A novel, air-assisted tunnel sprayer for vineyards

Pergher G., Petris R.
Department of Agriculture and Environmental Sciences, University of Udine, Viale delle Scienze, 208, 33100 Udine, Tel. 0432-558656, fax. 0432-558603, E-mail: pergher@uniud.it

Abstract

Tunnel (recycling) sprayers have long been recognised as an important tool to reduce drift losses. Depending on the crop and the growth stage, tunnel sprayers may recycle up to 60% of the spray volume, thus enabling the farmers to control pests even at reduced PPP dose rates. However, the introduction of tunnel sprayers in Italian vine-growing farms has been hindered by high machine cost, low working speed, and often unsatisfactory uniformity of deposition, generally related to the difficulty of correctly managing the air currents inside the tunnel.

Recently, a new prototype, air-assisted shielded sprayer has been has been developed by the University of Udine and Agricolmeccanica s.r.l. The two-row, tractor mounted sprayer uses a lamellae separator wall, placed in front of each nozzle boom, to recover the excess spray which has not deposited on the canopy.

Initial tests have been conducted to analyse the effects of the main sprayer settings (air flow rate, distance between the shields, and orientation of the air outlets) on spray recovery. Maximum recovery rate was 95.1% under static conditions. The sprayer was then used for spray application in the vineyard during the whole 2007 season, showing high reliability and work capacity. The recovery rate was 34% to 77% under field conditions, depending on the leaf area of the crop and other factors.

Keywords: recovery rate, air flow rate, static tests.

Introduction

Tunnel sprayers have long been recognised as an important tool to reduce both airborne drift (Schmidt, 1989) and soil contamination (Siegfried and Holliger, 1996). Because of their ability to recover and recycle most of the spray fraction that has not been retained by the canopy, these sprayers may make efficient pest control possible even at reduced PPP dose rates (by 15% to 50%, Siegfried and Holliger, 1996).

On the other hand, and despite of substantial benefits, the introduction of tunnel sprayers in Italian vine-growing farms has been hindered so far by several factors, mainly the higher machine cost, lower working speed, and poor manoeuvrability. However, the main problem seems related to the difficulty of developing a suitable air-assistance system, and of correctly managing the air currents inside the tunnel so as to ensure good distribution quality over the foliage, along with a satisfactory spray recovery rate. As a fact, most of the tunnel sprayers for vineyards available on the marked are sold without any air-assistance. This typically leads to insufficient spray penetration into the canopy and low deposition on leaf under sides (Siegfried and Raisigl, 1991; Siegfried and Holliger, 1996; Viret *et al.*, 2003).

A two-row, air-assisted prototype tunnel sprayer has been recently developed in a joint project conducted by the University of Udine and Agricolmeccanica s.r.l. (Torviscosa, Udine). The main objective of the project was to improve the quality of distribution as compared to existing tunnel sprayer models, and particularly spray coverage in the inside of the canopy and on leaf under sides, which may be critical for controlling some important diseases such as of downy mildew (as shown by Viret et al., 2003). Additional objectives were: to obtain a high spray recovery and recycling rate; to increase working speed and manoeuvrability even in narrow-spaced vineyards; and to keep the machine's structure as simple as possible, so as to reduce manufacturing costs and selling price.

Initial tests were conducted to gather baseline information on machine performance, and more particularly:

- to analyse the effects of various operational parameters on spray recovery rate under static conditions;
- to test the sprayer in the vineyard, under actual field conditions, during the whole 2007 growing season, and to analyse the spray recovery rate at different growth stages and leaf densities of the vines.

Materials and methods

The two-row prototype tunnel sprayer consisted of two identical spraying units, carried by a tractor-mounted, over-the row structure, while the 100-L tank was placed on a separated, trailed unit (

Figure 1). Each of the spraying units, or tunnels (Figure 2), consisted of a couple of symmetrical shields (height: 1700 mm; length: 1180 mm), each including:

- an axial-flow fan (maximum air flow rate: 1.20 m^3/s), driven by an hydraulic motor;
- a vertical air duct (height: 1700 mm; diameter: 250 mm), fitted with six air jets (total outlet section: 61.2 cm^2), spaced at 216 mm intervals;
- a vertical boom with six hydraulic nozzles;
- a lamellate panel (height: 1700 mm; length: 670 mm; thickness: 150 mm; pitch: 40 mm), designed to separate the excess spray, not deposited onto the canopy, and to capture its liquid fraction while discharging the air flow to the outside;
- a recovery basin, connected to the recycling system of the sprayer, to convey the recovered liquid back to the tank.

