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IMPACT OF TECHNICAL SPRAYING FACTORS ON LEAF AREA COVERAGE IN AN APPLE ORCHARD

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Original scientific paper
Research is conducted on an apple orchard with two different types of orchard sprayers, axial (Hardi Zaturn) and radial (Hardi Arrow). The influence of major technical spraying factors (type of nozzle, working speed and spray volume) were observed on coverage of the treated area, average droplet diameter, number of droplets per cm^2 and drift. The working speed of sprayer was set at 6 and 8 km/h, and spray volume on 250, 325 and 400 l/ha. In research, Lechler blue (TR 8003C), yellow (TR 8002C) and green (TR 80015C) nozzles were used. The research was set as three - factorial field experiment with 18 treatments in 4 repetitions, for each type of sprayer. Sixty water sensitive papers (WSP) were used for the treatment, which was processed with digital image analysis (DIA) and ImageJ software. The major technical spraying factors have a high significant statistical impact (**) on the main properties of the research. By decreasing the ISO number of nozzles and by increasing the working speed and spray volume, we found increasement of area coverage, number of droplets per cm^2 and drift, and decreasement of average droplet diameter. By comparing the results of the research by axial and radial orchard sprayer in apple orchard, better results (*) were achieved with a radial sprayer. The best adjustment of technical spraying factors (area coverage of 59,55 % and 21,10 % of liquid drift) was achieved by a radial sprayer and with green nozzle (TR80015C), working speed of 8 km/h, spray volume of 325 l/ha, and working pressure of 16,84 bar.

Keywords: *area coverage, axial sprayer, nozzle, radial sprayer, spraying norm, water sensitive paper, working speed*

Utjecaj tehničkih čimbenika raspršivanja na pokrivenost lisne površine u nasadu jabuke

Izvorni znanstveni članak
Istraživanja su obavljena u nasadu jabuke sa dva tipa raspršivača, aksijalni (Hardi Zaturn) i radijalni (Hardi Arrow). Istraživan je utjecaj glavnih tehničkih čimbenika raspršivanja (tip mlaznice, brzina rada i norma raspršivanja) na pokrivenost tretirane površine, prosječni promjer kapljica, broj kapljica/cm^2 i zanošenje tekućine. Brzina rada raspršivača podešava se na 6 i 8 km/mh, a norma raspršivanja na 250, 325 i 400 l/ha. Koriste se plave (TR 8003C), žute (TR 8002C) i zelene (TR 80015C) Lechler mlaznice. Istraživanje se postavlja kao trofaktorijalni poljski pokus sa 18 tretmana u 4 ponavljanja, za svaki tip raspršivača. Po tretmanu se na stablo postavlja 60 vodoosjetljivih papirića koji se obrađuju pomoću računalne analize slike i računalnog programa ImageJ. Glavni tehnički čimbenici raspršivanja ostvaruju statistički vrlo značajan utjecaj (**) na glavna svojstva istraživanja. Smanjivanjem ISO broja mlaznice, povećanjem brzine rada raspršivača te povećanjem norme raspršivanja povećava se pokrivenost tretirane površine, broj kapljica/cm^2 i zanošenje tekućine, a smanjuje se prosječni promjer kapljica. Usporedbom dobivenih rezultata istraživanja sa aksijalnim i radijalnim raspršivačem u nasadu jabuke, bolje rezultate (*) postiže radijalni raspršivač. Najbolje podešenje tehničkih čimbenika raspršivanja (pokrivenost tretirane površine od 59,55 % i zanošenja tekućine od 21,10 %) ostvaruje se sa radijalnim raspršivačem te zelenom mlaznicom (TR 80015C), brzinom rada od 8 km/h, normom raspršivanja od 325 l/ha i radnim tlakom od 16,84 bar.

