The Effect of Air Flow Rate on Spray Deposition in a Guyot-trained Vineyard

G. Pergher and R. Petris

Department of Agriculture and Environmental Sciences, University of Udine

Viale delle Scienze 208, 33100 Udine - Italy.

gianfranco.pergher@uniud.it; raffaela.petris@uniud.it

ABSTRACT

The objective of this study was to analyse the effects of different air flow rates on spray deposition in a Guyot-trained vineyard (2.0 m row spacing) using a commercial air-assisted sprayer. Two experiments were performed at growth stages 17 (inflorescences fully developed) and 33 (beginning of berry touch; Eichorn and Lorenz scale). The air flow rate treatments included: zero (fan off), 3.17 m^3/s, 4.19 m^3/s, and 5.33 m^3/s, with six replicates on randomised blocks. Spray deposits were measured on both the upper and under side of leaves, and on bunches, using a water-soluble dye (Tartrazine) as a tracer. At growth stage 17, the reduction of the air flow rate from 5.33 m^3/s to 3.17 m^3/s significantly increased overall mean deposition (+37%). The effect was mainly owing to an increase in deposits on the leaf upper side (+67%); on the under side, however, deposits were similar, while less variable for the high air flow rate (C.V. = 44% versus 63%). At growth stage 33, no significant differences were observed on either the leaves or the bunches. Total deposition on the canopy was in any case best for the low air flow rate (3.17 m^3/s) treatment (47% and 57%, respectively, at the first and second growth stages). The results showed the potential for reducing air flow rates in this type of vineyard in order to reduce spray drift and power consumption.

Keywords: Spray deposition, Guyot vineyard, Air flow rate, Italy

1. INTRODUCTION

Mitigation of spray drift is currently one of the main objectives of political strategies, intended to reduce the impacts of pesticides on human health and the environment, and more generally to achieve a more sustainable use of pesticides (European Union Commission, 2006). One way of reducing spray drift may be to correctly adjust the air flow rate of the sprayer, depending on the canopy size, leaf density, and row distance (Marucco *et al.*, 2008). In general, the air volumetric flow rate should be sufficient to carry the droplets onto the target and move the foliage to improve deposition in the inside of the canopy and on the under side of leaves. In apple orchards, too small air volumes (below 7.7 m^3/s) resulted in overspraying of the leaves nearest to the nozzles, and in underspraying of the tops of the trees (Randall, 1971). In smaller trees and in vineyards, on the other hand, too large volumes may reduce deposition owing to canopy compression (Hislop, 1991). Excessive air volumes have also been reported to increase drift losses in apple orchards (Cross *et al.* 1997) and in vineyards (Balsari and Marucco, 2004).

Pergher (2005) reported that the reduction of the air flow rate from 10.6 m^3/s to 6.3 m^3/s in a Casarsa-trained vineyard increased mean foliar deposits by 25% to 30%. However, a further reduction to 4.7 m^3/s had a much smaller effect (+10%) on mean deposition (Pergher, 2006), while increasing deposit variability in the middle portion of the canopy, where the foliage was particularly dense (> 5 leaf layers), and could not be recommended. These results suggest that air flow rates might be further reduced in vineyards with thinner canopies and narrower row distances. In fact, in the North-East of Italy, most vineyards are still trained to the traditional espalier systems, such as Sylvoz and Casarsa, with typically dense and large canopies. Recently, however, in an effort to improve grape and wine quality, they are increasingly being replaced by vertical shoot positioned (VSP) trellises, trained to the Guyot or Spur Cordon systems. Planting density have increased (from 2000 to 4000 or even 8000 vines/ha), and row distances have decreased (from 3.5 to 2.0 m, or less). Canopy management techniques, such as shoot trimming, positioning and tying, are becoming common in an effort to maintain a limited number of leaf layers (below 2.5, as recommended by Intrieri and Poni, 1995, and others).

The objective of this study was to analyse the effects of different air flow rates on spray deposition in a Guyot-trained vineyard, with a 2.0 m row spacing, using a commercial air-assisted sprayer.

