Scientific quarterly journal ISNN 1429-7264

Agricultural Engineering

2014: 4(152):71-80

Homepage: http://ir.ptir.org

DOI: http://dx.medra.org/10.14654/ir.2014.152.082

THE INFLUENCE OF NOZZLE CONFIGURATION IN ORCHARD SPRAYERS ON THE VERTICAL DISTRIBUTION OF SPRAY

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ARTICLE INFO

Article history:
Received: June 2014
Received in the revised form: September 2014
Accepted: November 2014

Keywords:
orchard sprayer
vertical spray distribution
vertical spray separator
spray share
patternator

ABSTRACT

The aim of the study was to determine the effect of the selected operating parameters of the two types of orchard sprayers on vertical distribution (expressed as spray percentage share in 50-cm segments) and quantitative changes in vertical distribution of spray measured on a vertical separator of drops. The study included measurements of vertical distribution of spray for two different settings of nozzles, two types of nozzles and two fan rotational speeds. Vertical distribution of spray depended significantly on the spray emission system, the configuration and the type of nozzles and in the slightest degree on the fan rotational speed. The smallest share of liquid fell on the edge segments (≤ 5.22%) and the largest on the middle ones – 29.33%. The change in the configuration of nozzles significantly affected the change in the spray vertical distribution (by the spray displacement between the 50-cm segments). The greatest changes in vertical distribution of spray – as affected by the nozzle configuration change – was observed for the sprayer with the horizontal spray emission with a maximum change in one segment of 14.0% (an average of 7 segments: 5.38%).

Introduction

Plant protection is effective when the appropriate quantity and uniformity of the plant protection product is deposited on the sprayed objects. The deposit is influenced by the type of a sprayer and its working parameters, characteristic of the sprayed plants (size, shape and density) and weather conditions. Among the parameters associated with a sprayer, the most important are: the sprayer type, spray volume, driving speed, the droplet size and the distance between the nozzles and the sprayed trees and their configuration and fitting to the shape of a tree (Byers et al., 1984; Ferree and Hall, 1980; Godyń et al. 2006). The impact of the majority of factors mentioned above was studied and the results of that studies and their analyses are available in numerous scientific publications. Only some trials related to the angle of nozzle orientation were carried out, among others, by Farooq and Landers (2004). These authors showed the relationship between the uniformity of the spray deposit in a tree and the nozzles direction. Furthermore, they pointed to the need to perform such regulation separately for each side of a sprayer, linking this to the asymmetric distribution of air flow.

Asymmetry in distribution of the air flow has been also confirmed by Godyń et al. (2009b). Research carried out in the Research Institute of Horticulture concerned the measurements of spray vertical distribution as well as individual nozzles distribution (Godyń et al., 2009a). The authors showed differences in vertical distribution of spray depending on the place of mounting nozzles in the air-stream.

During studies carried out on vertical distribution of spray for orchard sprayers performed outside the orchard, vertical patternators were used (devices measuring by volume vertical distribution of spray). The vertical patternators separate droplets from air on the wall a specific construction designed for this purpose (eg. HERBST patternators – Internet 2) or capture the spray, segment by segment, by means of tray collectors disposed vertically at some intervals to allow the air flow pass through the trays (eg. AAMS- Salvarani patternators - Internet 1). The first publications on vertical patternators come from the 80's of the 20th century (Pergher, 2004). There are still some research carried out on new methods of droplets separation or a different arrangements of collectors (Biocca et al., 2005; Balsari et al., 2007; Gil and Badiola, 2007; Landers, 2008).

The main practical aim of performing the measurements of vertical distribution of spray outside the orchard is related to calibration of a sprayer, including the nozzle setting in order to obtain spray distribution best suited for the sprayed plants. A change in direction of nozzle settings, which gives the changes in the spray discharge direction, is possible in most orchard sprayers offered on the market. For deflector sprayers the air deflectors may be adjustable. A few sprayers have also a limited ability to change the vertical position of the nozzles. The nozzle configuration may influence the biological efficacy of the plant protection carried out with such sprayers. Therefore, when the relationship between sprayer operating parameters together with nozzle configuration and obtained vertical distribution of spray is known, it will be possible to make recommendations for the users of orchard sprayers.

Pergher (2004) made trials on fitting the spray emission to the hedgerow vineyard by proper selection and angling of nozzles of a radial emission sprayer. He investigated three nozzle settings: factory settings with no regulation, visual adjustment in the orchard performed as matching the nozzles settings to the shape of sprayed plants and adjustment with the use of a patternator aiming to obtain the vertical distribution of spray closest to the shape of the outer contour of the sprayed plants. He achieved the best results for the factory settings or for adjustment in the orchard depending on the nozzles configuration and the adjustment method. The worst fit has been obtained for adjustment performed on a patternator. In that case the greatest discrepancies at corresponding heights between the amount of liquid collected at various heights of a patternator and spray deposit on plants were observed.

