Effect of air-assistance configuration on spray recovery and target coverage for a vineyard sprayer

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Panneton, B. and Lacasse, B. 2004. **Effect of air-assistance configuration on spray recovery and target coverage for a vineyard sprayer**. Canadian Biosystems Engineering/Le génie des biosystèmes au Canada **46**: 2.13 - 2.18. A new approach for a spray recovery sprayer (SRS) was developed for apple orchards (Panneton et al. 2001) and has been adapted to vineyards (Panneton et al. 2003). The vineyard version used two vertical air sleeves to create two air jets, one on each side of the row. The sprayer was equipped with an air-droplet separator for spray recovery. This work aimed to define the effect on spray coverage and spray recovery potential of different air jet angles relative to the row of vines, sprayer ground speed, and the partition of the air flow rate between the two air sources. Each variable was set at two levels to define a full factorial experiment with three replications. Spray coverage was measured on water sensitive paper targets and spray recovery was defined as the ratio of the amount of spray collected to the total amount of liquid emitted by the nozzles for each treatment. Results showed that the orientation of the air sources had a significant effect on both spray coverage and spray recovery. In the centre of the row, decreasing the sprayer ground speed improved coverage. For spray recovery, the distribution of the total air flow rate among the two sources was the most important variable. The best compromise for coverage and recovery was to partition total air flow rate such that 35% was emitted from the sleeve on the sprayer side and to direct this source of air at an angle of 45° to the row and to operate the sprayer at the lowest ground speed (4.4 km/h). **Keywords:** air-assistance, coverage, SRS, spray distribution, spray recovery, vineyards.

Un nouveau type de pulvérisateur muni d'un écran de récupération a été développé pour les vergers de pommiers (Panneton et al. 2001) et adapté pour la culture de la vigne (Panneton et al. 2003). Pour la vigne, le pulvérisateur était muni de deux manches d'air descendant à la verticale de chaque côté du rang de vigne et d'un écran récupérateur de bouillie. Cette étude avait pour but de déterminer l'effet de différentes combinaisons d'orientation du jet d'air par rapport au rang de vigne, de la vitesse d'avancement du pulvérisateur et de la répartition du débit d'air entre les deux sources d'air sur la couverture par la pulvérisation et le potentiel de récupération de bouillie. La couverture a été mesurée avec des cartons hydrosensibles et la récupération de la bouillie a été quantifiée par le ratio de la quantité de bouillie récupérée sur la quantité totale de liquide pulvérisé par les buses. Les résultats ont démontré que l'orientation du jet d'air a un effet significatif sur la couverture et la récupération de bouillie. Au centre du rang, une diminution de la vitesse d'avancement a amélioré la couverture. Pour la récupération de bouillie, la distribution de l'air entre les deux sources de sortie d'air a été l'élément déterminant. Le meilleur compromis pour obtenir une bonne couverture et une récupération a été de répartir le débit d'air de manière à obtenir 35% du débit du côté du pulvérisateur, d'orienter la manche d'air à 45° du rang de vigne et de travailler à la plus faible vitesse d'avancement (4.4 km/h). **Mots clés:** assistance pneumatique, couverture, récupération de bouillie, distribution de la bouillie, vigne.

INTRODUCTION

Restricting pesticides to the target is fundamental to proper pest management (Matthews 2000). The development of tunnel sprayers was an attempt to confine the released spray to the row of vegetation being treated. They also have potential for recycling pesticide waste (Hall 1993). Despite many inherent advantages, tunnel sprayers are not widespread in North America partly because of travel speed and maneuverability limitations (Panneton et al. 2001). A tower sprayer, where the air stream is mostly parallel to the ground, is another means of reducing pesticide loss through airborne drift (Van Ee 1998). A new approach for a spray recovery sprayer (SRS) was developed for apple orchards (Panneton et al. 2001) and adapted to vineyards (Panneton et al. 2003). This approach retained the benefits of tower sprayers and the spray recovery function of tunnel sprayers packaged in a simpler and more flexible implementation. A first series of experiments has been performed to select a suitable configuration (Panneton and Lacasse 2001). The most promising configuration used two air streams, one on each side of the row, and a single air-droplet separator panel on the sprayer side of the row. The air streams were horizontal two-dimensional jets having a uniform velocity profile over the height of the crop.

