Ecological efficiency assessment of a specific machine for distribution of pesticides in vineyards of Apulian Region

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Abstract: - The goal of the present research was to assess, through field tests, the environmental performance of a prototype of tunnel sprayer machine, specifically designed for the distribution of pesticides in Apulian espalier vineyards which cover a significant percentage of the national wine producing area, whereas there are no machines designed to meet the agronomic requirements of these crops.
The tests were characterized by a comparison between the prototype and a standard air sprayer, so also an assessment of the off-target during different distributions. The operating agronomic and weather conditions were extremely adverse: wind speeds exceeding 15 km/h, not pruning crop and, in one of the tests, speed of the machine close to the upper limit for the treated crops. Despite the conditions in which the tests were carried out, by the use of the prototype, the event of the drift affected an area at less than 4 m from the sprayed row, significantly reducing the risk of contamination of nearby crops and housing; it was, however, found the limit by the panels of not ensuring total effectiveness of containment of the drops, which led to high leakage into the ground (risk of moving to more far areas) even if only in correspondence of the row adjacent to the sprayed one. Overall, the prototype allows a recovery of the sprayed product by at least 19%, which results in a lower environmental impact and lower costs of crop protection.

Key-Words: Tunnel sprayer prototype, Apulian vineyard, spray deposition on the ground, spray dispersion in atmosphere, off-target recovering.

1 Introduction

A number of measures taken at European level, aimed to regulate the use of synthetic active ingredients, by placing strict limits for certain hazardous substances, are aimed to balance treatment efficacy and safety for humans and the environment [1, 2].

However the effects of these measures may result to unexpected consequences. As shown by a recent study published by EuroCARE (European Centre for Agricultural, Regional and Environmental Policy Research - 2008), which takes into account, among others, the results of the Italian Research Institute Nomisma, the new EU legislation tends to dramatically reduce the possibility of using some agricultural chemicals by farmers in Europe and could lead to a drop in production in Europe for all major crops (wheat, potatoes, cereals and wine grapes). This therefore may result in a reduction of crops and the relative increase in prices [3] and would endanger the EU's role as an exporter of key crops to the benefit of other countries.

The "Thematic Strategy on the sustainable use of pesticides" is one of the seven 'thematic strategies' identified by the Sixth Community Action Program on the Environment, adopted by Decision No.1600/2002/EC of the European Parliament and the Council. The goals of the strategy aim at:

- reducing the risks and dangers to human health and the environment;
- improving controls on the use and distribution of products;
- replacing hazardous substances with safer alternatives;
- promoting agricultural practices to lower use of plant protection products;
- establishing a transparent system for monitoring and reporting on progress.

Among the tools to achieve its objectives, there is the definition of specific construction requirements for new machines on the market, with the purpose of using them adjusted and maintained without damaging the environment unnecessarily. The strategy identifies a key point in the design phase of the sprayers, stating that their performance should also be evaluated in terms of results; it also recognizes an essential role in controlling recurring function and the proper adjustment of the machines for the distribution of pesticides.

Member States are establishing "National plans" that contain, among other things, specific provisions for sprayers. Till today, in Italy, buffer zones range in extensive crops, orchards and vineyards, were never to be imposed, but with the entry into force of the new legal provisions will need to take appropriate measures in this direction. Parliament rejected the amendments that the Commission proposed to set at EU level the amplitude of these “buffer areas" thus leaving the Member States the task of defining them. This will be achieved within two years after the entry into force of the Directive.

With the entry into force of the Directive was necessary to establish in Italy a system of evaluation of available technologies to contain the drift similar to those of Northern European countries and has started the creation of official lists with machines (over 1000 models available on the Italian market) and the components able to reduce the drift.