Objectives and scope

No studies on the effects of different adjustments on the spray quantitative displacement and changes in vertical distribution of spray in orchard sprayers have been carried out yet. Therefore, the studies were undertaken to determine the effects of different regulations of orchard sprayers on spray displacement and quantitative changes in its vertical distribution measured on the vertical separator of drops. The work included measurements of vertical distribution of spray for two different nozzle settings in orchard sprayers with a horizontal and air directed spray emission system, working with two rotational fan speeds and outfitted with two types of nozzles.

Materials and Methods

The tests were carried out in the Agroengineering Department of Research Institute of Horticulture in Skierniewice in 2013 year. In the study two sprayers with different air emission systems and different number of installed nozzles were used. The deflector sprayer with a horizontal spray emission system and an axial fan (100v Turbo AGROLA) had on each side 8 nozzles mounted on. A sprayer with a directed air emission system (Tifone 1000) had five individually adjustable air outlets on each side with one nozzle by each outlet (fig. 1).

Figure 1. Sprayers used at the test rigs at the vertical droplet separator (patternator): horizontal emission system sprayer AGROLA Turbo 100v (left hand) and air directed emission system sprayer Tifone 1000 (right hand)

The factory installed nozzles were adjusted in two ways. For the sprayer with horizontal emission it was assumed to spray 3.0 m high trees. Nozzles and air directing blades were set either horizontally – without matching the emission of spray and air to the shape and height of a tree canopy ("Horizontal setting") – or were redirected to match the shape of a tree (Godyń et al., 2014) ("Matched setting"). The matching adjustment was achieved by angling the selected nozzles or air directing blades upwards by an angle of approx. 20º. The setting of nozzles No: 1, 3 and 4 (from the bottom) was changed. For the sprayer with directed air emission system it was assumed to spray 3.5 m high trees. The air outlets were set in a vertical plane, perpendicular to the direction of the travel/sprayer longitudinal axis

(Table. 1). Matching sprayers to the tree shape adjustment was achieved by varying the direction of the air outlets and their location and, in addition to changing the nozzles position (see Tab. 1), nozzles 1 and 2 were directed upwards.

Table 1
Locations of nozzles (height from the ground/distance from the patternator) for sprayers with horizontal and air directed emission systems (cm)

Nozzle no. (from the bottom)	Horizontal emission system	Air directed emission system	
	Nozzles locations		
	Horizontal and matched	Horizontal	Matched
1.	67.0 / 104.5	86.0 / 100	84.0 / 119
2.	94.0 / 106.0	135.0 / 100	133.5 / 118
3.	118.0 / 107.0	181.5 / 100	183.0 / 109
4.	140.0 / 108.3	231.0 / 100	231.0 / 108
5.	161.0 / 109.8	282.0 / 100	283.0 / 100
6.	182.0 / 110.5	X	X
7.	204.0 / 111.0	X	X
8.	233.0 / 100.0	X	X

LECHLER nozzles were used in the tests: a standard hollow cone (TR 80-015) or flat fan air injector compact ones (IDK 90-015) with the nozzle flow rate of 0.83 $l \cdot min^{-1}$ at 0.6 MPa for a horizontal emission sprayer and 1.18 $l \cdot min^{-1}$ at 1.2 MPa for the air directed emission sprayer. The measurements were done at two fan rotational speeds: 1,400 or 1,800 $rpm \cdot min^{-1}$. In such conditions, the approximate air flow was 29.0 or 37.0 thous. $m^3 \cdot h^{-1}$ for the horizontal emission sprayer and 13.0 or 16.5 thous. $m^3 \cdot h^{-1}$ for the other one.

The measurements of the spray distribution were made on a vertical separator of drops (patternator) from Pessl (Austria), with a 10 cm resolution and the range of vertical measurement 20-350 cm. The measuring time of each measurement ranged 20-30 s and was chosen to collect spray volume not exceeding graduated capacity of measuring cylinders of a patternator (170 ml). The absolute values in ml read out from each of 33 cylinders scale corresponded to the quantity of liquid in the 10-centimeter vertical segments. That values were normalized and expressed as a percentage share of all the liquid collected on a patternator during a single measurement. For further calculations, the values read in five consecutive 10-centimeter segments, were combined to give the liquid share in 50-centimeter segments. Percentage share of the lowest segment (0-50 cm) was calculated by summing up the liquid shares in the three lowest segments (20-50 cm) because the measuring zone started only at 20 cm height. This gave seven 50-centimeter segments, from 0-50 cm to 300-350 cm. For each experimental combination three repetitions were made. A total of 48 measurements of vertical distribution of spray were carried out.

