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Development of two portable patternators to improve drift control and operator training in the operation of vineyard sprayers

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Abstract

Spray drift can be defined as the quantity of plant protection product that is carried out of the sprayed area by the action of air currents during the application process. Efficacy of pesticide applications in orchards and vineyards is highly dependent on matching the canopy characteristics with the liquid distribution on a vertical plane, this being influenced by the type of sprayer, the nozzle orientation and air outlet adjustment. Two simple vertical patternators were designed and developed with the express purpose to be used in field conditions for the adjustment of vineyard canopy sprayers. Three different orchard sprayers were selected for comparative field trials of two new patternators with an already commercially available portable vertical patternator designed at University of Turin (Italy). The objective was to evaluate their efficiency in terms of spray recovery, symmetry and repeatability. Results show the ability of the two prototypes to measure the vertical distribution of liquid, as well as the important similarities between the liquid distribution profiles obtained with both patternators in comparison to the reference one. Trials conducted with the three different orchard sprayers show the suitability of this kind of tool, not only for research purposes but also for training activities and as part of the sprayer calibration process. Important benefits from both an economic and a sustainable point of view can be obtained regarding adequate liquid distribution according to the crop characteristics, this being especially interesting in field conditions.

Additional key words: vertical patternator; crop profile; sprayer; nozzle adjustment.

Introduction

Spray drift, defined as the quantity of plant protection product that is carried out of the sprayed area by the action of air currents during the application process, continues to be a major problem when applying agricultural pesticides. Drift can cause crop protection chemicals to be deposited in undesirable areas with serious consequences (Ozkan *et al.*, 1993; De Snoo & De Wit, 1998). According to Nuyttens *et al.* (2007) most of the negative consequences can cause: (a) damage to sensitive adjoining crops and other susceptible off-target areas; (b) environmental contamination such as water contamination and illegal pesticide residues; (c) health risks to animals and people and (d) lower dose than intended on the target field, which can reduce the effectiveness of the pesticide, wasting both pesticide and money.

In order to improve the liquid distribution and to adapt it to the canopy characteristics, it is important to have available a device which can easily show and measure the spray distribution under field conditions. Good liquid distribution has been shown as one of the main aspects related to drift reduction in pesticide application in orchard and vineyard applications. It has been estimated that only 55% of the spray from an airblast sprayer actually reaches the intended target (Keen, 2010). The remaining 45% either hits the ground or becomes airborne as spray drift. An adequate adjustment of spray liquid distribution to the canopy structure can

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Abbreviations used: CU (Cornell University); LAI (leaf area index); NSR (normalized spray recovery); SE (standard error); UPC (Universitat Politècnica de Catalunya).

reduce spray drift up to 90% and reduce pesticide use up to 20%. The negative consequences following inefficient pesticide applications are both economic and environmental, due to up to 80% of product being lost during application (Balsari *et al.*, 2000).

Nevertheless, product saving and environmental pollution control can be achieved by a targeted application. This aspect is especially important in the case of fruit trees and grapevines, where the risk of drift is especially important and it is highly influenced by an adequate nozzle orientation procedure. An adequate adaptation of liquid distribution to canopy structure is fundamental in order to achieve an homogeneous pesticide distribution throughout the whole canopy reducing at the same time the risk of environmental contamination as a consequence of better control of pesticide losses into the soil and, most importantly, through a better control of the droplets passing over the canopy at the top part of the trees or vines.

An evaluation of the vertical distribution pattern is crucial in improving the quality of products being applied (Biocca *et al.*, 2005). In fact, this test allows the operator to: 1) direct the spray up to the tree crown, reducing the off-target drift, 2) adjust nozzle orientation to achieve the best spray pattern and 3) reduce differences between right and left side distribution in a conventional orchard sprayer with an axial fan avoiding the negative effect of fan rotation direction. The use of a device such as a vertical patternator allows the farmer to adjust the size, position and orientation of the spray nozzles to maximize the distribution of the spray within the plant canopy, reducing spray costs and increasing productivity from reduced pesticide use and better application. Vertical patternators allow the operator to quantify the vertical liquid distribution generated by the tested sprayer and this vertical profile can be evaluated in comparison with canopy structure. Cerruto *et al.* (2010) concluded that more spray deposition on the leaves could be obtained by using a distribution profile at the patternator strictly comparable to the leaf area index (LAI), but the profile related to the plant geometry could provide a more uniform deposition. Pergher *et al*. (2002) determined the relationship between vertical spray pattern obtained with vertical patternator and foliar deposits in vine canopies, using an air-assisted sprayer. Landers & Gil (2006) used a vertical patternator (MIBO, Italy) for the development of a new air deflector to improve the efficiency in vineyard sprayers in the USA. Landers *et al.* (2012) demonstrated the interest of vertical patternator for training and extension purposes. Hundreds of canopy sprayers were evaluated in a ten year period, in both orchards and vineyards, and the use of the vertical patternator enabled educators to demonstrate to grower audiences the quantity of spray plume going up and over the canopy, the spray symmetry, or lack of, between the left and right side of the sprayer, and the importance of adjusting the sprayer correctly to improve deposition and reduce drift.

