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Influence of speed and angle of spraying on area coverage and drift in the potato production

Utjecaj brzine i kuta prskanja na pokrivenost tretirane površine i zanošenje u proizvodnji krumpira

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ABSTRACT

This study investigated the influence of travel speed (6 and 10 km/h) and spray angle (-30°, 0° and +30°) on leaf surface coverage (LSC), on the area not treated (drift) and on droplet size. The leaf surface coverage, size and number of droplets, as well as the drift intensity, were determined using water-sensitive papers (WSP) that were scanned and processed with the DepositScan program. Research has shown an influence of working velocity and spray angle on LSC and drift. While the spray angle had very little effect on the droplet diameter, it had a significant effect on the LSC, where -30° adjustment had the lowest coverage on the treated surface and the highest drift, both at 6 and 10 km/h. The working velocity also had an impact on both LSC and droplet diameter, where a higher speed resulted in less coverage on the treated surface and higher drift.

Keywords: working velocity, spray angle, leaf surface coverage, drift, potatoes

SAŽETAK

U ovom radu istraživan je utjecaj brzine kretanja (6 i 10 km/h) i kuta prskanja (-30°, 0° i +30°) na pokrivenost lisne površine (PLP), na površinu koja se ne tretira (drift) i na veličinu kapljica. Pokrivenost lisne površine, broj i veličina kapljica, kao i zanošenje, utvrđeni su pomoću vodoosjetljivih papirića (VOP) koji su skenirani i obrađeni programom DepostScan. Istraživanja su pokazala utjecaj radne brzine kao i kuta prskanja na PLP i na drift. Iako je kut prskanja imao vrlo mali utjecaj na promjer kapljica, imao je značajan utjecaj na PLP, gdje je podešavanje od -30° imalo najmanju pokrivenost tretirane površine i najveće zanošenje, i pri 6 i pri 10 km/h. Radna brzina također je utjecala na PLP i promjer kapljica, gdje je veća brzina rezultirala manjom pokrivenošću tretirane površine i većim zanošenjem.

Ključne riječi: radna brzina, kut prskanja, pokrivenost površine, drift, krumpir

INTRODUCTION

Canopy coverage and plant height for the estimation of spray volume on potatoes are investigated by Xie et al. (2022), and their results show that the vegetation index-based method can accurately estimate canopy cover. They state that the key to improving precision agriculture is to define a field management schedule and predict the amount of herbicides and fertilizers. Hussain et al. (2020) investigate the design and development of a smart variable rate sprayer in potato protection. The results of their WSP analysis after spraying potatoes show > 40% saving of spray liquid when using a smart sprayer with a variable dose, and they also state a lower risk for the environment. Sayinci and Bastaban (2019) investigated the influence of different types of nozzles on the deposition of spray on potato plants at a working speed of 6 km/h. They conclude that air turbulence from air-assisted nozzles has a better effect in transporting drops to the lower part of the leaf. Yeary et al. (2018) study the influence of canopy density on the survival of insects after treatment and state that regardless of canopy density, the inner parts are significantly less sprayed than the outer ones. Off-target effects of pesticides are well-documented in crops such as corn and soybeans, whereas little effort has been made to evaluate these effects in potatoes, according to Thornton et al. (2010). Factors affecting spray parameters, along with possible solutions to reduce the excessive use of agrochemicals, are investigated by Mahmud et al. (2021). They state that for the successful deposition of droplets in the sprinkler system, the most important factors are the speed and size of the droplets, the characteristics of the canopy and the speed and direction of the wind. Kroschel et al. (2020) state that the extensive use of pesticides in potato protection is a major concern for human health and the environment, and that this concern will be further exacerbated by the impact of climate change. They state that the development and use of integrated pest management is important for future research in sustainable and economically profitable potato production in all regions of the world, and that emphasis should be placed on the application of biological approaches in the fight against pests, which would reduce dependence on insecticides. Kroschel and Schaub (2013) also state that the high use of pesticides in potatoes is a major concern for human and environmental health, which needs to be addressed through the development and widespread application of integrated pest management (IPM) approaches. Vučajnk and Bernik (2012) investigated the deposition and covering of potato leaves using injector nozzles by placing WSP on the upper, middle and lower parts of the plant. The results of their research show that the application of the IDK injector compact nozzle improves the deposition and coverage of potato leaves, while the TWIN nozzle (angle +30° and angle -30°) has too wide a jet for the droplets to penetrate to the lower parts of the plant. Water-sensitive papers from the Swiss manufacturer Syngenta were used to collect information on spraying. This method represents the most acceptable field method for determining the coverage of the treated surface and the size of the droplets (Tadić et al., 2014; Tadić et al., 2024).