The reciprocal position of the tunnels and of the shields could be adjusted by means of hydraulic actuators to fit the row distance of the crop (between 1.8 m to 3.6 m), and the width of the vine canopy (up to 1.0 m tunnel opening, as measured between the basins). Both the main air duct and the air outlets could be rotated in the horizontal or vertical plane, respectively, to adjust the directions of the outcoming air flows, relative to the canopy and/or

Figure 1. The prototype tunnel sprayer during application in the vineyard.

the separator panel. The tractor-mounted, main structure of the sprayer also included: the main circuit's membrane pump, fitted with a constant pressure regulator; the membrane pump of the recycling circuit, connected to the tank; suction filters before each pump; and a hydraulic power system, driven by the tractor's P.T.O. and used to operate the fans and the hydraulic actuators on the over-the-row structure.

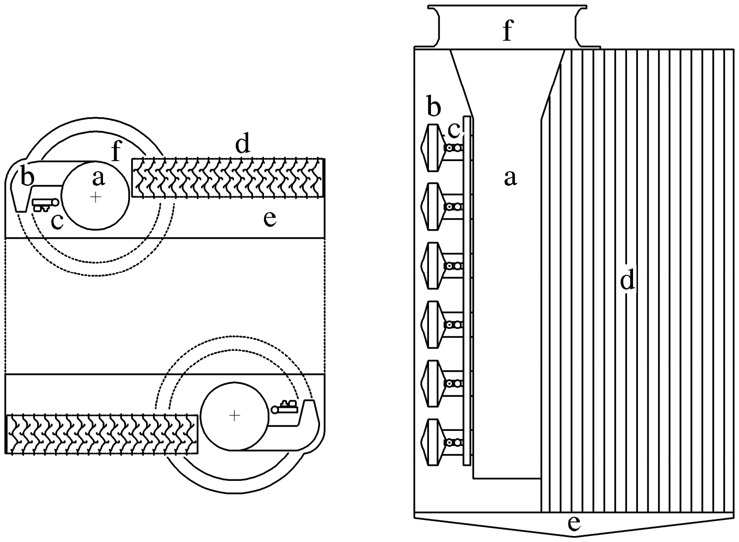
The performance of various configuration of the sprayer was evaluated on the basis of spray recovery trials, performed with water only under static conditions, and in the absence of vegetation. The sprayer was fitted with 12 Albuz ATR brown hollow cone nozzles (Very Fine BCPC spray quality at 10 bar), and the total flow rate was 7.92 l/min (at 10 bar pressure) in all experiments. The spray recovery rate was measured by collecting the water flow from the tube of the recycling system, previously disconnected from the tank. This involved: adjusting the operational parameters of the sprayer; starting the sprayer, and waiting until the water flow from the recycling pipe became steady; placing the end of the tube in a container (volume capacity: 50 l), so as to collect the water flow; after four minutes, removing the tube's end, and measuring the volume of water collector using graduated cylinders. In each test, the machine was let to spray for at least five minutes before taking the first measurement, in order to completely soak all inside surfaces.

Four different tests were performed. Test No. 1 was a factorial experiment, in which the following settings were compared:

- tunnel opening: 0.50 m, 0.75 m and 1.00 m;
- outlet angling: 10°, 20° and 30°; both air booms were symmetrically rotated towards the centre of the tunnel, clockwise as seen from above;
- fan speed: 36.1 rev/s, 46.8 rev/s and 52.4 rev/s (at 350, 450 and 540 rpm of the tractor's P.T.O., respectively; corresponding to air flow rates of 1.46 m^3/s, 2.05 m^3/s, and 2.40 m^3/s, respectively).

In test No. 2, the effect of different outlet orientations (10°, 15°, 20°, 25° and 30°) was further analysed at medium fan speed and three tunnel openings.