Appropriate use of air-assistance is required to improve the distribution of deposits and collection efficiency of plant parts (Matthews 2000). At the leaf scale, a better balance between the coverage of the upper and lower surfaces requires some form of air-assistance (Viret et al. 2003). At a larger scale, spray partition within the canopy is affected by airflow rate (Pergher and Gubiani 1995) and airspeed (Randall 1971) as well as the orientation of the airflow and the number of air outlets used to direct the air and the spray to the canopy (Furness and Pinczewski 1985; Gohlich 1985; Pergher et al. 1997; Pezzi and Rondelli 2000). Proper use of air-assistance is not straightforward as a too strong or a too weak air jet may cause inadequate deposit, uneven distribution within canopy and increased environmental contamination (Doruchowski et al. 1997). For the same amount of power, a higher air flow rate at a lower airspeed penetrated trees better and produced better leaf

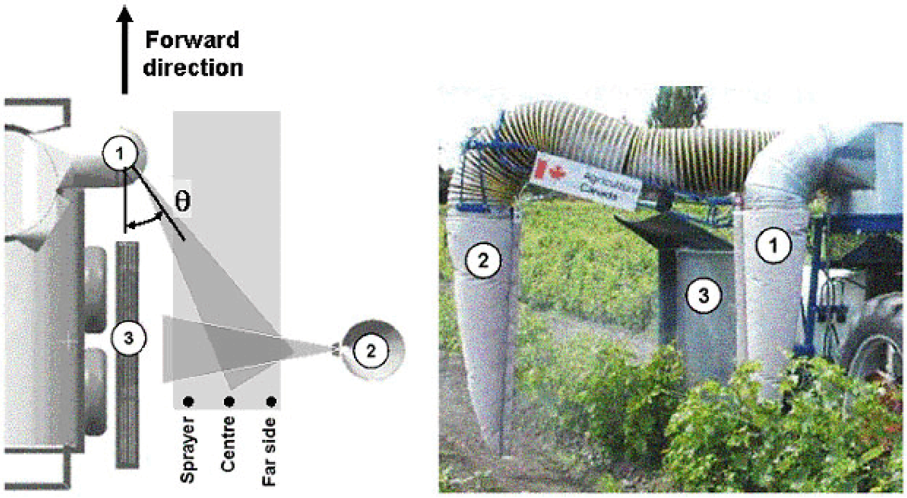

Fig. 1. **Top and front views of the spray recovery sprayer. 1 - Air sleeve on the sprayer side; 2 - Air sleeve on the far side; 3 - Air-droplet separator.**

coverage than lower volumes of higher velocity air (Randall 1971). This held true provided that the airspeed was high enough to form openings for the air stream to penetrate. More air does not automatically imply better coverage. Total deposit was better using a lower air flow rate, while for a higher air flow rate the amount of spray blown through the canopy was increased (Holownicki et al. 2002). These results were reproduced when wind speed was low, but in higher wind speeds mean deposits were lower at the lowest air flow rate (Cross et al. 2003). The type of fan and the shape of the resulting air jet should also be considered. Air speed decays more slowly from a cross-flow fan which produces a 2-dimensional jet (Abramovich 1963) and it was demonstrated that directed air jet sprayers with a converging flow resulted in higher deposits and lowest spray loss even when the flow rate was decreased by a factor of 3 (Doruchowski et al. 1996).

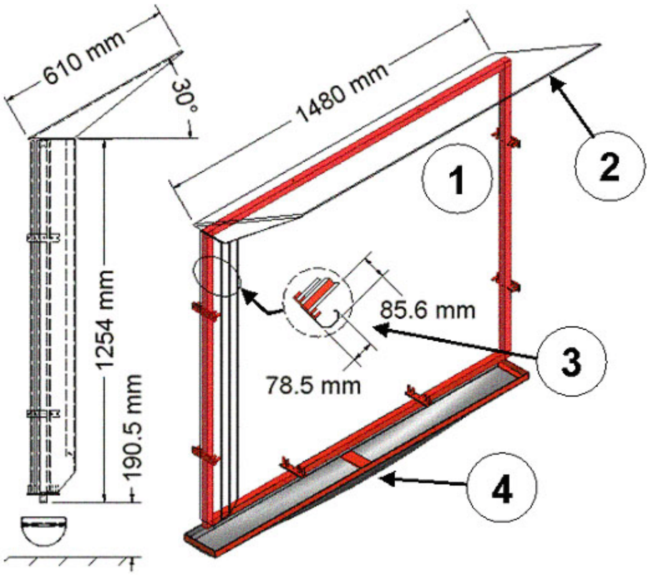

Fig. 2. **Geometry of the air-droplet separator. 1 - air-droplet separator area; 2 - top solid deflector; 3 - trailing edge deflector cross-section; 4 - collection gutter.**