2. MATERIALS AND METHODS

2.1 The Vineyard

The experiments were performed in Villanova di Farra (GO, N.E. Italy), in a Guyot-trained vineyard (cv: Chardonnay). Planting distances were 2.00 m between the rows, and 0.80 m in the row; thus, the plant density was 6250 vines/ha. Posts were 1.65 m high, and placed every five vines. Two fixed trellis wires were used, at 0.70 m and at 1.60 m height, to support the horizontal canes and the shoots, respectively; two couples of movable catch wires, placed at 0.95 and 1.30 m height, were used for vertical shoot positioning. Standard canopy management operations were performed, including side and top trimming, suckering (or the removal of shoots arising from below the cordon), manual and mechanical leaf removal in the fruit zone, and cluster thinning. The vineyard floor was managed with alternate-row tillage and alternate-row cover.

2.2 The Sprayer

The sprayer was a trailed, air-assisted model (Friuli ATI 600, Agricolmeccanica, Figure 1), fitted with an axial-flow fan (diameter: 700 mm), and 10 hydraulic nozzles (Albuz ATR brown; orifice diameter: 1.00 mm), arranged in a semi-circle around the fan's outlet. The fan was driven by hydraulic transmission, connected to the external links on the tractor, allowing continuous adjustment of the rotational speed by means of a flow limiting valve. The air flow rate was assessed according to the standard ISO/FDSIS 9898 (1999), based on 44 air speed measurements across the section of a pipe (diameter: 1.05 m; length: 2.00 m), connected to the suction side of the fan. The resulting volumetric air flow rates were 5.33 m^3/s, 4.19 m^3/s, and 3.17 m^3/s, at maximum, intermediate, and minimum fan speed, respectively. The air speed was measured on the right-hand side of the sprayer, at a horizontal distance of 1.0 m from the fan's centre (equal to half the row distance of the vines), every 0.25 m height between 0.50 m and 2.00 m (or the maximum expected range of the vine canopy), using a

Figure 1. The sprayer and the tractor used for the experiment.

HHF23 anemometer (Omega Engineering, Inc.). Average air velocities were 5.1 m/s, 7.1 m/s, and 9.3 m/s, respectively, for the low, medium and high air flow rate treatments.

2.3 First Experiment

The first experiment was performed on 25 May 2005, at growth stage 17 (inflorescences fully developed; Figure 2) of Eichorn and Lorenz classification (Eichorn and Lorenz, 1977). The experimental design included one main factor (air flow rate) and two sub-plot factors (leaf side and leaf location), arranged in six randomised blocks. The treatments included:

- air flow rate: zero (no fan), low (3.17 m^3/s), and high (5.33 m^3/s);
- leaf side: adaxial and abaxial (which will be further referred to as "upper" and "under" side, respectively);
- leaf location: outside and inside, at a horizontal distance of more or less than 0.06 m, respectively.

Each of the 18 plots was 36 m long and 24 m wide (11 rows). The treatments were applied with one pass on each side of the middle row in each plot, using the nozzles on the right-hand side of the sprayer only.

Before the experiment, mechanical suckering and manual vertical shoot positioning had been performed, the latter by using the first couple of catch wires at 0.95 m height. The canopy ranged from 0.60 to 1.70 m height on the ground. In order to adjust the sprayed area to the canopy size, only three nozzles (No. 2, 3 and 4 from below) were used, following visual assessment of the droplet trajectories. The total flow rate was 2.02 l/min at 10 bar, and the spray volume, at 6.09 km/h forward speed, was 199 l/ha.

Figure 2. The vineyard at the first stage (25 May 2005; left) and at the second stage (11 July 2005; right). Height zones for leaf sampling are shown.

Before treatment, 36 untreated leaves were taken for the assessment of background deposits and placed each in a Petri dish. The spray mixture contained 8.2 g/l of a water-soluble food dye as a tracer (Tartrazine, Novema s.r.l.), and 16.4 g/l of a pesticide (Siaram® 20, Siapa; containing 13.5% metallic copper). The addition of this pesticide was shown by Pergher (2001) not to affect deposit assessment, and was considered necessary to retain the physical properties of a ''normal'' spray mixture, particularly because of the surfactants contained as additives. A sample of 200 ml of the spray solution was taken from the nozzles before spraying each plot. Air temperature ranged from 24.6 to 28.5° C, with 33% to 43% RH, and wind speed was 0.4 to 0.6 m/s during spray application.