Figure 2 - Schematic views of the prototype. Left: from the top; right: from the (inner) side. (a) main air duct; (b) air jets; (c) nozzles; (d) air/droplet separator; (e) basin; (f) fan.



Tests No. 3 and No. 4 were conducted to quantify the potential advantages of the prototype, relative to different possible configurations, such as:

- tunnel sprayer without air-assistance;
- tunnel sprayer with air-assistance, but with full walls and no air/droplet separators.

In test No. 3, the fans were shut off, and this adjustment compared with the medium fan speed, in order to assess the effect of air-assistance on the spray recovery rate. Six measurements were performed (two fan settings combined with three tunnel openings as above). Finally, in test No. 4 the separator panels were made ineffective by covering their inner or outer side with plastic foils in the inside or in the outside, so as to simulate a tunnel sprayer with full containment walls, in order to assess the effect of the spray separating system on the recovery rate.

Further tests were performed with the tunnel sprayer in motion at 6.2 km/h forward speed along a 250 m long, smoothly paved lane. Tunnel opening was adjusted at 0.50 m, and the fan speed was set to the maximum (52.4 rev/s, giving a 2.40 m^3/s air flow rate). Outlet orientation was initially set at 25° backwards (front boom) and 25° forward (rear boom). Preliminary visual observation suggested that the spray and air flows generated by the nozzles and air outlets were, by some extent, being deflected backward by the additional flow of air, entering the tunnel from the front opening owing to motion. This was causing a relatively small, but clearly visible loss of droplets from the rear opening. In order to compensate for this effect, additional runs were made after rotating either the front or rear outlets towards the back of the tunnel, in steps of 5°, and repeating the procedure until no further improvement in the spray recovery rate was recorded.

The measuring procedure was the same as described above, except for the following. Two separate containers (volume capacity: 20 l each) for liquid recovery were used, and placed in a metallic frame, fitted in the back of the tank trailer. After the water flow from the recycling pipe had become steady, the sprayer was put in motion; liquid recovery was started as soon as the forward speed of the sprayer had stabilised, and was stopped after two min. The same was done during a second run in opposite direction, to compensate for the effect of the wind. At the and of both runs, the volume of water collected was measured, and the spray recovery rate was assessed.

During 2007, the tunnel sprayer was used for pesticide application in a commercial vineyard estate, located in San Martino al Tagliamento (PN, N.E. Italy). The vineyard (cv: Merlot) was trained to a spur-pruned low cordon, with planting distances of 2.4 m between the rows, and 0.8 m between the vines). Standard canopy management was performed, including side and top trimmings, and vertical shoot positioning using movable catch wires, which helped to limit the canopy width to 0.5 m or less at all growth stages.

Six treatments against powdery mildew and downy mildew were performed. After each application, six vines were randomly chosen in the vineyard for the assessment of the leaf area index (LAI); all their leaves were counted, and one leaf every five was taken. The area of the leaves sampled were measured with an area meter (Model LI-3100C, LI-COR Inc.). Based on the number of leaves per vine and their mean area, the total leaf area (S, in m^2) were determined for each sample vine.

The leaf area index (LAI) was then calculated as:

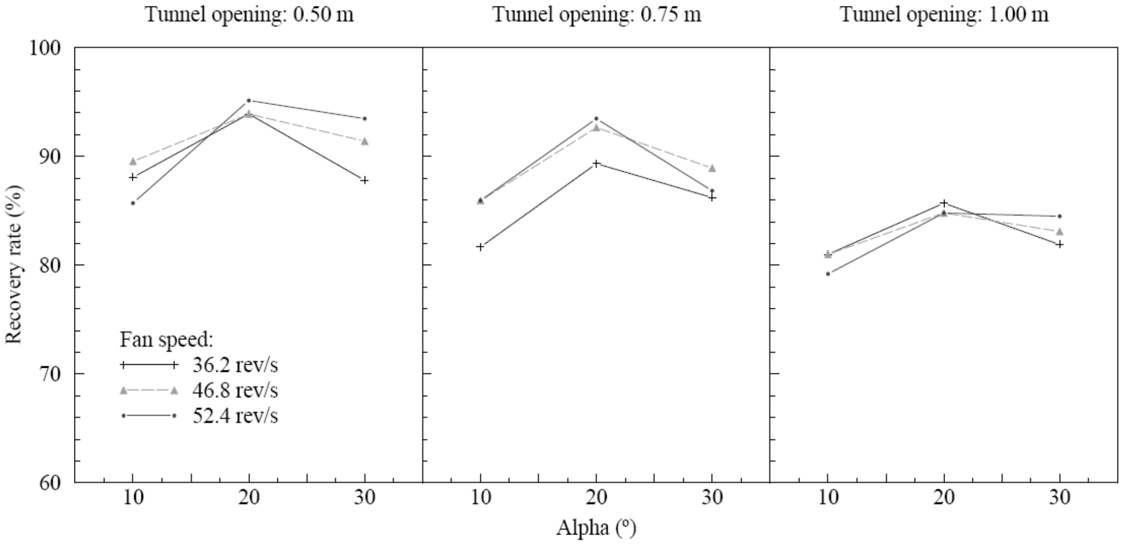
$$LAI = \frac{S}{xb}$$

where: x, in m, is the planting distance between the vines length (0.8 m); and b, in m, is the row spacing (2.4 m).

Results

The maximum recovery rate in static test No. 1 (95.1%; Figure 3) was recorded after adjusting the distance between the tunnel's walls at the minimum distance, 0.50 m, the outlet orientation at 20°, and the fan speed at the maximum. The reduction in the recovery rate at increasing distances between the tunnel's walls was largely expected. However, this effect was very small at the 0.75 m tunnel opening (maximum recovery: 93.5%; at the same outlet and fan speed adjustments as above), while clearly visible at the 1.00 m distance (85.7%; same outlet orientation, but at the minimum air flow rate, 1.18 m^3/s).

Figure 3. Static test No. 1: effect of tunnel opening, fan speed and outlet orientation on spray recovery rate.



The spray recovery rate was little affected by the air flow rate adjustments. This was indeed a good result, since it suggested that it would be possible, during spray application in the vineyard, to choose the correct air flow rate in order to obtain sufficient penetration into the vine canopy, without affecting the spray recovering and recycling potential of the sprayer.

Also the effects of different outlet orientations were comparably small. In general, the best angling of the air outlets was 20°, so as to point towards the middle of the opposite separator panel. At 10° inclination, in fact, part of the spray plume was not completely captured by the separator panel, but visibly escaped through the front and rear openings of the tunnel. On the other side, the 30° inclination of both air booms towards the centre of the tunnel visibly increased the turbulence of the air flows, particularly at the minimum distance between the shields (0.50 m, Figure 3), and this may have reduced droplet penetration through the separating panels.

Test no. 2 allowed a more complete analysis of the effects of outlet orientation. In fact, the best angling was different, depending on the distance between the air outlets and the opposite separator panel, and was 15°, 20° or 25° for openings of 1.00 m, 0.75 m and 0.50 m, respectively. This was consistent with the fact that, for a given angle of inclination, the air flow would impact the separator panel in slightly different points, depending on the distance between the shields.

Test No. 3 showed that air-assistance was important to improve the recovery rate. In the no-fan treatment, in fact, part of the droplets did not even have sufficient energy to reach the

Table 1. Static test No. 3: no fan versus medium fan speed (46.8 rev/s).

Tunnel opening, m	Recovery rate, %	
	No fan	Medium fan speed
0.50	74.6	94.2
0.75	71.7	92.5
1.00	61.8	84.7

separator panel at the facing tunnel wall, and were mainly lost through the opening at the bottom of the tunnel. As a consequence, the recovery rate was decreased at 61.8% to 74.6%, depending on tunnel opening (Table 1).

Test No. 4 showed that a similar reduction could be expected from a tunnel sprayer fitted with air-assistance and full containment walls (60.6% to 79.9%).

The dynamic tests performed with the sprayer in motion at 6.23 km/h showed that the orientation of the air outlets, and particularly the front ones, needed to be differently adjusted, in order to compensate for the effect of the additional flow of air, entering the tunnel from the front opening. In fact, the symmetrical rotation by 25° of both air booms, giving a 95.0% recovery under static conditions, resulted in a substantially lower recovery rate (83.8 %; Table 2) at 6.23 km/h forward speed. This was associated with a relatively small, but clearly visible loss of droplets from the rear opening. The best outlet orientation found in these tests was: 5° backwards and 25° forwards (front and back air booms, respectively), giving a recovery rate of 87.4% (Table 2). Thus, complete compensation of the effect of motion was therefore not

Table 2 . Dynamic tests: effect of outlet orientation.