Designing the SRS for vineyards raised questions about the proper placement of the air outlets with respect to the vine and the effect of the air flow rate from each of the outlets. The objective of the work presented here was to define the effect of the air jet angles with respect to the row of vine, the partition of the air flow rate among the two air sources, and the sprayer ground speed on coverage of the vine by the spray and the spray recovery potential.

MATERIAL and METHODS

The SRS used two vertical air sleeves to create air jets, one on each side of the row of vine (Fig. 1). Air exited from the sleeves through a slot of fixed width over the full length of the sleeves. The sleeve design was such that the air speed profile at the exit was uniform (Panneton et al. 2001). On the sprayer side, the slot was 38 mm wide and it was 64 mm on the far side. Horizontal baffles 50 mm long and covering the full width of the exit slots were installed to make the flow parallel to the ground. The sleeves were 1500 mm high and their bottom was 140 mm above the ground. The axis of the air jet from the far side was perpendicular to the row of vines. On the sprayer side, the jet axis was at angle θ with respect to the sprayer axis and vine row (Fig. 1). The distance between the two air exit slots, perpendicular to the row of vines, was 1220 mm. Six nozzle bodies were installed inside each sleeve, laterally in the centre of the exit slots and vertically at 510 mm spacing, the lowest nozzle being at 255 mm above the ground.

The air-droplet separator had four basic components (Fig. 2). The separator itself was a rectangular panel with three layers of screens. Screen material had 700 × 625 wires per metre with a wire diameter of 0.28 mm. Each layer of screen had an open area of 66.1%. The panel was 1480 mm long and 1254 mm high. It was suspended parallel to the vine in line with the air sleeve on the sprayer side and centered with the air sleeve on the far side. A solid plastic deflector was installed above the panel and a second deflector was installed at the trailing edge of the panel to force more air through the air-droplet separator. Finally, a gutter was suspended underneath the panel to collect the liquid intercepted by the separator and to serve as a pumping well.

Experiments were performed in a commercial vineyard planted with Seyval. The vines were trimmed to a width of 500 mm and a height of 1200 mm. All experiments were performed on mature and healthy foliage. During the coverage experiments, the vine was shorter than the height of the air sleeves and the top two nozzles on each side of the row were not used leaving a total of eight nozzles for treating the vine. During the experiments on spray recovery, few shoots were growing above the third nozzle. It was therefore decided to keep only three nozzles active on the sprayer side and four on the far side.

Spray coverage and spray recovery were measured for different combinations of sprayer ground speed, the angle θ (Fig. 1), and the flow rate balance between the air jet on the far side and the one on the sprayer side. Each of these three

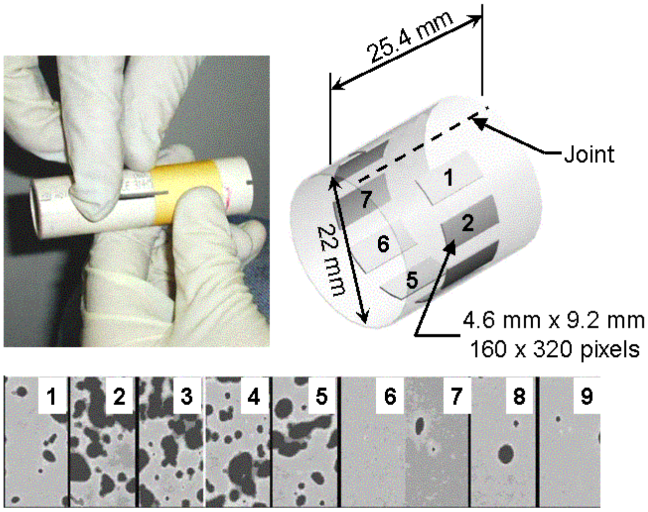

Fig. 3. Tubes of water-sensitive paper used in coverage sampling. Top left: insertion of the metal clip. A slot was made in the PVC tube for inserting the clip. The notch at the right end of the tube served as an alignment guide for positioning tubes in the field and in the camera system.

variables was set at two levels to define a full factorial experiment with three replications. The two travel speeds were 4.4 and 5.8 km/h. The flow rate balance defined the proportions of the air volume delivered on each side of the row. The first number is the percentage of the total flow emitted on the sprayer side. The two values were 35-65 and 47-53. The total output from the fan was fixed at 2.58 m³/s. The angle θ was 35 or 45°.

