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Assessment of the Wind Influence on Spray Application using an Artificial Vineyard

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Summary

Chemicals are usually applied to fruit tree orchards with air-assisted sprayers. This involves a significant risk of off-target contamination by spray drift and losses on the ground. Wind is one of the most significant climatic factors influencing the efficiency of chemical distribution, since it may account for a large drift.

The aim of the research was to evaluate the wind effect on the efficiency of an air-assisted sprayer in terms of spray coverage and leaf deposit on the canopy. An artificial vineyard was used to perform the different tests under standard conditions in terms of vegetation structure, and microclimate. Canopy coverage and leaf deposit were measured. The former did not allow to point out the influence of a moderate wind (2 m s^{-1}), while the latter made it possible to evaluate the influence of wind speed ≥ 2 m s^{-1} on the efficiency of the spray distribution. In windy conditions (5 m s^{-1}) treatment efficiency was reduced by approximately 70 % compared to no wind condition.

Key words. canopy coverage – chemical sprayer – leaf deposit

Introduction

The efficiency of chemical spray distribution influences both crop yield and quality, and remarkably affects environmental and production costs, depending on the number of applications per year and the drift losses.

Spray distribution in orchards are mostly performed using axial fan air-assisted sprayers fitted with hydraulic hollow cone nozzles, producing a large radial spray plume and involving a significant risk of off-target contamination by spray drift and losses on the ground (Jamar et al. 2010). This is also a subject of increasing public concern.

Properties (temperature, relative humidity, etc.) and movement of the pesticide droplets, together with the nature of target plant and sprayer (forward speed, nozzles type and flow), are among the main factors determining the accuracy of placement and coverage of pesticide air-assisted spraying in orchards, (Pergher and Gubiani 1995;Walklate et al. 1996; Phillips et al. 2000; Cross et al. 2001a, b, 2003; Delele et al. 2007; Balsari et al. 2008).

Wind is one of the most significant climatic factors influencing the efficiency of chemical distribution, since it may account for a large drift, and, in turn, for environmental pollution, increase of production costs, etc.

Wind tunnel is useful to evaluate the efficiency of air distribution, the size and velocity of the drifting liquid droplets, without the effects caused by the sprayer or the tractor (Miller et al. 1993; Bayat et al. 1999; Murphy et al. 2000; Fietsam et al. 2004; Bayat and Bozdogan 2005; Wolf 2005; Guler et al. 2007; Hewitt 2008; Qi et al. 2008, Nuyttens et al. 2009).

Cross et al. (2003) showed that considerable reductions in spray drift and increases in deposits can be achieved reducing the air volumetric flow rate from 11.3 to 4.1 m^3 s^{-1}; however, the reduction in drift was least when wind mean speed was 6.1 m s^{-1}, and early in the season when the density of apple tree canopies was very low. Cunha (2008) evaluated the theoretical horizontal distance travelled by droplets of known size, subjected to different wind velocities, demonstrating that wind influences spray drift, particularly small diameter drops (lower than 120 µm) that reaches distances higher than 15 m when wind speed is 5 m s^{-1}.

The effect of wind speed and direction on sprayer airflow was studied through a computational fluid dynamics modelling approach and validated for sprayers having different axial flow fans (Endalew et al. 2010a, b). Authors obtained a little effect of wind speed on jet velocity before the canopy and a considerable deflection of the jet centre towards the wind direction behind the canopy for high wind speed (more than 3 m s^{-1}). Moreover the effect of wind speed was more evident at distances 3.5 m far from the jet source, due to the decay of the air jet and at heights from the ground higher than 1.5 m.

Very low wind speed (below 2 m s^{-1}) did not have any significant influence on the results in terms of spray deposits (Jamar et al. 2010).

It is well known that chemicals distribution should not be performed when wind speed is higher than 3 m s^{-1}, anyway, few studies have looked at the spray distribution and its quality inside the canopy of a vineyard in presence of wind higher than the mentioned above value.

The research reported herein was designed to evaluate the possible use of an artificial vineyard to study in laboratory the effect of the wind on the efficiency of an air-assisted sprayer in terms of spray coverage and leaf deposit on the canopy. Indeed, the artificial vine may allow to carry out many replications in a standard way with non-destructive sampling. Therefore, it enables to perform experimental tests and studies on the same vegetative area having the same characteristics as number, dimensions, position and exposure of the natural leaves of a mature vine. The natural vineyard, on the other hand, fails to provide constant vegetative characteristics during the application of the different tests, because they disturb the vegetative structure, making it difficult to work under directly comparable and repeatable conditions (Nuyttens et al. 2010).