Ključne riječi: *aksijalni raspršivač, brzina rada, mlaznica, norma raspršivanja, pokrivenost površine, radijalni raspršivač, vodoosjetljivi papirić*

1 Introduction

Agriculture is an inseparable part of the overall global ecological system, where humans, animals, plants, climate factors and agricultural engineering are in interaction. Therefore, aim is to improve, enhance or develop new technical solutions (using of sensors for precise crop protection; sprayers with recyclable system; enhanced radial sprayers, etc.) for agricultural machinery to introduce measures and procedures that would result in minimal interventions in the ecosystem [1]. With the technical correctness of the working machine in plant protection, it is particularly important to adjust the technical parameters of spraying – working speed of sprayer, working pressure, air flow and velocity, spraying norm, type of nozzle, etc. Only synergy of properly configured technical parameters and technical accuracy of the machine provide adequate results.

The most commonly used method, to test the settings of technical parameters in field conditions on the area coverage, is with water sensitive papers and with digital (computerized) image analysis [2 ÷ 6].

One of the main technical factors is droplet diameter, which is decreasing by increasing the working pressure [7]. Also, by increasing the working pressure, the number of droplets in spray is increasing [8]. This implies that by reducing the droplet diameter and by increasing the working pressure, coverage of treated area is increasing [9]. Coverage of treated area is the main goal of whole plant protection process, and the main task of technical spraying factors is to increase this property. If this is not the case, with small area coverage pests are appearing again and previous treatments are futile.

Negative side of increasing the working pressure is increasing of liquid drift. This is undesirable property and should be minimized. Performance of the plant protection in adverse weather conditions and with bad adjustment of technical spraying factors, can cause a loss (drift) up to 40 % (loss of liquid, pesticides and working time - higher inputs in production and higher environmental pollution) [10]. So, droplets smaller than 200 μm in diameter are subject to drift – removal from the orchard and vaporization [11]. Smaller droplets are obtained with nozzles with smaller ISO numbers (01, 015, 02) and bigger droplets are obtained with higher ISO numbers (03, 04, 05), at same working pressure [12].

Some authors suggest that the increased fan air speed is first precondition for good area coverage and deposit [13]. But in earlier developmental stages of the orchard, this can be counterproductive - increased occurrence of drift. Also, due to the friction of surrounding air and air flow from the fan, the air velocity is decreasing [14].

This research is a part of the modern world trends where the application of agricultural engineering in plant protection aspires to achieve the highest possible coverage of the treated area with the least losses of liquid in the form of drift. Also, it is particularly important to further investigate the technical spraying factors of the plant protection, because in Croatia the new law is in the force (NN 14/2014), linked to sustainable use of pesticides and mandatory inspection of all technical systems in plant protection (European Directive: 2009/128/EC and 2006/42/EC) [15].

2 Objective of the research

The objective of this research is to determine the influence of major technical spraying factors (type of nozzle, working speed and spray norm) on average area coverage, average droplet diameter, number of droplets per cm^2 and drift. This will be examined through the exploitation of two different orchard sprayers with different settings of the major technical factors of spraying.

3 Materials and methods

The researches were conducted at OPG Žilić (Kunovci, Požeško-slavonska county, Croatia) in June, 2013.

3.1 Orchard sprayers

In this study two mounted orchard sprayers were used. Sprayer Hardi Zaturn has an axial fan with the plane rectangular air flow (Fig. 1) and sprayer Hardi Arrow has a radial fan with axisymmetrical air flow (Fig. 2). Both of the sprayers are tested according EN 13790 standard [16] through European directive 2009/128/EC and 2006/42/EC.

Figure 1 Hardi Zaturn

Figure 2 Hardi Arrow

3.2 Nozzles

The study used three types of new nozzles as a technical spraying factor A in statistical analysis: Lechler TR 80015C, TR 8002C and TR 8003C. All selected nozzles are marked according ISO 10625:2005 standard, where TR denotes the type of spray (hollow cone); 80 is spray angle; 015, 02 and 03 are nozzle flows in U. S. gallons per minute at 2,75 bar and C is the material of which they are made (polyoxymethylene with a ceramic insert) [17]. Dimensions of nozzles are shown in Fig. 3. Adjustment of nozzles at both of the sprayers is shown in Tab. 1.