For the spray coverage experiments, TXVS3 hollow cone nozzles (Spraying Systems Co. Wheaton, Il) operating at 345 kPa were used to generate a fine spray (ASAE 2001). The application volume was 83 and 110 L/ha for a ground speed of 5.8 and 4.4 km/h, respectively. Hollow cone nozzles were used to keep the application volume low enough to avoid saturation of the samplers used for spray coverage measurements (see next paragraph). For spray recovery experiments, XR11002 flat fan nozzles operated at 345 kPa were used generating a medium spray. The application volumes were 225 and 295 L/ha for ground speeds of 5.8 and 4.4 km/h, respectively.

Spray coverage was measured on water sensitive papers (Spraying Systems, Wheaton, IL). Sampling was performed by deploying arrays of water-sensitive tubes (Fig. 3). Tubes were used because sampling is not sensitive to local air flow direction projected in the plane perpendicular to the tube axis. Tube axis was set vertical. Strips of water-sensitive paper were wrapped around PCV tubes (22 mm diameter) and held in place with a metal clip near the joint (Fig. 3). Tube supports holding three tubes were installed such that one tube was directly over the centre of the row of vines and the other two tubes where just at the outer limits of the vine canopy. The tube mid-point was at 600 mm above ground. The joint in the sampling tubes (Fig. 3) was always oriented facing the direction 180° from the travel direction of the sprayer. A total of six tube supports was deployed at random locations along two adjacent rows of vines. The two rows were sprayed travelling in opposite directions to remove any bias from the wind direction. A total of 18 sampling tubes was necessary for each experiment. Great care was taken to maintain the tubes in as dry an environment as feasible. Tubes were always manipulated wearing latex gloves. Except during the actual experiments, tubes were kept in sealed boxes with a packet of desiccant. As a result, the contrast between stained and unstained areas of the water-sensitive paper was always excellent.

Image analysis of sampling tubes was performed to extract the surface of the stained area using a procedure developed previously (Panneton 2002). A motorized sample holder was constructed. By rotating the sample in front of the camera, a series of nine images was grabbed for analysis (Fig. 3). For each image, the percentage of the area that was stained by water was measured. This variable will be referred to as the coverage in this paper. Each image is centered in a 36°sector on the cylinder and no image was acquired at the location of the joint in the wrapped paper. Image numbers (1 to 9 on Fig. 3) identified a unique angular location.

The application volume was not constant since the travel speed was varied while the nozzle output remained constant. For comparing treatments at different application volumes, the following data correction scheme was applied to the coverage raw data. A simple linear correction based on travel speed cannot be applied to coverage data because of overlaps caused by droplets landing one on top of the other on the sampling surface. This is the reason for using a more complex correction scheme. For a spray made from droplets of equal diameter, the coverage is (Spillman 1987):

$$C = 1 - \exp\left\{\frac{kd^2n}{A}\right\} \tag{1}$$

where:

C = coverage,
k = constant depending on spread factor of droplet on sampling surface,
d = droplet diameter,
n = number of droplets, and
A = sampling surface area..

To apply Eq. 1, two hypothesis are required: (1) Equation 1 applies approximately to a polydisperse spray replacing kd^2 with a suitable constant; (2) When the application volume changes, the droplet spectra remains the same which was our case as changes in the application volume resulted solely from changing the sprayer travel speed. Applying these two hypotheses, Eq. 1 can be used to write:

$$C_c(5.8) = 1 - \left\{1 - C(4.4)\right\}^{\frac{4.4}{5.8}} \tag{2}$$

where:

$C_C(5.8)$ = coverage corrected to a ground speed of 5.8 km/h, and
$C(4.4)$ = coverage measured at a ground speed of 4.4 km/h.

