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Comparison of the pesticide coverage achieved in a trellised vineyard by a prototype tunnel sprayer, a hydraulic sprayer, an air-assisted sprayer and a pneumatic sprayer

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Abstract

Spraying is the main method used to apply pesticides to trellised vines in Castilla-La Mancha, Spain. If the efficiency of spray applications is to be improved, the amount of pesticide employed is to be reduced, and the performance of existing and new spray technology enhanced, the leaf coverage achieved must be known and a system developed that can rapidly determine it. With these aims in mind, the authors built and tested a prototype tunnel sprayer and compared its efficiency to the three types of sprayer most commonly used in the region: the hydraulic sprayer, the air-assisted sprayer and the pneumatic sprayer. To determine and compare the coverage produced by these four machines, a rapid analysis system that combines the use of water-sensitive paper strips and an artificial vision system was developed. All four machines were used to spray a commercial fungicide (dose 200 L ha^{-1}) at working pressures of 0.1, 0.3 and 0.6 MPa onto vines in a trellised vineyard. With all four models, the quality of the application improved with the spraying pressure, although the best spraying coverage was obtained with tunnel sprayer. Even though the results obtained were not optimum (the formation of a uniform film of fungicide on the leaf surface), the mean coverage achieved by the tunnel sprayer (as recorded by the water-sensitive papers attached to the leaves) was 54%, and on occasion over 79%.

Additional key words: drift, fungicide, trellised vines, water-sensitive paper.

Resumen

Comparación del recubrimiento con productos fitosanitarios alcanzado en viña en espaldera por un prototipo de pulverizador tipo túnel, un pulverizador, un atomizador y un nebulizador

La pulverización es el principal método usado en Castilla-La Mancha para aplicar productos fitosanitarios a la viña en espaldera. Si la eficiencia de las aplicaciones se incrementa, la cantidad de pesticida empleado se reduce y el rendimiento de las máquinas existentes y de las nuevas tecnologías aumenta. Para ello, debe conocerse el recubrimiento alcanzado en las hojas y desarrollarse un sistema que pueda determinarlo rápidamente. Con estos objetivos se construyó y ensayó un prototipo de pulverizador tipo túnel, y se comparó su eficiencia con los tres tipos de máquinas de aplicación de productos fitosanitarios más utilizados en esta región: pulverizadores, atomizadores y nebulizadores. Para determinar el porcentaje de recubrimiento logrado por las máquinas, se desarrolló un sistema rápido que combina el uso de cartulinas de papel hidrosensible con la visión artificial. Con todos los pulverizadores se usó el mismo fungicida comercial (200 L ha^{-1}) y se ensayaron, a tres presiones diferentes (0,1 MPa, 0,3 MPa y 0,6 MPa), en un viñedo en espaldera. Se demostró que en los cuatro modelos la calidad de la aplicación mejora con la presión de la pulverización, y que el mejor recubrimiento se obtuvo con el prototipo de pulverizador tipo túnel. Aunque los resultados obtenidos no fueron óptimos (formación de una película uniforme de fungicida), el valor medio alcanzado por el prototipo fue del 54%, y en ocasiones superó el 79%.

Palabras clave adicionales: deriva, fungicida, viña en espaldera, papel hidrosensible.

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Introduction

Castilla-La Mancha has almost 300,000 ha of vines (*Vitis vinifera* L.). It is the most important vine-growing region in Spain; indeed, it has the largest continuous extension of vineyards in the world. The cultivars Airén (white) and Cencibel (red), which are cultivated with a short trunk, occupy the largest area. Over the last decade, however, the number of trellised vineyards has increased. This type of viticulture is inconceivable without the use of pesticides, and vine growers require machinery that can efficiently apply these products (Hidalgo and Hidalgo, 2001).

The main method used to control vine pests chemically is spraying. The advances made in application technology over the last ten years have allowed the doses used to be reduced (Doruchowski and Holownicki, 2000). In fact, spraying can now be considered a high precision technique.

The machines used to spray vines in Castilla-La Mancha can be classified into three groups: hydraulic sprayers, air-assisted sprayers and pneumatic sprayers.