After spraying, 15 sample vines were chosen in the middle of each sprayed row, and two sets of 24 leaves were taken from the inside and outside of the canopy; leaves partially included in the ± 6 cm range were considered as inside leaves. This gave 288 sample leaves per treatment, and 864 for the whole experiment. Sampling was restricted to the height range between 0.60 m and 1.10, since most leaves above this level were too small for processing by the method described later. Each sample leaf was set in a Petri dish (diameter: 150 mm), alternately placed with its upper side, or under side, facing upwards.

On the same day, six more vines were randomly chosen in the vineyard for the assessment of the leaf area index; all their leaves were counted, and one leaf in every five was taken and classified into the above defined locations (outside and inside of canopy).

2.4 Second Experiment

The second experiment was performed on 11 July 2005, at full foliage development (beginning of berry touch, stage 33, Eichorn and Lorenz code, 1977; Figure 2). Before the test, the following canopy management operations had been performed: side and top hedging (at 0.30 m from the row, and at 2.00 m height, respectively), suckering, shoot thinning, partial leaf removal in the fruit zone (0.60 m to 1.00 m height), and vertical shoot positioning, using the second couple of movable catch wires, placed at 1.30 m of height.

The experimental treatments included:
- low (5.33 m^3/s), medium (4.19 m^3/s), and high (3.17 m^3/s) air flow rate;
- leaf side: upper and under side;
- leaf location: outside and inside;
- height range in the canopy: H1: 0.55 to 0.95 m, H2: 0.95 to 1.45 m, H3: 1.45 to 2.00 m; was added as a third subplot factor.

The height range of the canopy was from 0.55 to 2.00 m from the ground; therefore, four nozzles (No. 2, 3, 4 and 5 from below) were used. The total flow rate was 2.57 l/min at 10 bar, and the spray volume, at 6.09 km/h forward speed, was 253 l/ha. The second test was performed in the same way as the first one, except for the following: Before treatment, 36 leaves and 24 bunches were collected for background deposit assessment. Air temperature was 24 to 27 °C, with 47% to 71% RH, and wind speed was 0.5 to 1.4 m/s during spray application. The concentration of spray mixture was 7.4 g/l (Tartrazine) and 14.8 g/l (Siaram® 20).

After spraying each plot, eight sample leaves were taken from each of six canopy zones, divided into three height ranges (H1: 0.55 to 0.95 m; H2: 0.95 to 1.45 m; H3: 1.45 to 2.00 m), and two locations across the canopy (inside and outside, defined as in the first test). This gave 48 leaves per plot, and 864 for the whole experiment. In each plot, eight sample bunches were collected, and each placed in a plastic bag. Four bunches were taken at the outside of the canopy, and four in the inside, covered by leaves on almost one side. This gave 48 bunches per treatment, and 144 for the whole experiment.

2.5 Measurements, Calculations and Statistical Analysis

The day after the field experiment, sample leaves were processed with the following method (Figure 3):

(a) 15 ml deionised water was added in a plastic cylinder (diameter: 3.2 cm);