Applying Eq. 2 for data correction did not require k and d to be specified explicitly.

During the coverage experiments, a series of reference runs was performed. The data from these reference runs were used as

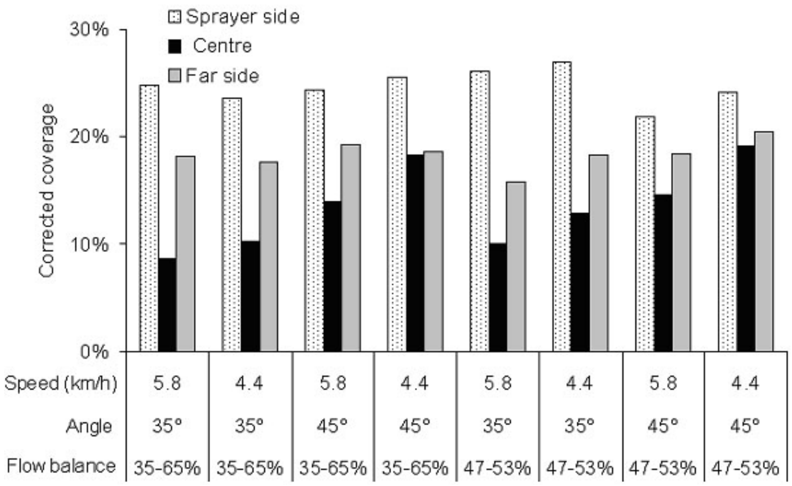

Fig. 4. Corrected coverage per position across row for all treatments.

co-variables in the analysis of variance (Unistat 2002). Using co-variables permitted to account for day-to-day variations in the field conditions (canopy development, air temperature, humidity, etc.). In addition, the amplitude of these variations was limited in two ways. First, the experiment started only after the first time the canopy had been trimmed to a known height (1.2 m) and width (0.5 m). In Quebec, mechanical trimming is done on a regular basis, keeping the canopy volume fairly constant over time. Secondly, experiments were not performed if the mean wind speed (5 min average) recorded on site (Young propeller anemometer, model 5107) exceeded 3 m/s. On each day, a reference run was performed. During the day, a new reference run was performed when the average wind speed changed by more than 1 m/s or the wind direction changed by more than 45°. When treatments were compared, data were transformed according to the linear model that takes into account the effect of the co-variable. The basic linear model was:

$$C_{i,j} = \mu_c + V_i + \theta_i + R_i + V_i\theta_i + V_iR_i + \theta_iR_i + \beta\tilde{C}_{Ci,j} + \varepsilon_{i,j} \tag{3}$$

where:

$C_{i,j}$ = mean coverage for treatment i and replicate j,
μ_C = overall mean coverage,
V_i = effect of sprayer ground speed for treatment i
θ_i = effect of angle for treatment i,
R_i = effect of air flow balance for treatment i,
$V_i\theta_i$ = interaction,
V_iR_i = interaction,
θ_iR_i = interaction,
β = slope of linear regression between co-variable and $C_{i,j}$,
$\tilde{C}_{Ci,j}$ = deviation of co-variable from its mean value associated with treatment i and replicate j, and
$\varepsilon_{i,j}$ = error term.

The mean coverage was the average of the coverage values (corrected for application volume) from a single tube. Prior to averaging, data from image 5 was removed to maintain sampling symmetry around the tube as no data were available over the joint in the sampling tube. The slope β was the slope of the linear regression for $C_{i,j}$ with $C_{Ci,j}$ as the independent variable. The corrected coverage, $\hat{C}$, was defined as:

$$\hat{C}_{i,j} = C_{i,j} - \beta\tilde{C}_{Ci,j}$$

$$= \mu_c + V_i + \theta_i + R_i + V_i\theta_i + V_iR_i + \theta_iR_i + \varepsilon i, j \tag{4}$$

Spray recovery experiments were performed during a single day where wind was less than 1 m/s. Conditions were steady and no reference runs were incorporated in the experimental design. Spray recovery was defined as the ratio of the amount of spray collected by the air-droplet separator to the total amount of liquid emitted by the nozzles. Two swaths were sprayed travelling in opposite directions for a total travel distance of about 500 m. The time required to spray the two rows was measured with a stop watch. The spray collected by the air-droplet separator was pumped using a small electric pump in a dedicated tank. Before each experiment, spray was emitted until the air-droplet separator was saturated with water and then sufficient time was allowed for the separator to drain. The electric pump was operated until no more liquid was aspirated. The dedicated tank was emptied and then the two rows were sprayed. During the turn between the two rows, the nozzles and the stop watch were stopped. At the end of the two rows, the sprayer was stopped. The electric pump ran until no more liquid was aspirated and the collected liquid was measured with a graduated cylinder while emptying the recovery tank. The amount of liquid emitted by the nozzles was calculated from the recorded time and the calibrated nozzle output (0.86 L/min per nozzle).