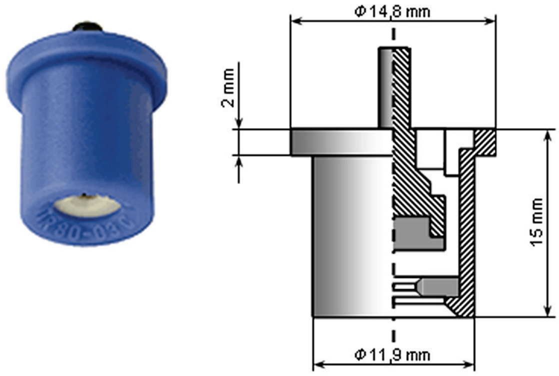

Figure 3 Dimensions of Lechler TR 80 nozzles

3.3 Working speed, pressure and spraying norm

Second technical spraying factor of this research is an average working speed of sprayers (factor B) which was set to the two speeds - 6 and 8 km/h. Average working speed of the sprayer was followed by tractor board computer and is checked by the stopwatch at the exact distance in the orchard (Fig. 4) through equation:

$$v_r = \frac{s_r}{t_r}, \tag{1}$$

where is: v_r – working speed, m/s; s_r – travelled distance, m; t_r – time required to cross the default distance (100 m), s.

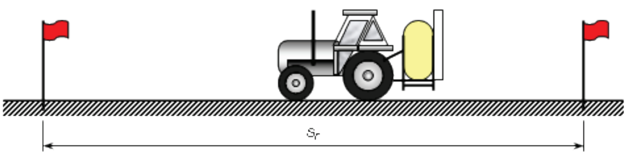

Figure 4 Measuring of sprayer speed

The third technical spraying factor in the study is spraying norm - factor C. The study used three spraying norms: 250, 325 and 400 l/ha. The spraying norm was determined with respect to the volume of orchard with the equation [18]:

$$N_r = \frac{TRV \cdot k}{1000}, \tag{2}$$

where is: N_r – spraying norm, l/ha; TRV – three row volume, m^3; k – theoretical norm required for the treatment (depend on LAI (m^2/m^2) and LAD (m^2/m^3); in

Croatian conditions from 10 ÷ 125 l/1000 m^3). The volume of orchard (*TRV*) is calculated from equation [19, 20]:

$$TRV = \frac{h_n \cdot b_k \cdot 10000}{b_r}, \quad (3)$$

where is: *TRV* – tree row volume, m^3; h_n – average orchard height, m; b_k – average treetop width, m; b_r – row width, m.

After determination of orchard volume and spraying norm, the next step of sprayer calibration is to calculate required nozzle flow and pressure. Nozzle flow is calculated from equation [21]:

$$Q_m = \frac{N_r \cdot v_r \cdot b_r}{n \cdot 600}, \quad (4)$$

where is: Q_m – nozzle flow, l/min; N_r – spraying norm, l/ha; v_r – working speed, k/mh; b_r – row width, m; n – number of nozzle in exploitation. Final step of calibration is to calculate required pressure with equation [17]:

$$\frac{Q_1}{Q_2} = \sqrt{\frac{p_1}{p_2}}, \quad (5)$$

where is: Q_1 – liquid flow at pressure p_1, l/min; Q_2 – liquid flow at pressure p_2, l/min; p_1 – pressure at Q_1 liquid flow, bar; p_1 – pressure at Q_2 liquid flow, bar. During the research, the row with was 3,5 m and 10 nozzles are installed on both sprayers. In Tab. 2 overall calibration of sprayers is shown.