Materials and Methods

The tests were carried out in 2009 at the Agricultural Mechanics laboratory of the Department of Agro-environmental Systems (SAGA) of the University of Palermo.

The research procedure was developed as follows:
- design and implementation of an artificial vineyard;
- determination of the operating parameters of the sprayer;
- artificial generation of the wind conditions;
- qualitative and quantitative analysis of the spray distribution.

Artificial vineyard

An artificial vineyard was designed and realized in the Agricultural Mechanics laboratory of SAGA Department using a structure made up of iron tubes. For the hedgerow, zinced iron door-bolts and steel wires were used.

The canopy of the vineyard was realized using synthetic sprouts consisting of leaves of different sizes (Fig. 1); after measuring the surface of the leaves of the sprouts, they were distributed on the hedgerow in order to obtain two leaves layers and a leaf area index (LAI) equal to 3. The canopy extended from 0.40 to 1.60 m from the ground. These conditions simulate a vineyard with a complete growth (Fig. 2).

The artificial hedgerow, 5.00 m long, was divided into two horizontal strips named “A” and “B” from the top to the bottom, each 0.60 m wide. Two layers of leaves were identified and named, respectively, “external” (the nearest to the sprayer) and “internal” (the deepest inside the canopy) so that 4 sectors were identified: Aext, Aint, Bext and Bint (Fig. 3) A sampling area, 3 m long, has been identified within the artificial hedgerow in a central position.

Sprayer used in the tests

The sprayer used during the tests was the Oktopus 45-600P (Nobili SpA, Molinella, Bologna, Italy), a tractor-mounted air-assisted machine with a 600 L tank having separated and singularly adjustable “spraying modules” (nozzle and air jet) fitted with a radial fan (450 mm diameter, maximum air flow rate 3.90 $m^3 s^{-1}$) (Fig. 4). Nozzles and air jets were positioned at a distance of 0.75 m from the sprayer centreline and at a distance of 0.50 m from the outside of the vineyard canopy.

The sprayer was set referring to the field conditions; the regulation was the same for all the tests. The distribution was carried out using a “middle volume” (600 l ha^{-1}); the travel speed of the machine was 3 km h^{-1} and the working width was 2.5 m, equal to the supposed distance

Fig. 1. Synthetic leaves of different sizes making the sprouts used in the tests.

Fig. 2. Artificial vineyard used during the tests to evaluate the wind effect on the efficiency of an air-assisted sprayer in terms of spray coverage and leaf deposit on the canopy, year 2009.

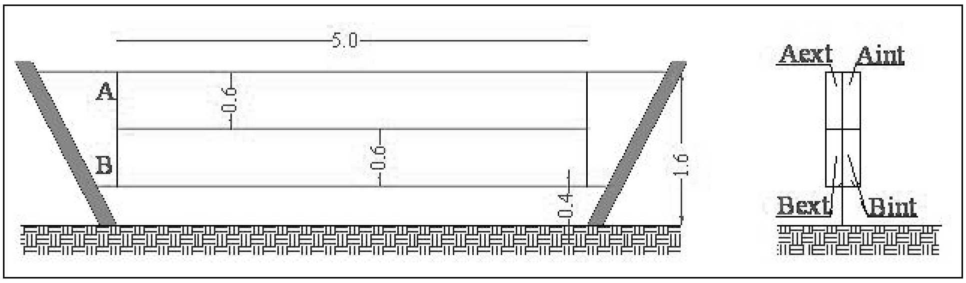

Fig. 3. Scheme of the artificial vineyard showing the two horizontal strips named "A" and "B" and the two layers of the canopy named "external" and "internal". Dimensions are in meters.

Fig. 4. Sprayer used during the tests, model Oktopus 45-600P (Nobili SpA, Italy).

between the rows. During the tests, the following operating parameters were used: total flow rate 3.75 l min^{-1}, yellow Albuz ATR nozzles, operating pressure 14 bar, air flow rate 3.90 m^3 s^{-1}, engine speed 183 rad s^{-1}, power takeoff speed 56.5 rad s^{-1}, pressure of the pump 20 bar.

Wind simulation

Two different wind conditions – 2 and 5 m s^{-1} (respectively named Tests 2 and 3) – were realized using an axial fan.