Europe has been the leading region for developing vertical patternators for orchard and vineyard sprayers. Patternators are in use in Europe to test airblast sprayer design and calibration. Different types of devices (vertical patternators) have been developed with the aim of collecting the amount of liquid sprayed at varying heights and to compare the collected spray with the canopy characteristics. Various methods of collecting the spray plume have been developed such as the fluid separation method by means of a lamellate spray separator (Kûmmel *et al.*, 1991; Ade & Venturi, 1994), the absorption method (Balsari & Tamagnone, 1995), rectangular plates (Pergher & Gubiani, 1997), or even measuring fluid and air distribution (Porskamp *et al.*, 1993). Technical solutions developed up to now vary mainly in the size, shape, and material of the capturing system. In all cases, whatever the solution adopted, the devices were evaluated according to their efficiency (amount of recovered liquid in relation to the total sprayed), their repeatability and their ability to reproduce the effect of the spraying technique on the real vegetation (Balsari *et al.*, 2000; Biocca *et al.*, 2005).

Sprayer calibration for fruit trees and grapevines is directly dependent on canopy characteristics. It is widely recommended to adapt the amount of liquid (L ha^{-1}) and its distribution following the canopy structure. However, the usefulness of vertical patternators for orchard sprayers has been questioned (Pergher *et al.*, 1994; Schmidt & Koch, 1995; Pergher & Gubiani, 1997; Pergher, 2004), mainly because of the difficulty in establishing a clear relationship between the vertical spray pattern, the crop features and the resulting spray deposition. But contrary to those results, other authors (Landers *et al.*, 2012) have demonstrated the effectiveness of these devices for training and extension activities. It demonstrated to grower audiences the quantity of spray plume going up and over the canopy, showed the symmetry, or lack of, between left and right side of the sprayer, and underlined the importance of adjusting the sprayer correctly to improve deposition and reduce drift.

The commercially available patternators in Europe are quite expensive for an individual grower's use and not adaptable for field conditions. The majority of the currently available vertical patternators have been designed for use in laboratory conditions, where real canopy characteristics are difficult, if not impossible, to reproduce. This fact reduces considerably their applicability in extension and training activities.

The aim of this research was to design, develop and test two simple, inexpensive and practical tools for spray distribution adjustment in the field and to improve the process of pesticide application in the vineyard spray process. This paper shows the main characteristics of the two different patternators developed and the results of comparative tests carried out with a commercial version to assess their utility in field conditions.

Materials and methods

Characteristics of vertical patternators

Two different proposals were developed, with remarkable differences in the method of spray capture and development process.

UPC patternator

A revised version of the mobile patternator designed by UPC (Gil & Badiola, 2007) was constructed. Ten 0.16 m diameter PVC elbows were mounted in plastic frames attached to a 3.8 cm angle steel frame. Each elbow faced outwards and at the other end a plastic funnel was attached. A plastic hose connected the funnel to a box containing graduated measuring cylinders. The spray cloud entered the open end of the elbows, passed into the funnels and then ran down to the collection cylinders. A 2.85 m tall version was constructed and this was very robust but quite heavy. It was decided that a taller version would be too difficult to erect due to the weight. The frame was constructed in two halves for ease of assembly. Fig. 1 shows details of the UPC patternator.

Cornell patternator

Nine 0.35 m × 1.20 m wide fly screens were connected via hooks to two 4.25 m high, 10 cm × 5 cm wooden boards. A small gutter was attached, at an angle, to the bottom edge of each screen. The gutter sloped to one end where a plastic hose was connected which ran down to a box containing graduated measuring cylinders.