The drift is the movement of the pesticide in the atmosphere of the treated area to any non-target site, when the distribution is made (ISO 22866); A distinction is made between: the endodrift or ground sediment represented by the proportion of the mixture that falls on the ground near the treated area and the esodrift or atmospherical drift constitutes by the part of the mixture which is lost off target. Inevitably when a pesticide treatment is made, a certain amount of chemical molecules (active ingredient and adjuvants) it is subject to drift, causing various forms of pollution.

The factors influencing the phenomenon are several [4] and, essentially, are constituted by the type of mixture in use, the dose of use, the weather conditions, the crops, the size of the particles, the type of equipment used, the level of maintenance and from the conduct of the operator.

In fact, the amount of active ingredient that actually reach the target, using standard spraying machines, is very low, still considerably less than 100%, even according to some authors could be equal only 37% of sprayed product [5]; in any case, the amount dispersed in the environment, beginning with the immediate impact on the soil during treatment, is always very substantial [6].

Hence, it is clear that there can be an health risk not only for the agricultural operator but also for the general population and every effort must be produced for the minimize this impact.

In this context, the role of mechanical technologies applied to the plant protection is of strategic importance in achieving a synthesis between phytoiatric efficacy and safety of use; In fact, it has been amply demonstrated that technical solutions that can be used in the distribution have reduced gradually over time the amount of synthetic chemicals released into the agricultural ecosystem, also increasing the effectiveness of treatments [5, 6].

Whereas the types of espalier adopted in Apulia there are no machines properly designed, in order to reduce the environmental impact, the present paper was aimed at studying the environmental performance of a machine specifically designed for the realization of the pesticide application in vineyards in Apulian espalier vineyards, with particular regard to the control of the drift and to off-target product recovering.

2 Problem Formulation

2.1 Apulian current status

In Apulia Region wine grapes take up an area of about 105.000 ha and the annual production of wine is about 7.5 - 8 million hectoliters (ISTAT 2010). In 2007 grapes production exceeded 8.4 million of quintals; the medium value of this production, that was of 82.6 q/ha, set Apulia Region in second place in Italy behind Veneto Region. Actually this district produces over 10.4 millions of quintals and the medium value of this production is over 150 q/ha , comparable with that one of Australia, Germany and Portugal (ISTAT 2007).

The Apulian vine growing and wine producing has the following positive conditions:

- especially propitious peculiarities of soil;
- high number of native species of wine adapted to increase the regional vine growing and wine producing;
- an excellent basic quality, especially in the medium-high band of the market;
- a large selection of wine able to offer an amply differentiated range and to satisfy every demand;
- a close connection among wine, art, history, culture, typical products, traditions, gastronomy;
- the growing touristic value of Apulia as promoter of local wine products.

Negative conditions are:

- too much breaking up of the production that makes supply organization hard;
- farms and cultivars characterized by irregular shape, both during the vegetation is poor and in full leaf; in this last growth stage, the width of the tree rows can reach 1.3 m and the passage of machines 1,4-1,6 m (Fig. 1) [8];
- Insufficient availability of mechanical solutions specifically designed for the agricultural and environmental management of these vineyards;
- general aging of vineyards and disappearance of plant nurseries topical of Apulia;
- persisting presence of vineyards with an high yield but a mediocre quality;
- presence of many brokers in the business of grapes and wine that pull producer's return down.

In accordance with Reg (CE) n. 379/2008, Apulia is developing a "Regional project to restructure and to change vineyards with grapes cut out for wine" in order to settle procedural and mechanical solutions, to make investments in viticultural farms, to reactivate Apulian vine growing and wine producing put today in a critical position.