3.4 Air flow and velocity

Velocity of an air current is measured with a mobile meteorological station, Kestrel, Weather and Environmental meters – model 4500 (wireless data transmission). With the data of the average air velocity, it is easy to express the real air flow of both orchard sprayers with the equation:

$$Q_r = A_{fo} \cdot v_a, \quad (6)$$

where is: Q_r – real air flow, m^3/h; A_{fo} – fan outlet area, m^2; v_a – air velocity, m/s. Also, through technical parameters of application we can calculate theoretical and specific air flow. Theoretical air flow is calculated with equation [21]:

$$Q_t = \frac{1000 \cdot v_r \cdot b_m \cdot h_n}{f}, \quad (7)$$

where is: Q_t – theoretical air flow, m^3/h; v_r – working speed of sprayer, km/h; b_m – spray width, m; h_n – average height of orchard, m; f – foliation factor (for larger orchards 1,5 ÷ 2,5, and for smaller 2,5 ÷ 3,5). Specific air flow is calculated from equation [22]:

$$Q_s = \frac{Q_r}{1000} \cdot v_r, \quad (8)$$

where is: Q_s – specific air flow, m^3/km; Q_r – real air flow, m^3/h; v_r – working speed of sprayer, km/h. The results of air flows are shown in Tab. 1.

3.5 Water sensitive papers (WSP)

WSP are yellow rectangular strips (75 × 25 mm). On surface they have a thin layer of bromophenol, which in contact with water turns blue. Therefore, the droplets that fall on a WSP were used for determination of average area coverage, number of droplets per cm^2, average droplet diameter and drift. This has become the most popular method for field evaluation of spray pattern [23 ÷ 31]. WSP with droplets is shown in Fig. 5.

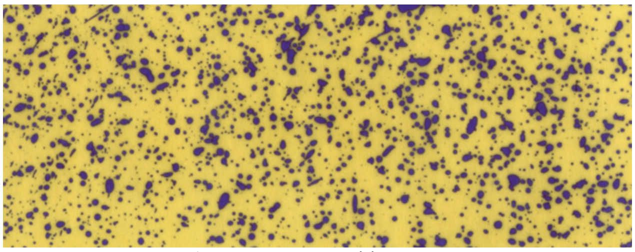

Figure 5 Water sensitive paper

The study used WSP from the Swiss manufacturer Syngenta. Papers were placed at 3 levels of canopy: peak, the middle and lower levels. On each level 5 papers was set on both side of the leaves, with the use of 4 trees in repetition. So, for each tree 15 WSP was used, and for each treatment 60 WSP [32] - 36 treatments in total = 2160 WSP.

WSP were also used for the evaluation of drift intensity. Drift is measured in 2 untreated side rows in 4 repetitions for each treatment. In each repetition 6 WSP was used (3 vertical and 3 horizontally).

3.6 Digital image analysis (DIA)

After field research, the WSP samples were collected and each one was analyzed by using the DIA. The basic elements of the DIA system used in this research were a lightening chamber with 8 halogen lamps arranged in a circle that form top lighting (CE Lighting, DX MR16-18LED, 2 W, 12 V, 15 ÷ 60° with temperature of 6500 K - illumination of 850±10 lux to the sample area), and lower lighting with energy saving bulb (Philips Genie, 8 W, 405 lm), which is located below the surface of sandblasted glass on which the sample is placed. Inside of lightening chamber there is a digital camera (Canon EOS – 1100D; image sensor: CMOS, resolution ≈ 10,10 MP; lens: Canon EF – S18 – 55 mm (*f*/3,5 – 5,6 IS)), located in the upper part of the chamber within 60 cm from the sample.

Before the analysis, the entire system needs to go through the calibration process [33, 34]. The illumination inside the chamber was measured with digital light meter (YF-170, YU – Fong Electronics, Taiwan), and white balance calibration is performed by using the standard white ceramic tile (CR – A43, Konica Minolta, Japan).