Kierzek and Waschoviak (2007) determined the best coverage of the potato plant using a flat nozzle with a spray jet -30° from the vertical. Farooque et al. (2023) investigate a sprayer that uses neural networks to detect targets and apply agrochemicals within a potato field. The results of their research show that the smart sprayer with variable speed (CA) had a more significant effect when applying the agent compared to the sprayer with constant speed (VA), and the analysis of data from water-sensitive leaflets gave very little differences between CA and VA. Five different potato protection systems are investigated by Roten et al. (2016) and state that all treatments related to new technologies provide greater coverage of the underside of potato leaves than with conventional spraying. They also recommend that the most important thing is that the research of technologies for reducing drift progresses proportionally to the protection of agriculture. In order to improve the potato protection process, Longfei et al. (2023) designed a variable nozzle. The experiments of their research show that targeted and variable spraying pushes the lower surface of the leaf better (about 66%), that it is more uniform than standard spraying and that it reduces the application of liquid by

37.9%. Wolf (2015) explains the theory of spraying in four steps. He states that in a maturing canopy, the upper leaves can prevent the spray from reaching other targets, then more water will be needed, and droplet size can be critical in getting the spray to its destination. Wolf (2017) suggests not to skimp on water because larger amounts of water make the application more uniform and safer for crops, and the spray coverage is better. Nansen et al. (2011) conducted a field study of the application of 14 sprays, 8 with aircraft and 6 with ground sprayers. Their conclusion is to optimize spray deposition as a pillar of successful integrated pest management programs to increase the effectiveness of protection and reduce the risk of resistance development in the target pest population. Anderson (2022) states that there is little information on the effect of nozzle type under the potato canopy and that angled spray placement when treating potatoes can significantly improve spray efficiency compared to conventional vertical flat fan nozzles. Deveau (2020) investigates the quality of spraying potatoes with nozzles set at +15° and -15° compared to classic ones and states that the angled spray helped a little but not more than tiny droplets from hollow nozzles. Scudeler and Reatano (2006) investigate the quality of potato spraying with nozzles placed at +30°, 0° and -30° angles. They conclude that the angle of attack of the nozzles of 0° and +30° in the presence of air support allows the largest spray deposits on the abaxial surface. Lamischane et al. (2015) suggest that farmers look for pesticide application efficiency in the selection of air-assisted nozzles or angled nozzles. Sijs et al. (2021) state that droplet size distribution is important in many applications and everyday life events, and their work compares four different methods for measuring droplet size distribution: VisiSizer image analysis technique, internal stroboscopic imaging method, particle phase Doppler analysis (PDPA) and laser diffraction (Malvern Spraytec). Their results emphasize the need to select a size measurement technique that matches the physical nature and expected range of droplet parameters. Kooij et al. (2018) investigate parameters that determine spray quality. By varying spray parameters such as pressure and nozzle geometry, they find that the spray quality is determined by the competition between fluid inertia and surface tension, which allows predicting the spray from Weber and nozzle geometry. Zhang et al. (2019) studied mechanisms related to fluid mobility on biological surfaces with special structures. They also believe that the mechanism of directed fluid mobility on materials that have the ability to superwet should be further investigated to evaluate the influence of the consumption of natural resources and environmental pollution. João et al. (2019) consider that knowledge of the spectrum of droplets created by nozzles is important for the quality of application of the plant protection agent. They also conclude that the use of WSP for the characterization of the droplet spectrum is an important tool for improving the application of pesticides, but it must be carried out with great discretion because there is an underestimation of fine and very fine droplets. Beyaz et al. (2017) evaluate the droplet size and size range that affect the quality of pesticide application using the WSP image analysis technique. In addition to their opinion that the use of WSP is an important tool for estimating spray parameters, they also emphasize the importance of droplet size in the application of plant protection agents, and the spectrum of droplet size must be as uniform as possible for the agent to reach the target. Mangado et al. (2013) consider that although it is possible to visually determine whether the treatment was insufficient or correct, it is recommended to analyse the WSP images to obtain reliable results and to quickly and efficiently check the percentage of treatment coverage. According to the US EPA (2022), pesticide spray drift is the movement of dust or droplets through the air at the time of application or shortly thereafter to any location other than intended (drift) and can pose a health risk to humans, flora and fauna as well as various water resources. Srinivasarao et al. (2021) states that droplet size and density are key parameters for determining sprinkler efficiency and that smaller droplets tend to drift and do not stick to the plant while larger droplets also stick to the plant. Therefore, it is important to consider droplet size as a critical parameter when evaluating the performance of any sprinkler.