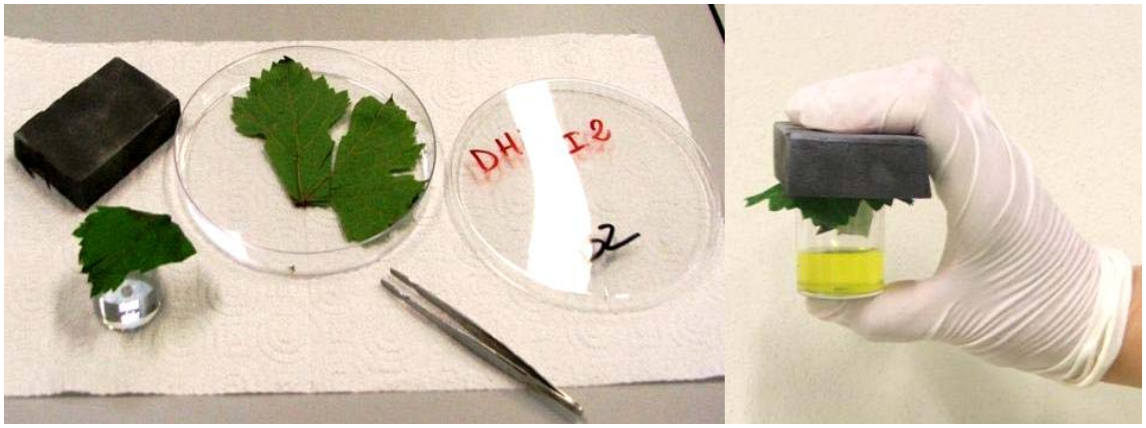

Figure 3. The washing procedure used for leaf deposit assessment.

(b) one portion of leaf, of approx. 30 cm^2 area, was cut out and placed with tweezers on top of the cylinder, with its undisturbed side facing down (i.e., the side that had not been in contact with the bottom of the Petri dish);

(c) after placing a plastic foam disk (height: 2.5 cm) on top, and holding it pressed so as to seal the pot's opening, the latter was vigorously shaken for 10 s.

All above steps were repeated for two more portions of the same leaf, having care not to touch the sampling surface on the leaf (area: 8.04 cm^2) with either the hands or tweezers. Untreated leaves were processed by adding 100 ml deionised water in the Petri dish; each leaf was then gently stirred with tweezers, turned after 1 h to wash the other side, stirred again and allowed to stay for another 1 h. The leaves were then dried and their area was measured with a photometric area-integrating meter (Model LI-3100C, LI-COR Inc.).

Sample bunches (both treated and untreated) were first weighed; after that, 100 ml deionised water was added in each bag, which was then inflated and shaken vigorously for 10 s. A 6 ml sample of the washing solutions from both leaves and bunches was taken, filtered through a 0.22 µm microfilter (Millex-GS, Millipore), and optical absorbance was measured with a spectrophotometer (UV-VIS Lambda 5, Perkin-Elmer: resolution: 0.0001; error: ± 0.002), at 425 nm wavelength. The same was done with the samples of the spray mixture taken in the field.

Tracer deposits per unit leaf area (*d*, in µl/cm^2) were determined for each sample leaf as:

$$d = 1000 \frac{wA}{SA_0} \qquad (1)$$

where: *w*, in ml, is the amount of water used to remove the tracer (15 ml, or 100 ml); *A* is the absorbance of the washing solution; *S*, in cm^2, is the sample area (8.04 cm^2, or double the area of untreated leaves); and A_0 is the absorbance of the spray mixture.

Deposits on bunches were calculated in the same way, but expressed in µl/g fresh weight. Background deposits on untreated leaves were 0.2% (first test) or 0.1% (second test) of the mean deposits of treated samples, while 2.0% for bunches. No correction was made to account for background deposits.

The area of the leaves, taken from the six sample vines in each experiment for the assessment of the LAI, was measured with an area meter (Model LI-3100C, LI-COR Inc.). Based on the number of leaves per vine and their mean area, the partial leaf areas (S_i, in m^2) in each sampling location *i* (height and depth zone), and the total leaf area (*S*, in m^2) were determined for each sample vine. The leaf area index (*LAI*) was then calculated as:

$$LAI = \frac{S}{xb} \quad (2)$$

where: *x*, in m, is the vine length in the row direction; and *b*, in m, is the row spacing.

The leaf layer index (*LLI*) was calculated for each canopy location as:

$$LLI = \frac{S_i}{x\Delta h_i} \quad (3)$$

where: Δh_i, in m, is the corresponding height range.

Total foliar deposition (*D*, % of dose applied) was determined as:

$$D = 2 \cdot 10^4 \, LAI \, \frac{\sum d_i p_i / 100}{V} \quad (4)$$

where: d_i, in µl/cm^2, is the mean foliar deposit (average of leaf upper and under side) in sampling location *i*; p_i is the percentage leaf area in location *i*.

Analysis of variance was applied to the mean deposits calculated from each canopy location, assuming a split-plot design, with one main factor (air flow rate), and all other factors (height and depth on the canopy, and leaf side when applicable), assumed as randomised inside each plot, although formal randomisation had not been possible. The transformation: $d = d^{0.4}$ was applied to normalise the frequency distribution of leaf deposits in the second experiment, and to equalise the variances. However, non-transformed (arithmetic) means were reported in all of the following Tables.

