Dual-fan Orchard Sprayer with Reversed Air-stream – Preliminary Trials

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ABSTRACT

The dual-fan concept was developed to spray on high trees (up to 5 meters). The aim of the preliminary trials was to evaluate the idea of a dual-fan orchard sprayer before producing sprayer prototype. After laboratory measurements of spray and air distribution the measurements of air distribution, spray distribution and spray drift potential were made in the apple orchard. Four fan settings were studied. Spray volumes applied (150÷400 l/ha) caused significantly different spray deposits in the tree canopy. The highest deposit was observed for the lower fan alone. The coverage on lower surfaces for "Lower+Upper+30cm" fan was higher than for the other combinations. Total losses were proportional to deposits in the trees.

Keywords: Dual-fan, orchard sprayer, reversed air-flow, spray deposit, spray drift, spray volume, air distribution, Poland

1. INTRODUCTION

The night ground-frosts during blossom time usually cause serious damage to flowers on apple trees in Polish orchards. Therefore growers tend to let the trees grow up to 4.0÷4.5 m high in order to move the flowering zone higher above ground level. To ensure an even spray and air-stream distribution in such high trees, there is a need for a new solution of air and spray discharge system on orchard sprayers. Standard axial fan sprayers, although can make that the spray reaches tops of the trees, produce high spray drift. There are constructed some dual-, triple- or four-fan sprayers (Tifone s.r.l., Italy; BAB Bamps N.V., Belgium) designed for spraying on high trees. In those constructions the air inlet of the fans is located in the rear of the sprayer. Such solution makes that the part of spray is sucked (redirected) to the air inlet. The reversed air-stream lets to direct outgoing air-stream backwards. In the sprayers with reversed air-stream the backward deviation of air-stream usually varies between ten and twenty degrees. This makes that the spray penetration distance in the tree canopy is extended, and the airborne losses may be decreased even by 50% (Holownicki et al., 2000a, 2000b). In the trials with multi-fan sprayers (Svensson, 1994, 2001; Furnes at al., 2006) the cross-flow converging fans or Quantum Mist® fans were used also. Authors obtained coverage and deposit enhancement and drift reduction. Sprayer adapted to high tree crops (up to 6.0 m) increases spray deposit in the tree and homogeneity of the distribution in comparison with standard axial fan sprayer (Van de Zande *at al.*, 2005).

The aim of the project, carried out together with the sprayer manufacturer AGROLA (www.agrola.com.pl), is to start production of the dual-fan sprayer with reversed air-stream to spray on high trees (up to 5 meters). The aim of the preliminary trials was to evaluate the idea of a dual-fan orchard sprayer before producing sprayer prototype

2. MATERIALS AND METHODS

2.1 Experimental Stands

The experimental stands were constructed and the laboratory measurements of spray distribution and air distribution were made prior to the development of the mobile stand. The mobile, trailed stand was equipped with the set of two fans (Fieni, ø 800mm, blades angling $35 \div 50^{o}$) with water tank, pump, valves and nozzle holders (Figure 1). The hydraulic drive for upper fan was used and the mechanical drive for the lower one. The upper fan location was adjustable within the range of 70 cm in height (fan axis at 2.20÷2.90 m). The upper fan outlet was moved forward by 73 cm with reference to lower fan outlet. Lower fan deflector had rectangle air outlet of 12.5 cm in width and 150 cm in length (height) and the upper one 8.7 cm and 100 cm respectively, with semicircular shape of upper part of deflector.

Figure. 1. Mobile stand with dual-fan.

2.2 Laboratory Measurements of Air Distribution

The laboratory and field measurements of the air distribution and spray distribution were carried out. For the laboratory measurements of air distribution the hot-wire anemometers were used (8450-51M-V-STD-NC-GB, TSI Inc.). The anemometers (8 per fan) were placed in the air centerline of outlet and within the distance of 50 cm from the outlet. The measurements were made: for the upper fan at 1630 rpm, and for the lower one at 1480 rpm and 1850 rpm.