Jomantas et al. (2023) state that the drift of sprayed pesticides is a worldwide concern in terms of possible environmental pollution and ecosystem damage. Their research on the effects of newly developed spray drift reduction agents. They showed that wind speed and nozzle design have the greatest influence on droplet movement. Sarkar et al. (2021) publish a study that provides a broad perspective regarding the use of pesticides in developing countries and their effects on human health and food safety. Their recommendations are intended to improve the ability of all people, including future generations, to have access to healthy food in accordance with United Nations declarations as well as to strengthen research and education in alternatives to pesticide use. Sybertz et al. (2020) investigate the dispersion of pesticides in soil and conclude that the limit value defined in the risk assessment is exceeded when several substances are considered over a longer period. They also state that due to the high frequency of pesticide application, organisms in the soil are exposed to a negative impact and suggest that when assessing the risk of pesticides, the accumulation of residues during multiple treatments should be included. Hilz and Wermeer (2013) state that although the physicochemical properties of spray solutions are known to influence spray drift, they are not yet included in regulatory risk assessments at the European level. They conclude that improvements such as low-drift nozzles are widely used in modern agricultural production, while air-assisted spray equipment may not be adopted due to application limitations or increased costs. He et al. (2022) investigate the size distribution of spray droplets using a machine learning method. They state that droplet size is the main factor affecting deposition in a treated crop, and the results of their research show that machine learning methods provide a new and feasible method for quantitatively estimating droplet size distribution. McGinty et al. (2016) evaluated the spray droplet size spectrum for 5 different nozzles and concluded that pre-orifice nozzles resulted in larger mean droplet diameters and fewer very small diameter droplets while additional drift reductions were achieved with nozzles that used pre-orifice induction design. One of the technical factors of agricultural nozzles and overall plant protection is the droplet diameter, which solely depends on the operating pressure, ISO number and nozzle type (Tomantschger et al., 2021).

MATERIALS AND METHODS

Research on the influence of technical factors on the quality of work and the treatment of unwanted crops was carried out on an area with potatoes, where the distance between rows was 0.6 m and the distance within the row was 0.3 m. In the study of leaf surface coverage (LSC), drift, average droplet size, working velocity, nozzle angle, a sprayer from the company "Agromehanika" model AGS 600EN with a working width of 12 m and steel profile reinforcement with 25 nozzles was used, Teejet XR 110-04 VP with a distance of 0.5 m. The sprayer is equipped with a piston-diaphragm pump with a flow rate of 105 L/min and a working pressure of 0-30 bar, a control system with a suitable manometer for precise measurement of the working pressure. In the application process, in addition to the main factors, weather conditions, temperature, humidity and air flow speed were also monitored.

Weather conditions were determined using a Kestrel 4000 device (±0.3%) for air flow speed, a P470 device for measuring temperature and air humidity (±0.5 °C / ± 2% r.H).

Before the research itself, a design intervention was carried out on the sprayer in order to enable different positions (working angles) of the nozzles during the spraying process. Determining the quality of work is based on three different nozzle angles, -30°, 0° and +30° (Figure 1). The nozzle placement was done using a protractor.

The distance between the nozzles and the treated object measured at the time of treatment was 0.9 m, and the working pressure was 3.5 bar. With regard to the operating speed of the sprayer, the research is based on speeds of 6 and 10 km/h, which are assumed to be optimal in exploitation conditions.