Table 1 Air flows and adjustment of nozzles

Statistical parameters	Axial		Radial			Axial	Radial
	Air velocity, m/s				Nozzle orientation		
	Left side	Right side	Left side	Right side	Position	Angle / °	
$\overline{X}$	19,38	15,58	24,45	26,00	1.	off	+10
σ	5,17	4,24	2,57	1,46	2.	+15	+10
C.V., %	26,68	27,20	10,51	5,61	3.	+10	+10
	Air flow, m^3/h				4.	+5	0
v_r / km/h	6	8	6	8	5.	0	–5
Q_r / m^3/h	14 154,75		10 265,16		6.	–5	off
Q_t (f=1,5) / m^3/h	13 980,00	18 400,00	12 116,00	16 154,67	7.	off	off
Q_s / m^3/km	84,92	113,23	61,59	82,12	8.	off	off

Table 2 Calibration parameters for both of the sprayers

Nozzle	N_r / l/ha	v_r / km/h	Q_m / l/min	p / bar	Nozzle	N_r / l/ha	v_r / km/h	Q_m / l/min	p / bar
TR 8003C	250	6	0,87	1,51	TR 8002C	250	8	1,16	5,78
TR 8003C	325	6	1,13	2,56	TR 8002C	325	8	1,51	9,78
TR 8003C	400	6	1,40	3,88	TR 8002C	400	8	1,86	14,81
TR 8003C	250	8	1,16	2,69	TR 80015C	250	6	0,87	5,60
TR 8003C	325	8	1,51	4,56	TR 80015C	325	6	1,13	9,47
TR 8003C	400	8	1,86	6,90	TR 80015C	400	6	1,40	14,35
TR 8002C	250	6	0,87	3,25	TR 80015C	250	8	1,16	9,96
TR 8002C	325	6	1,13	5,50	TR 80015C	325	8	1,51	16,84
TR 8002C	400	6	1,40	8,33	TR 80015C	400	8	1,86	25,52

```
requires("1.33n");
  dir = getDirectory("Choose a Directory ");
  list = getFileList(dir);
  run("Set Measurements...", "area bounding display redirect=None       decimal=0");
  roi = "";
  start = getTime();
  titles = newArray(list.length);
  run("Clear Results");
  setBatchMode(true); // runs up to 20 times faster
  j = 0;
  for (i=0; i<list.length; i++) {
      path = dir+list[i];
      if (endsWith(path, ".roi"))
          roi = path;
      else {
          open(path);
          title = getTitle();
          titles[j++] = title;
          //print(i+"  "+title);
          selectImage(title);
        run("Set Scale...", "distance=118 known=10 pixel=1 unit=mm");
        run("8-bit");
        //run("Threshold...");
        setAutoThreshold("Otsu");
        setThreshold(0, 142);
        run("Convert to Mask");
        run("Watershed");
        run("Set Measurements...", "area perimeter bounding feret's area_fraction display redirect=None decimal=3");
        run("Analyze Particles...", "size=0-Infinity circularity=0.00-1.00 show=Nothing display include summarize add");
        close();

      }
  }
```

Figure 6 Program code for digital image analysis (DIA) in *ImageJ* software

After taking the samples, images are stored on computer in TIFF format. On images, automatic computer command (macro) was applied in Adobe Photoshop® software, with the purpose of segmentation and separation of the sample surface.

The next step is image processing with ImageJ software [35, 36]. In order to conduct computerized image analysis of WSP samples, in ImageJ software a macro command is created, and the code of the program is shown in Fig. 6.

As a result of image analysis in ImageJ software, obtained values are: A (area) total area of WSP, mm^2 or pix^2; TPA (total particle area) total area swept by droplets on WSP, mm^2 or pix^2; AF (area fraction) share of droplets on WSP, %; PC (particle count) number of droplets on WSP; PS_{avg} (average particle size) average size of droplet on WSP, mm^2, pix^2 or µm.