2.3 Laboratory Measurements of Spray Distribution

The laboratory measurements of the spray distribution were made on a vertical spray patternator (PESSL- Austria) of 330 cm height. To obtain the required (half-ellipse) vertical spray distribution, both position and angling of nozzles were adjusted, as well as upper fan position. Because of patternator vertical measure range, only the lowest and "lowest +30 cm" positions of upper fan were used in the tests.

2.4 Field Measurements of Air Distribution

The field measurements of the air distribution were carried out in apple orchard (full leaf stage) with spindle trees of 4.5 m in height and 2.0 m in width (at 1.5 m height) with 4.0 m row spacing. The anemometers were placed on two 4.0 m masts and spaced 0.5 m in height. The masts were located in the outer canopy zone and in the axis of the tree row. After recording of the air flow changes during the sprayer pass, the data were send from the data logger (Intab AAC) to the PC. Then the maximum air flow velocities were read from the diagrams of air flow changes.

2.5 Field Measurements of Spray Distribution

The field measurements of spray distribution were carried out in apple orchard (full leaf stage) with spindle trees of 3.5 m in height and 1.4 m in width (at 1.5 m height), row spacing of 4.0 m. The measurements of spray deposit and coverage in the trees and drift potential were made. Samples and its locations are presented in Figure 2, Figure 3 and Table 2. Application parameters are presented in Table 1. Atmospheric conditions were as follows: setting no 1 (wind speed, at right angle to rows: 1.5÷2.5 m s^{-1}; temperature: 27^{o}C; humidity: 37% RH), setting no 2 (0.0÷1.2; 29; 34), setting no 3 (2.5÷3.5; 27; 37) and setting no 4 (0.5÷2.0; 27; 37). The upper fan position and number of nozzles opened were altered. The following settings of the fans were used:

1. lower fan (5 nozzles) + upper fan (+ 30 cm, 3 nozzles),
2. upper fan in the higher position (+ 30 cm) (3 nozzles),
3. upper fan in the lowest position (5 nozzles),
4. lower fan (with 6 nozzles per side).

Table 1. Application parameters for spray treatments.

Parameter	Fans and nozzles setting			
	Lower + Upper+30 cm	Upper +30 cm	Upper +0 cm	Lower
Number of nozzles per sprayer side	5+3	3	5	6
Nozzles distance from ground [cm]	75÷179 195÷262	195÷262	174÷270	46÷188
Spray volume [l ha^{-1}]	400	150	250	300
Fan axis (distance from ground) [cm]	90; 250	250	220	90
Fan rotational speed [r min^{-1}]	2000; 1800	1800	1800	2000
Deflector outlet: width x height [cm]		8.7 x 100		12.5 x 150
	Sprayer parameters			
Tractor, travel velocity [km h^{-1}]	MF 255 at 450 rpm PTO, 6.0			
Nozzle type, size, working pressure	Hollow cone, Albuz ATR Yellow at 10 bar, 1.0 l min^{-1}			

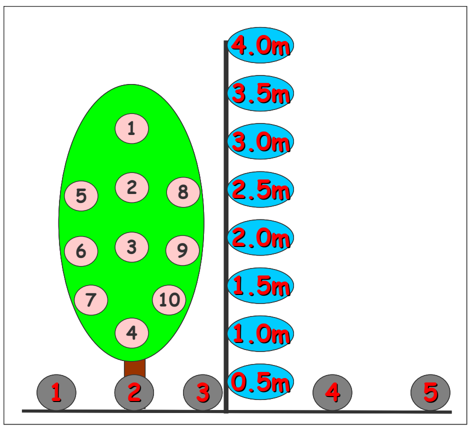

Figure 2. Layout of collectors for spray deposit, coverage and spray loss measurements.

Figure 3. Samples of WSP and filter paper – on the leaf.

Table 2. Distance from the ground (m) of in-tree measurement points.