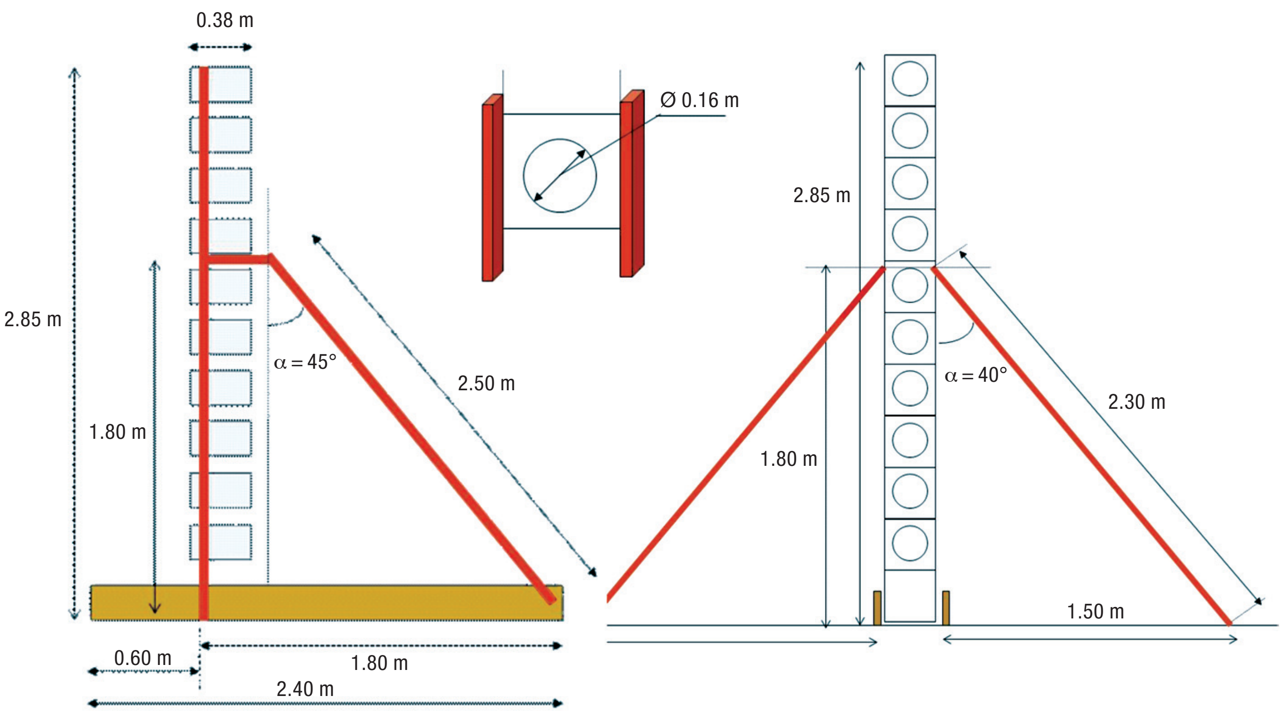

Figure 1. Construction and design details of UPC vertical patternator. Lateral view of the patternator (left), detail of circular capture area (center), and frontal view of the patternator (right).