3. RESULTS

3.1 First Test

At growth stage 17 (inflorescences fully developed), the leaf area index (LAI) was 0.51 ± 0.09 (mean ± standard deviation; n = 6 samples). The leaf layer index (*LLI*) was 1.44 in the sampled height range (0.60 m to 1.10 m), inside leaves being 44% of the total leaf area. Most of the leaf surfaces were standing vertical, particularly in the outside of the canopy, facing the nozzles with their adaxial (upper) side. The mean foliar deposit (d) was 0.79 µl/cm^2, and the coefficient of variation (C.V.) between single leaves was 76 %. Analysis of variance (

Table 1. First test: probability level (P) for all effects, obtained from analysis of variance of leaf deposits (d, µl/cm^2).

Source of variation	P
Air flow rate	0.003
Air flow rate x Leaf side	0.000
Air flow rate x Leaf location	0.310
Air flow rate x Leaf location x leaf side	0.370
Leaf side	0.000
Leaf location	0.237
Leaf location x Leaf side	0.929

Table 1) showed that deposits were significantly affected by the air flow rate (p = 0.003), the leaf side (p < 0.000) and their interaction (p = 0.000). The location of leaves across the canopy had no significant effects; in fact, owing to the low leaf layer index, no differences were observed between deposits in the inside and in the outside of the canopy, respectively.

The effect of air flow rate on both leaf sides is shown in Table 2. Relatively to the low (3.17 m^3/s) air flow rate, the zero (no fan) treatment gave similar (1.20 µl/cm^2 vs. 1.17 µl/cm^2) deposits on the leaf upper side, but significantly lower (0.31 µl/cm^2 vs. 0.69 µl/cm^2) on the under side, with a 55% decrease. On the other hand, the high (5.33 m^3/s) air flow rate significantly decreased deposits on the upper side (0.70 µl/cm^2 vs. 1.17 µl/cm^2; -40%), while giving similar deposits on the under side (0.66 µl/cm^2 vs. 0.69 µl/cm^2), relative to the low (3.17 m^3/s) air flow rate treatment.

Table 2. First test: average leaf deposit (d, in µl/cm^2) and coefficients of variation of deposits on single leaves (%) for each air flow rate treatment and leaf location.

Air flow rate	upper side		under side		mean	
	d (µl/cm^2)	C.V. (%)	d (µl/cm^2)	C.V. (%)	d (µl/cm^2)	C.V. (%)
Zero (no fan)	1.20^a	62	0.31^b	92	0.76^b	95
Low: 3.17 m^3/s	1.17^a	59	0.69^a	63	0.93^a	67
High: 5.33 m^3/s	0.70^b	60	0.66^a	44	0.68^b	53

Means in the same column with the same letter do not differ significantly (at p<0.05; Student - Newman – Keul's test).

Deposit variability, as expressed by the coefficient of variation between single sample leaves, was highest for the zero (no fan) treatment (C.V. = 95%; Table 2), while lowest for the high air flow rate (C.V. = 53%), particularly on the under side of leaves (C.V. = 44%). This meant that the low air flow rate gave both the highest average deposit per unit leaf area (0.93 µl/cm^2; Table 2), and the maximum total deposition over the canopy (46.9% of volume applied; Table 3). These values were by 24% or 37% higher, relatively to the zero (no fan) or high (5.33 m^3/s) air flow rate treatments, respectively.

Table 3. Total foliar deposition (D, % of dose applied).

