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THE EFFECT OF THE TUNNEL SPRAYING TECHNIQUE AND NOZZLE TYPE ON THE SPRAY DEPOSIT AND DRIFT DURING SPRAY APPLICATION IN STRAWBERRIES IN GROUND CULTIVATION

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ABSTRACT

The measurements of spray deposit on filter paper samples attached to strawberry leaves and spray drift to the ground up to the distance of 7.5 m from the sprayed strawberry plants were performed. A multi-tunnel type tunnel sprayer (Klip Klap, Denmark) and an AGROLA mounted field crop sprayer with a 10 m boom were used. Four types of nozzles were used representing single- or double-jet flat-fan nozzles. The tracer (BSF) deposit on the upper leaves surfaces was generally higher for the field crop sprayer (14,775.0–23,205.5) than for the tunnel sprayer (6,189.4–12,417.7 ng·cm^{-2}). The deposit on the lower surfaces of leaves was 1.9 to 18.0 times lower than on the upper surfaces and ranged from 540.6–1599.4 ng·cm^{-2} for the tunnel sprayer to 893.9–3007.1 ng·cm^{-2} for field crop sprayer. There was no significant effect of double-jet nozzles on the deposition on the lower surfaces and on the uniformity of application (CV% and U/L). The spray drift differed significantly between the tested sprayers. For the field crop sprayer, the drift up to the distance of 7.5 m beyond the sprayed area ranged 0.89–6.31% of the applied spray dose, while for the tunnel sprayer it was not more than 0.07%.

Introduction

Strawberries (*Fragaria x ananassa* Duch.) have an established position among horticultural crops in Poland. In 2010-2021 its yields (GUS, 2022) ranged from 153.4 to 204.9 thousand tonnes per year, with a tendency to decrease since 2015. The area of strawberry cultivation in Poland is about 50 thousand hectares, e.g. in 2015-2021 33.7–52.1 thousand hectares. According to the data compiled by KOWR, in 2021 (KOWR, 2021 - based on the data from i.e. FAO and EUROSTAT), Poland ranked 9th in the world (in 2021) and second in the EU (in 2021) and second in the EU (in 2020) in strawberry production.

Row cultivation in ground is still the dominant method of cultivation. On a smaller scale, bed or strip tillage is used. Strawberries are also grown in a system using frames and special gutters in which the plants are planted, and such cultivation is usually carried out under cover (e.g. greenhouse). In commercial production there are dessert varieties used (e.g. Elsanta) and those intended for processing (e.g. Senga Sengana), but also new, more prolific ones and better adapted to the climatic and soil conditions of Poland, e.g. intended for large-scale cultivation, a breeding of The National Institute of Horticultural Research (InHort) – Grandarosa variety (Żurawicz and Masny, 2012).

One of the most important problems faced by the strawberry producer is effective protection against diseases and pests, which, if not sufficiently controlled, reduces the yield and quality of the crop. Besides that, the plant protection equipment used and the method of performing the treatment are of great importance.

Plant protection techniques used in the cultivation of strawberries in Poland were chosen mainly in terms of protection effectiveness. In recent years, many new solutions have come to the market, such as tunnel sprayers. Among the nozzles, dual-jet nozzles are particularly promising, giving better distribution of spray on plants and reduced drift. New commercially available technical equipment, such as tunnel sprayers for row crops and dual-jet nozzles, need to be tested in the field. It is assumed that the row tunnel sprayer and dual-jet nozzles allow to achieve better chemical protection of different strawberry varieties, achieving it by better spray deposition, while reducing spray drift.

For chemical protection of strawberries various sprayers are used, e.g. row sprayers of the Fragaria type, equipped with tiltable frames, or row sprayers with a directed air stream. The technique of row spraying using a frame configuration of nozzles was proposed for strawberries as early as 1973 by Fisher and Hikichi (1973). For spraying of strawberries, the field crop sprayers are also used. Plants are sprayed better (higher and more even spray deposit and less loss) with a boom sprayer with air assistance. In some non-specialized farms, boom sprayers without air assistance are also used to spray strawberries.