The success or failure obtained when applying pesticides is usually attributed to the product used. However, the moment of application, the developmental stage of the pest or disease, and the uniformity of coverage of the target area, all affect the degree of pest/disease control achieved (Herbst and Wolf, 2001). Poor uniformity in the spray coverage can lead to poor disease control, even when sprayings are well timed (Furness *et al.*, 2001). Proper coverage, achieved by improving the efficiency of spraying, can reduce the quantity of pesticide required (McFadden-Smith, 2003).

The number of pesticide droplets per square centimetre of plant surface is often used as a value for quantifying spray coverage. Evans *et al.* (1967) showed that for a constant amount of pesticide, the efficiency of a treatment improves as the plant surface covered increases. In an ideal world, the entire plant surface would be covered by a uniform, continuous barrier of pesticide (Soriano, 1994).

The aim behind the construction of the prototype tunnel sprayer was to allow ideal application efficiency to be approached by reducing drift losses (drift is one of the main phenomena preventing the arrival of sprayed products at their targets) (Ozkan *et al.*, 1997; Rautmann, 2002), by reducing evaporation losses, and by ensuring that the majority of droplets reach their target. The nozzles of this sprayer are mounted on two booms that form tunnels on either side of the machine; these travel over the plants, spraying as they go, without the need for auxiliary fluid (Fig. 1).

The evaluation of the percentage target coverage achieved by sprays has been of interest for more than 75 years (Ginsburg, 1928; Panneton and Lacasse, 2003). Different methods have been developed to study this (Soriano, 1994), including analytical (Yates, 1962), fluorimetric (Himel, 1969), colorimetric (Hebblethwait, 1956; Carlton and Bouse, 1987), «fingerprinting» (Bennet and Furmidge, 1956; Soriano *et al.*, 1987), water-sensitive paper strip (Blinn and Lowell, 1965; Panneton and Lacasse, 2003) and artificial vision techniques (Porras *et al.*, 1996, 2001; Gedalyahu and Yossi, 2002).

In this work, spray coverage was recorded using water-sensitive paper strips to detect droplet contact via a yellow-to-blue colour change. An artificial vision system then determined the coverage achieved by each machine.

This paper reports the comparison of a prototype tunnel spraying machine for use in trellised vineyards, with the three most common types of sprayer used in Castilla-La Mancha.

Material and Methods

All assays were performed in July 2003 in a 12 ha plot containing 304 trellised vines (cv. Sirah). These plants were grown 1.5 m apart in rows separated by 3 m. One hundred and eighty of these were used directly in the assays; the rest were used to separate the areas sprayed by the different machines and thus eliminate interference.

Characteristics of the four spraying machines tested

Tunnel sprayer prototype

The booms of the prototype tunnel sprayer (Fig. 1) are metal tubes that form two arcs on either side of the machine. These arcs are covered in a plastic screen to form tunnels that prevent the drift and reduce the evaporation of the sprayed droplets. Spraying occurs as the tunnels travel over the rows of plants. The arched booms also hold the spray nozzles and form the pipes transporting the pesticide from the pump. The tunnels

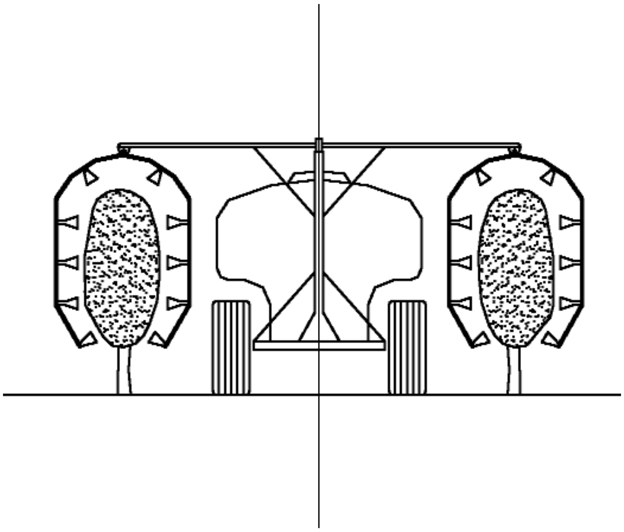

Figure 1. Tunnel sprayer.

