Alinteri J. of Agr. Sci. (2019) 34(1): 67-75
e-ISSN: 2587-2249
info@alinteridergisi.com
http://dergipark.gov.tr/alinterizbd
http://www.alinteridergisi.com/
DOI: 10.28955/alinterizbd.578538

Alinteri Journal of Agriculture Sciences

RESEARCH ARTICLE

Comparison of Spray Transfer and Penetration of Different Hydraulic Nozzles at Low Application Volume

Bahadır Sayıncı[1*], Bünyamin Demir[2], Ruçhan Çömlek[3], Mustafa Gökalp Boydaş[4]

[1]*Mersin University, Faculty Engineering, Mersin/Turkey*
[2]*Mersin University, Vocational School of Technical Sciences, Mersin/Turkey*
[3]*Atatürk University, Graduate School of Natural and Applied Science, Erzurum/Turkey*
[4]*Atatürk University, Faculty of Agriculture, Erzurum/Turkey*

ARTICLE INFO

Article History:

Received: 07.12.2018
Accepted: 12.03.2019
Available Online: 10.06.2019

Keywords:

Nozzle Position Angle
Pesticide Application
Spray Coverage
Sprayer
Spray Pressure
Water Sensitive Paper

ABSTRACT

Seven hydraulic nozzle types (standard-ST; hollow cone-KH; multirange-LU; standard with narrow angle-STD; antidrift-AD; air-induction-IDK; twinjet air-induction-IDKT) were compared in terms of spray transfer and drop penetration. Spray treatments were carried out at a constant application volume of 90 L ha^{-1} with a linear-motion simulator. WSP's were placed onto metal poles and into artificial plant at both horizontal and vertical planes. Two different operating pressures (250 and 500 kPa) and the nozzle position angles (0° and 45°) were used in the experiments. Spray transfer levels at vertical plane were quite lower than the spray transfer levels at horizontal plane. The greatest spray coverage was achieved with LU and ST nozzles producing fine droplets. The greatest drop penetration at vertical plane was obtained from IDK nozzle. Only 25% of the drops transferred to the open target reached the stem and root collar region of the plant canopy. With increasing operating pressures, spray coverage increased by 1,17 times at horizontal plane and 1,50 times at vertical plane. With increasing nozzle position angles, spray coverage at vertical plane increased by 40%. The greatest coverage was achieved on front surface of the vertical target and drops reaching to side and rear surfaces were quite low.

Please cite this paper as follows:

Sayıncı, B., Demir, B., Çömlek, R. Boydaş, M. G. (2019). Comparison of Spray Transfer and Penetration of Different Hydraulic Nozzles at Low Application Volume. *Alinteri Journal of Agriculture Sciences*, *34*(1): 67-75. doi: 10.28955/alinterizbd.578538

Introduction

Success of chemical treatments largely depends on sufficient transfer of the active ingredient to the targeted harmful agent and adsorption of the active ingredient by the targeted surface. Such a case is then closely related to spray technology serving a bridge between the target and the chemical and application performance of these sprays (Azimi et al. 1985). Spray droplets have low transfer energy within a certain trajectory to the target and they may also be transferred to off-target because of drifts. Such cases increase pesticide losses, thus reduce application performance. Just because of losses, excessive pesticide doses are applied for sustainable impact on target. However, excessive applications ultimately end up with residue problems over foodstuffs.

Hydraulic nozzles are commonly employed to generate a spray pattern and spray drops transferred from a certain height toward to ground plane at a position along the direction of propulsion. Drop transfer efficiency of these type of nozzles is low, thus application volumes are frequently increased (Coates and Palumbo, 1997). However, in excessive applications, spray drops are not able to be adsorbed by the target and flow over to soil surface. Such applications then become uneconomic (Bode et al., 1983; Hoffmann and Salyani, 1996; Piche et al., 2000; Zhu et al., 2004). Although high-volume applications seem to increase pesticide adsorption of the target surface in

* Corresponding author
E-mail address: bsayinci@mersin.edu.tr

theory, experimental researches revealed less adsorption levels, increased variation in pesticide distribution and greater loss of drops at high-volume applications (Salyani and Whitney, 1988; Whitney et al., 1989; Reed and Smith, 2001; Wolf, 2005). Considering the biological efficiency, it was pointed out that low-volume applications even increased application efficiencies. Reed and Smith (2001) carried out a study to investigate the effects of different application volumes (56 L ha^{-1}, 112 L ha^{-1} and 168 L ha^{-1}) on biological efficiency of treatments applied against the tobacco budworm (*Heliothis virescens* F. [Lepidoptera: Noctuidae]) larvae and reported significantly reduced pest population with 56 L ha^{-1} application volume as compared to the greater application volumes. In standard nozzles, although use of large orifice nozzles was seen as a proper strategy to reduce drifts, the variation in pesticide distribution of the nozzles with a pre-chamber orifice providing coarse pulverization confute such a strategy (Wolf, 2005).