2.2 Tested machine

The tunnel type sprayer subject of this paper is a recovery certified machine, type pulled, developed by DISAAT Dept. of the University of Bari and the “Maggio” Company (Figs. 1-2). The prototype is an air convection type, single-row and it is characterized by a spraying tunnel equipped with:

- two vertical boards;
- two opposite series of air diffusers, each supplied by an axial flow fan with external suction, with air flow rate determined by means of different speeds of the fan, between 1890 and 2500 rpm; the air diffusers hallow to an uniform distribution around the nozzles, by means of internal baffles and holes;
- two bars with 9 nozzles each, positioned outside of the air flow with respect to the diffusers;
- hydraulic system controlling the horizontal and vertical movements of the boards;
- devices for the side closing of the air;
- two lower recovery trays, connected to the recovered mixture recirculation circuit;
- electronic system for adjusting the distributed volume as a function of the forward speed (DPA).

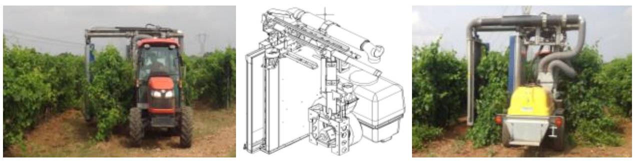

Fig. 1. Prototype of tunnel type sprayer, made by the “Maggio” Company (Italy) working in full leaf stage; it is evident the short passage between the rows tree and a CAD rendered isometric picture.

The prototype can be considered an original version of straddle sprayer. Innovations characterizing the machine are mainly the type, position and orientation of the air flow system, in the shielding and in the geometry of the straddle tunnel. Each of these technical characteristics were specifically studied and designed, with a view to meeting the sizes and types of cultivation of local cultivars, for which there are currently no machines on the market. Other changes were made by building each new component, testing first by mounting them on a test bench, using already built and operating machines.

The recovering system (Figs. 1-2) consists of:

- shielding made by 2 recovery vertical boards (1.012 m x 2.0 m) with the purpose of interception of the drops which, carried by the air, leap over the vegetation; that rearing wall has a shape such as to generate a vortex motion which makes the liquid that has overpassed the plant, to go back to the inner part of the tunnel and collect it in the bottom of in order to bring it back into the tank;
- n. 2 recovery trays on the lower part of each recovery board;
- n. 2 Venturi hydroinjectors between the pipe to the bars and the inlet conduits from the recovery trays;
- n. 2 tank return lines consisting of a live liquid (liquid that comes out the tank by means a membrane pump) pipe entering the hydroinjector, a draw pipe from the recovery trays to inductor, an outlet pipe from the inductor to the tank of the machine; on each return pipe to the tank, before discharge, the liquid goes through n.2 thinner metal mesh filters;
- an Electronic Control System which measures the flow rate of the product sent to the panels and the flow returning to the tank, providing the flow of recovered product during distribution.

Fig. 2. Recovering system (left); recovery tray (center); hydroinjectors, return lines, filters (right), the inserted flowmeters during the tests are shown.

2.3 Experimental tests

2.3.1 Evaluation of the environmental performance of the prototype

The experiment was carried out at the vineyard Maci Melissa in Cellino San Marco (BR - Italy) which is traditionally carried on. The vineyard under test, in which it is planted the variety "Falanghina", has an area of approximately 33,000 m^2, the planting distance in full vegetation was 2.2 m x 1.00 m with a height of horizontal cordon of 0.75 m. The vegetation, deliberately, has not been standardized by pruning and it appeared very irregular on the sides of the rows. The drift tests were carried out simulating the distribution of 350 l/ha, in the way normally adopted by the Company, in the presence of highly developed vegetation and in sunny weather with the prevailing wind from the north at 15.0 to 18.0 km/h; from the agronomic point of view, the latter condition is not fully suited to carry out the treatments but it has been accepted in order to obtain an extremely disadvantageous context in relation to the movement of the pesticide in the atmosphere of the treated area.

The evaluation of the environmental performance of the prototype has been mainly carried out by comparing a machine already present in the farm: an air convection sprayer Kubota-85 equipped with a polyethylene tank (2000 l), axial fan provided with a static blades rectifier, air flow conveyors where 4 cone type hydraulic nozzles (ATI 60 ALBUZ yellow, with a flow rate of 0.73 l/min each) per side were installed. The machine has carried out the distribution to a pressure of 5 bar and with a feed speed of 5.0 km/h.