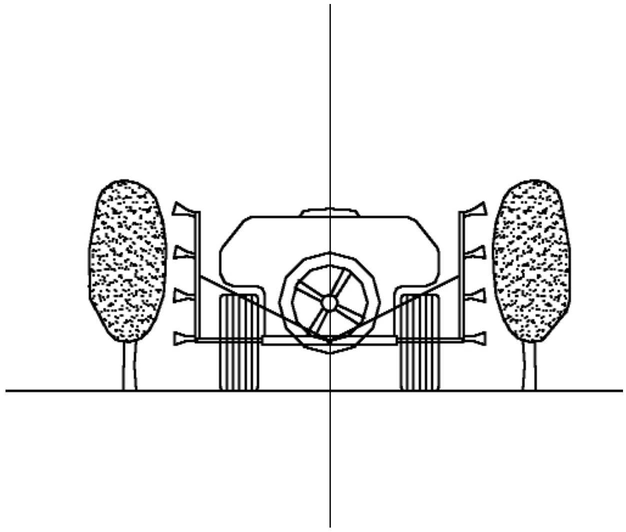

Figure 2. Hydraulic sprayer.

are fixed to the structure in such a way that they can be adapted to different planting patterns. The orientation of the nozzles was adjusted to direct the sprayed droplets towards the inside of the tunnel and onto the plants (Farooq and Landers, 2004).

The sprayer nozzles used in this assay were the full jet swirl type. The flow formed is a cone, the angle of which can be changed manually from 20º to 80º. A 45º angle was used during the assays. This also aids in directing the spray towards the inside of the tunnel. Five nozzles were placed at the front and back of each tunnel. The machine's «equivalent performance» (i.e., the number of rows of plants to which pesticide can be applied in one pass of the machine) is two rows per pass.

Hydraulic sprayer

The machine used (Fig. 2) (basically the same as the air-assisted sprayer but with a fan to produce an auxiliary air current that blows the droplets towards the leaves; in this case the fan is not connected via the clutch to the power transmission outlet of the tractor) had two vertical spraying booms, one on either side. To adapt the machine to the height of the vines in the present assay, only four full jet swirl-type nozzles were attached to each boom. Fungicide applications were made by moving the machine along two consecutive crop rows. In this way the vines were sprayed on both sides. The equivalent performance is one row per pass.

Air-assisted sprayer

The machine used (Fig. 3) had two spraying booms running around a fan. To adapt the machine to the height of the vines in the present assay, only four full jet swirl-type nozzles were used. The fan, in this case connected to the power transmission outlet via the clutch, produces an auxiliary air current to blow the droplets towards the leaves. Fungicide applications were made by moving the machine along two consecutive rows of crops. In this way the vines were sprayed on both sides. The equivalent performance is one row per pass.

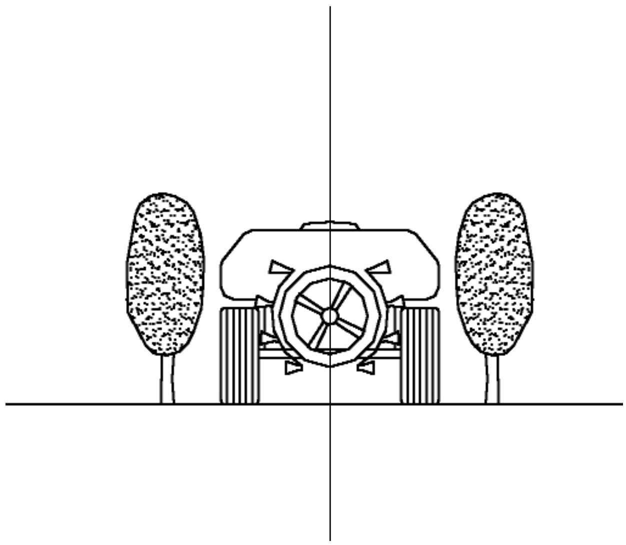

Figure 3. Air-assisted sprayer.

Pneumatic sprayer

The machine used (Fig. 4) had two spraying booms arranged like a gantry, one on either side. Each boom had eight full cone nozzles mounted in pairs at the end of flexible tubes from which an air jet (produced by a fan) is expelled. The fungicide was therefore applied to two vine rows in a single pass, and from both sides. The equivalent performance is two rows per pass.

Fungicide application

The fungicide used in all assays was copper oxychloride 22% plus Mancozeb 17.5% w w^{-1} [Cuprevel Wettable Powder (Kenogard)]. This was applied at a dose of 200 L ha^{-1} (10 g L^{-1} water), calculated by taking into account a leaf area index (LAI) of 2.75, a mean droplet diameter of 250 µ, 80 droplet impacts per cm^2 of leaf, and a 10% loss of product (Moreno and Pávez, 2000; Johnson *et al.,* 2001).