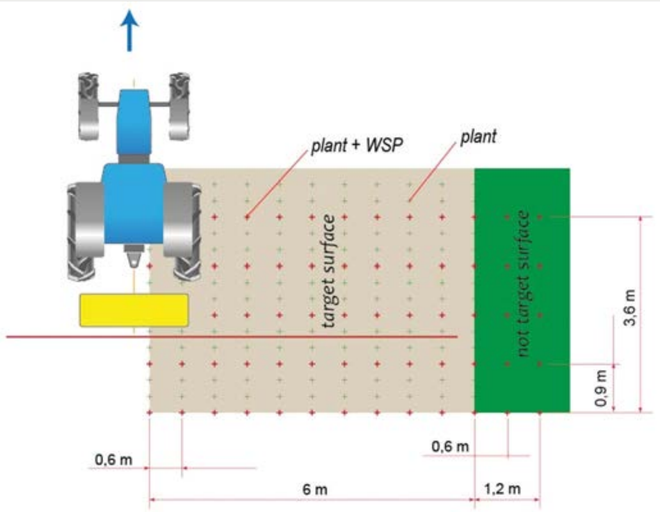

Figure 1. Presentation of the sample with regard to the position of the plants on the test surface

Leaf surface coverage (LSC) and evaluation of the number of droplets per unit area will be determined using WSP (water-sensitive paper). Determining the quality of spraying or the mentioned factors using WSP has been accepted by many scientists in the world as well as agricultural producers due to its simple and not too expensive application (Beyaz et al., 2017; Mangado et al., 2013). In practice, WSPs of different dimensions are used, while 26 x 76 mm from the company Syngenta are planned for the mentioned research. WSPs were placed according to the scheme in Figure 1. One sample was a target area (CP) 3.6 x 6 m with 55 plants with 165 WSP, a non-target area (NP) 3.6 x 1.2 m with 10 WSP. 3 WSP were placed on each plant, and the same scheme was used regardless of the speed and angle of the nozzles (Figure 2).

For each setting, speed of movement and nozzle angle, the experiment was conducted on a different plot. The measurement of LSC and the mean value of the droplet diameter ($\bar{x}$) was performed when the potato was in full vegetation (BBCH – 19). WSP were placed at the top, middle and bottom of the plant. Figure 3 shows an example of WSP for a speed of 10 km/h and a nozzle angle of +30° after spraying.

After treatment, the WSP were dried, recorded and processed using an image analysis program. Processing of image analysis, i.e. determination of leaf surface coverage (LSC), size and number of droplets, was performed using the computer program DepositScan. The DepositScan software processed WSP that were previously scanned using a Canon 9000 F scanner, with a resolution of 9600 x 9600 dpi. Given that upon impact in the WSP, the droplet from 3d turns into 2d, it is necessary to determine the actual diameter of the droplet, which was done using correction factors that have already been determined experimentally (João et al., 2019). The research results show that the high correlation between the estimated coverage percentage, the application of DepositScan software can save time and be an easy way to study pesticide application in crops (Hussain et al., 2020).

Statistical data processing was done in the SAS V9.4 software package using analysis of variance (ANOVA) and the Tukey post hoc test with a significance level of P<0.05.