The spray deposit on the lower surfaces of leaves is important, especially in the case of spraying against spider mites or aphids, which live mainly on the lower leaf surfaces. This factor becomes even more important for PPP of contact action. Pickel and Welch (1988) point out that the correct spraying technique for strawberries should cover the lower surfaces of the lowest leaves, where mites feed and where infections with diseases such as strawberry powdery mildew (*Podosphaera aphanis* (Wallr.) U. Braun & S. Takam) or strawberry white leaf spot (*Ramularia tulasnei* Sacc.) occur. According to these researchers, when using a boom sprayer without an air assistance, adequate coverage of hard-to-reach places cannot be achieved either by changing the nozzles or changing the height of the boom. According to them, some improvement may be achieved by changing the nozzle configuration, e.g. use the frame configuration – which has the features of a row sprayer.

In boom sprayers without air assistance and in a Fragaria type ones, the spray volumes of 400–600 $l \cdot ha^{-1}$ are used. For air assisted boom sprayers, volumes of 200–300 $l \cdot ha^{-1}$ are used.

Sprayers designed for spraying strawberries in the field are usually equipped with hollow cone nozzles or flat fan ones. Flat fan dual-jet nozzles have been known for more than 20 years. They achieve better coverage of vertical surfaces of plants (Szewczyk and Łuczycka, 2011), when producing fine-droplets they reduce spray drift by several percent (research by the Department of Agroengineering of InHort - unpublished), and double-jet air-induction nozzles, e.g. IDKT or AITTJ60, reduce drift by 50% (Anonim, 2023).

The aim of the experiments was to determine the effect of the tunnel spraying technique of strawberries and double-jet nozzles on the quality of strawberry spraying and the loss of spray. This issue was the first part of a larger study, in which biological studies were carried out for 5 selected combinations of sprayer and nozzles used for three consecutive years on the impact of spraying technique on the yield and biological effectiveness of chemical protection of three strawberry cultivars. This issue has not been the subject of such comprehensive research so far, neither in Poland nor in the world.

Material and Methods

The experimental object was set on a strawberry plantation planted in the spring of 2014, where experimental spraying with various plant protection techniques was performed. Different combinations of sprayer types (without air assistance): boom sprayer and tunnel sprayer for row crops, and nozzle type: flat-jet single-jet, and double-jet were evaluated. Field trials were carried out on 6 October 2014 on the experimental field of InHort in Skierniewice, on strawberry plants of the Granda Rosa, Senga Sengana and Elsanta cultivars (each sprayed row was a different variety – the variety influence was not taken into analysis, because the plants do not differ significantly in shape and size) planted in spring 2014 at a spacing of 1.0 × 0.30 m. The spraying was carried out with the use of a three-tunnel sprayer (prod. Klip Klap, Denmark, Fig. 1, Bjugstad and Hermansen, 2009) mounted in front of the tractor, where each of the tunnels was equipped with 5 nozzles, with the possibility of disabling two of them (Fig. 2) and an Agrola rear mounted field crop sprayer with a 10 m boom (Fig. 3). In the field crop sprayer, only the nozzles located above the sprayed plots were turned on. Weather conditions (wind speed, temperature, and humidity) are shown in Table 1.

Double-jet nozzles: TJ60 80 (double-jet flat fan) and DGTJ 110 (double-jet flat fan with drift protection) and single-jet flat fan nozzles: AIXR air-inclusion and XR 80 extended pressure range were used in the study. The operating parameters of the sprayers and the codes of the nozzles are shown in Table 2.



Figure 1. (the left hand one). Multi-tunnel sprayer Klip Klap (Denmark)
Figure 2. (the middle one). The arrangement of the nozzles in the tunnel, the nozzles marked in red were switched off in the variant combination
Figure 3. (the right hand one). AGROLA rear mounted field crop sprayer with a 10 m boom

Double-jet nozzles: TJ60 80 (double-jet flat fan) and DGTJ 110 (double-jet flat fan with drift protection) and single-jet flat fan nozzles: AIXR air-inclusion and XR 80 extended pressure range were used in the study. The operating parameters of the sprayers and the codes of the nozzles are shown in Table 2.