Fungicide was applied at three different pressures by all four machines: 0.1, 0.3 and 0.6 MPa. In order that the four machines should apply the same amount of pesticide per hectare, laboratory test were made before the field trials to define the operating characteristics of the sprayers. The equation for the flow-pressure curve of the spraying boom nozzles was first calculated. For this, the flow rates of the spraying nozzles at working pressures of 0.1, 0.3, 0.6, 0.9, 1.2 and 1.5 MPa were measured; the data obtained were fitted to a potential function using Curve Expert v 1.3 software.

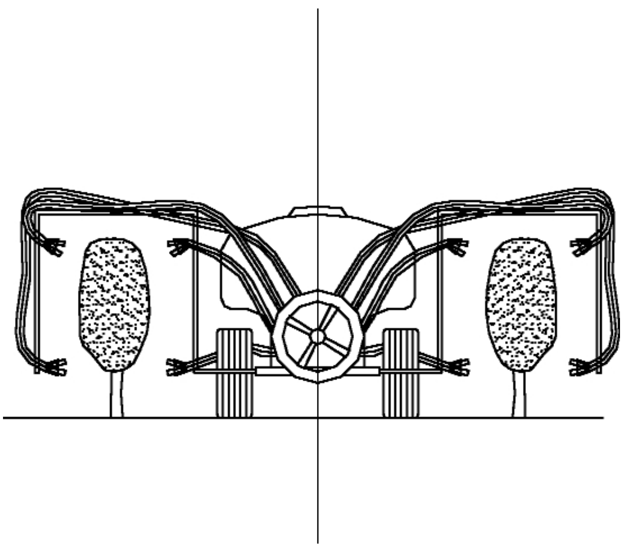

Figure 4. Pneumatic sprayer.

With their spraying tanks ¾ full of water, the machines were then hitched to a tractor (nominal power 60 kW) equipped with a four combination reducer, neutral and four forward change gearbox. The machinery travelled around the lanes of the test vineyard to obtain the equations of the straight lines representing their displacement velocities in terms of engine rotation speed. This test was performed twice. The vehicle's tachometer was used to measure the rotation speed of the tractor engine during the assay, after previously verifying its performance using a digital reflection tachometer (Sony model DT5350-C). This provides measurements with only a $\pm 2\%$ error.

Water-sensitive paper strips

Water/oil-sensitive papers (76×26 mm) (TeeJet, Spraying Systems Co.) were used to detect the impacts of the droplets sprayed from the four machines and at the different pressures. For each type of machine and pressure, pairs of water-sensitive strips were fixed with clips to the upper and lower faces of three external leaves (40, 80 and 120 cm above the ground) belonging to six different plants. These plants were 3 m apart.

During the assay period (all assays were performed on the same day), the temperature rose from 24ºC to 28.3ºC, and the relative humidity fell from 53% to 40%.

When the water-sensitive papers were dry (30 min), they were collected, individually digitised and stored as BMP files (resolution 640×480 pixels, 100 pixels per inch). Digitisation was performed using a Hewlett Packard Vectra PC computer and a Hewlett Packard Intelligent Scanner. The red, green and blue (R, G and B) coordinates corresponding to the blue (indicators of droplet impact) and yellow pixels (the original paper colour) were determined using commercial Aldus Photostyler software. An in-house programme written in Turbo-basic (available free from the authors upon request), which compares the R, G and B coordinates, was used to calculate the percentage area covered by blue pixels and yellow pixels in each image (precision 6.45×10^{-2} mm^2 per pixel). This provided the total area hit by the droplets.

The Student t-test was used to compare the mean percentage coverage achieved by each sprayer. All calculations were performed using Statgraphics Plus 2.1 software.

Results

None of the pairs of water-sensitive paper strips attached to the leaves were lost during the assays. This was expected since the nozzles did not touch them during spraying, nor were any of the air currents used strong enough to detach them from the leaves.

With respect to individual machines, no significant differences ($p > 0.05$) were seen between the percentage coverage achieved at the three different paper strip heights.

Table 1 shows the mean, maximum and minimum percentage coverages obtained at the different assay pressures by each of the four sprayers.