On the prototype, however, the distribution system was equipped with 14 nozzles (60 ALBUZ ATI brown with a flow rate of 0.48 l/min each) opened: n. 7 each side, excluding from the distribution n. 1+1 nozzles (those located further down) which were lower than the vegetation to be treated. The machine has carried out the distribution to a pressure of 5 bar, with a speed of 5.2 km/h.

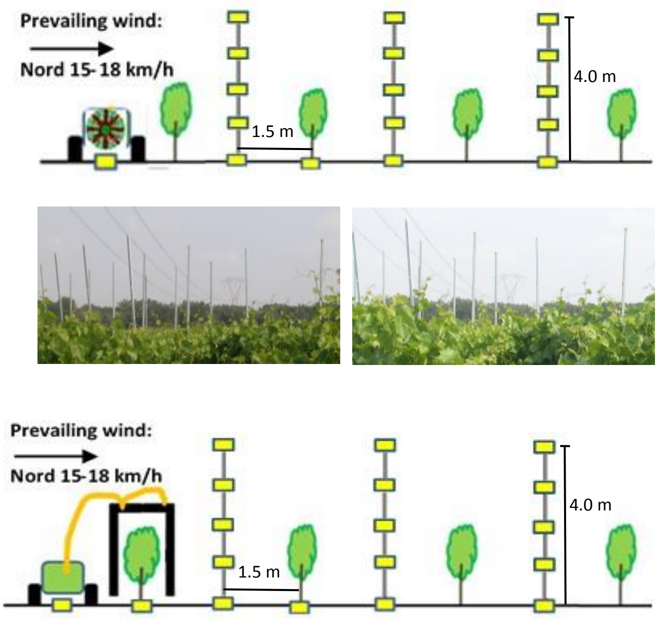

Fig. 3. Layout and images of the location of the collectors.

Starting from the row adjacent to the sprayed one, 5 poles have been positioned with a height of 4 m. On every pole the collectors (at intervals of 1 m from each other) were placed. For each pole, along the sprayed row (in the adjacent row and in the transit one of the sprayer) further collectors were placed at a height of 3 cm from the ground for the determination of losses into the ground (Fig. 3).

The stages were done in succession on a single row in order to ensure the constancy of the positioning of the collectors. After the passage of the machine, the collectors were collected according to the diagram of spatial location and placed in containers for the following data acquisitions by the computer.

A digital image of each plate exposed on the vegetation was acquired in RGB (24bit) format by a flatbed scanner (Epson WF-7525, EPSON inc., Suwa, Nagano, Japan) using 1200 dpi of spatial resolution. The RGB acquired images were stored in tiff format without compression and then processed by an algorithm coded in Matlab (The Mathworks inc., Natik, Massachusetts, USA). The algorithm performed a colour-space conversion from RGB to HSV. The H (hue) plane was used to threshold the sprayed area. This choice was taken because the background (plate surface) and the foreground (sprayed drops) were chromatically opponents: yellow and blue respectively. The optimal threshold value was calculated using the ‘graythresh’ function included in the Image Processing toolbox of Matlab. Then, the images were segmented and the binary images obtained were used to calculate the pixel percentage of plate’s sprayed area.

2.3.2 Evaluation of the efficiency of the recovery system of the machine

Assessments of the recovery system installed on the machine were made by field tests, simulating two different treatments on an area of 1.0 ha of the same vineyard: 350 l/ha and 250 l/ha.

The percentage of recovered product compared to that dispensed was calculated by relating the volume recovered and the total distributed by the machine. The total volume distributed by the machine was determined, in the time of distribution, by means of a mechanical flow-meter inserted on the delivery duct of the feed pump; the volume recovered was determined by entering n.2 flow-meters, respectively, on each of the return lines to the tank (Fig. 2).