The fixed axial fan used to generate the wind was placed at a distance of 2 m from the end of the row and 4.5 m from the center of the area of the artificial vineyard, with the axis parallel to that of the hedgerow. Thus, the position of the fan with respect to the hedgerow resulted in a constant wind speed over the area of the vineyard subject to testing, particularly on the vertical profile.

The choice of the direction of the wind is due to the architecture of the hedgerow; in fact, a wind direction orthogonal to the air flow coming out of the sprayer is the one that most influences the efficiency of the treatment. Each test was repeated three times. A control set with no wind was also performed (Test 1).

Ambient conditions were 30 °C and 60 % RH, measured using the data logger Babuc E (LSI Lastem, Italy) equipped with a thermo hygrometric probe (BSU401, LSI Lastem, Italy with a range from −30 to +80 °C and 0 to 100 % R.H., resolution 0.1 °C and 0.1 % for R.H., precision ± 0.1 with 25 °C and 3 % for R.H.). The data logger was also equipped with a hot wire anemometer (BSV101 with a range from 0 to 45 m s^{-1}, resolution 0.01 m s^{-1}, precision ± 0.05 m up to 0.5 m s^{-1}, ± 0.10 m between 0.5 and 1.5 m s^{-1}, 4 % over 1.5 m s^{-1}) used to measure wind speed.

Analysis of the spray distribution

In order to evaluate the success of the distribution from the qualitative point of view, the canopy coverage (COV) was measured using water sensitive papers and image analysis. The quantitative assessment of the distribution was instead performed through the leaf deposit (DEP); it was measured through colorimetric analysis carried out on a sample of leaves by means of the spectrophotometer UV-mini 1240 (Shimadzu Scientific Instruments).

A water solution with a food dye (Ponceau 4R – E124), having molarity 8.27 × 10^{-2} and concentration 44,292.7

ppm was distributed only from the right side of the machine, opening the three lower nozzles, respectively 0.60, 1.03, 1.56 m from the ground.

After each test, the artificial vineyard was subjected to a complete wash made with pure water in order to completely remove the solution deposited on the leaves. The following treatment was performed when the canopy was absolutely dry.

Data on canopy coverage and leaf deposit were analyzed using analysis of variance and Tukey's test or t-test (Statgraphics centurion, Statpoint inc., USA, 2005).

Canopy coverage

For each test, in each sector of the hedgerow 15 water sensitive papers were placed (26 × 76 mm, 20301-1N, TeeJet Spraying Systems Co.), for a total of 60 across the sampling area of the artificial hedgerow. After the treatment, they were removed and stored in Petri dishes; then, in laboratory, image analysis was carried out to perform qualitative analysis on the results of the pesticide treatment (Sundaram et al. 1987; Salyani and Fox 1994, 1999; Ade and Fabbri 2000; Degrè et al. 2001; Theriault et al. 2001; Panneton 2002; Fox et al. 2003; Vallone et al. 2004; Marcal and Cunha 2008; Jamar et al. 2010; Zhu et al. 2011).

The image acquisition was performed by a flatbed scanner with optical resolution of 300 dpi; each pixel corresponded to 85 µm, therefore objects having representative size less than this value were not considered. The image analysis was performed using the Image Pro Plus software version 6.3 (Media Cybernetics, USA), first, performing the calibration image both horizontally and vertically, then counting the objects and determining the required parameters. In the present case the total area of the footprints of the drops that impacted the support was derived. Canopy coverage, expressed as a percentage of the covered area respect to the examined surface, was determined from the analysis of the water sensitive papers.

Leaf deposit

In order to measure the quantitative analysis of leaf deposit, a sample of 32 leaves, 8 per sector, was taken after each test along the whole hedgerow. After the spray distribution, artificial leaves were put inside hermetic boxes and then transferred to the laboratory.

Every leaf was washed with 50 ml of distilled water; the obtained solution was poured into a volumetric flask and diluted till 100 ml. In this way a diluted solution with an unknown concentration was obtained. This solution was analysed by means of the spectrophotometer that gave the absorbance of each sample and then its concentration. Since the concentration of the initial solution was known, it was possible to obtain the volume arrived on the leaf that, divided by the leaf surface (both faces), made it possible to obtain the deposit per unit leaf surface (µl cm^{-2}).

For each analysis session, the spectrophotometer was adjusted to convert the absorbance given by the instrument into concentration of the analysed solution.