With regard to spray characteristics, while fine droplets are transferred to the target parallel to ground plane, mid-size and coarse droplets are delivered more to the plant canopy sections close to the ground (Zhu et al., 2002; Zhu et al., 2004). However, there is not any information about the transfer of spray droplets to stem and branch-like upright sections of the canopy. In vegetables, cutworm (*Agrotis* spp.), russet mite (*Aculus lycopersici* Massee), white mold (*Sclerotinia sclerotiorum* Lib) and grey rot (*Botrytis cinerea* Pers) disease agents are generally encountered over the stems and root collars of the plants and pesticides are recommended to be applied to green parts of the plants. Therefore, spray should be transferred vertically toward to frontal surfaces of the target for an efficient fight with the disease and pests encountered over plant stems and root collars.

The present study was conducted to determine the most appropriate hydraulic nozzle types able to transfer spray droplets to the targeted sections vertically and horizontally and to put forth the effects of nozzle position angle and operating pressure on spray transfer in horizontal and vertical planes.

Materials and Methods

Experimental Site

Experiments were conducted in a closed facility and indoor temperature and relative humidity were regularly measured with a digital thermo-hygrometer (TFA 30.5013 Dostmann GmbH & Co.KG, DE).

Hydraulic Nozzle Types and Operational Parameters

Seven different types of nozzles were used in this study and nozzle characteristics are provided in Table 1. Nozzle discharge rate was measured with a digital sensor-type flow meter (Sprayer Calibrator, Spot On®, Model: SC-1, IL, measurement precision: ±2.5%; measurement range: 0,08-3,79 L min^{-1}). Experiments were conducted within the range of low application volume (LV) (50-200 L ha^{-1}) at constant 90 L ha^{-1} application volume and forward speed was calculated with the aid of Equation (1);

$$V = \frac{1}{3.6} \cdot \frac{600 \cdot q}{B \cdot N} \quad (1)$$

V : Forward speed, m s^{-1}
q : Nozzle discharge, L min^{-1}
B : Nozzle spacing, m (0,5 m)
N : Application volume, L ha^{-1} (90 L ha^{-1})

Table 1. Hydraulic nozzle types and operational parameters

Nozzle type*	Material*	Screen type	Pressure (kPa)	Discharge (L min^{-1})	Spray height (cm)	Spray angle (°)	Application volume (L ha^{-1})	Forward speed (m s^{-1})
ST110015	POM	Cylindrical	250	0,54	40 cm	110°	90	2,00
		(50 mesh)	500	0,76			90	2,83
LU120015	POM	Cylindrical	250	0,54	40 cm	120°	90	2,00
		(50 mesh)	500	0,76			90	2,83
IDK120015	POM	Cylindrical	250	0,54	40 cm	120°	90	2,00
		(50 mesh)	500	0,76			90	2,83
IDKT120015	POM	Cylindrical	250	0,54	40 cm	120°	90	2,00
		(50 mesh)	500	0,76			90	2,83
STD80015	POM	Cylindrical	250	0,54	70 cm	80°	90	2,00
		(50 mesh)	500	0,76			90	2,83
KHØ1.2	POM	Cylindrical	250	0,67	70 cm	68°	90	2,48
		(50 mesh)	500	0,91			90	3,37
AD120015	POM	Cylindrical	250	0,54	40 cm	120°	90	2,00
		(50 mesh)	500	0,76			90	2,83

*ST: standard flat spray nozzles (Lechler, DE); LU: multi-range flat spray nozzles (Lechler, DE); IDK: air injector flat spray nozzles (Lechler, DE); IDKT: symmetrical twin flat spray air injector nozzles (Lechler, DE); STD: standard narrow-beam flat spray nuzzles (Lechler, DE); KH: hollow cone nozzles (Toyman, TR); AD (Lechler, DE): anti-drift flat spray nozzles
**: polyacetal

Six polyacetal (POM) nozzles were sequentially installed over a boom arm with 50 cm spacing. In each nozzle head (Arag SRL 40642W7 Model, IT), 50 mesh cylindrical screen was used to prevent clogging. Spray height of the nozzles was determined based on spray beam angle. Narrow-angle ones were adjusted to spray from 70 cm distance and standard beam angles were adjusted to spray from 40 cm distance. In spray transfer experiments, effects of two different operating pressures (250 kPa and 500 kPa) and two different spray position angles (0˚ and 45˚) were investigated. For position angle, spray line over which the nozzles were installed was positioned along the forward direction.