Measurement point number (look at fig. 1)						
1	2	5 & 8	3	6 & 9	4	7 & 10
2.8÷3.0	2.4÷2.6	2.0÷2.2	1.5÷1.7	1.3÷1.5	0.4÷0.7	0.5÷09

The BSF (Brilliant Sulpho Flavine, WALDECK-Gmbh & Co KG, Division Chroma) fluorescent tracer was added (0.05%) to the spray and then Perkin-Elmer fluorometer was used in the laboratory. During deposition and drift potential tests the filter paper (Filtrak 132) was used. The water-sensitive paper strips (CIBA-GEIGY Ltd.) and computer image analysis was used in the coverage tests and measurements of vertical range of the spray. In deposition and coverage tests the samples (filter paper: 20 x 40 mm + WSP: 26 x 50 mm) were attached on both sides of leaves in each of five trees (repetitions). The samples were placed in ten locations in each tree (Figure 2). The filter paper was placed vertically on the double lines attached to the frames placed behind the sprayed trees. Samples were located at eight heights (every 50 cm) up to 4.0 meters above the ground. Samples on the ground were placed in five lines (repetitions): under the sprayed trees (3 samples in each repetition), one in the inter-row and one under the neighbor tree downwind (Figure 2).

After spraying of windward side of the trees, the frames were removed and then the leeward side was sprayed. The deposit on lower and upper leaf surfaces was calculated basing on sample area (8 cm^2), rinsing liquid (deionized water) volume (20 ml) and measured BSF concentration. Then the deposit on both surfaces and upper-to-lower leaf surface deposit ratio (U/L) were calculated. The spray in-tree deposit vertical evenness was evaluated by calculating Top-to-Bottom and Top-to-Lower ratios being the quotients of mean deposit in upper part of the trees (locations 1, 2, 5 and 8) and bottom (4,7 and 10) or lower part (remained locations) respectively. For airborne drift the Upper-to-Lower ratio between spray measured at upper part of the frame (from 2.5 to 4.0 m) to that on the lower one (from 0.5 to 2.0 m) was calculated.

The (2005) STATISTICA version 7.1. data analysis software system (StatSoft, Inc.) was used for the statistical analysis of gathered data (ANOVA followed by Duncan's Multiple Range Test ($P<0.05$) to separate means).

3. RESULTS

3.1 Laboratory Measurements of Air Distribution

In the laboratory tests, the essential question was symmetry of air discharge and air output of the fans. The air output on the right side of the fans was 8-11 % higher than that on the left side. For the parameters applied the total maximum air output (air speed * slot width) for lower and upper fan varied form 26 to 30 m^3/h. Because the upper fan outlet was moved forward with reference to the lower one, the interaction of the air-flows from the fan was very small. The measurements of air-flow were done in main stream of air-flow. Although it was spreading with distance from the outlet, the air-speed close to the stream-border was small in comparison with that measured in the middle of air-stream.

3.2 Laboratory Measurements of Spray Distribution

The best fit of spray vertical distribution to the required one (half-ellipse), was obtained for the setting with 8 (5+3) nozzles per sprayer side and the upper fan installed 30 cm above the lowest position (setting no 1).

3.3 Field Measurements of Air Distribution

In the field trials, the velocity of air-streams in the tree (at various heights) depended on fan setting, in case of upper fan – on its position. For upper fan located at the lowest position, the air velocity measured in the axis of the tree row, at 1.5 m height, was higher than that for the fan lifted by 30 cm (Table 3). Higher air velocities for lower fan than for the upper one (in both positions) were observed at 0.5 and 1.0 m heights. The upper one at lifted position caused lower air velocities still at 1.5 m. Starting at 2.0 m height the upper fan caused higher air flow velocities than the lower one. There is no explanation for lower air velocity measured at 3.5 and 4.0 m for lower and upper fan working simultaneously, than for upper one alone. The same no explanation concerns higher air velocity for lower fan alone than for both fans at 0.5 and 1.0 m heights.