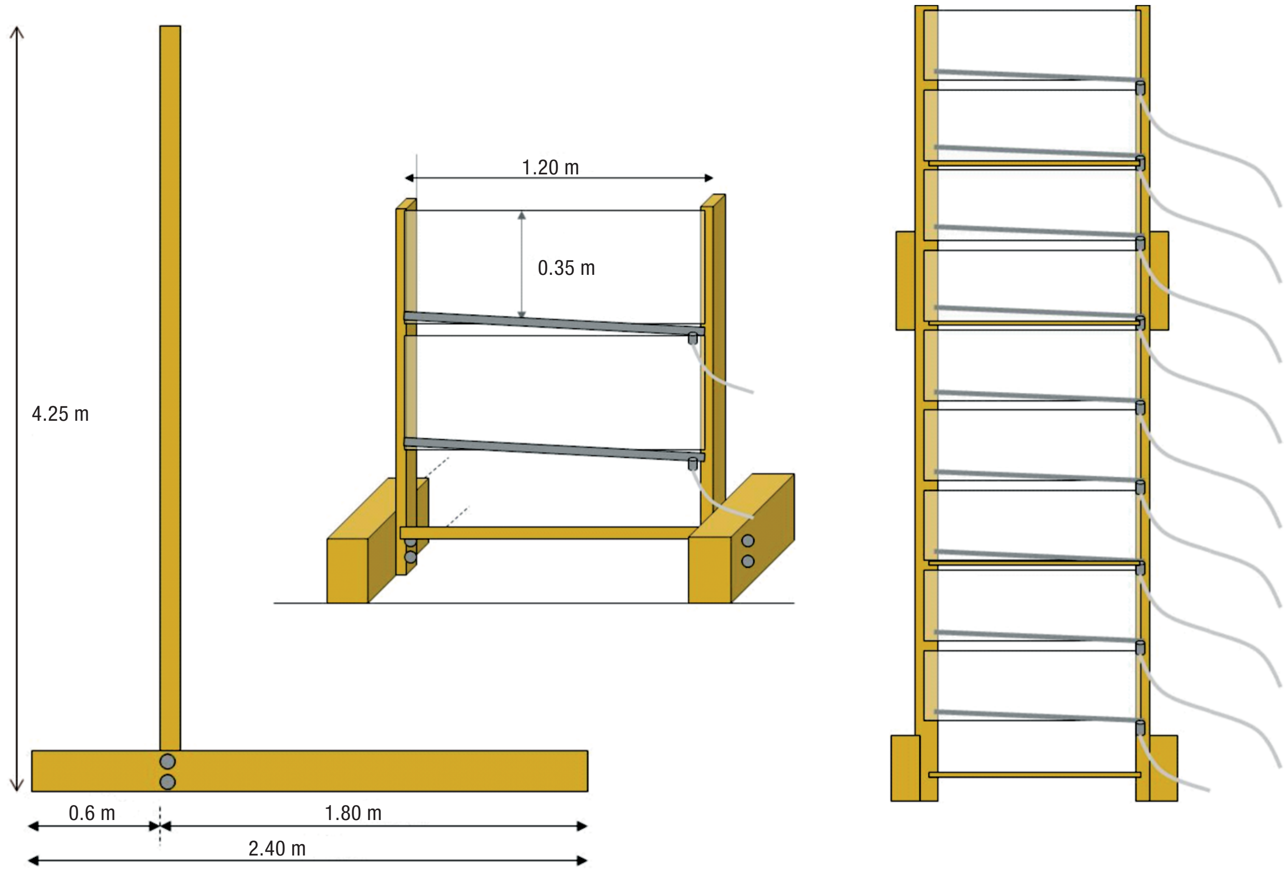

Figure 2. Construction and design details of Cornell vertical patternator. Lateral view of the patternator (left), detail of a single capture module (center), and front view of the patternator (right).

The spray cloud hit the fly screen, the air passing through and the liquid ran down the front of the screen, into the gutter and then, via the plastic hose into the collecting cylinders. The frame was constructed in two halves for ease of assembly. Fig. 2 shows details of Cornell patternator design.

Reference patternator-MIBO

In order to assess the technical and functional characteristics of the two new devices, a reference vertical patternator was selected. Results from UPC and Cornell patternators were compared with those obtained with a commercially available vertical patternator. The MIBO (Milano, Italy) designed and constructed at the Department of Agricultural Forest and Environmental Economics and Engineering of University of Turin (Balsari *et al.*, 2007) was selected as the reference patternator. The MIBO vertical patternator comprises a vertical mast which travels through the spray cloud. The liquid collectors —consisting of a series of squared stainless steel plates (200 mm × 185 mm)— are inserted on a 4-m high aluminum frame. The liquid collected by the trapping systems is carried —by silicone hoses— to a series of graduated measuring tubes supported by an aluminum frame. The amount of liquid collected by each plate is determined by reading its level on the corresponding tube's scale. The MIBO patternator has been widely used since its development both in research, inspection and extension activities (Balsari *et al.*, 2004; Biocca *et al.*, 2005). Table 1 shows the technical characteristics and major dimensions of the three patternators. Fig. 3 shows photographs of three patternators.

Comparison tests

The three vertical patternators were tested under field conditions. For this purpose three different orchard sprayers were selected (Fig. 4): Berthoud S600EX airblast sprayer (Berthoud Agricole, Lyon, France);

Table 1. Technical characteristics of the three patternators: CU (Cornell University), UPC (Universitat Politècnica de Catalunya) and MIBO (Italy)

	CU	UPC	MIBO
Height (m)	4.25	2.85	4.50
Nº capture units	9	10	20
Distance among capture units (m)	0.25	0.40	0.20
Capture area (cm^2)	39,019	1,819	7,226
Capture material	Nylon	Plastic	Stain steel
Min. capture height (m)	0.41	0.51	0.64
Max. capture height (m)	3.75	2.65	4.36

Hardi Mercury airblast sprayer (Ilemo-Hardi, S.A., Lleida, Spain); and Turbomist 250 airblast sprayer (Slimline Mfg. Ltd., Penticton, BC, Canada). Table 2 shows the technical characteristics of the sprayers tested.

In order to avoid the influence of external factors, the same working parameters were maintained as constant as possible among the three sprayers during the trials. The three sprayers were equipped with 10 Albuz ATR green nozzles (Albuz Saint Gobain, France) delivering 2.64 L min^{-1} at a constant pressure of 11 bar. Vertical distribution of liquid was measured from the left and right side of each sprayer maintaining a constant distance of 2.0 m between the spray capture area and the center of the sprayer. Three replicates of every single test were carried out in order to guarantee

Table 2. Technical characteristics of the three sprayers tested

	Berthoud S600 EX	Hardi Mercury	Turbomist 250
Tank capacity (L)	1,000	1,500	1,000
Fan diameter (mm)	762	980	762
Fan type	Axial	Axial	Axial
Nº of nozzles	10	10	12

Figure 3. Three vertical patternators compared. Developed prototypes: UPC (left) and Cornell (center) were compared with MIBO commercial vertical patternator (right).