Air flow rate	First test	Second test
Zero (no fan)	37.7	-
Low: 3.17 m^3/s	46.9	56.8
Medium: 4.19 m^3/s	-	53.6
High: 5.33 m^3/s	34.3	49.1

3.2 Second Test

At growth stage 33 (beginning of berry touch), the mean leaf area index (LAI) was 1.71 (SD = 0.55; n = 6 samples). The increase in leaf area, relative to the first test (+235%) was owing both to an increase in canopy height (from 1.70 m to 2.00), and in the leaf layers (LLI = 2.36, or 60% more than at the first growth stage). Most of the foliage was located in the medium and top parts of the canopy (height zones H2 and H3: LLI = 2.72 and 2.60, respectively; Table 4). At height range H2, the canopy was relatively compact, because of the movable catch wires embracing the shoots and leaves, and forming a kind of wall; in the H3 range, on the contrary, the vegetation was more mobile, with frequent gaps, and upper leaf surfaces mostly facing upwards. In the fruit zone (H1), the LLI was only 1.59, because of partial leaf removal, as reported above. The mean foliar deposit (d) was 0.44 µl/cm², and the coefficient of variation (C.V.) between single leaves was 91 %. Analysis of variance showed that deposits were not significantly affected by any of the air flow rate treatments (Table 5). In fact, all treatments yielded comparable deposits (Table 6); the small increase (+10%) from the low (3.17 m^3/s) air flow rate treatment was not significant. However, the interaction air flow rate x location was significant, consistently with lower deposits from the high (5.33 m^3/s) air flow rate on the outside of the canopy (Table 6). The coefficients of variation (C.V.), although higher than at the first growth stage, were similar for all treatments (89% to 94%, Table 6).

Table 4. Second test: leaf layer index (*LLI*) for each canopy location and height range.

Height range	outside		inside		Total	
	LLI	p_i (%)	LLI	p_i (%)	LLI	p_i (%)
1 (0.55-0.95 m)	0.82	10	0.77	9	1.59	19
2 (0.95-1.45 m)	1.74	25	0.98	14	2.72	40
3 (1.45-2.00 m)	1.23	20	1.37	22	2.60	42
Total	1.29	55	1.07	45	2.36	100

The interactions of the main factor (air flow rate) with all other subfactors were not significant. However, all other secondary effects, related to the canopy structure, were statistically significant, indicating that spray deposits were not uniformly distributed over the canopy. In particular (Figure 4), deposits on leaf upper sides were maximal at height zone 1 (0.55m to 0.95 m), nearest the nozzles. On the other hand, deposits on leaf under sides were much more uniform (Figure 4); this was a consequence of the orientation of leaf surfaces, relative to the sprayer. In fact, the deposit ratio between upper and under sides was > 1 on the top of the canopy (leaves mostly facing upwards), while < 1 at the bottom of canopy (leaves mostly facing the nozzles with their upper sides). This gave relatively uniform deposits on leaf under sides (C.V. were 62%, 72% and 66%, respectively, for the low and medium air flow rate treatments).

Low deposition on upper sides on top of canopy may result in insufficient control of some pests, such as powdery mildew. This seems dependent on the geometry of the standard sprayer used in this tests, and might be improved using different sprayers, in order to reduce the distance between the nozzles and the upper part of the canopy. However, the distribution pattern observed was substantially the same for all air flow rate treatments, as signalled by the absence of significant interactions with the canopy locations (Table 5); and excepting the small effect air flow rate x location, as commented above.

Table 5. Second test: probability level (P) for all effects, obtained from analysis of variance of leaf deposits (d, µl/cm²).

Source of variation	P
Air flow rate	0.421
Height range	0.000
Leaf location	0.035
Leaf side	0.000
Air flow rate x Height range	0.145
Air flow rate x Leaf location	0.042
Air flow rate x Leaf side	0.599
Height range x Leaf location	0.481
Height range x Leaf side	0.000
Leaf location x Leaf side	0.000
Air flow rate x Height range x Leaf location	0.558
Air flow rate x Leaf side x Height range	0.536
Air flow rate x Leaf side x Leaf location	0.103
Leaf location x Leaf side x Height range	0.008
Air flow rate x Height range x Leaf location x Leaf side	0.284

Table 6. Second test: average leaf deposit (d, in µl/cm^2) and coefficients of variation of deposits on single leaves (%) for each air flow rate treatment and leaf location.

Air flow rate	outside		inside		mean	
	d (µl/cm²)	C.V. (%)	d (µl/cm²)	C.V. (%)	d (µl/cm²)	C.V. (%)
Low: 3.17 m^3/s	0.52[a]	90	0.41[a]	86	0.46[a]	89
Medium: 4.19 m^3/s	0.47[ab]	86	0.39[a]	97	0.43[a]	91
High: 5.33 m^3/s	0.40[b]	94	0.43[a]	94	0.42[a]	94

Means in the same column with the same letter do not differ significantly (at p<0.05; Student - Newman - Keuls test).

