendencies observed in the previous year: increase of the air velocity reduced the spray deposition on the external canopy (Fig. 10), while the best coverage of leaves inside the canopy was obtained employing an air velocity of about 10 m s^{-1} (Fig. 11).

In both cases, however, curves of the normalised average spray deposits achieved applying different volume rates were similar. Comparing the average spray deposits registered on the external and on the internal leaves in function of the different spray volumes tested (Fig. 12), slight and not statistically significant differences were found, especially not concerning external leaves. Regarding inner leaves, the lowest spray deposition was observed applying the volume of 700 l ha^{-1}, with an average deposit below 1.0 µl cm^{-2}.

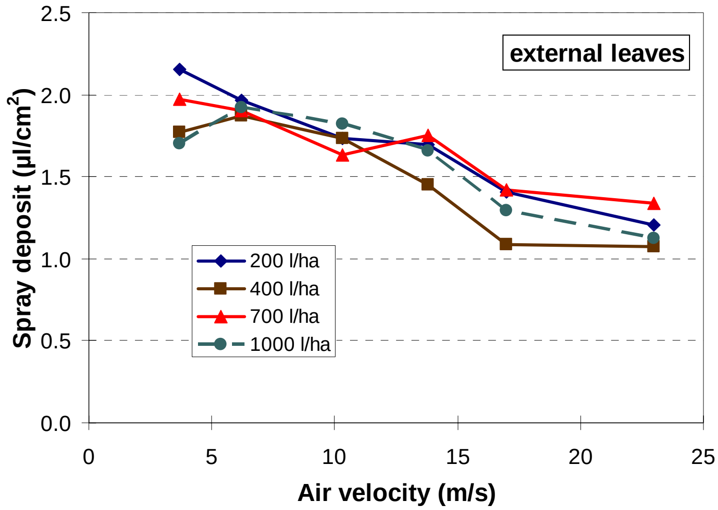

Figure 10. Average spray deposits measured on the leaves of the external part of the canopy in function of the air velocity adopted and applying different volume rates.

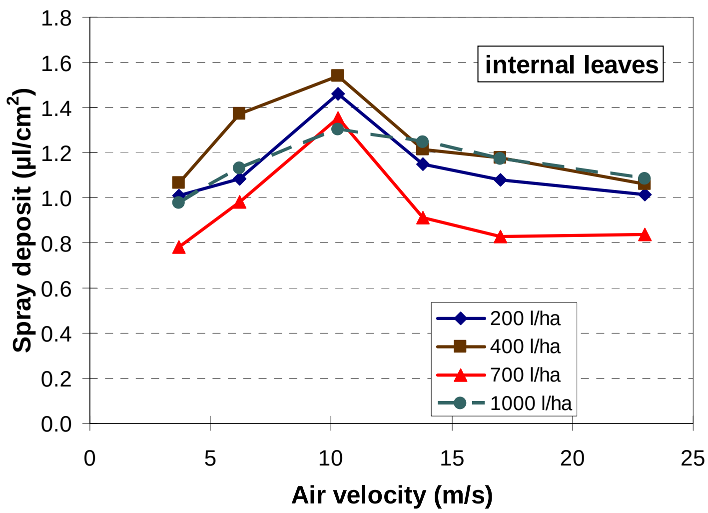

Figure 11. Average spray deposits measured on the leaves of the internal part of the canopy in function of the air velocity adopted and applying different volume rates.

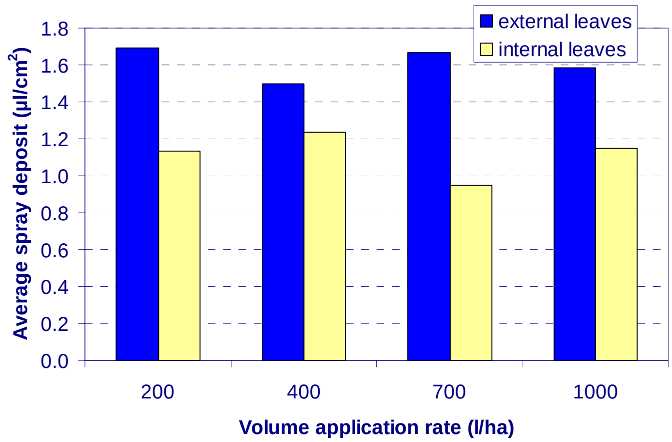

Figure 12. Average spray deposits measured on external and internal leaves in function of the volume applied in the tests carried out in 2006 averaged for all air velocities.

4. DISCUSSION AND CONCLUSION

Test results pointed out that, in our operating conditions, spray deposits on the external canopy are generally improved adopting a high forward speed (13 km h^{-1}), while deposits on the inner leaves can be significantly increased adopting a forward speed of 7 km h^{-1} with respect to the lowest (4 km h^{-1}) or highest (13 km h^{-1}) values of the range investigated.

In general terms, the use of air velocities measured on the target in the range between 10 and 15 m s^{-1} enabled to achieve an even distribution of spray deposition on the canopy. Values of spray deposits on the inner and on the outer leaves in such conditions, in fact, got closer (0.65 µl cm^{-2}) and the best compromise between the decreasing curve of deposits on the external leaves and the increasing curve of the deposits on the internal leaves was found (Fig. 13).