Figure 4. (the left hand one). Method of attaching filter paper samples to the leaves
Figure 5. Containers with a capacity of 50 ml into which filter paper samples were collected

The amount of a chemical agent on the sprayed target (spray deposit) and outside it (drift, loss) is commonly determined by quantification methods. One of the most used and accurate methods is the use of fluorescent tracers as an additive to the spraying liquid. Then, in the laboratory, the tracer is washed from the test surface, or from samples placed on and off plants, and its concentration in the washing solution is evaluated fluorometrically. These methods have been known for about 60 years (Staniland, 1959, 1960; Sharp, 1974). One of the most used markers was BSF (Brilliant SulphoFlavine) used in the studies of spray application and drift measurements (Doruchowski et al., 2000; Godyń et al. 2006, 2008, 2010). This method is now used as a standard, and the procedure can be applied to different types of crops.

Table 1.
Weather conditions during spray deposit and drift measurements for spraying combinations (see: table 2). Skierniewice, October 6, 2014.

Spraying combination	Sprayer	Wind speed ($m \cdot s^{-1}$)	Air temperature (°C)	Air relative humidity (%)
A	Multi-tunnel tunnel × 3	1.5–2.0	16.1	44.0
B		2.5–4.0	16.2	44.0
C		3.3–4.0	16.4	43.5
D		1.8–2.5	16.7	41.0
E		1.2–2.3	16.8	41.0
F		3.0–4.5	16.9	40.0
G	Field crop sprayer, boom 50 cm above plants	4.0–4.5	17.0	40.5
H		3.0–5.0	17.1	41.0
I		2.5–3.5	17.5	41.0
K		2.5–3.5	18.2	41.5

Table 2.
Operating parameters and spraying combinations, driving speed 6.0 $km \cdot h^{-1}$, Skierniewice, October 6, 2014.

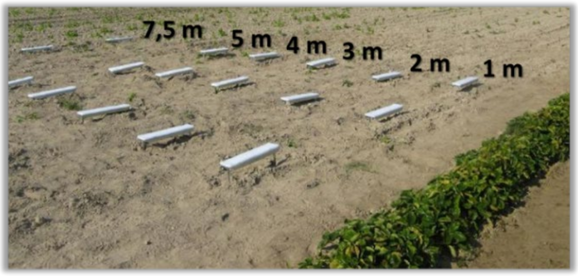
Spraying combination	Sprayer	Spray volume ($l \cdot ha^{-1}$) 1 nozzle output ($l \cdot min^{-1}$)	Nozzle type / size	Table pressure / drop size *	No of nozzles (pcs. / tunnel)
A	Multi-tunnel tunnel × 3	400 / 0.8	TJ60 80 02	3.10 / F	5
B		325/ 0.65	TJ60 80 02	2.00 / F	5
C		250 / 0.83	TJ60 80 02	3.40 / F	3
D		400 / 1.33	TJ60 80 03	3.75 / F	3
E		600 / 2.0	XR 110 06	2.15 / M	3
F		400 / 0.8	AIXR 110 025	2.00 / EC	5
G	Field crop sprayer, boom 50 cm above plants	400 / 2.0	DGTJ 110 06	2.25 / C	20 nozzles (Nozzle spacing 50 cm)
H		600 / 2.74	DGTJ 110 06	4.00 / C	
I		600 / 3.0	XR 110 08	2.75 / M	
K		400/ 2.0	XR 110 08	1.25 / C	

* Droplets size (acc. to BCPC/ASAE)l: F – fine droplets VMD (150–200); M – medium droplets (200–300); C – coarse droplets (300–400); EC – extremely coarse droplets (>575µm).

Each time, 3 rows of plants were sprayed (the outermost ones on the leeward side of the plots and the adjacent ones to each other, Fig. 6). A spray liquid containing 0.3% of the fluorescent tracer Brilliant SulphoFlavine BSF (prod. Waldeck GmbH & Co. KG, Havixbecker Straße 62, 48161 Münster, Deutschland) was used.