The minimum and maximum values obtained for the four machines differed widely at all pressures, indicating that the uniformity of coverage was low. Further, the coverage of the undersides of the leaves was less than that achieved for the upper sides; this means that treatments may sometimes be ineffective. However, the tunnel sprayer achieved better upper and underside coverage. Although the ideal of a uniform fungicide barrier was not achieved, the mean coverage obtained was 54%, and on occasions more than 79% coverage was achieved. The coverages achieved by all four machines increased with spraying pressure.

The differences between the spraying efficiencies of the different machines was very clear. The tunnel sprayer provided the highest percentage coverages, followed by the pneumatic sprayer, the air assisted sprayer, and finally the hydraulic sprayer.

Discussion

The wide range of coverage values obtained with each sprayer type shows that uniformity of coverage was low. This can result in poor disease control (Furness *et al.,* 2001). The cause of such wide variation may be the high density of leaves and the variability in their orientation.

In all tests, the percentage coverage achieved on the underside of the leaves was significantly lower ($p \leq 0.05$) than that achieved on the upper side. In agreement with Tu *et al*. (1988), it may be more difficult for the droplets to reach the undersides of the leaves.

It is important to note that two rows of vines can be sprayed per pass with the tunnel sprayer. This is only equalled by the pneumatic sprayer; both the hydraulic sprayer and the air-assisted sprayer have an equivalent performance of only one row per pass.

As the spraying pressure increased so too did the percentage coverage obtained. This may be because the diameter of the droplets issued by the nozzles are smaller at higher pressures. Therefore, for the same volume of liquid sprayed, the droplets can cover a wider area. At a spraying pressure of 0.6 MPa, the maximum coverage recorded was achieved by the tunnel sprayer, which at times exceeded 79%. Such a high value was reached by none of the other three machines. This shows that the tunnel sprayer comes closest to forming a continuous film of fungicide on the plant surface. The coverages achieved with this machine can be explained by the fact that: 1) spraying occurs inside

Table 1. Spraying pressure 0.1, 0.3 and 0.6 Mpa: mean, minimum and maximum percentage coverage obtained with the different machines

Sprayer	Pressure (MPa)	Upper side of leaf			Under side of leaf		
		Mean	Min	Max	Mean	Min	Max
Hydraulic	0.1	6.65 a	1.96	11.19	1.26 a	0.27	2.93
Air-assisted	0.1	10.72 b	4.45	15.54	2.11 ab	0.88	3.85
Pneumatic	0.1	18.36 c	7.88	29.38	3.77 b	1.63	6.23
Tunnel	0.1	21.60 d	9.88	30.02	5.79 c	3.69	9.55
Hydraulic	0.3	11.15 a	7.41	17.43	1.92 a	0.38	3.95
Air-assisted	0.3	19.24 b	14.37	23.24	3.53 a	1.34	4.87
Pneumatic	0.3	28.50 c	17.65	36.43	7.03 b	3.45	8.78
Tunnel	0.3	36.07 d	15.86	78.95	9.87 c	6.31	14.76
Hydraulic	0.6	13.63 a	2.54	23.13	3.29 a	0.62	3.38
Air-assisted	0.6	25.40 b	17.92	33.88	5.58 b	3.03	8.88
Pneumatic	0.6	46.66 c	17.65	27.07	6.21 b	3.45	9.27
Tunnel	0.6	54.30 d	15.86	79.53	9.87 c	6.31	14.76

For each pressure, values in columns followed by different letters indicate significant differences ($p \leq 0.05$).

the tunnels formed by the covered booms; at the higher pressures, when the droplets issuing from the nozzles are smaller, drift and evaporation are minimal; 2) the distance travelled by the droplets from the nozzles to the plant surface is greatly reduced; thus, although the droplets are small, they have sufficient kinetic energy to reach the plant surface without the need of an auxiliary fluid.

Under these test conditions, the best spraying quality was obtained with the tunnel and pneumatic sprayers, and the worst by the hydraulic sprayer.

In conclusion, the prototype tunnel sprayer provided the highest percentage coverages of all the machines tested. Although ideal fungicide treatment —the formation of a continuous barrier of the product on the plant surface— was not achieved, at the maximum pressure assayed the mean percentage coverage was 54%, a figure clearly greater than that achieved in similar vineyards (35%) by Panneton and Lacasse (2003) using other machines and other water-sensitive paper strip. In some cases, the coverage achieved was over 79%. However, these values may differ depending on the target employed.

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