Relative to the first test, average foliar deposits were lower (e.g. 0.46 µl/cm^2, versus 0.93 µl/cm^2, for the low air flow rate, second and first tests, respectively). However, it should be considered that only the height range from 0.50 m to 1.10 m had been sampled in the first test, for the reasons explained in the Material and method section. At nearly the same height range, or height zone 1 (0.55 m to 0.95 m) in the second test, the mean deposit was 0.68 µl/cm^2. While the reasons for this decrease (-26%) were not obvious, they may be connected with the presence of the bunches at the later growth stage, which might have reduced foliar deposition by some extent.

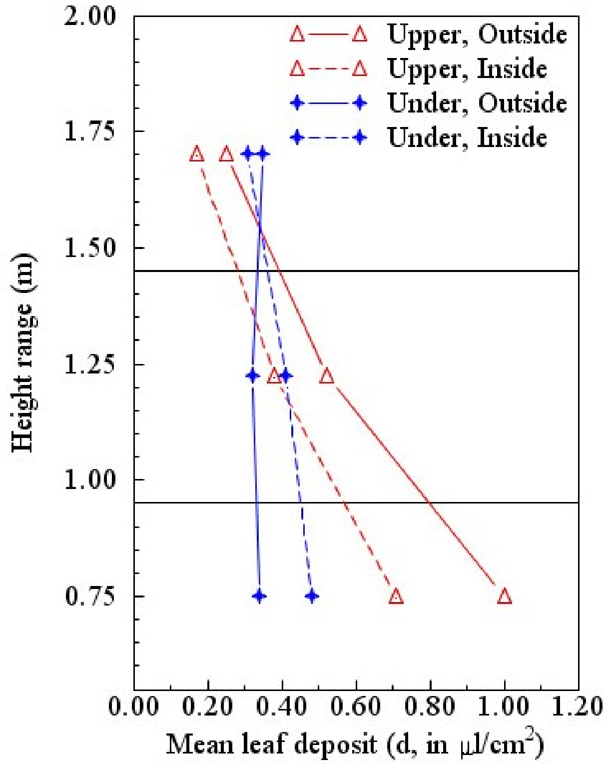

Figure 4. Second test: mean deposit distribution over the canopy (average of all air flow rate treatments).

Deposition on bunches was not significantly affected by the air flow rate treatments (at $p<0.05$; Table 7). Analysis of variance showed a significantly higher deposition on bunches in the outside of the canopy, which was largely expected. This effect was increased by the high air flow rate (5.33 m^3/s) treatment which, on the other hand, also increased deposit variability (C.V. = 47%, versus 22% and 39%, respectively, for the low and medium air flow rates; Table 8).

Table 7. Second test: probability level (P) for all effects, obtained from analysis of variance of bunch deposits (d, µl/g).

Source of variation	P
Air flow rate	0.099
Air flow rate x Bunch location	0.131
Location	0.000

4. DISCUSSION

Based on the present data, it was not possible to determine whether the observed effects were entirely owing to the different air volumes, or by some extent to the different air velocities at

Table 8. Second test: average bunch deposit (*d*, in µl/g) and coefficients of variation of deposits on single bunches (%) for each air flow rate treatment and location across the canopy.

Air flow rate	outside		inside		mean	
	d (µl/g)	C.V. (%)	d (µl/g)	C.V. (%)	d (µl/g)	C.V. (%)
Low: 3.17 m^3/s	1.21[b]	22	0.56[a]	69	0.88[a]	53
Medium: 4.19 m^3/s	1.24[b]	39	0.56[a]	45	0.90[a]	57
High: 5.33 m^3/s	1.81[a]	47	0.57[a]	39	1.19[a]	74

Means in the same column with the same letter do not differ significantly (at p<0.05; Student - Newman - Keuls test).

canopy level. In fact, both quantities were closely associated in this type of sprayer, as in most commercial airblast sprayers, and could not be adjusted independently. Anyway, excessive energy in the air current might have reduced the ability of the foliage to retain or to collect the droplets, e.g. by deflecting the leaves so as to reduce their section, normal to the direction of the spray flux (as suggested by Pergher, 2005). A "shingling effect" (Dibble and Steinke, 1992) owing to foliage compression, on the other hand, seemed of lesser importance; in fact, this would decrease deposition mainly in the inside of the canopy, which was not observed in these experiment.