The measurements of the spray deposit on the plants were carried out on three (not consecutive) plants in each of the three sprayed rows and leaves located in the outer zone of the plants. Samples of filter paper (Filtrak no. 132) with dimensions of 30×30 mm were attached with paper clips to the upper and lower surfaces of the leaves (Fig. 4). After spraying, the samples were collected into separate labelled and sealable 50 ml containers (Fig. 5) in which they were stored and then transported to the laboratory. In the laboratory, filter paper samples were flooded with 30 mL of deionized water and then (after 10 minutes shaking) quantified with a Perkin Elmer LS55 spectrophotometer. The measured values of the tracer concentration ($ng \cdot ml^{-1}$) were then converted into the spray deposit expressed in $ng \cdot cm^{-2}$ considering samples area (9 cm^2) and volume of deionized water used for flooding (30 mL). In order to standardise the spray deposit value, as different doses of spray and tracer (per hectare) were used in different combinations, the unit application on the leaf surfaces was related also to the dose of the tracer per unit area of the sprayed field.

The fluorescent tracer method was also used in drift measurements. Spraying of the experimental plot was used for spray deposit and drift measurements. During the spray drift measurements, strips of filter fleece (Technofil BV, www.technofil.nl) with dimensions of 0.1×0.5 m were used, which were attached with Velcro on special metal stands, arranged in three parallel rows (2.0 m apart, Fig. 6 and 7). The samples were placed on the leeward side of the sprayed plants, at the distance of 1.0; 2,0; 3,0; 4,0; 5.0 and 7.5 m from them. The drift distance range was determined in a preliminary study. After spraying, the filter fleece was collected (rolled into a roll) into 2.0 l plastic jars and stored under a blackout until transported to the laboratory. In the laboratory, filter fleece samples were poured with 1000 mL of deionized water and then (after 10 minutes shaking) quantified with a Perkin Elmer LS55 spectrophotometer. The measured values of the tracer concentration ($ng \cdot ml^{-1}$) were then converted into the spray deposit expressed in $ng \cdot cm^{-2}$. Then the value of the application was converted into a drift constituting a percentage of the applied tracer dose per unit area (tracer doses – Table 3, column 2). The total losses to the ground up to the distance of 7.5 m was calculated by summing up the spray deposits in the strips determined by the positions of the samples.



Figures. 6 and 7. Arrangement of sprayed plants and distribution of samples in sedimentary drift measurements

The data of spray deposit was statistically analysed using the STATISTICA 7.0 program. Prior to the statistical analysis, a few erroneous readings were corrected. The aim of the experiments was to assess the quality of application and the number of losses during spraying of strawberry plants, in order to select 5 combinations of the sprayer and nozzle type for further biological tests carried out in subsequent years (2015-2017).

Results and Discussion

The spray deposit on the upper (U) and lower leaf surfaces (L) and the total deposit on both leaf surfaces (U+L) significantly depended on the sprayer-nozzle type combination. The deposit on the upper leaf surfaces was generally higher for the field crop sprayer (14,775.0–23,205.5) than for the tunnel sprayer (6,189.4–12,417.7 ng·cm^{-2}, Table 3). Only one combination for tunnel sprayer (F - MT/400/EG/1/5) achieved a similar deposit as for the two combinations of the field crop sprayer (combination G and K, Tab. 3). Taking into account the spray recovery (deposit of the tracer expressed as the share of the applied dose per hectare), for one more combination of tunnel sprayer (C - MT/250/D/2/3) a similar result was obtained as for the combination G and H (Table 3). The observed differences in the spray deposit on the upper, more easily accessible, leaf surfaces, between the two tested sprayers may be due to the different configuration of the nozzles on both sprayers. A field crop sprayer "loses" part of the spray for spraying the soil between the plant rows, where the strawberry plants do not grow, i.e. the spray dose is divided between the zone with plants and the zone without plants, not hitting the entire target of spraying. Despite this unfavourable factor, the spray distribution is good enough - when emitted from a distance suitable for the proper spray cloud formation - to provide an adequate amount of spray to cover entire plants. On the other hand, the nozzles in a tunnel sprayer are located inside the tunnel at distances of approx. 30 cm from each other, and they also operate at a shorter distance from the sprayed plants. This creates a risk of uneven spray distribution on the plants, but also a lower spray deposit in the plant zones where filter paper samples are placed on the leaves. In order to verify this hypothesis, it would be necessary to build a test stand that would allow the measurement of the spray distribution for the tunnel sprayer used, measured on the outline of the outer surface of strawberry plants. Such devices are not known to the authors for the present time.