RESULTS and DISCUSSION

In the centre of the canopy, the coverage was significantly affected by the angle ($p < 0.001$) and the ground speed ($p = 0.002$). The effect of the air flow balance was not significant ($p>0.10$) in the centre. On the far side, the angle had a less significant effect on the coverage ($p = 0.073$) than in the centre and none of the other independent variables did have a significant effect ($p>0.10$). On the sprayer side, none of the independent variables did produce a significant effect on coverage. At all locations, 2-way interactions were not significant ($p > 0.10$). In the centre of the row width, a large angle and a lower sprayer speed increased the coverage (Fig. 4). On the far side, a larger angle was associated with a larger coverage. On the far side and on the sprayer side, the coverage did not change by a large amount. On the sprayer side, the average coverage taken over all treatments was 25% with a range from 22 to 27% (Fig. 4). On the far side, the average was 18% with a range from 16% to 20%. Conversely, coverage in the centre did change by a larger amount with a mean value of 13% and a range from 9 to 19%. As a result, the uniformity of coverage across the row was highly dependent on the coverage in the centre. The best uniformity was obtained when the coverage in the centre was maximised. In general, the uniformity across the row tended to be better when the coverage in the centre was higher. The angle of the air jet on the sprayer side had the greater impact on coverage. When the angle was larger, the flow from this air jet penetrated further inside the canopy before interacting with the air jet coming from the far side. At 35°, the jet from the sprayer side was curved towards the recovery panel before it reached the centre of the row of vine. Qualitatively, this explanation is in agreement with simulation results (Fig. 5) obtained using a computational fluid dynamic model (Leroy et al. 2002).

Spray recovery was significantly affected by the flow balance ($p = 0.001$), angle ($p = 0.003$) and ground speed ($p = 0.013$). None of the two-way interactions did produce a statistically significant effect ($p > 0.10$). The 35-65 flow balance, a 35° angle and a ground speed of 4.4 km/h were all associated with increased recovery (Fig. 6). The reason for these results was similar to the one explaining the effect of the angle on spray coverage. As relatively more air was coming from the far side and as the angle of the air jet on the sprayer side was smaller, a larger portion of the droplet carrying flow from the sprayer side was forced to turn under the action of the air jet from the far side (Fig. 5). As a result a larger portion of the total spray was recovered by the air-droplet separator.

As the experiments have pointed out, optimising both coverage and spray recovery imposes conflicting requirements. For coverage, the flow balance was not a significant variable and the 35-65 balance resulted in higher recovery. Jet angle had a greater impact on coverage than it had on recovery (Fig. 7). On average, increasing angle from 35 to 45° increased coverage in the centre from 9 to 16% while it decreased recovery from 14 to 12%. As a compromise, an angle of 45° is recommended. Finally, the sole significant effect of the sprayer ground speed was for the coverage in the centre with a value of 4.4 km/h associated with a larger coverage and a better coverage uniformity across the row.

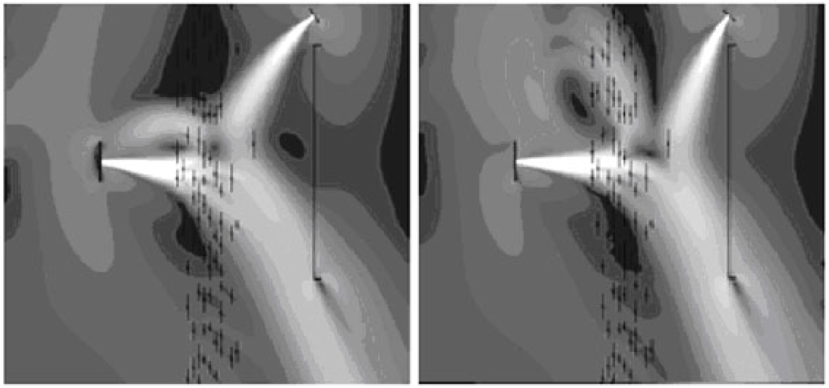

Fig. 5. **Results of a numerical simulation. White to black represents higher to lower airspeed. Left: $\theta = 45°$; right: $\theta = 35°$.**