Table 3. The maximum air-flow velocity (m/s) in the centre of the tree, at elevations from 0.5 to 4.0 m.

Fans setting	Measurement point elevation (m)							
	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0
Lower+Upper+30cm	2.1 b	1.2 b	2.4 b	3.0 b	2.2 b	2.4 b	2.8 ab	3.1 a
Upper+30cm	1.2 a	0.6 a	0.6 a	4.2 c	2.1 b	2.5 b	3.5bc	4.4 b
Upper+0 cm	1.1 a	0.7ab	2.3 b	3.7 c	2.0 b	2.8 b	4.2 c	4.0 b
Lower	4.5 c	2.3 c	1.7 b	1.4 a	1.2 a	1.5 a	2.0 a	2.5 a

Means in columns followed by the same letter do not differ significantly (Duncan's multiple range test at P=0.05).

3.4 Field Measurements of Spray Distribution

Because of different spray volumes applied (Table 1) the differences in in-tree deposits were expected. The one unexpected effect obtained was the highest total deposit on both leaf surfaces for "Lower" fan setting (Table 4). This tendency was also reflected for deposit and coverage on upper surfaces, but did not on the lower ones. The coverage on lower surfaces for "Lower+Upper" fan was higher than for the other combinations (Table 6).

Table 4. Deposit of BSF (μg/cm^2) in the trees and upper to lower (U/L) leaf surface ratio.

Fans setting	l/ha	Upper surface	Lower surface	Both surfaces	U/L ratio
Lower+Upper+30cm	400	1.84 b	1.58 b	3.42 c	3.18 a
Upper+30 cm	150	1.06 a	0.59 a	1.65 a	4.06 a
Upper+0 cm	250	1.65 ab	0.82 a	2.47 b	3.86 a
Lower	300	2.87 c	1.38 b	4.25 d	3.68 a

Means in columns followed by the same letter do not differ significantly (Duncan's multiple range test at P=0.05).

The most uniform vertical spray distribution in trees (Top-to-Bottom ratio closest to 1.0) was observed for both fans working simultaneously and for lower fan alone (Table 5). The relation between deposit at upper part of the trees and the rest of the tree (Top-to-Lower ratio) was the most uneven for "Upper+30cm" fan setting.

Table 5. Evenness of spray deposit in the trees and vertical distribution of airborne drift: ratios for mean deposits in measurement zones.

Fans setting	In-tree deposit: Top-to-Bottom ratio	In-tree deposit: Top-to-Lower ratio	Airborne drift: Upper-to Lower
Lower+Upper+30 cm	1.83 a	1.46 a	1.16 b
Upper+30 cm	7.09 c	3.80 b	1.86 b
Upper+0 cm	4.59 b	1.48 a	0.99 b
Lower	0.50 a	0.57 a	0.06 a

Means in columns followed by the same letter do not differ significantly (Duncan's multiple range test at P=0.05).

Table 6. Coverage (%) of WSP samples in the tree.

Fans setting	Upper surface	Lower surface
Lower+Upper+30cm	26.7 bc	14.7 b
Upper+30 cm	15.2 a	3.6 a
Upper+0 cm	26.0 b	4.6 a
Lower	32.4 c	6.6 a

Means in columns followed by the same letter do not differ significantly (Duncan's multiple range test at P=0.05).

Airborne drift measured behind the tree canopy (Table 7) corresponded to the air velocities (Table 3) in the tree at the lower part of the canopy (elevations 0.5 - 1.5 m). At the elevation of 3.5 m the higher drift was observed for upper fan at lowest position than for upper one lifted by 30 cm. The same tendency was observed at 4.0 m.

Table 7. Airborne drift potential (%) behind the tree canopy, as a percentage of a dose applied, at elevations from 0.5 to 4.0 m.