Preliminarily to the tests, a simulation of treatment on a sample of 30 leaves, 15 natural and 15 synthetic, was carried out in order to compare the artificial leaves with the natural leaves of a vineyard. The leaves were fixed on a vertical support, properly prepared, and treated with the sprayer used for the tests; three replications were carried out. There were no statistically significant differences between the values of leaf deposit obtained on the natural leaves and the values obtained on the artificial ones (Table 1). Therefore, it can be assumed that the tests carried out on the artificial hedgerow can be considered valid in terms of leaf deposit, even for a natural vineyard.

Results

No significant differences were found in canopy coverage between the two strips of the vegetation A and B both in the external and the internal layer (Fig. 5). On the other hand, statistically significant differences ($P \le 0.05$) were found between the external and the internal layer both in the two strips of the vegetation A and B in the three tests (Fig. 5).

Mean values of leaf deposit (µl cm^{-2}) didn't result in statistically significant differences ($P \le 0.05$) between the high and the low strip of vegetation A and B both in the external and the internal layer (Fig. 6). Statistically significant differences ($P \le 0.05$) were found between the external and the internal layer both in the two strips of vegetation A and B, only in Test 1. The COV values decrease as wind speed increase in every layer and strip of vegetation.

Comparing the three tests statistically significant differences emerge both in the two strips (A and B) and in the two leaf layers (int and ext) only between the Tests 1 and 3 resp. 2 and 3 (Table 2).

This shows that the COV method, which uses water sensitive papers as targets, with the same vegetative condition of the vineyard, provides different results in terms of canopy coverage only in presence of strong winds (higher than 2 m s^{-1}) (Table 2).

In particular, in the highest strip of the external layer (Aext) there is a COV decrease by 62 % comparing Test 1 (no wind) with Test 3 (wind of 5 m s^{-1}) and a COV reduction by 38 % going from Test 2 (wind of 2 m s^{-1}) to Test 3 (wind of 5 m s^{-1}).

In the external layer of the low strip (Bext) the COV decreases by 55 % going from Test 1 to 3 and by 27 % from Test 2 to 3.

In the internal layer of the high strip (Aint) there was a 58 % COV reduction between Tests 1–3 and 46 % between 2 and 3. In the low strip of the same layer (Bint), there was a COV reduction equal to 40 % between Tests 1 and 3 and 34 % between 2 and 3.

In other words, the high strip of the internal layer suffers a higher COV decrease with wind velocity over than 2 m s^{-1}.

Table 1. Colorimetric analysis results for the comparison between natural and artificial leaves. Data are reported as means ± standard deviations of the three replicates (t-test at the 95 % confidence level).

Leaf type	Deposit [µl cm^{-2}] – Mean
Artificial	0.9756 ± 0.062 a
Natural	0.9645 ± 0.053 a