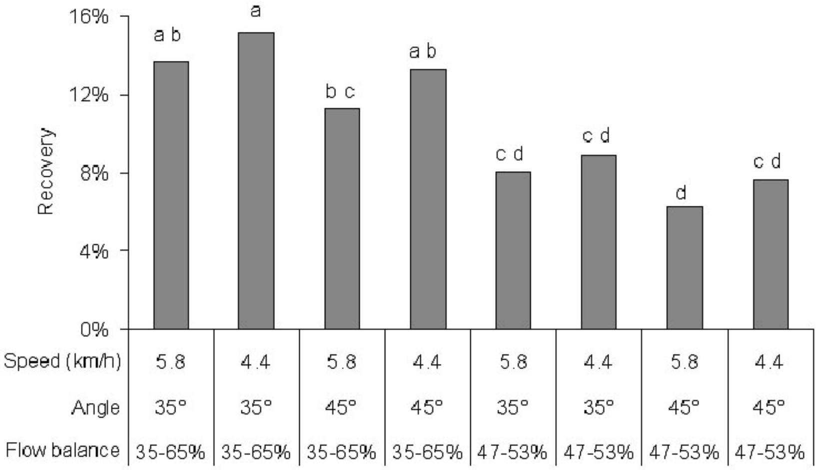

Fig. 6. **Spray recovery for all treatments. Bars labelled with the same letter represent values that are not statistically different at the 5% confidence level. Tukey HSD test (Unistat 2000).**

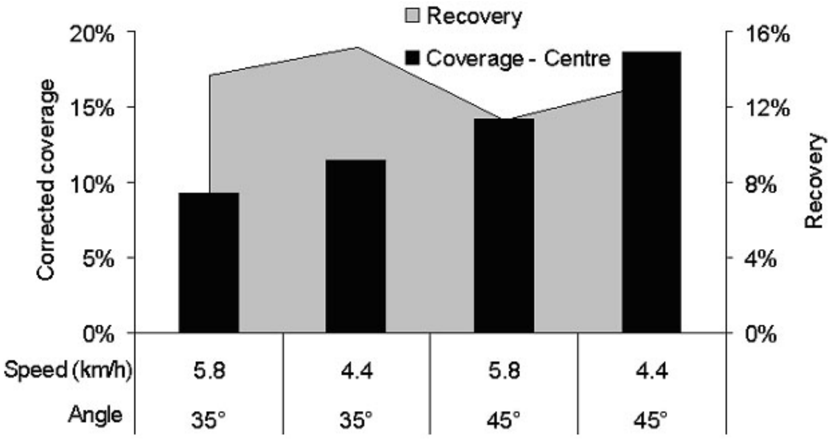

Fig. 7. **Effects on coverage and recovery of angle and specific flow rate at a flow balance of 35 - 65.**

CONCLUSION

Implementing air-assistance on an agricultural sprayer can be a subtle process. For the spray recovery sprayer used in these experiments, the process was complicated by the use of two interacting sources of air-assistance. Results have shown that the orientation of the air jets had a significant effect on both spray coverage and spray recovery. In the centre of the row, decreasing the ground speed improved coverage. For spray recovery, the distribution of the total air flow rate between the two sources was the most important variable followed by the orientation of the jets and the ground speed. In the end, the selection of proper design parameters must resolve the conflicting requirements for optimised coverage and recovery. The best compromise was to partition the total air flow rate such that 35% of the flow was emitted from the sleeve on the sprayer side, next to the air-droplet separator used for spray recovery. The best compromise further resulted from the axis of this source of air pointing at an angle of 45° with respect to the row of vine and from using the slower ground speed (4.4 km/h).

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REFERENCES

Abramovich, G.N. 1963. General properties of turbulent jets. In *The Theory of Turbulent Jets,* ed. L.H. Schindel, 3-49. Cambridge, MA: The Massachusetts Institute of Technology.