Spray Simulator

For spray treatments, a 12-meter long, linear-motion speed-controlled spray simulator was used as presented in Figure 1. The simulator moves over two heavy-type industrial profiles (90×180 mm) and uses a power supply of 1000 W servomotor (Delta ASDA-B2, Taiwan, TW). It is equipped with guide pulleys with a transmission rate of 1/2.5 for power transmission. Vehicle motion is controlled by a personal computer connected to servomotor. The communication between the driver and the motor is realized over a Modbus protocol. Forward speed of the vehicle is adjusted through changing rotation of servomotor shaft. Motor shaft speed changes between 1-5000 rpm and there is a linear relationship of [$n=118{,}03 \cdot V$] (R^2=1) between vehicle speed (V, km h^{-1}) and motor speed (n, rpm). Boom arm of spray simulator is 2,2 m long, located at one side of the vehicle and has an adjustable spray height.

Figure 1. Spray simulator

A field type sprayer (TP600 Piton Taral®, TR) with 600 litres polyethylene tank was used to generate hydraulic pressure for the fluid (Figure 2). The sprayer is equipped with TAR30-type piston-membrane pump (double piston, 40 kg cm^{-2} nominal pressure, 30 L min^{-1} nominal discharge, 67% yield, Taral®, TR). Pump shaft of the sprayer is operated at 600 rpm with an electrical gear-motor (MSD 90L2, 2780 rpm, Gamak, TR).

Figure 2. Sprayer and electro-valve installation

Method of Sampling

As sampling material for spray treatments, 26×76 mm water-sensitive papers (WSP, Novartis, Syngenta Crop Protection, Basel, CH) papers were used. About 40 cm long metal poles were used to place WSP samples. Papers were placed vertically at the top and bottom of the poles in a three-sided fashion. The first side constituted frontal surface along the spray forward direction; the second side constituted the side surface of the spray; the third side constituted the rear face behind the spray forward direction. To place WSP samples at three different sides, 30×30×80 mm wooden chocks were used and samples were attached to frontal sections of all three sides with clips. To determine spray transfer along the horizontal plane, extra WSP samples were placed at the top and bottom horizontally parallel to the ground (Figure 3).

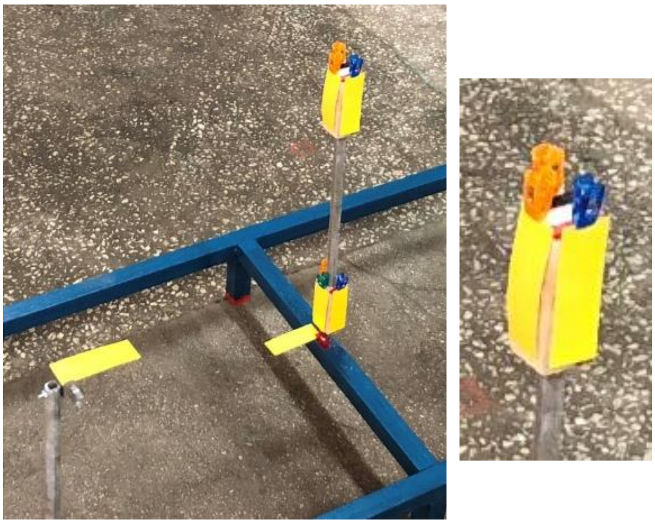


Figure 3. Placement of water sensitive papers onto sampling pole

Wooden chocks used on metal poles were also placed into root collar of the artificial plant canopy in the same fashion and WSP samples were again attached to front, side and rear surface of the chocks. Another WSP was placed horizontally at root collar close to ground to determine spray penetration into the canopy (Figure 4). The artificial plants in pots were positioned under the boom arm at 3×3 matrix arrangement and 50×50 cm row spacing. Total number of leaves and total leaf area were determined and proportioned to canopy projection area and then leaf area index was calculated as 1,17.