Calculating the recovery value is a mathematical procedure. That makes it possible to compare the effects of spraying (with addition of tracer) between different combinations of the same experiment, where different spray volumes or tracer doses per unit of sprayed area are applied. That usually significantly affects the spray deposit and may "cover" the effects of other factors (like driving speed, nozzle type etc.).

In some combinations (all for the field crop sprayer and 1 for the tunnel sprayer, Table 3) recovery values greater than 100% were achieved. This may mean some kind of "thickening" of the distribution of the spray on the plants. If we assume a certain level of losses (for spraying the surfaces between plants and for drift), then theoretically we should find on the plants recovery values of less than 100% of the applied dose. It seems that the calculated values of >100% may be the result of a specific retention (and "not releasing" further) of the applied spray on the filter paper samples. It is also possible for the spray applied to the leaves to drip or move in other way towards the filter paper samples. The "recovery" indicator is rarely found in the literature regarding quantitative measurements of the spray on sprayed plants.

The deposit on the lower leaf surfaces was 1.9 to 18.0 times lower than on the upper ones and ranged from 540.6–1599.4 for the tunnel sprayer to 893.9–3007.1 ng·cm^{-2} for the field crop sprayer (Tab. 3). The deposit values on the lower leaf surfaces were generally not statistically different from each other. Only the "tunnel" combinations B and D indicated a difference with the field crop sprayer combination H. Neither the tunnel sprayer nor the field crop sprayer had the ability to deposit larger amounts of spray to the lower surfaces of the leaves, even when using double-jet nozzles. This is consistent with the results obtained by Szewczyk and Łuczycka (2011). The effect of improving coverage (here: deposit) of hard-to-reach places indicated by Pickel and Welch (1988) was not observed in our experiment.

The variability of spray deposit on the upper surfaces of leaves (Coefficient of Variation - CV%) ranged 32.21–52.24% for the field crop sprayer and 61.96–99.22% for the tunnel sprayer. This shows that for smaller deposits - in given conditions - greater variability of this deposit is observed. For the total spray deposit on both leaf surfaces, similar values were observed as for the upper leaves' surfaces, that is 29.08–91.63%. The variability of the spray deposit on the lower surfaces (CV%) was 53.92–185.02% and 78.87–135.79% for the tunnel sprayer, respectively (Tab. 4). The ratio of spray deposit on the upper vs. lower leaf surfaces (U/L) maintained high values of 9.86–21.84, which confirms the large discrepancy in the amount of spray deposit on the upper and the lower leaf surfaces. Moreover, no statistically significant differences were found for this parameter (U/L) between most of the combinations, except for combination F, which differed significantly from the four combinations with the highest values, and combination J, which differed significantly from the two combinations with the smallest values. It was observed that for some combinations with single-jet nozzles, where the lowest value of the U/L ratio occurred, the CV% value was the highest (combination F) or vice versa - the highest U/L values and the lowest CV% values (combinations I, J, tab. 4). This may indicate a greater randomness of application to the lower leaves' surfaces using single-jet nozzles.

However, there was no significant impact of the number of spray jets from the nozzles (single-jet or double-jet) on the uniformity of spray deposit (CV% and U/L). It is possible that this should be attributed to the lack of effect of twin-jet nozzles on increasing the spray deposition on the lower surfaces of leaves, which largely determines the uniformity of spray deposit on the entire plants.

Spray drift differed significantly between the tested sprayers. For the tunnel sprayer, the total drift (up to 7.5 m) did not exceed 0.19% of the applied dose, with no statistical differences both for total drift and at individual measurement distances (Tab. 5). That means no influence of atmospheric wind speed on drift level, despite it was measured in the wide range from 1.5–2.0 to 3.0–4.5 $m \cdot s^{-1}$ (Tab. 1).

For a field crop sprayer, the total drift up to the distance of 7.5 m ranged 0.89% for coarse-drop flat fan nozzles with single jet to 6.31% for the medium drop single jet nozzles. Significant differences at individual distances from the sprayed plants were found only at 1.0 m distance, where the lowest value was measured for coarse drops with one jet, and the highest for medium drop nozzles and one jet. Double-jet coarse drop nozzles showed intermediate drift, although it was used at the highest wind speed (up to 4.5 and 5.0 $m \cdot s^{-1}$ vs. up to 3.5 $m \cdot s^{-1}$ for the other field crop sprayer combinations, Tab. 1).