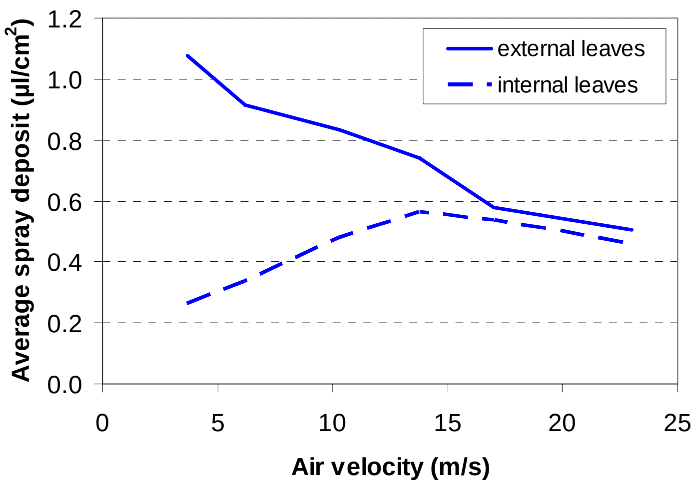

Figure 13. General trend of average spray deposits on external and internal leaves in function of the air velocity employed.

To apply different volume rates, keeping constant the forward speed and the air velocity on the target, did not significantly affect spray deposition, especially on the external leaves. The use of high spray volumes seemed to slightly inhibit the penetration of droplets inside the canopy as average deposits on the internal leaves when 700 or 1000 l ha^{-1} were applied sometimes tended to decrease with respect to the values registered applying 200 or 400 l ha^{-1} (Fig. 14).

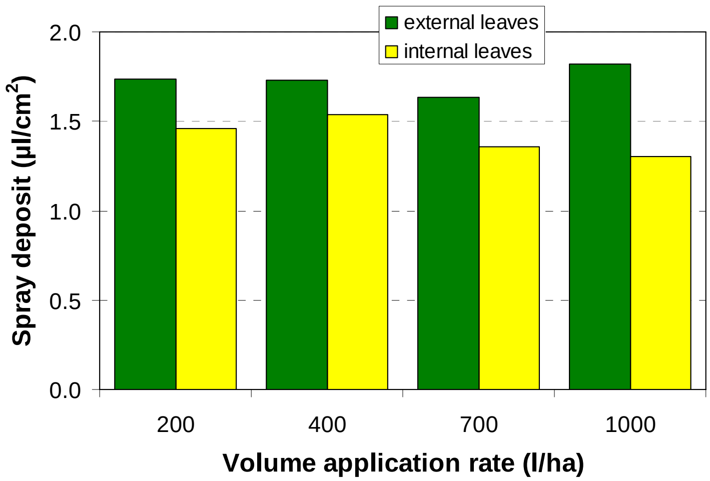

Figure 14. Average spray deposits registered on external and internal leaves in function of the volume applied: tests carried out adopting a forward speed of 6.8 km h^{-1} and an air velocity of 10.3 m s^{-1}.

On the basis of all the data collected, the best combination of parameters to maximise spray deposits and to reach a uniform coverage of the canopy was the one featured by a forward speed of 7 km h^{-1}, an air velocity on the target of 14 m s^{-1} and a volume of 400 l ha^{-1}.

Test results proved the importance of having the possibility to make a fine adjustment of the air velocity addressed to the target. To obtain an even vertical air profile, both in terms of velocity and direction, is certainly helpful to achieve a good evenness of spray distribution within the whole canopy. From this point of view, all new orchard sprayer designs should aim at providing nozzles and air spouts fixed on vertical supports, so that liquid and air outlets are closer to the vegetation.

Nevertheless, significant improvements for air adjustment can be obtained also on conventional air-assisted sprayers, which actually are the most spread ones. They are still preferred to new sprayers developed in height because of their major handiness, for instance working in orchards covered by hail nets where there are height limits for tractors and operating machines.

Research aimed at obtaining a better repartition of the air flux from conventional axial fans, in order to guarantee a more even coverage of the whole canopy, are actually under their way.

5. ACKNOWLEDGEMENTS

Authors wish to thank Nobili company for providing the sprayer used in the tests and Brunetti farm for the support in the execution of orchard tests.

6. REFERENCES

Cross, J., P. Walklate, R. Murray and G. Richardson. 2003. Spray deposits and losses in different sized apple trees from an axial fan orchard sprayer: 3. Effects of air volumetric flow rate. *Crop Protection* 22 (2), 381-394.

Holownicki, R., G. Doruchowski, A. Godyn and W. Swiechowski. 2000. Effects of air jet adjustment on spray losses in orchard. *Aspects of Applied Biology*, 57, 293-300.

Kaul, P., H. Koch, H. Knewitz, K. Schmidt and S. Gebauer. 2004. Proposals for the improvement of orchard sprayer instructions - limits and adjustment of the vertical distribution. *Nachrichtenblatt des Deutschen Pflanzenschutzdienstes,* 56 (4), 77-82.

ISO 5682-1. 1996. – Equipment for crop protection – Spraying equipment – Part 1: test methods for sprayer nozzles.

Marucco, P. and M. Tamagnone. 2004. Performance of an adjustable and multiple air flow sprayer in orchards. *Aspects of Applied Biology*, 71 (1), 261-266.

Pergher, G. 2006. Calibration of air-assisted sprayers for applications in orchards. *Informatore Fitopatologico*, 56 (11), 8-11.

Vereecke, E., J. Langenakens, A. De Moor, M. Pieters and P. Jaeken. 2000. The air distribution generated by air-assisted orchard sprayers. *Mededelingen - Faculteit Landbouwkundige en Toegepaste Biologische Wetenschappen, Universiteit Gent,* 65 (2b), 991-1000.