Figure 4. Three different orchard sprayers were used for the comparative purpose: a) Berthoud S600EX airblast sprayer (left); b) Hardi Mercury airblast sprayer (center); and c) Turbomist 250 airblast sprayer (right).

adequate statistical and representative management of the data.

Evaluated parameters

Spray recovery

Spray recovery (%) shows the ratio between the recovered volumes collected in the graduated cylinders of the patternator and the total output liquid emitted by the sprayer. It was calculated following Eq. [1]:

$$R\ (\%) = \left(\frac{\sum_{i=1}^{n} V_i}{\sum_{i=1}^{m} q_i \cdot \mathrm{t}} \right) \cdot 100 \qquad [1]$$

where R is the percentage of spray recovery; n is the number of graduated cylinders; V_i is the recovered volume collected in each graduated cylinder; m is the number of nozzles; q_i is the individual flow rate of each nozzle and t is the total time of spraying in minutes.

Normalized spray recovery

Due to the direct influence of the capture area on the amount of spray recovered (*i.e.* higher capture area implies higher spray recovery), a normalized spray recovery parameter was also calculated. Assuming in this case the MIBO vertical patternator as a reference, the normalized spray recovery for each vertical patternator was calculated following Eq. [2]:

$$NR = (R \cdot A_{MIBO})/A \qquad [2]$$

where NR is the normalized spray recovery, R is the percentage of spray recovery of the evaluated patternator; A_{MIBO} is the sum of collection area of reference patternator (MIBO), in cm^2; and A is the sum of the collector area of the evaluated patternator.

Symmetry

Symmetry (%) evaluates the difference between percentage of liquid recovered on the left and right sides of the sprayer at each patternator height and was calculated according to Eq. [3]:

$$S\ (\%) = 1 - \sum_{i=1}^{n} \left| \frac{V_{i(\mathrm{L})}}{\sum_{i=1}^{n} V_{i(\mathrm{L})}} - \frac{V_{i(\mathrm{R})}}{\sum_{i=1}^{n} V_{i(\mathrm{R})}} \right| \times 100 \qquad [3]$$

where S is the symmetry value (expressed in percentage); V_i is the volume collected on each i graduated cylinder at right (R) and left (L) sides.

The symmetry value of every single sprayer can be used as a comparative assessment among vertical patternators in order to check the capability to detect differences between left and right side of the sprayer.

Statistical analysis

For the evaluated parameters, two-way and one-way ANOVA's were performed in order to compare the results of the evaluated parameters in the sprayers. Moreover, in order to study the correlation among the vertical spray distribution results of patternators, the recovery results of each patternator were expressed in common intervals. The intervals (in m) were 0.41-0.90; 0.91-1.31; 1.32-1.71; 1.72-2.12; 2.13-2.52 and 2.53-2.93 and were established from the heights of the Cornell patternator collectors, due to its higher dimension of collector's spacing. All statistical analyses were carried out using in R 2.12.2 (R Development Core Team, 2011).

Results

According to Balsari *et al*. (2007) vertical patternators must ensure good measurement repeatability, the collectors must ensure the recovery of the largest part of the sprayed mixture and the whole system must be able to reproduce the effect of the spraying technique on the real vegetation. All these aspects and others we proposed have been widely analyzed for the two new developed vertical patternators, always taking as a reference the commercial version developed by MIBO.

Spray recovery

Table 3 shows the single values of spray recovery for every combination of patternator-sprayer with separate values between left and right side. CU patternator presented the highest spray recovery values in all the three sprayers tested. MIBO and UPC patternators gave similar values in all cases, with an absolute magnitude around three times less than the CU. It is also remarkable the higher differences between left and right side generated by CU patternator, always higher than those obtained with MIBO and UPC ones. This fact can be probably due to the shape and size of the captive area. Minor differences on the nozzle's

Table 3. Spray recovery (%) for each patternator, side and sprayer (mean ± SE of the mean). Mean column shows the mean of the spray recovery for each patternator, undifferentiating sprayers

	Berthoud		Hardi		TurboMist		Mean	
	Left	**Right**	**Left**	**Right**	**Left**	**Right**	**Left**	**Right**
CU	82.3 ± 4.0	93.2 ± 3.5	58.0 ± 5.6	48.6 ± 6.6	77.3 ± 2.3	47.3 ± 2.8	72.5 ± 4.2	63.0 ± 7.9
MIBO	21.4 ± 0.2	20.3 ± 1.2	20.8 ± 1.1	17.8 ± 2.6	19.3 ± 1.2	17.8 ± 1.1	20.5 ± 0.6	18.6 ± 1.0
UPC	13.9 ± 0.4	19.1 ± 2.4	23.2 ± 0.2	23.3 ± 1.7	16.5 ± 1.9	21.1 ± 1.1	17.9 ± 1.5	21.1 ± 1.1

adjustment (orientation) between left and right side of the sprayers affect much more on the vertical profile obtained in the case of small captive area. Also higher were in all cases the values of the standard error (SE) for CU patternator, as a consequence of the great variability of the samples in the three replicates. The average values of spray recovery for the three patternators indicate a clear and statistically significant difference of CU (67.8%) in comparison with the very similar values obtained with MIBO (19.5%) and UPC (19.6%).