Each distribution has been repeated 3 times and the experimental data were obtained compared with those supplied by the electronic control system of the machine and those obtained with similar tests carried out with the machine sitting idle in a previous study [8].

3 Problem Solution

Figures 4 to 7 summarize the amount of liquid detected in the various collectors located, respectively, on the ground (Figs. 3-4), at the various levels of the row of poles arranged at 1.5 m from the sprayed row (Figs. 3-5), at the various heights of the row of poles placed at 4.5 m from the sprayed row (Figs. 3-6) and at the various heights of the row of poles placed at 7.5 m from the sprayed row (Figs. 3-7). The size of the histograms is proportional to the amount detected in the relative positions of the sampling, expressed as average percentage of the area occupied by the absorber drops in captators at the same level. Table 1 reports the average data of the detected amount of tracer on the totality of the collectors arranged on the ground, 1.5 m, 4.5 m and 7.5 m.

As it is shown by the charts, by using the standard atomizer the extent of losses into the ground was high on the transit row of the machine (Fig. 4). While within the sprayed row the readings are comparable; on the "adjacent row", that is 3 m from the treated one (Fig. 3), the extent of losses into the ground by the prototype was higher (Fig. 4).

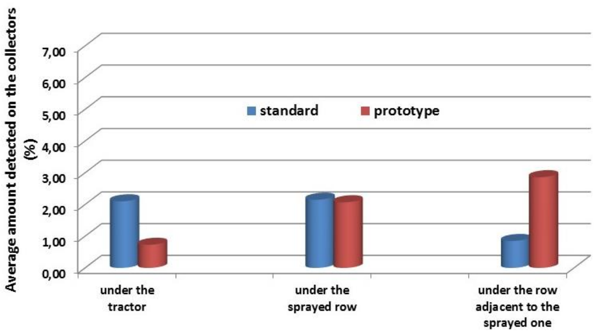

Fig. 4. Comparison of spray deposition.

The latter result it is not so much related to the limits of the machine but to the purposely heavy test conditions. In fact, the not uniform vegetation prevented to perfectly adjust the distance between the panels and the target; in such a situation, the product, in some areas of the row, is not adequately penetrated inside of the vegetation, In other areas it is deposited on it and, in some cases, resulted in the leakage of the smaller droplets from the rear of the tunnel [9]. Under these conditions the very high wind speed has favored the shift to low-level drops, which have easily bypassed the obstacle of the collectors present at 1.5 m from the sprayed row but, on the contrary, have been hold from the adjacent row [9] which has worked as a capturing barrier and the leaf deposit was then accumulated on the ground.

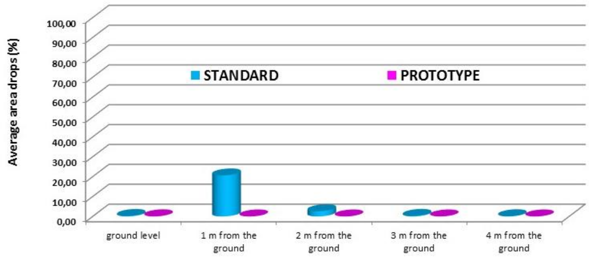

Fig. 5. Comparison of spray dispersion using the prototype and the standard machine, at 1.5 m from the sprayed row.

To confirm that, deposits fell to the ground under the sprayed row are very low and almost absent at the bases of the poles of the first row, that is 1.5 m from the sprayed one; this is evident both in Figure 5, and in Table 1. This table, in particular, shows percentages of the total ground loss comparable between the standard machine and the prototype; however, the standard deviation of the average value which characterizes the prototype is very high, in particular because of the dispersion of data due to the measured values at the base of the row adjacent to the sprayed one, which significantly differs from the others (Fig. 4).