Area fraction (AF) or average area coverage is calculated from equation:

$$AF = \frac{A}{TPA} \cdot 100. \tag{9}$$

Droplet which falls on the WSP has a lager diameter than in reality so we must use correction factors [5, 23] to transform droplet diameter. For statistical analysis of the results, STATISTICA operating software was used (StatSoft, Inc., 2011 – data analysis software system, version 10.0).

3.7 Weather condition and leaf factors

During the research weather conditions (air temperature and humidity, sun insolation, wind speed and direction) were measured using the Hobbo meteorological station - data were stored every 30 s on a hard drive. Also, leaf area index and leaf area density were measured. These two parameters are the main indicators of treetop verdure (form of slender spindle - 16 trees in research), Tab. 3.

4 Results

In Tab. 3 are shown average weather condition during the research, and average *LAI* and *LAD* for trees in research, where is: E_e is solar radiation; T_z is air temperature in the orchard; ω_z is relative air humidity in the orchard; v_v is wind speed; ↑ is wind direction; *LAI* is leaf area index and *LAD* is leaf area density.

In Tabs. 4 and 5 are shown the main properties and results of the research with an axial and radial orchard sprayer, where are: $\overline{A}_p$ – average area coverage / %; $\overline{n}_k$ /cm^2 – average number of droplets per area; $\overline{d}_k$ – average droplet diameter / µm; A – type of nozzle (A_1 – TR 8003; A_2 – TR 8002; A_3 – TR 80015), B – working speed (B_1 – 6 km/h; B_2 – 8 km/h), C – spraying norm (C_1 – 250 l/ha; C_2 – 325 l/ha; C_3 – 400 l/ha).

Tabs. 4 and 5 (axial and radial orchard sprayer) show that the main technical spraying factors (nozzle type, working speed and spraying norm) have a high significant impact (**) on the main properties of the research (average area coverage, average number of droplets per area, average droplet diameter and drift). With decreasing of ISO nozzle number (from TR 8003C to TR 80015C) and with increasing of working speed from 6 to 8 km/h) and spraying norm (from 250 to 400 l/ha), the average area coverage, average number of droplets per area and drift are statistically increasing.

Table 3 Weather conditions and leaf factors

Statistical parameters	Weather conditions during the experiment					Leaf area	
	E_e / W/m^2	T_z / °C	ω_z / %	v_v / m/s	↑ / °	*LAI* m^2/m^2	*LAD* m^2/m^3
$\overline{X}$	376,14	19,07	53,29	0,83	203,57	1,76	4,59
σ	186,86	2,20	6,76	0,29	42,75	0,20	0,52
C.V., %	49,34	11,24	13,63	50,69	19,97	11,62	11,25

With the same nozzle and spraying norm but with higher working speed, higher working pressure was required for spraying default norm, equation 4 and 5 (ex. with TR 8002C nozzle, spraying norm of 400 l/ha and with working speed of 6 km/h required working pressure was 8,30 bar; with the same nozzle and spraying norm but with working speed of 8 km/h required working pressure was 14,81 bar, Tab. 2). So, with this pressure increasing, *LSD* test and coefficient of correlation determined that an average area coverage is increasing (axial sprayer, r = 0,89; radial sprayer, r = 0,92 – Tab. 6).

Different movement shows the average droplet diameter - with decreasing of ISO nozzle number (from TR 8003C to TR 80015C) and with increasing of working speed from 6 to 8 km/h) and spraying norm (from 250 to 400 l/ha), the average droplet diameter is decreasing. All these cases, through the correlation coefficient are shown in Tab. 6.