Table 3.
Deposit of fluorescent tracer in absolute values (ng·cm^{-2}) and in relation to applied dose of tracer on field area (recovery, % of applied dose) for Multi-tunnel sprayer and field crop sprayer applying different spray volumes and using flat fan nozzles with single jet or double jets, Skierniewice, October 6, 2014

Sprayer* / Spray volume / Droplet size** / No. of nozzle jets / No. of nozzles per one tunnel	Tracer dose per sprayed area (ng·cm^{-2})	Tracer deposit on upper leaf surfaces (ng·cm^{-2})	Tracer deposit on lower leaf surfaces (ng·cm^{-2})	Tracer deposit on upper leaf surfaces (% of dose)	Tracer deposit on lower leaf surfaces (% of dose)
MT/400/F/2/5	12 000	9380.9 ab	1599.4 ab	78.2 bc	13.3 a
MT/325/F/2/5	9 750	7617.1 a	1033.46 a	78.1 bc	10.9 a
MT/250/F/2/3	7 500	6865.7 a	1224.6 ab	91.5 b-d	16.3 a
MT/400/F/2/3	12 000	7639.1 a	540.6 a	63.7 ab	4.5 a
MT/600/M/1/3	18 000	6189.4 a	801.1 ab	34.4 a	4.5 a
MT/400/EC/1/5	12 000	12417.7 bc	955.0 ab	103.5 c-e	8.0 a
FC/400/C/2	12 000	14775.0 c	1615.1 ab	123.1 de	13.5 a
FC/600/C/2	18 000	21034.0 d	3007.1 bc	116.9 de	16.7 a
FC600/M/1	18 000	23205.5 d	2465.2 a-c	128.9 e	13.7 a
FC400/C/1	12 000	16088.7 c	893.9 ab	134.1 e	7.4 a

The means in columns marked with the same letter do not differ significantly according to Duncan's test (alpha = 0.05).
* Sprayer: MT – multi tunnel, 3 tunnels; FC – field crop sprayer, boom 10 m
** Droplets size (acc. to BCPC/ASAE)l: F – fine droplets VMD (150–200); M – medium droplets (200–300); C – coarse droplets (300–400); EC – extremely coarse droplets (>575µm).

Table 4.
Variability of the deposit of fluorescent tracer (CV%) and the ratio of the deposit on upper and lower leaf surfaces (U/L) for a Multi-tunnel sprayer and a field crop sprayer applying different spray volumes and using flat fan nozzles with single jet or double jets, Skierniewice, October 6, 2014

Sprayer* / Spray volume / Droplet size** / No. of nozzle jets / No. of nozzles per one tunnel	Deposit variability on upper leaf surfaces (CV%)	Deposit variability on lower leaf surfaces (CV%)	Deposit variability on total upper+lower leaf surfaces (CV%)	Ratio of the deposit on the upper and lower leaf surfaces (U/L)
MT/400/F/2/5	61.96	135.79	59.02	14.52 a-c
MT/325/F/2/5	63.20	101.65	60.28	14.21 a-c
MT/250/F/2/3	85.43	128.58	80.44	11.38 ab
MT/400/F/2/3	68.78	78.87	67.75	20.18 bc
MT/600/M/1/3	99.22	101.07	91.63	9.86 a
MT/400/EC/1/5	73.21	90.81	69.69	19.93 bc
FC/400/C/2	52.24	104.21	47.40	15.95 a-c

FC/600/C/2	42.63	185.02	47.42	17.57 a-c
FC600/M/1	32.21	126.42	29.08	20.66 bc
FC400/C/1	43.67	53.92	42.30	21.84 c

The means marked with the same letter do not differ significantly according to Duncan's test (alpha = 0.05).
* Sprayer: MT – multi tunnel, 3 tunnels; FC – field crop sprayer, boom 10 m
** Droplets size (acc. to BCPC/ASAE)l: F – fine droplets VMD (150–200); M – medium droplets (200–300); C – coarse droplets (300–400); EC – extremely coarse droplets (>575µm)