ASAE. 2001. ASAE S572. Spray nozzles classification by droplet spectra. In ASAE Standards 20001, 401-403. St. Joseph, MI: ASAE.

Cross, J.V., P.J. Walklate, R.A. Murray and G.M. 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: 381-394.

Doruchowski, G., S.A. Svensson and L. Nordmark. 1996. Deposit and loss of spray in orchard as affected by spray discharge system and air jet setting. *Acta Horticulturae* 422: 383-384.

Doruchowski, G., R. Holownicki and A. Godyn. 1997. Effect of spray emission system and air-jet setting on deposit and loss of spray in apple orchard. *Journal of Fruit and Ornemental Plant Research* 3: 145-156.

Furness, G.O. and W.V. Pinczewski. 1985. A comparison of the spray distribution obtained from sprayers with converging and diverging airjets with low volume air assisted spraying on citrus and grapevines. *Journal of Agricultural Engineering Research* 32: 291-310.

Gohlich, H. 1985. Deposition and penetration of sprays. In *Symposium on Application and Biology,* BCPC Monogram No. 28: 173-182.

Hall, F.R. 1993. Applications to plantation crops. In *Application Technology for Crop Protection*, eds. G.A. Matthews and E.C. Hislop, 187–213. Wallingford, U.K.: CAB International.

Holownicki, R., G. Doruchowski, A. Godyn and W. Swiechowski. 2002. The effect of air jet velocity on spray deposit in an apple orchard. *Aspects of Applied Biology* 66: 277-283.

Leroy, V., B. Panneton, D.R. Rousse and R. Thériault. 2002. Simulation of a pesticide air stream within a vineyard. NABEC Paper No. 02-017. St. Josephs, MI: ASAE..

Matthews, G.A. 2000. A review of the use of air in atomisation of sprays, dispersion of droplets down wind and collection on crop foliage. *Aspects of Applied Biology* 57: 21-27.

Panneton, B. 2002. Image analysis of water-sensitive cards for spray coverage experiments. *Applied Engineering in Agriculture* 18: 179-182.

Panneton, B. and B. Lacasse. 2001. Projet Pulvigne - Rapport d'étape 2001. Programme de Partage de Frais à l'Investissement en R&D d'Agriculture et Agroalimentaire Canada. Agriculture et Agroalimentaire Canada, St-Jean-sur-Richelieu, QC.

Panneton, B., R. Thériault and B. Lacasse. 2001. Efficacy evaluation of a new spray-recovery sprayer for orchards. *Transactions of the ASAE* 44: 473-479.

Panneton B., V. Leroy, B. Lacasse, R. Thériault and D. Rousse. 2003. Simulation and experimentation in the development of a spray recovery sprayer for vineyards. CSAE Paper No. 03-230. Winnipeg, MB: CSAE/SCGR.

Pergher, G. and R. Gubiani. 1995. The effect of spray application rate and airflow rate on foliar deposition in a hedgerow vineyard. *Journal of Agricultural Engineering Research* 61: 205-216.

Pergher, G., R. Gubiani and G. Tonetto. 1997. Foliar deposition and pesticide losses from three air-assisted sprayers in a hedgerow vineyard. *Crop Protection* 16: 25-33.

Pezzi, F. and V. Rondelli. 2000. The performance of an air-assisted sprayer operating in vines. *Journal of Agricultural Engineering Research* 76: 331-340.

Randall, J.M. 1971. The relationships between air volume and pressure on spray distribution in fruit trees. *Journal of Agricultural Engineering Research* 16: 1-31.

Spillman, J.J. 1987. Improvements required in spray droplet formation to improve application technology. In *Proceedings of Symposium on the Aerial Application of Pesticide in Forestery,* 37-42. Ottawa, ON: NRC.

Unistat. 2002. *Unistat® 5.5 Statistical Package for Windows - User's Guide,* London, UK: Unistat Ltd.

Van Ee, G. R. 1998. Reducing drift from air assisted sprayers using timing targeting and towers. In *Proceedings of the North American Conference on Pesticide Spray and Drift Management*, 221–223. Orono, ME: University of Maine Cooperative Extension.

Viret, O., W. Siegfried, E. Holliger and U. Raisigl. 2003. Comparison of spray deposits and efficacy against powdery mildew of aerial and ground-based spraying equipment in viticulture. *Crop Protection* 22: 1023-1032.