Table 4 Analysis of variance for the main properties of the research with an axial orchard sprayer

ANOVA		$\overline{A}_p$ / %				$\overline{n}_k$ / cm^2			
		$\overline{X}$	$LSD_{0,05}$	$LSD_{0,01}$	*F*-test	$\overline{X}$	$LSD_{0,05}$	$LSD_{0,01}$	*F*-test
A	A_1	34,07	3,17	4,30	34,76**	65,70	7,44	10,01	153,48**
	A_2	39,39				87,64			
	A_3	43,38				108,88			
B	B_1	35,22	0,87	1,14	66,31**	80,11	3,74	4,93	52,56**
	B_2	42,67				94,70			
C	C_1	32,75	2,37	3,22	72,48**	75,53	4,26	5,78	62,37**
	C_2	37,96				84,20			
	C_3	46,13				102,50			
AB			1,67	2,35	6,76**	*AB*	7,21	10,11	9,49**
AC			4,60	6,70	1,46 n.s.	*AC*	8,25	12,01	5,78**
BC			3,55	4,98	3,26*	*BC*	6,37	8,93	1,86 n.s.
ABC			7,84	13,00	2,39 n.s.	*ABC*	14,05	23,31	5,83**
ANOVA		$\overline{d}_k$ / µm				drift / %			
		$\overline{X}$	$LSD_{0,05}$	$LSD_{0,01}$	*F*-test	$\overline{X}$	$LSD_{0,05}$	$LSD_{0,01}$	*F*-test
A	A_1	183,33	5,34	7,24	16,47**	17,66	0,40	0,55	629,3**
	A_2	175,79				20,08			
	A_3	156,87				22,09			
B	B_1	181,02	5,23	6,8	21,68**	18,14	0,19	0,26	1239,6**
	B_2	162,97				21,74			
C	C_1	186,91	7,22	9,78	17,68**	15,16	0,21	0,29	7202,8**
	C_2	170,25				16,07			
	C_3	158,83				28,60			
AB			10,07	14,12	0,46 n.s.	*AB*	0,38	0,53	1301,7**
AC			13,97	20,32	2,31 n.s.	*AC*	0,41	0,60	97,4**
BC			10,78	15,11	0,21 n.s.	*BC*	0,32	0,45	997,2**
ABC			23,78	39,45	2,37 n.s	*ABC*	0,71	1,17	166,4**

Table 5 Analysis of variance for the main properties of the research with a radial orchard sprayer

ANOVA		$\overline{A}_p$ / %				$\overline{n}_k$ / cm^2			
		$\overline{X}$	$LSD_{0,05}$	$LSD_{0,01}$	F-test	$\overline{X}$	$LSD_{0,05}$	$LSD_{0,01}$	F-test
A	A_1	37,41	1,44	1,95	113,47**	69,33	7,75	10,51	222,12**
	A_2	43,78				92,64			
	A_3	51,31				113,50			
B	B_1	38,97	1,62	2,13	189,49**	84,56	2,33	3,07	72,05**
	B_2	49,36				99,09			
C	C_1	36,85	1,72	2,33	150,42**	76,43	3,72	5,04	123,65**
	C_2	42,91				88,08			
	C_3	52,73				109,86			
AB			3,12	4,38	21,54**	*AB*	4,49	6,30	11,83**
AC			3,33	4,85	6,03**	*AC*	7,20	10,48	4,07**
BC			2,57	3,60	4,78*	*BC*	5,55	7,79	1,36 n.s.
ABC			5,67	9,41	5,62**	*ABC*	12,26	20,34	5,30**
ANOVA		$\overline{d}_k$ / µm				drift, %			
		$\overline{X}$	$LSD_{0,05}$	$LSD_{0,01}$	F-test	$\overline{X}$	$LSD_{0,05}$	$LSD_{0,01}$	F-test
A	A_1	171,95	4,39	5,94	15,87**	16,34	0,69	0,94	268,37**
	A_2	165,08				19,40			
	A_3	148,66				21,81			
B	B_1	170,75	4,85	6,39	26,02**	17,12	0,28	0,37	456,29**
	B_2	153,05				21,25			
C	C_1	175,87	6,46	8,76	19,58**	14,86	0,48	0,65	1287,17**
	C_2	160,41				16,65			
	C_3	149,41				26,04			
AB			9,35	13,11	0,94 n.s.	*AB*	0,54	0,76	149,42**
AC			12,51	18,20	2,45 n.s.	*AC*	0,93	1,36	23,50**
BC			9,65	13,53	0,16 n.s.	*BC*	0,72	1,01	175,48**
ABC			21,30	35,32	2,58*	*ABC*	1,59	2,65	43,58**