The collectors of the first row of sampling, that is 1.5 m from the sprayed row (Fig. 5), should have intercepted the drops of bigger size dispersed in the environment [9]. With the standard machine greater losses to the drift are showed, especially at a height of 1 m. The highest values were measured between 1 and 2 meters. The phenomenon is much lower with the prototype, which shows slightly greater losses at 1 m (Fig. 5). However, the improvement of the environmental performance of the prototype is already very evident at 1.5 m from the sprayed zone, with an average total value of the percentage coverage of the collectors, corresponding to 1.4% of that obtained with the standard machine (Tab. 1).

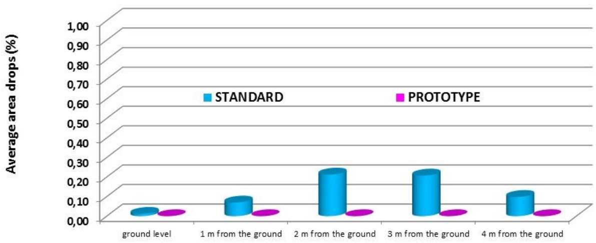

Fig. 6. Comparison of spray dispersion using the prototype and the standard machine, at 4.5 m from the sprayed row.

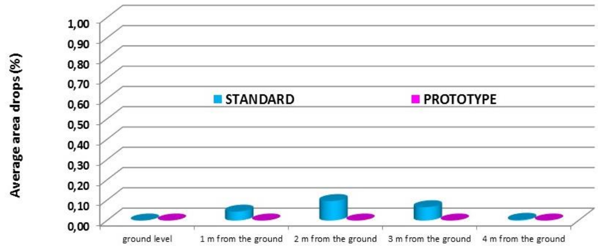

Fig. 7. Comparison of spray dispersion using the prototype and the standard machine, at 7.5 m from the sprayed row.

By the use of the standard machine drift losses are still evident on the row of sampling positions, at 4.5 m from the sprayed one, especially at an height of more than 2 m; the highest values were measured between 2 and 3 meters (Fig. 6; Tab. 1); as the amount of residue decrease with the distance (Tab. 1), a similar trend is found in the sampling positions at 7.5 m. (Fig. 7; Tab. 1). However, in the case of the prototype, the drift phenomenon, despite the adverse weather conditions, it was not manifested, not being highlighted on all the captators in appreciable quantities (Figs. 6-7; Tab. 1).

Table 1. Total spray deposition and dispersion (average values).

EVALUTED PARAMETERS	Prototype	Standard
Ground deposit (average amount detected on the collectors)	1.674	1.699
σ	1.328	0.732
Leakage at 1.5 m (1st rods row) (average amount detected on the collectors)	0.0723	4.959
σ	0.044	1.143
Leakage at 4.5 m (2st rods row) (average amount detected on the collectors)	0	0.139
σ	0	0.071
Leakage at 7.5 m (3rd rods row) (average amount detected on the collectors)	0	0.070
σ	0	0.019

On the other hand, it should not be overlooked the importance of the possible ground deposition of the active mixture, for the purposes of public health; in fact, it is true that the drift reaches a larger area, increasing the possibility of contamination of nearby crops and housing but the deposit may also involve the possibility of a further contact and the subsequent conveyance in more distant areas by the atmospheric agents in relation to the stability of the product [4, 10, 11].

So, in the heavy agronomic and extreme weather conditions in which the tests were carried out, the prototype has highlighted the advantage of limiting the drift to less than 4 m but also the limit of not ensure total effectiveness of containment of the drops on the part of panels recovery and the relative devices for side closing of the air.

Table 2. Recovered product (average values).