The vertical distribution of spray liquid was evaluated in order to find the influence of the experimental factors (nozzle setting, nozzle type and rotational speed of a fan) on the collected spray share (CSS) and the collected volume change (CVC) in the 50-centimeter segments, as well as the repeatability of the spray share measurements. For the spray share collected (CSS) in individual 50-centimeter segments the analysis of variance has been done and significance of differences between the mean (Duncan test) were rated. Two analyzes were done – for each of the fan rotational speeds separately (results – Table 2 and 3). Such a method of analysis was taken due to the possibilities of the statistical software. Further analyzes were performed for the parameter "collected volume change" (CVC) due to difficult assessment of the impact of nozzle configuration and other sprayer parameters on the magnitude of the collected spray share (CSS) changes in a 50-centimeter segments. The collected volume change (CVC) was calculated as the absolute value of the difference between the values of spray share collected (CSS) for "Matched setting" and "Horizontal setting" (with no change in other parameters). This was followed by statistical evaluation of the effects of the sprayer parameters (emission system, nozzle type, fan rotational speed and the segment) on the collected volume change (CVC) in the 50-centimeter segment (results - Table 4). Since the study did not assume any "optimal distribution", there was no basis for evaluating the "direction" of changes (getting closer or further from the optimum) due to regulations made. Repeatability of the measurements of the spray share collected (CSS) in 50-centimeter segments was assessed by calculating the coefficients of variation for replicates (Formula 1).

$$CV\% = \frac{\sqrt{\frac{\sum\left(x-\bar{x}\right)^2}{n}}}{\bar{x}} \cdot 100\% \qquad (1)$$

The statistical analyzes were done using Statistica 7.1. software.

Results

The smallest spray share (CSS) was collected in the extreme segments No. 1 and 7 (≤5.22%) and the biggest in the middle ones (No. 3-5) – up to 29.33% (tab. 2 and 3). Despite the relatively large divergence of the results obtained in the outer segments 1 and 7 (0.00-5.22%), no statically significant differences were observed there, only some trends. In many middle segments (No. 3-5), the spray share (CSS) exceeded 20% (38 of 48 observations).

The collected volume change (CVC) depended on the evaluated segment. The biggest changes were observed in segments 2 and 5 (average: 5.84-5.99%) and the lowest ones in segments 7 and 1 (respectively 1.23 and 2.42%). Statistical analysis showed a significant influence of the evaluated parameters of the sprayer on the average collected volume change. The average values were calculated for 7 segments. The nozzles configuration had the biggest impact on the magnitude of these changes. When the nozzles configuration has been changed, on average 3.56% of the total spray volume collected on a patternator was displaced for each 50-centimeter segment. When the nozzle type has been changed, leaving other settings unchanged, the average changes were only of 1.81 and as low as 0.88% for fan rotational speed changes.

Table 2

Spray share (by volume) collected on PESSL vertical patternator at different heights from the ground (50-centimeter segments), during the spraying simulation with horizontal and directed air emission system sprayers depending on nozzle type and configuration at fan rotational speed: 1400 r·min^{-1}.

Segment no. / Height above ground	Spray emission system							
	Horizontal (AGROLA Turbo 100v)				Air directed (Tifone 1000)			
	Nozzle type and size							
	TR 80-015		IDK 90-015		TR 80-015		IDK 90-015	
	Matching of nozzles configuration to the tree shape							
	Yes	No	Yes	No	Yes	No	Yes	No
1/0÷50 cm	0.0 a	2.1 a-c	0.00 a	1.42 ab	2.89 a-c	0.93 ab	5.22 a-e	1.28 ab
2/50÷100 cm	7.77 b-f	20.8 l-u	3.77 a-d	13.59 f-l	11.19 e-h	13.47 f-l	12.72 f-j	12.88 f-k
3/100÷150 cm	21.52 m-u	25.22 r-w	11.60 e-i	25.58 s-w	22.03 o-u	24.79 r-w	22.72 o-w	21.82 o-u
4/150÷200 cm	29.33 w	25.81 s-w	21.60 n-u	27.42 uw	23.35 p-w	19.89 j-u	21.51 m-u	21.68 n-u
5/200÷250 cm	26.24 t-w	14.18 f-m	18.34 h-s	17.77 h-r	20.17 k-u	22.04 o-u	20.04 j-u	20.78 l-u
6/250÷300 cm	14.3 f-n	10.09 d-g	9.14 c-g	10.21 d-g	15.51 g-o	16.43 h-p	14.09 f-l	18.71 i-t
7/300÷350 cm	0.84 ab	1.8 a-c	2.21 a-c	4.01 a-d	4.86 a-e	2.45 a-c	3.69 a-d	2.85 a-c