Table 6 Coefficient of correlation for the main properties of the research

Correlation (r)	Axial orchard sprayer				Radial orchard sprayer			
	x axis →							
y axis ↑	p / bar	$\bar{n}_k$ /cm^2	$\bar{d}_k$ / µm	drift / %	p / bar	$\bar{n}_k$ / cm^2	$\bar{d}_k$ / µm	drift / %
$\bar{A}_p$ / %	0,89	0,82	–0,87	0,72	0,92	0,88	–0,90	0,85
$\bar{n}_k$ / cm^2	0,96	-	-	-	0,96	-	-	-
$\bar{d}_k$ / µm	–0,90	–0,83	-	-	–0,90	–0,85	-	-
drift / %	0,74	0,74	-0,78	-	0,81	0,81	–0,86	-

Table 7 Differences of the main properties in an apple orchard

Orchard sprayer	$\bar{A}_p$ / %	$\bar{n}_k$ / cm^2	$\bar{d}_k$ / µm	drift / %
Axial	38,90	87,41	172,68	19,94
Radial	44,12	91,83	161,30	18,63
Difference / %	11,83	4,81	5,81	6,56
Z^+	4,06*	3,53*	4,00*	1,17 n.s.
p^+	0,000	0,000	0,000	0,238
Z^{++}	3,72*	3,50*	3,72*	1,80 n.s.
p^{++}	0,000	0,000	0,000	0,070

With regard to the constructional differences (axial and radial fan) of used sprayers, it is realistic to expect that the results of the main properties are different. Comparison is done using a nonparametric Sign Test ($^+$) for all treatments of the research (one variable for axial and one variable for radial orchard sprayer), with statistical significance α = 0,05. Also, a comparison of variables pairs is performed using the Wilcoxon Matched Pairs Test (α = 0,05; $^{++}$). Results of achieved values are shown in Tab. 7.

Tab. 7 shows that all main properties of the research have have a significant difference, except drift (sign test: Z = 1,17; p = 0,238 n.s., and Wilcoxon Matched Pairs Test: Z = 1,80; p = 0,070 n.s.). The biggest difference is in average area coverage, where radial sprayers achieved greater coverage by 11,83 %.

5 Conclusion

According to the measurements of weather conditions during the study, the application is carried out according to the rules of plant protection in almost ideal conditions (wind speed less than 3 m/s, air temperature less than 22 °C and air humidity higher than 50 %). Used spraying norms are suitable for the form and volume of the orchard, and they follow global trends of spray norm reduction. Also, the working speeds of the orchard sprayers are located within the optimal agritechnical operational speeds. Used nozzles and working pressures are suitable to the row width and they are ensuring required spraying norms.

The major technical spraying factors have a high significant impact (**) on the main properties of the research. By decreasing the *ISO* number of nozzles and by increasing the working speed and spray volume, we found increasement of area coverage, number of droplets per cm^2 and drift, and decreasement of average droplet diameter. By comparing the results of the research by axial and radial orchard sprayer in apple orchard, better results (*) were achieved with a radial sprayer. During the settings of the technical spraying parameters, the main object must be the largest area coverage with the minimal liquid drift. This is possible only with technical correctness of the orchard sprayer and with spraying in good weather conditions.

The results and scientifically based conclusions can serve all agricultural producers, because so far in Croatia there is no scientifically based research related to this issue. Also, it is particularly important to further investigate the technical spraying factors of the plant protection, due to the bigger reduction of production costs with the same biological effect.

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