TEST CONDITIONS	RECOVERED PRODUCT Experimental measure (% of total distributed volume)	σ	RECOVERED PRODUCT Measure of the electronic control system (% of total distributed volume)	σ
250 l/ha - Plates distance: 1.3 m - Opened nozzles: 7 for side - Operating pressure: 5.0 bar - Speed machine: 7.3 km/h - Product flow rate: 3.78 l/min	Internal side 11.7 % External side 7.6 % Total 19,3%	1.2 0.6	Total 19,1 %	0.29
350 l/ha - Plates distance: 1.3 m - Opened nozzles: 7 for side - Operating pressure: 5.0 bar - Speed machine: 5.2 km/h - Product flow rate: 6.72 l/min	Internal side 14.07 % External side 8.52 % Total 22,59%	1.9 0.9	Total 22,2 %	0.68

That it is confirmed by tests carried out with the purpose of determining the efficiency of the recovery system of the prototype. Experimental tests carried out previously with the same machine, stops and in absence of vegetation, have highlighted the potential of the system to recover from 34% to 42 % of the product distributed, with the highest percentages corresponding, for the same nozzle, the minimum distance between the panels and the working pressure lower [8].

It was predictable that these values were not confirmed in the presence of vegetation, considering also that the weather and the agronomic conditions during tests have been made even more adverse in the case of distribution of 250 l/ha, during which the machine proceeded at a speed next to that indicated in the literature as a limit not to be exceeded for the type of treated crop: 7 km/h [9].

The test shows a percentage of the total recovered product variable between 19% and 22.6%, with full correspondence between the electronic measuring system installed on the machine and the data experimentally measured (Tab. 2). As in the tests the same nozzles (60 albuz ATI brown), the same pressure and the same distance from the panels (Tab. 2) have been used, it can be said that, for equal distribution of the drops, the efficiency of the system recovery may have been influenced by the speed of the wind and the speed of the machine. The components of these two vectors have contributed to increase the leakage phenomenon of the drops from the rear of the tunnel, already noted with the losses distribution into the ground [9].

In particular, there is a reduction of the effectiveness of the recovery system in correspondence with the greater speed of the machine during the distribution (Tab. 2) and, in all cases, the percentage intercepted by the external panel is less than that relating to the inner panel, also because of the direction and speed of the wind, that have reduced the capturing capability of the inner panel.

Overall the prototype allows a recovery of the pesticide that, considering the heavy test conditions, can be considered at least of 19%. This value results into a lower environmental impact and lower costs of crop protection [11], because it is evident that not all unrecovered product reaches the target.

4 Conclusions

Whereas the machine is a summary of agronomic, mechanical, economic, environmental and legislative requirements, the aim of the present research was to study the ecological efficiency of a specific machine for the distribution of pesticides in wine-growing reality of Apulia Region, through the development of field tests.

To compare the innovative sprayer and a traditional machine a series of captators were placed in different positions on the canopy and on the ground. Performing the calculation of the sprayed area on the plates by an image analysis technique it was possible to objectified the amount of product loss.

The differences of the average values of the acquired data and their statistical analysis in the comparison between the prototype and the traditional machine, highlight how the use of a specifically designed tunnel type sprayer works much better in terms of reducing either risks of nearby crops and the risk of conveying in more distant locations as well as in the terms of crop protection costs.

Anyway, the highlighted limits of the prototype operating in espalier vineyards (as shown during the heavy test conditions) allow to define technical-operational factors that may determine different values from those obtained:

- correct preparation of the crop to be treated, with adequate shearing of the vegetation, before the passage of the machine;
- compliance with the conditions of the wind;
- speed of the machine related to the distance between rows and to the depth of the vegetation, by suitably selecting the type of nozzles and caring for their maintenance status;
- correct behavior of agricultural operators [12] during treatment (opening panels, adequate vegetation, limitation of the jet to the bottom row);
- specific design study of devices for side closing and control of the drops in support of the recovery panels.

In this regard, to gather useful data for evaluation of the risk to public health in rural areas nearby to the fruit growing, this type of experimental evaluations must be continuously upgraded, in order to obtain even more generalizable results.

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Author Contributions
All the authors contributed equally to this work.

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