The results from the first experiment indicated that air-assistance was necessary to improve deposition on leaf under sides, which may be important in order to ensure sufficient control of those fungal diseases, such as downy mildew, that preferably infect through the stomata (generally much more abundant on the lower epidermis of leaves). A higher air flow rate (5.33 m^3/s) might be preferable in this case, because of reduced deposit variability. On the other hand, a lower airflow rate (3.17 m^3/s) would give similar deposition on the leaf under sides, while improving the coverage of the upper sides, thus ensuring better control of pests or diseases that preferably attack there (such as powdery mildew). More importantly, a reduced air flow rate would decrease the potential for spray drift, particularly because of the higher proportion of spray volume that is deposited on the canopy (Table 3).

The effects of the air flow rate treatments on spray deposition were comparably smaller at growth stage 33 (beginning of berry touch), than at the earlier stage. This had been observed before (Pergher, 2005 and 2006), and seemed to be related to the reduced mobility of older, thicker leaves, as well as of the shoots, which at this stage were laden with grapes. Because of this, a low (3.17 m^3/s) air flow rate may be recommended even at this stage, because of reduced drift potential, and power consumption of the fan. The total amount of spray deposited on the foliage (49.1% to 56.8% of volume applied; Table 3) was similar as previously recorded (48.6% to 57.1%) in a Cordon-trained vineyard, with good canopy management and a small number of leaf layers (LLI = 2.49 to 2.59) (Pergher and Petris, 2007). On the contrary, up to 83% total deposition had been recorded in a traditional, Casarsa-trained vineyard with a typically large and dense canopy (LLI = 4.69; Pergher and Petris, 2007). This suggests that the current trend from traditional vineyards towards new, improved training systems, while necessary to meet the increasing demand of high quality products, may also increase environmental concerns, because of a lower percentage of spray retained by the canopy, and a higher risk of spray drift.

5. CONCLUSIONS

At growth stage 17 (inflorescences fully developed), the reduction of the air flow rate from 5.33 m^3/s to 3.17 m^3/s significantly increased mean foliar deposits (+37%). The effect was mainly owing to an increase on the leaf upper side (+67%); on leaf under sides, deposits were similar, but less variable from the higher air flow rate. Relative to the low air flow rate treatment, the no air (fan off) treatment gave similar (+3%) deposits on the upper side, while significantly lower (-55%) on the under side. This shows that a higher air flow rate may give better control of diseases that preferably attack the leaf under sides (downy mildew). However, the lower air flow rate (3.17 m^3/s) may be recommended because of better control of other pests and diseases (powdery mildew) and, more importantly, because of the lower drift potential, partly owing to an increase of the fraction of the spray volume that was retained by the canopy (from 37.7%, high air flow rate, to 46.9%). At growth stage 33, very little effects were observed, probably owing to reduced mobility of both leaves and shoots. The highest foliar deposits were recorded from the low air flow rate (3.17 m^3/s) on both upper and under leaf sides, but differences were in any case small (<10%) and not statistically significant.

Increasing the air flow rate also proved ineffective for improving deposition on bunches located in the inside of the canopy, and partially covered by leaves. This suggests that fungal diseases that affect the grapes may be better controlled through agronomical measures, such as leaf removal. Because of this, a lower (3.17 m^3/s) airflow rate may be recommended even for this later stage. However, total foliar deposition on the canopy was smaller (34% to 57%) in this kind of vineyard, than previously recorded in traditional, Casarsa-trained vineyards with larger denser canopies (up to 82% at full foliage development, Pergher and Petris, 2007). This suggests that the current trend from traditional vineyards towards new, improved training systems, while necessary to meet the increasing demand of high quality products, may also increase environmental concerns, because of a lower percentage of spray retained by the canopy, and higher risks of spray drift.

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