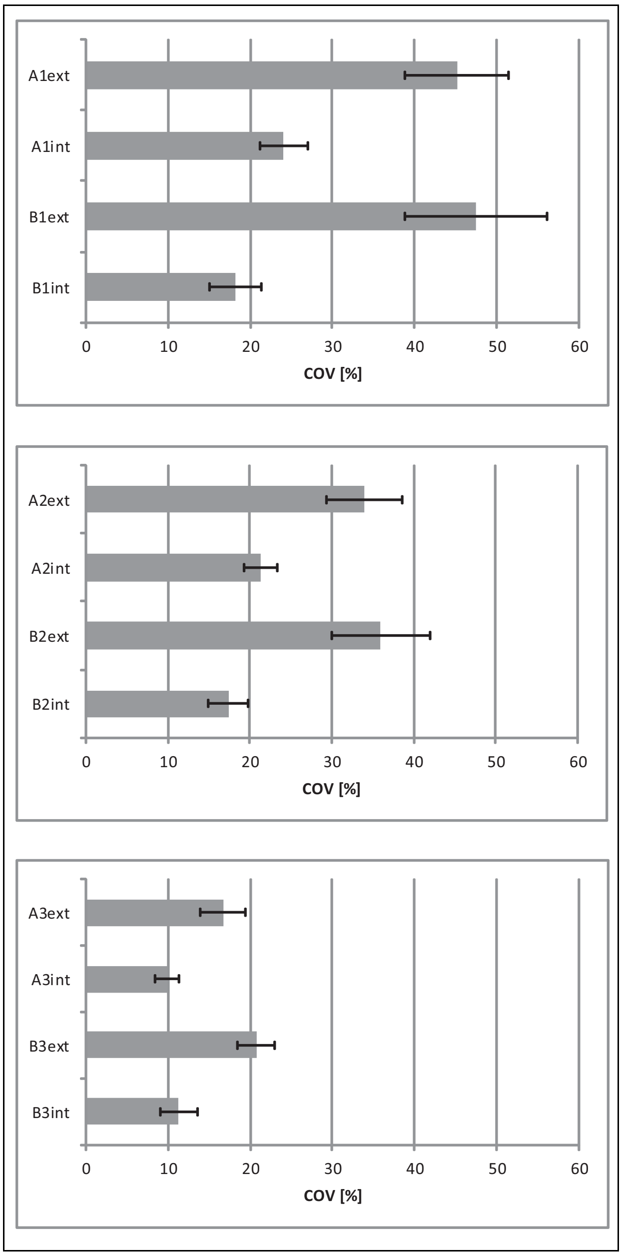

Fig. 5. Canopy coverage values (%) in the three tests. Data are reported as means ± standard deviations of the three replicates (t-test at the 95 % confidence level).

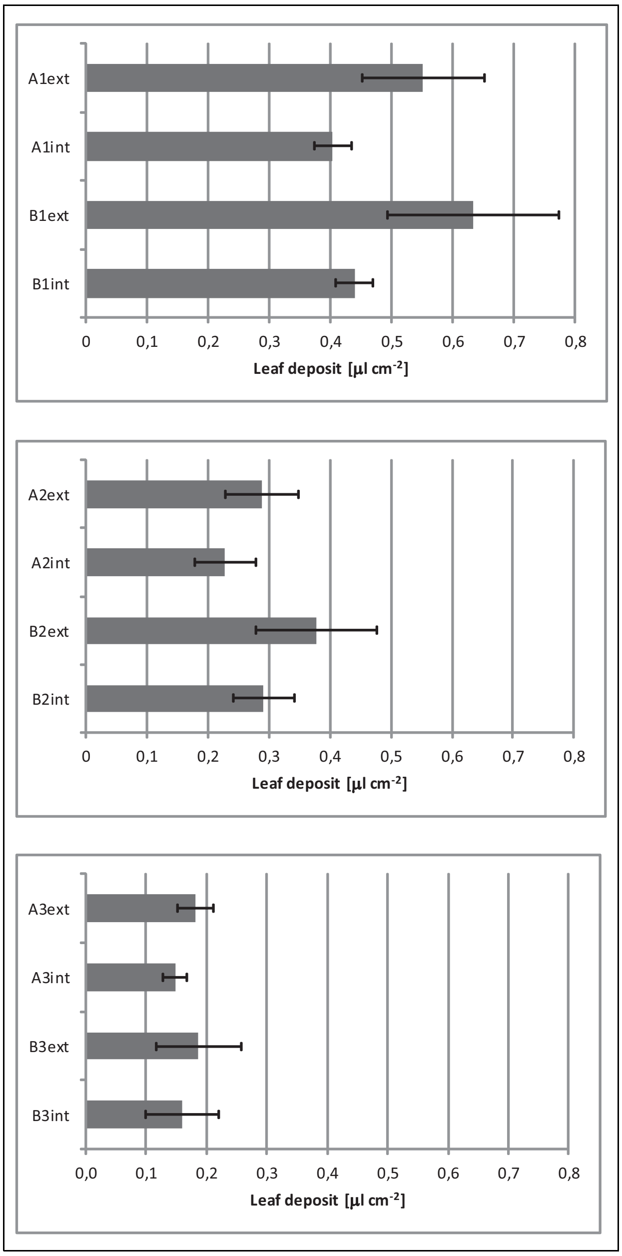

Fig. 6. Leaf deposit values (µl cm^{-2}) in the three tests. Data are reported as means ± standard deviations of the three replicates (t-test at the 95 % confidence level).

The leaf deposit values generally decrease as wind speed increase in every layer and strip of vegetation; statistically significant differences were always obtained among the three tests (Table 3).

In particular, in the high strip of the external layer (Aext) there is a 48 and 67 % DEP decrease respectively going from conditions of no wind to wind values of 2 and 5 m s^{-1}. Similar results were obtained in the low strip of the same layer (Bext) where DEP reduced by 40 and 70 % respectively in presence of 2 and 5 m s^{-1} wind.

DEP values obtained in Test 2 and 3, for the internal layer of the high strip (Aint), were lower than those obtained in Test 1 respectively of 44 and 64 %. In the low strip of the same layer (Bint) there was a 34 and 64 % DEP reduction respectively in Test 2 and 3 respect to Test 1.