Fig. 5a shows the averaged values of spray recovery obtained with the three vertical patternators for every one of the sprayers tested. It is clear the advantage of the CU patternator with the three sprayers, also interesting is the most uniformity occurred with the obtained values from the different sprayers with the MIBO and UPC patternators.

In general, the most frequent value of spray recovery considering all the field tests has been around 20% with great repeatability. Fig. 6 shows the relation between spray recovery and SE during the field tests. It seems that the best results in terms of repeatability were obtained for low spray recovery values, while in the case of high efficiency the difference among replicates was increased.

Normalized spray recovery (NSR)

The spray recovery values described in the previous paragraph have been transformed, according Eq. [2] into normalized spray recovery (NSR), in order to avoid the influence of the big differences on the capture area (see Table 1) of the different patternators analyzed. Fig. 5b shows the UPC patternator presents the highest NSR values for the three sprayers tested (in average 77.9%), significantly different that those obtained with MIBO patternator (19.5%) and CU patternator (12.6%). A deeper analysis of the obtained values indicates an adequate uniformity of the values for all the three

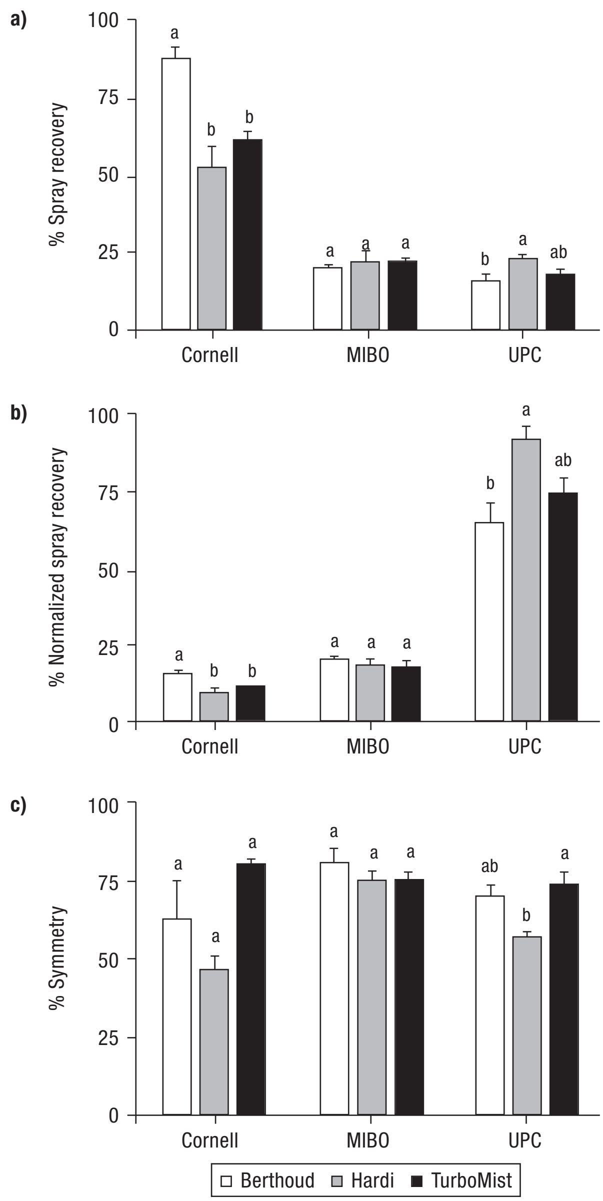

Figure 5. For each patternator and sprayer, it is shown in percentages: spray recovery (a), normalized spray recovery (b) and symmetry (c). Bars show means + SE of the mean. For each patternator, different letters mean significant differences among sprayers.