Outlet orientation, degrees		test conditions	Recovery rate, %
front air boom (forwards)	rear air boom (backwards)		
25	25	static	95.0
25	25	dynamic, at 6.23 km/h forward speed	83.8
5	25		87.4
0	25		86.7
0	30		79.6

Table 3. Static test No. 4: effect of separator panel covering.

Tunnel opening, m	Outlet orientation, degrees	Recovery rate, %		
		panels covered at the inside	panels covered at the outside	panels not covered
0.50	25	77.7	79.9	93.3
0.75	20	70.6	72.0	92.1
1.00	15	60.6	62.1	86.3

Table 4. Amount of spray recycled by the tunnel sprayer in 2.71 ha Merlot vineyard during 2007

Trial Date (2007)	LAI	Tunnel opening, m	Recovery rate, %	Open nozzles per side	Volume sprayed, l/ha	nozzle type
3-April	0.00	0.60	77	3	319	ATR brown
3-May	0.33	0.55	40	2	219	ATR orange
9-May	0.53	0.60	47	3	323	ATR orange
21-May	0.46	0.60	47	3	323	ATR orange
31-May	0.61	0.60	50	4	444	ATR orange
8-June	0.96	0.65	40	5	555	ATR orange
11-July	1.79	0.65	34	6	433	ATR yellow

possible; and this may suggest that the prototype could be somewhat improved by increasing the air flow rate, or by using additional air jets to better shield the front opening from the incoming air flux.

Spray recovery in the vineyard was 77% at beginning of season (April 3, before bud break) to 34% on July 11 (full foliage development; Table 4). This was largely expected, since the increase in the leaf area index of the crop also increased the fraction of spray retained by the canopy, and decreased the amount of spray that could be recovered by the tunnel sprayer. However, the recovery rate was relatively constant between May 3 and June 8 (40% to 50%), despite an increase in the LAI by nearly three times (from 0.33 to 0.96).

Conclusions

These preliminary tests showed that the choice of using an air-assistance system, combined with a lamellae separator wall, allowed to obtain a high recovery rate from the tunnel sprayer. In fact, maximum potential recovery under static conditions was 95.1% or 93.5%, at 0.50 m 0.75 m tunnel openings, respectively, but clearly decreased at 1.00 m, suggesting that better performances are to be expected when using the tunnel sprayer in vineyards with thin canopies, and in VSP (vertical shoot positioned) training systems such as Guyot or Low Spur Cordon.

Under dynamic conditions, however, the maximum spray recovery rate decreased, owing to the effect of the additional flow of air, entering the tunnel from the front opening at 6.23 km/h forward speed. Adjusting the orientation of the air outlets to 5° backwards (front air boom) and 25° forward (rear boom) could partially compensate for this effect, resulting in a recovery rate of 87.4%. This suggested that the prototype could be possibly improved by increasing the air flow rate of the fans, or by using additional air jets to shield the front opening from the incoming air flux.

The actual recovery rate in the vineyard was maximum before bud break (77%), but still very good during the whole growing season of the vines (34% to 50%), and was relatively little affected by the LAI development. These values were generally better than those reported in the literature from tunnel sprayers both without air-assistance (Bäcker and Rühling, 1990; Siegfried and Raisigl, 1991; Siegfried and Holliger, 1996), or fitted with centrifugal fans (Baraldi et al., 1994; Planas et al., 2002).

These preliminary tests were also useful to set up the tunnel sprayer for further analyses, in order to assess the spray distribution over the foliage, penetration into the canopy and coverage of the under side of the leaves. The objective of further research will be to determine whether the new air-assistance system, developed for this sprayer, will be efficient in improving spray distribution uniformity, which has often been reported as unsatisfactory from most models of experimental or commercial tunnel sprayers proposed so far (Siegfried and Raisigl, 1991; Siegfried and Holliger, 1996; Viret *et al.*, 2003; Planas et al., 2002).

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