Means in table followed by the same letter do not differ significantly Duncan Multiple Range Test (α=0.05)

Table 3

Spray share (by volume) (%) collected on PESSL vertical patternator at different heights from the ground (50-centimeter segments), during the spraying simulation with horizontal and directed air emission system sprayers depending on nozzle type and configuration at fan rotational speed: 1800 r·min^{-1}.

Segment no. / Height above ground	Spray emission system							
	Horizontal (AGROLA Turbo 100v)				Air directed (Tifone 1000)			
	Nozzle type and size							
	TR 80-015		IDK 90-015		TR 80-015		IDK 90-015	
	Matching of nozzles configuration to the tree shape							
	Yes	No	Yes	No	Yes	No	Yes	No
1/0÷50 cm	0.00 a	2.10 a-c	0.00 a	1.42 ab	2.89 a-c	0.93 ab	5.22 a-e	0.99 ab
2/50÷100 cm	7.77 b-f	20.80 l-u	3.77 a-d	13.59 fl	11.19 e-h	14.47 f-l	12.72 f-j	12.88 f-k
3/100÷150 cm	21.52 m-u	25.22 r-w	11.60 e-i	25.58 s-w	22.03 o-u	24.79 r-w	22.72 o-w	21.82 o-u
4/150÷200 cm	29.33 w	25.81 s-w	21.61 n-u	27.42 u-w	23.35 p-w	19.89 j-u	21.51 m-u	21.68 n-u
5/200÷250 cm	26.24 t-w	14.18 f-m	18.34 h-s	17.77 h-r	20.17 k-u	20.04 o-u	20.04 j-u	20.78 l-u
6/250÷300 cm	14.30 f-n	10.09 d-g	9.14 c-g	10.21 d-g	15.51 g-o	16.43 g-p	14.09 f-l	18.71 i-t
7/300÷350 cm	0.84 ab	1.80 a-c	2.21 a-c	4.01 ad	4.86 a-e	2.45 a-c	3.69 a-d	2.85 a-c

Means in table followed by the same letter do not differ significantly, Duncan Multiple Range Test (α=0.05)

The significant influence of the spray emission system (sprayer) on the magnitude of spray vertical distribution changes has been shown. The nozzle configuration and the type of nozzles significantly influenced the vertical distribution changes with varying intensity, depending on the type of the spray emission system. The fan rotational speed affected that at low level for both emission systems, without significant differences between them (tab. 4).

Table 4 presents the mean and maximum values of the collected volume change in 50-centimeter segments depending on the sprayer type and its working parameters that were changed. Significantly greater changes in the spray vertical distribution due to nozzle configuration changes were observed for the sprayer with a horizontal emission system (on average 5.38, maximum 14.00%) than for the air directed one (on average 1.88, maximum 4.76%).

The nozzle type also influenced the vertical distribution of spray. That means that replacing the nozzles to get droplets of different size produced (eg. coarse vs. fine), even without any change in their arrangement and fan rotational speed, the different vertical distribution of spray may be obtained. For the horizontal emission sprayer there were observed bigger changes (on average 2.24%, maximum 7.57%) than for the air directed one (on average of 1.41%, maximum 3.75%). This could mean that the additional adjustment of nozzles settings could be needed in case of nozzle replacement e.g. in windy weather condition.

Table 4

Mean and maximum values of collected volume change (%) in 50-centimeter segments depending on sprayer emission system and its working parameters that were changed.

Emission system	Changed parameter	CVC in 50-centimeter segment (%) Mean*	Maximum**
Air directed	Fan rotational speed	0.93 a	3.17
	Nozzle type	1.41 b	3.75
	Nozzle configuration	1.88 c	4.76
Horizontal	Fan rotational speed	0.83 a	3.16
	Nozzle type	2.24 c	7.57
	Nozzle configuration	5.38 d	14.00

* Average of 7 segments. Means in columns do not differ significantly, Duncan Multiple Range Test (α =0.05)
** Maximum change observed in individual 50-centimeter segment.