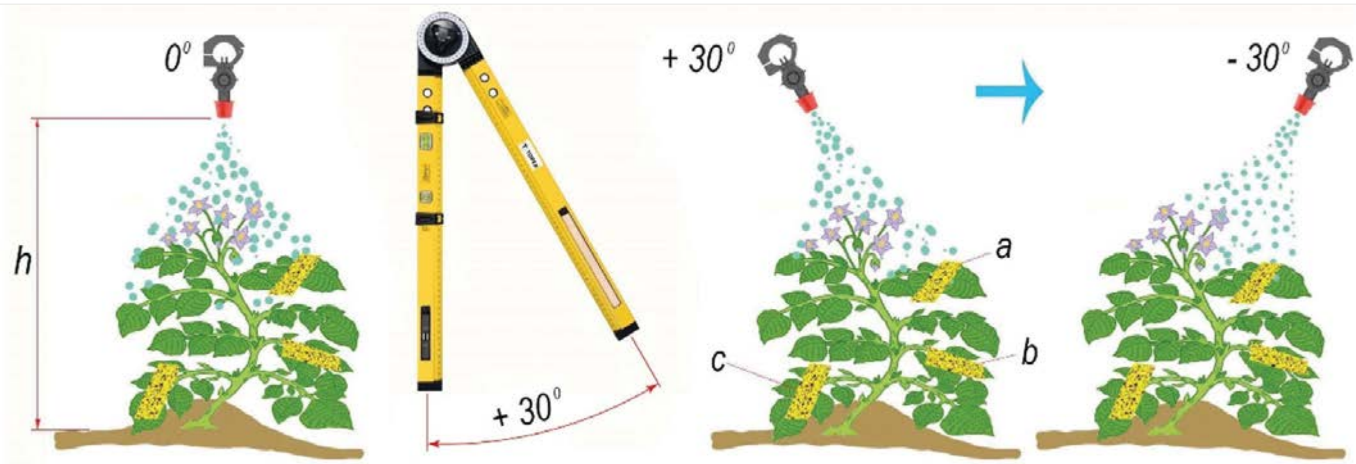

Figure 2. Representation of the position of VOP on the potato crown

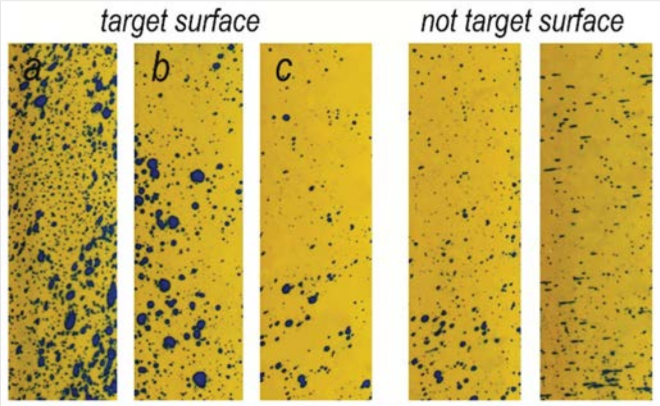

Figure 3. View of VOP after treatment at 10 km/h and angle +30°

RESULTS AND DISCUSSION

Droplet size distribution

After scanning the WSP, 3 from each plant, an average was calculated that was taken into further consideration and the values of LSC and $\bar{x}$ diameter of the droplets are found in Table 1. On the non-target surface, there were 10 WSP whose values of LSC and $\bar{x}$ diameter of the droplets are in the same table.

Influence of working velocity

After determining the coverage and average droplet diameter, statistical analysis determined the influence of movement speed and spray angle on the quality of treatment of the target and non-target surfaces. Results are presented as mean ± standard deviation (Table 2).

The movement speed did not significantly affect the LSC and droplet diameter on the target surfaces. Movement speed had a significant ($P < 0.05$) influence on LSC (%) on the non-target surface, while it did not significantly influence droplet diameter.

Effect of spray angle

The influence of the spray angle at a movement speed of 6 as well as at 10 km/h had a significant ($P < 0.05$) influence on LSC (%) and droplet diameter on both the target and non-target surfaces (Table 3).

The interaction of travel speed and spray angle had a significant effect on LSC and droplet diameter both on the target and non-target surface (Table 4).

Table 1. Leaf surface coverage (LSC) and average droplet diameter

		Target surface						Drft						
		Spray angle - 30°		Spray angle 0°		Spray angle + 30°		Spray angle - 30°		Spray angle 0°		Spray angle + 30°		
Working velocity (km/h)	WSP sample[1]	LSC[2] (%)	Droplet diameter (µm)	LSC (%)	Droplet diameter (µm)	LSC (%)	Droplet diameter (µm)	LSC (%)	Droplet diameter (µm)	LSC (%)	Droplet diameter (µm)	LSC (%)	Droplet diameter (µm)	Wind speed (m/s)
6	1	25.19	0.18	35.50	0.19	53.67	0.27	17.06	0.26	12.77	0.19	4.03	0.13	0.7-0.8
	2	28.81	0.23	35.86	0.21	56.25	0.19	23.55	0.25	14.87	0.19	12.84	0.19	
	3	32.43	0.22	39.55	0.21	56.88	0.21	24.92	0.24	16.97	0.19	16.01	0.19	
	$\bar{x}$	**28.81**	**0.21**	**36.97**	**0.20**	**55.60**	**0.22**	**21.84**	**0.25**	**14.87**	**0.19**	**10.96**	**0.17**	
10	1	26.45	0.23	36.76	0.19	51.85	0.20	24.05	0.23	15.21	0.20	12.67	0.19	0.7-0.8
	2	25.06	0.23	34.19	0.24	52.34	0.21	21.76	0.29	25.47	0.24	13.90	0.21	
	3	26.12	0.22	34.15	0.22	50.96	0.22	25.59	0.27	17.20	0.23	12.12	0.18	
	$\bar{x}$	**25.88**	**0.23**	**35.03**	**0.22**	**51.72**	**0.21**	**23.80**	**0.26**	**19.29**	**0.22**	**12.90**	**0.19**	