Table 5.
Drift of the fluorescent tracer at a distance of 1, 2, 3, 4 and 5 meters from the sprayed strawberry plants and total drift up to a distance of 7.5 m (% of the dose) for the Multi-tunnel sprayer and field crop sprayer applying different spray volumes and using flat fan nozzles with single jet or double jets, Skierniewice, October 6, 2014

Sprayer* / Spray volume / Droplet size** / No. of nozzle jets / No. of nozzles per one tunnel	Tracer drift in relation to the applied dose (% of dose) at subsequent (1.0 to 5.0 m) distances from the sprayed strawberry plants ***					Total drift up to a distance of 7.5 m from the plants (% of dose) ****
	1.0 m	2.0 m	3.0 m	4.0 m	5.0 m	
MT/400/F/2/5	0.0172 a	0.0098 a	0.0000 ab	0.0000 ab	0.0000 ab	0.027 A
MT/325/F/2/5	0.0274 a	0.0030 a	0.0000 ab	0.0000 ab	0.0000 ab	0.030 A
MT/250/F/2/3	0.0475 ab	0.0039 a	0.0000 ab	0.0000 ab	0.0080 a	0.069 A
MT/400/F/2/3	0.1756 ab	0.0074 a	0.0073 a	0.0000 a	0.0000 ab	0.190 A
MT/600/M/1/3	0.0049 a	0.0000 a	0.0000 ab	0.0000 a	0.0000 ab	0.005 A
MT/400/EC/1/5	0.0049 a	0.0049 a	0.0098 a	0.0024 a	0.0000 ab	0.022 A
FC/400/C/2	1.3941 bc	0.5055 ab	0.3939 ab	0.2899 ab	0.2536 ab	3.266 B
FC/600/C/2	2.4915 c	0.8504 ab	0.5382 ab	0.3663 ab	0.2729 ab	5.020 B
FC600/M/1	4.9892 d	0.4724 ab	0.3089 ab	0.1864 ab	0.1157 ab	6.311 B
FC400/C/1	0.4562 ab	0.1607 ab	0.0815 ab	0.0543 ab	0.0492 ab	0.891 A

* Sprayer: MT – multi tunnel, 3 tunnels; FC – field crop sprayer, boom 10 m
** Droplets size (acc. to BCPC/ASAE)l: F – fine droplets VMD (150–200); M – medium droplets (200–300); C – coarse droplets (300–400); EC – extremely coarse droplets (>575µm).
*** The means marked with the same **small letter** do not differ significantly according to Duncan's test (alpha = 0.05).
**** The means in column marked with the same **CAPITAL LETTER** do not differ significantly according to Duncan's test (alpha = 0.05).

The results of Doruchowski (1996) study, when using the Fragaria sprayer and the Wisus row sprayer with a directed air stream and fine-drop nozzles, showed that spray losses to the ground did not differ for various spray volumes. At the distance of 10 m from the sprayed field, losses did not exceed 1.9% of the applied dose. In our experiment, fine-drop nozzles were used only for the tunnel sprayer, which (tunnel) significantly reduced drift, and for the field crop sprayer, medium to extremely coarse drops were used, which also did not generate drift at a level close to 1.9% obtained by Doruchowski (1996).

Field measurements of spray drift in strawberries have been carried out to a small extent worldwide (Bjugstad and Hermansen, 2009). The mentioned authors have shown that the use of a row tunnel sprayer can reduce the spray drift in strawberries by up to 45-90%. In the study done by Jensen and Spliid (2005), the use of a tunnel sprayer and anti-drift LD nozzles reduced drift by 90-95%. The results of these studies confirm the results of our drift measurements. Daugaard et al. (2000) suggest the possibility of reducing the plant protection products doses by using the tunnel sprayer. Although in their two-year study they did not show the influence of the tunnel sprayer technique on the control of gray mold in strawberries effectiveness.