The minor changes of spray vertical distribution for the air directed sprayer than for the horizontal emission are related to the method and the range of the air flow regulation. In the first sprayer the position in the space of nozzles and air outlets and angling of nozzles were changed (see tab. 1). The angling of air outlets in both variants was horizontal. In the horizontal emission sprayer the angling of air directing blades was changed together with the control of nozzles angling (horizontally or 20º upward). The nozzle position in relation to the sprayer remained unchanged – which was a constructional limitation. The above mentioned observation indicates – but indirectly - that there is a greater effect of changes in the air flow direction than the spray flow direction on the vertical distribution of spray in orchard sprayers. This thesis needs to be confirmed by research specifically scheduled for this purpose.

By adjusting the nozzles settings (matched arrangement) the spray displacement between the vertical segments has been achieved. In the experiment it was assumed to spray 3.50 m high trees for a horizontal emission sprayer or 3.0 m high trees for the air directed one. The nozzles were adjusted to fit that dimensions. By adjusting the lower nozzles to the assumed tree shape it was possible to limit the amount of spray directed to the lowest 0-50 cm segment ("under the crown"), or – in case of a horizontal emission sprayer – to the upper zone above 300 cm ("above the tree"). Such spray "redirection" should always be consistent with the tree height and the shape of the sprayed zones.

Statistical analysis showed no effect of the estimated parameters on the variation between repetitions. Average coefficients of variation (of 7 segments) did not exceed 5.80% with maximum variation in the middle segments (50-300 cm) 7.66%. Balsari et al. (2007), by formulating a criterion for assessing the suitability of patternators to measure the vertical distribution of spray, proposed that the variability between the measurements should not exceed 10% (coefficient of variation). This means that the measuring method used in the present studies meets the mentioned requirements. Another issue is to evaluate the usefulness of methods using vertical patternators for calibration of the orchard sprayer. The quality of the fit and the convergence of the vertical distribution of the spray measured on a patternator with the spray distribution in the sprayed trees was the subject of further analysis. Its results are presented in a separate publication (Godyń et al., 2014).

Conclusions

1. The vertical distribution of spray depended significantly on the applied spray emission system, nozzles configuration and the type and in the slightest degree on the sprayers fan rotational speed.
2. The largest spray share (CSS) was collected in the middle segments of a patternator – up to 29.33%, and the smallest one in the extreme segments (0.0-5.22%).
3. The change of nozzles configuration significantly affected the change in the spray vertical distribution by the vertical displacement of spray between the 50-centimeter segments. The biggest collected volume changes (CVC) were observed in segments no. 2 and 5 (5.84-5.99%) and the lowest ones in the extreme segments no. 7 and 1 (respectively 1.23 and 2.42%).
4. The biggest change in the spray vertical distribution due to nozzles configuration changes were observed for the horizontal emission sprayer (average: 5.38%, maximum in single segment: 14.0%).
5. The average coefficients of variation between repetitions did not exceed 5.80% with maximum variation in the middle segments (50-300 cm) 7.66%. This means that the method meets the criteria of usefulness of patternators to measure the spray vertical distribution, formulated by Balsari.

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WPŁYW KONFIGURACJI ROZPYLACZY W OPRYSKIWACZACH SADOWNICZYCH NA PIONOWY ROZKŁAD CIECZY UŻYTKOWEJ

Streszczenie. Celem pracy było określenie wpływu wybranych parametrów roboczych dwóch typów opryskiwaczy sadowniczych na pionowy rozkład i ilościowe zmiany rozkładu pionowego cieczy – wyrażanego jako procentowy udział cieczy w 50-centymetrowych segmentach. Pomiary prowadzono na pionowym separatorze kropel. Zakres pracy obejmował pomiary rozkładu pionowego cieczy dla dwóch różnych sposobów ustawienia rozpylaczy, dwóch typów rozpylaczy i dwóch prędkości obrotowych wentylatora. Pionowy rozkład cieczy zależał istotnie od zastosowanego systemu emisji cieczy, konfiguracji rozpylaczy i typu rozpylaczy, a w najmniejszym stopniu od prędkości obrotowej wentylatorów opryskiwaczy. Najmniejszy udział cieczy przypadał na dwa skrajne segmenty (≤5,22%), a największy na segmenty środkowe – 29,33%. Zmiana konfiguracji rozpylaczy istotnie wpływała na zmiany pionowego rozkładu cieczy poprzez przemieszczenie cieczy między pionowymi 50-centymetrowymi segmentami. Największe zmiany pionowego rozkładu cieczy w wyniku zmiany konfiguracji rozpylaczy obserwowano dla opryskiwacza o poziomej emisji cieczy – średnio: 5,38%, maksymalnie w jednym segmencie: 14,0%.

Słowa kluczowe: opryskiwacz sadowniczy, pionowy rozkład cieczy, udział cieczy, pionowy separator kropel, paternator