[1] WSP - water-sensitive paper
[2] LSC – Leaf surface coverage

Table 2. Effect of movement speed on LSC (%) and droplet diameter on the target and non-target surfaces

Speed of movement (km/h)	Target surface		Drift	
	LSC (%)	Droplet diameter (µm)	LSC (%)	Droplet diameter (µm)
6	38.118 ± 12.708[a]	0.2118 ± 0.0463[a]	11.287 ± 5.777[a]	0.1917 ± 0.0560[a]
10	38.356 ± 10.625[a]	0.2059 ± 0.0312[a]	17.309 ± 5.347[b]	0.2063 ± 0.0276[a]

[a,b] Values within a column marked with different letters are significantly (*P* < 0.05) different

[1] LSC - Leaf surface coverage

Table 3. Effect of spray angle on LSC (%) and droplet diameter on target and non-target surfaces

Spray angle (°)	Target surface		Drift	
	LSC (%)	Droplet diameter (mm)	LSC (%)	Droplet diameter (mm)
-30	25.819 ± 3.462[a]	0.2039 ± 0.0350[a]	20.556 ± 3.912[a]	0.2435 ± 0.0223[a]
0	36.131 ± 3.618[b]	0.1863 ± 0.0210[b]	13.988 ± 2.664[b]	0.1925 ± 0.0281[b]
+30	52.761 ± 3.847[c]	0.2360 ± 0.0416[c]	8.351 ± 4.717[c]	0.1610 ± 0.0345[c]

[a,b,c] Values within a column marked with different letters are significantly (*P* < 0.05) different

[1] LSC - Leaf surface coverage.

Table 4. Influence of the interaction of movement speed and spray angle on LSC and droplet diameter on the target surface

Speed of movement (km/h)	Spray angle (°)	Target surface				Drift			
		LSC (%)		Droplet diameter (mm)		LSC (%)		Droplet diameter (mm)	
		$\bar{x}$	σ	$\bar{x}$	σ	$\bar{x}$	σ	$\bar{x}$	σ
6	0	35.497[a]	4.886	0.185[a]	0.021	12.771[a]	2.293	0.188[a]	0.022
	-30	25.189[b]	4.530	0.183[a]	0.017	17.057[b]	1.105	0.258[b]	0.017
	+30	53.667[c]	4.747	0.268[b]	0.030	4.032[c]	1.771	0.129[c]	0.009
10	0	36.764[a]	1.313	0.189[a]	0.021	15.205[ab]	2.535	0.197[a]	0.033
	-30	26.448[b]	1.691	0.225[c]	0.036	24.054[d]	1.972	0.229[d]	0.017
	+30	51.854[dc]	2.380	0.205[d]	0.023	12.669[a]	1.549	0.193[a]	0.013

[a,b,c,d] Values within a column marked with different letters are significantly (*P* < 0.05) different

[1] LSC - Leaf surface coverage

CONCLUSIONS

By researching the influence of movement speed and spraying angle on the quality of the application in the process of treating potatoes, crops with a large proportion of leaf surface, it can be concluded:

- Given that the speed of movement did not significantly affect the quality of the treatment of the target surface, this points to the application of higher speeds of movement from the aspect of work performance, but given that a higher working speed had a significant impact on the drift, this would mean a negative impact on the environment, therefore, the optimal working speed should be sought in order to obtain a compromise between work performance and environmental protection.
- The spray angle had very little effect on the droplet diameter, while it had a more significant effect on the LSC, where a -30° adjustment had the lowest coverage on the treated surface and the highest drift, both at 6 and 10 km/h.
- The working velocity had a significant impact on both LSC and droplet diameter; higher speed resulted in less coverage on the treated surface and higher drift, and higher speed also resulted in a larger droplet diameter.
- Considering that the spraying angle had a significant influence at speeds of 6 and 10 km/h and on the target and non-target surfaces (LSC and drift), this points to the importance of the structure of the armature (nozzle carrier) both from the aspect of application quality and from the aspect of spreading the agent (pesticide) to the target surface, i.e. environmental pollution.
- As other factors were not considered in this research (different types of nozzles, greater choice of movement speeds, different types of crops, etc.), further research is certainly recommended with regard to the position of the nozzles different from 00 in order to make the application of pesticides as efficient as possible from an economic point of view, more rational application of insecticides and fungicides, as well as from the aspect of having as little impact on the environment as possible.

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