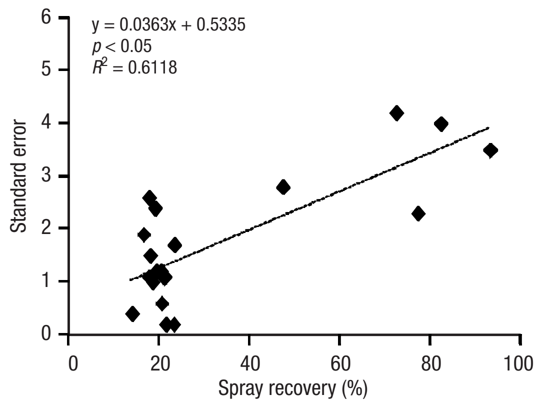

Figure 6. Correlation between spray recovery obtained in all combination tests (sprayer-patternator) and the standard error during replicates.

sprayers, especially in the case of MIBO patternator. These great differences between UPC patternator and the other two can be explained by the fact that with UPC patternator the capture area was not covered by any kind of material. The nylon net (CU patternator) and the stainless steel surfaces (MIBO) can generate some splashing, affecting the capture efficiency.

Symmetry

Data obtained in the three replicates were used also to compare the symmetry recorded by each patternator. Excellent symmetry would be in the region of 90-95% of a sprayer output pattern occurring on both the left and right hand side of the sprayer. Results in Fig. 5c show that the MIBO patternator gave the best indication of symmetry (78.8% in average), followed by UPC and Cornell patternators (67.3% and 63.5% respectively). A deeper analysis of the data indicates that there are no significant differences among the three sprayers tested neither with CU nor with MIBO patternators. However, important differences on symmetry were observed with CU patternator, with noticeably low values in the case of Hardi sprayer. The statistical analysis of the results shows great value of SE (± 6.2) in the case of CU patternator, which influences on the results of the statistical analysis. On the other side, symmetry values were significant lower for the combination Hardi sprayer-UPC patternator, specifically when compared with the Turbo Mist sprayer.

In general the information derived from the symmetry analysis can be used as informative data for a selective arrangement/orientation of nozzles on each side of the sprayer, trying to compensate for the negative effect of fan rotation.

Spray pattern

One of the main objectives for the use of whichever vertical patternator is chosen to obtain the most adequate vertical spray distribution in accordance with the canopy characteristics. The field data were managed in order to check the relationship among the three vertical profiles obtained with each one of the three vertical patternators, and to evaluate the influence of the type of sprayer on the liquid distribution. Fig. 7 shows the average spray pattern (and SE considering the three replicates) obtained with the three devices for each type of sprayer. The different capture heights and capture areas of the three designs must be taken into consideration in Fig. 7. In general the obtained patterns for every type of sprayer (columns in Fig. 7) follow the same trend, *i.e.* the case of Hardi sprayer, where in all cases some defect (diminution of liquid recovered) was detected at the height of 1.5 m in both sides for the three patternators.

In order to quantify the correlation among spray pattern obtained in all tests, the Pearson correlation coefficients were obtained for all the combinations, including spray side, sprayer type and vertical patternator. Table 4 shows the obtained values of Pearson's coefficient for all combinations. Results indicate significant correlation for all combinations in the case of Hardi sprayer, while the opposite, no correlation, was detected in the trials with Turbo Mist sprayer.

Discussion

Results obtained in the comparative tests carried out with the two new concepts of portable vertical patternators for field measurements allow us to propose devices to improve the sprayer adjustment according to the canopy structure. The detailed comparison with a commercial vertical patternator already in use indicates that whatever the method proposed, the information obtained about the spray distribution is similar, in spite of the significant differences in the construction costs of all the three devices.

Design characteristics of capture devices have an influence on the spray recovery. Larger capture areas result in larger capture efficiencies. To increase capture