Fans setting	Measurement point elevation (m)							
	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0
Lower+Upper	0.64 a	0.67 b	0.57 a	0.46 a	0.60 b	0.69 b	0.69 b	0.68 b
Upper+30cm	0.15 a	0.18 a	0.22 a	0.26 a	0.53 b	0.41 ab	0.22 a	0.24 ab
Upper+0 cm	0.35 a	0.71 b	1.33 b	0.41 a	0.40 ab	0.38 ab	0.87 b	0.81 bc
Lower	2.10 b	1.24 c	0.33 a	0.25 a	0.09 a	0.05 a	0.04 a	0.04 a

Means in columns followed by the same letter do not differ significantly (Duncan's multiple range test at P=0.05).

The total (ground + airborne) spray drift corresponded to the in-tree spray deposit, showing higher losses for higher deposits and *vice versa*. Losses to the ground and to the air considered separately did not show so clear correlation, but still the upper fan alone gave the lowest losses (Table 8). The higher input to total losses came from ground losses for "Lower" fan working alone.

Table 8. Drift potential (%) as a percentage of the dose applied.

Fans setting	Airborne	Ground	Total
Lower+Upper	5.01 c	4.72 b	9.73 c
Upper+30 cm	0.83 a	1.13 a	1.96 a
Upper+0 cm	3.29 b	3.37 b	6.67 b
Lower	3.11 b	16.76 c	19.86 d

Means in columns followed by the same letter do not differ significantly (Duncan's multiple range test at P=0.05).

4. DISCUSSION

The various spray volumes applied caused difficulties in analyses of fans setting influence on spray deposition. However, when comparisons of the deposits in individual locations are made, one may see whether spray reaches all locations in the tree. The same observation may be done for air distribution in the tree and airborne drift behind the tree canopy. Drift at the top of the tree did not reflect exactly the air distribution in the tree. It can be explained by nozzles setting, because the fan height did not correspond exactly to the nozzle height. For “Upper+0” fan setting the highest nozzle was located 8 cm above the highest one for “Upper+30” setting. The same explanation concerns relations of ground drift for lower and upper fans working simultaneously and a lower one alone. For the lower fan 5 or 6 nozzles were used. When the lower fan was used alone, the 6^{th} nozzle (the lowest one) was additionally opened. It suggests that the nozzle location is of higher importance for spray drift, than the fan location. Using the highest or the lowest nozzle when it is not needed may cause incredibly higher drift – independently on fan location.

The results of the laboratory and field trials will be used during construction of the sprayer prototype and development of the operating recommendations for the growers.

In this paper there are presented only an idea of a dual-fan sprayer and a part of methodology which will be used in future trials. The sprayer prototype is already constructed and some trials on it were done. During procedure of publishing this paper some data on laboratory trials of power demand (Godyń at al., 2008b) and air and spray distribution (Godyń at al., 2008a) were published. Comparisons of spray distribution and losses for mobile stand and sprayer prototype will be presented in 2008 (Godyn *at al.*, 2008c). One may ask: “Is there a need for dual fans?”. The answer will come from the market.

5. CONCLUSIONS

1. The effect of lifting up or down the upper fan, on air velocity in the tree centre, was observed at 1.5 m height.
2. A higher air-flow velocity for “Upper+30cm” fan, than for “Lower” one was observed at 2.0 m and higher in the tree centre line.
3. Spray volumes applied (150÷400 l/ha) caused significantly different deposits. The higher deposit was observed for “Lower” fan alone, applying 300 l ha^{-1}.
4. The highest coverage on lower surfaces was observed for “Lower+Upper+30cm” fan and was reflecting the highest spray volume applied.
5. The most uniform vertical spray distribution in the trees was observed for both fans working simultaneously and for lower fan alone.
6. The highest disproportion between deposit on tops of the trees and on the rest of the tree was observed for “Upper+30cm” fan setting.
7. Total (airborne + ground) loses were proportional to in-tree deposits.
8. The higher spray loss behind the tree for „Upper+0” fan setting, than for “Upper+30” was observed at 1.0 and 1.5 with reverse relation at 3.5 and 4.0 m.

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