After completing the experiment, three combinations of a tunnel sprayer (A, C, E) and two for field crop sprayer (G, I) were selected for further tests. The final choice was a compromise between obtaining the highest spray deposit on the lower leaf surfaces, the smallest drift value and the possibility to choose various spray volumes applied. In the continuation of this experiment, the influence of plant protection technique and reducing the dose of a plant protection product (reduction of spray volumes of constant concentration of PPP) on - among others - the biological effectiveness of protection of strawberries against diseases and pests were investigated. A preliminary analysis of the results showed some possibilities of reducing the PPP dose in strawberry diseases control by the use of tunnel sprayer technique (Godyń, 2017).

Conclusions

On the upper surfaces of leaves the significantly greater spray deposit was obtained for the field crop sprayer (14,775.0–23,205.5) than for the tunnel sprayer (6,189.4–12,417.7 $ng \cdot cm^{-2}$). These differences may result from different nozzle configurations on both used sprayers.

The spray deposit on the lower leaf surfaces ranged from 540.6–1599.4 for the tunnel sprayer to 893.9–3007.1 $ng \cdot cm^{-2}$ for the field crop sprayer. It was 1.9 to 18.0 times smaller than on the upper leaves' surfaces. That observation was confirmed by high values of the ratio of spray deposit on the upper and lower leaves' surfaces (U/L), ranging from 9.86 to 21.84.

Both the tunnel sprayer and the field crop sprayer did not show the ability to deposit higher amounts of spray liquid on the lower leaves' surfaces, even when using double-jet nozzles. The consequence of that was the lack of significant influence of the dual-jet nozzles on improving the uniformity of spray deposit (CV% and U/L).

The variability of spray deposit on the upper leaf surfaces (CV%) was 32.21–52.24% for the field crop sprayer and 61.96–99.22% for the tunnel sprayer, and on the lower surfaces 53.92–185.02% and 78.87–135.79% respectively. The higher deposit variability on lower leaf surfaces is typical for smaller spray deposits.

The amount of spray drifted outside sprayed area differed significantly between the tested sprayers. For the field crop sprayer, the total drift up tothe distance of 7.5 m beyond the sprayed area ranged 0.89–6.31% of the applied dose, while for the tunnel sprayer, regardless of the nozzles used, it was no more than 0.19%. This observation confirms the prevailing role of the tunnel technique in spray drift reduction.

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WPŁYW TUNELOWEJ TECHNIKI OPRYSKIWANIA I TYPU ROZPYLACZY NA NANIESIENIE I ZNOSZENIE CIECZY OPRYSKOWEJ PODCZAS OPRYSKIWANIA TRUSKAWEK W UPRAWIE GRUNTOWEJ

Streszczenie. Podczas opryskiwania roślin truskawek prowadzono pomiary naniesienia cieczy opryskowej na próbki z bibuły filtracyjnej mocowane na liściach truskawek i znoszenia cieczy opryskowej na ziemię do odległości do 7,5 m od opryskiwanych roślin. Stosowano opryskiwacz tunelowy typu multi-tunel (Klip Klap, Dania) i opryskiwacz polowy zawieszany Agrola z belką 10 m. Na opryskiwaczach montowano rozpylacze płaskostrumieniowe jedno- albo dwustrumieniowe. Naniesienie znacznika na górne powierzanie liści było generalnie większe dla opryskiwacza polowego (14 775,0–23 205,5) niż dla opryskiwacza tunelowego (6 189,4–12 417,7 $ng \cdot cm^{-2}$). Naniesienie na dolne powierzchnie liści było mniejsze o 1,9 do 18,0 razy niż na górne powierzchnie i wynosiło od 540,6–1599,4 dla opryskiwacza tunelowego do 893,9–3007,1 $ng \cdot cm^{-2}$ dla opryskiwacza polowego. Nie wykazano istotnego wpływu rozpylaczy dwustrumieniowych na wielkość naniesienia na dolne powierzchnie oraz na równomierność naniesienia (CV% i G/D). Wielkość znoszenia istotnie różniła się między badanymi opryskiwaczami. Dla opryskiwacza polowego znoszenie w odległości do 7,5 m poza opryskiwany obszar wynosiło 0,89–6,31% stosowanej dawki cieczy, natomiast dla tunelowego nie więcej niż 0,07%.

Słowa kluczowe: opryskiwacz tunelowy, rośliny truskawki, rozpylacze dwustrumieniowe, naniesienie cieczy opryskowej, znoszenie cieczy opryskowej