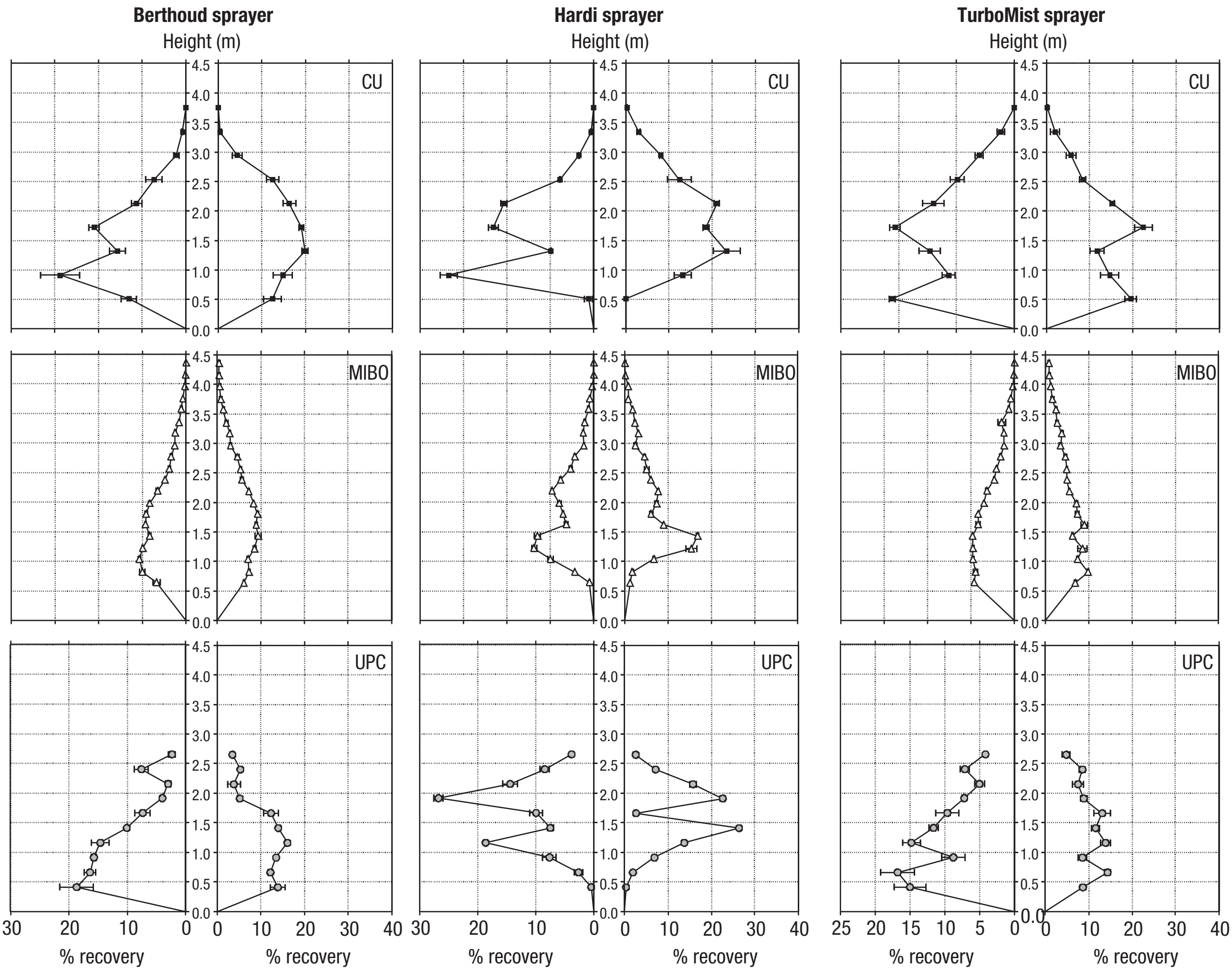

Figure 7. Vertical spray distributions for each patternator and sprayer. Figures show mean + SE of the mean of the spray recovery in each height.

efficiency, the capture area should be free from materials such as screen material or steel plate, in order to avoid splashing.

The patternator is a very useful tool in both research and extension. In extension it demonstrates to grower audiences the quantity of spray plume going up and over the canopy, it shows the symmetry, or lack of, between left and right side of the sprayer, and it demonstrates the importance of adjusting the sprayer correctly to improve deposition and reduce drift.

The results show the importance of correct nozzle orientation if pesticides are to be applied effectively onto the target. It should be noted that each sprayer design will vary, due to fan size and air volume, so no generalized recommendation can be made. Good targeting should give better pest and disease control and lead to less drift.

As a consequence of this research, in 2010 the Northeast SARE (Sustainable Agriculture Research & Education; http://www.nesare.org/) started a research and extension program based on the use of portable vertical patternator and concluded that the use of a patternator can reduce spray drift up to 90% and reduce pesticide use up to 20%. This action derived on the launch of a patternator website (http://www.patternator.com).

Acknowledgements

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Table 4. Pearson correlation coefficients for the comparison of vertical spray distribution (Pearson coefficients)

Sprayer	Side	Patternator	CU	MIBO	UPC
Berthoud	Left	CU	1	**0.858***	0.604
		MIBO	**0.858***	1	0.726
		UPC	0.604	0.726	1
	Right	CU	1	**0.846***	–0.009
		MIBO	**0.846***	1	0.415
		UPC	–0.009	0.415	1
Hardi	Left	CU	1	**0.821***	**0.893***
		MIBO	**0.821***	1	**0.837***
		UPC	**0.893***	**0.837***	1
	Right	CU	1	0.741	**0.851***
		MIBO	0.741	1	**0.834***
		UPC	**0.851***	**0.834***	1
TurboMist	Left	CU	1	0.449	0.142
		MIBO	0.449	1	0.801
		UPC	0.142	0.801	1
	Right	CU	1	0.526	0.095
		MIBO	0.526	1	0.728
		UPC	0.095	0.728	1

Numbers in bold mean significant correlation between the vertical spray distribution of the compared patternators.

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