Discussion

The use of an artificial vineyard allowed to perform the different tests under standard conditions in terms of vegetation, structure and microclimate and provided important information on the methodology applied to assess the efficiency of the treatment. In fact, comparing the two analysis methods (canopy coverage and leaf deposit), it comes out that the COV analysis, performed through water sensitive papers and image analysis,

Table 2. Canopy coverage values and statistical analysis. Data are reported as means and standard deviations of the three replicates (Tukey's test at the 95 % confidence level).

Sector	Mean [%]	Standard deviation	Sector	Mean [%]	Standard deviation
A1ext	45 a	6.32	A1int	24 a	2.94
A2ext	34 a	4.62	A2int	21 a	2.00
A3ext	17 b	2.70	A3int	10 b	1.44
B1ext	47 a	8.63	B1int	18 a	3.21
B2ext	36 a	6.01	B2int	17 a	2.45
B3ext	21 b	2.23	B3int	11 b	2.20

Table 3. Leaf deposit values and statistical analysis. Data are reported as means and standard deviations of the three replicates (Tukey's test at the 95 % confidence level).

Sector	Mean [µl cm^{-2}]	Standard deviation	Sector	Mean [µl cm^{-2}]	Standard deviation
A1ext	0.551 a	0.10	A1int	0.404 a	0.03
A2ext	0.288 b	0.06	A2int	0.228 b	0.05
A3ext	0.182 c	0.03	A3int	0.148 c	0.02
B1ext	0.633 a	0.14	B1int	0.439 a	0.03
B2ext	0.378 b	0.10	B2int	0.291 b	0.05
B3ext	0.187 c	0.07	B3int	0.160 c	0.06

doesn't allow to point out the influence of a moderate wind (2 m s^{-1}) on the efficiency and accuracy of canopy coverage. The DEP method, however, allows to evaluate the influence of wind speed equal to or greater than 2 m s^{-1} on the efficiency of the spray distribution, because the values of leaf deposit were significantly reduced by about 40 %.

At a wind speed of 5 m s^{-1} the treatment efficiency was reduced by approximately 70 % compared to no wind condition; it is, therefore, advisable in such circumstances, do not perform the phytoiatric treatment.

With no wind (Test 1) differences (DEP) were obtained between the internal and the external layer; while at a wind speeds of 2 and 5 m s^{-1} (Tests 2 and 3) the leaf deposit, greatly reduced compared to Test 1, was similar in both the external and the internal layer. This is due to the wind action that reduces the amount of product deposited, more on the outer than in the internal layer of vegetation.

On the other hand, the machine efficiency can't be adequately appreciated by the COV analysis in windy conditions as the results have the same trend in the three tests with no significant differences between the external and the internal layer of vegetation.

Both, the high and the low strip of the external layer of the hedgerow suffer a similar reduction in COV justified by the type of machine used and in particular by the presence of three spraying modules allowing the mixture distribution near the vegetation with flow direction perpendicular to it. This prevents the formation of turbulence in the low strip, caused by the combination of the air flow generated by the air-assisted sprayer fan and the wind that instead occurs with the use of a traditional sprayer.

The results in terms of DEP (Table 3) allow to assert that in windy conditions, the amount of the phytoiatric product distributed on the unit area of vegetation should be increased in order to obtain the optimum treatment efficiency.

The research pointed out that the results of the chemical distribution are affected by the ambient conditions and particularly by the wind, under the same operative parameters.

The results obtained with wind lower than 2 m s^{-1} agree with other authors results (Jamar et al. 2010) in terms of spray deposits.

The results obtained in this study with wind speed higher than 2 m s^{-1} agree with those obtained by other authors in standard operating conditions using only the wind as a variable (Cross et al. 2001a, b).

The study highlights, therefore, that the agrochemical treatment efficacy, apart from the type of pesticides, it is certainly influenced by the wind and that the COV method is less reliable than DEP particularly when working under moderate wind conditions.

Conclusions

In this study the efficiency of agrochemicals distribution with an air-assisted sprayer on an artificial vineyard is evaluated in relation to wind conditions.

The results show the efficiency of the artificial vineyard in assessing the influence of the wind on spray distribution in the vineyard. During the execution of a pesticide treatment, the wind is a relevant factor as regards the right amount of product to be deposited on the vegetation. In fact, intervening in presence of wind equal or higher than 2 m s^{-1} requires an increase in the dose of the phytoiatric solution in order to obtain the same amount of agrochemical on the unit area of vegetation as with no wind. This should cause negative consequences on the farm income due to increased operating costs, on environment and operator's health for the considerable drift increment.

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