Figure 4. Placement of water sensitive papers into the plant canopy

Spray Coverage

All of the WSP samples at horizontal and vertical orientation were classified based on treatments and recorded at 600 dpi resolution *.jpeg image files into a computer. Card samples were analysed through the following process steps:

- Card samples were scanned through a scanner (HP Scanjet 4850, US) at 600 dpi resolution *.jpeg files and recorded into a computer as classified based on nozzle type, operating pressure, position angle, sampling section and frontal surface.
- With the aid of an image processing software, each image was clipped referenced to image boundaries.
- Coloured WSP images were converted into grayscale images with the aid of ImageJ (Wayne Rasband, National Institutes of Health, USA, Java 1.6.0_02) software. The threshold (t) value to be applied in the range of 0-255 to card images was calculated with the linear equation specified by Sanchez-Hermosilla and Medina (2004) (Equation 2).

$$t = 0.38g + 78.75 \quad (R^2 = 0.91) \tag{2}$$

- Mean grey level (g) of the images was determined with the aid of a macro module written in image processing software. Before to determine grey level, each image was filtered and stain images over the card surface were decoupled. The "enhancement-sharpen" module of the software was used for filter process and mask matrix size was adjusted as 3×3. A separate threshold was applied to each card image and spray coverage ratios were determined as percentage (%).

Statistical Analysis

The effects of nozzle type, operating pressure and nozzle position angle on spray transfer were assessed through repeated-measures ANOVA. Drop transfer at top and bottom sections were assessed as repeated measure factor and results were assessed for front, side, rear and horizontal surfaces separately. In assessments made for spray penetration, the card samples taken from plant canopy were used. Assessments were made through two-way ANAVO in accordance with randomized blocks design. Significant means were separated with Duncan's multiple range test at 5% level.

Results

Experiments were conducted in a closed facility under controlled conditions. Indoor temperatures varied between 21,2 ˚C -21,7 ˚C and relative humidity values varied between 39%-43%.

Spray Transfer at Horizontal and Vertical Plane

The effects of nozzle position angle on spray transfer were not found to be significant (Table 2). The LU and ST nozzles had the greatest spray coverage ratios; they were followed by KH nozzles and the lowest spray coverage ratios were observed in IDKT nozzles. In all spray treatments, spray coverage ratios increased distinctively with increasing operating pressures (Figure 5). Such an increase was not found to be significant in LU nozzles. It was observed that position angle significantly increased spray coverage ratios.

Table 2. Spray transfer at horizontal plane

Nozzle type	Nozzle position angle		*Mean±SD (F=95,13; p<0,01)
	0˚	45˚	
LU120015	28,0±4,9	34,0±5,0	31,0±5,7 a
ST110015	32,2±5,8	28,7±6,5	30,4±6,3 a
KHØ1.2	28,4±10,5	28,4±8,6	28,4±9,4 b
STD80015	26,8±5,6	23,4±4,7	25,1±5,4 c
AD120015	22,2±2,4	24,7±4,0	23,5±3,5 c
IDK120015	18,1±2,8	18,2±2,7	18,2±2,7 d
IDKT120015	11,8±2,8	12,6±2,3	12,2±2,5 e
Mean±SD (F=0.43; p=0.516)	23,9±8,5^{ns}	24,3±8,3^{ns}	

^{ns}: not significant; p<0.01: highly significant; *: the means indicated with different letters in the same column (a-e) are significantly different at 5% level.

Table 3. Spray transfer at vertical plane

Nozzle type	Nozzle position angle		*Mean±SD (F=48,3; p<0,01)
	0˚	45˚	
LU120015	3,8±5,1	6,4±9,3	5,1±7,5 a
ST110015	3,8±3,8	5,8±8,5	4,8±6,6 ab
IDK120015	2,8±2,5	5,6±5,9	4,2±4,7 bc
AD120015	3,7±2,9	4,5±5,0	4,1±4,1 bc
STD80015	4,0±6,6	3,6±6,5	3,8±6,5 c
IDKT120015	3,3±2,2	2,7±2,6	3,0±2,4 d
KHØ1,2	1,6±2,3	4,3±7,5	3,0±5,6 d
**Mean±SD (F=252,3; p<0,01)	3,3±4,0^{y}	4,7±6,8^{x}	

p<0,01: highly significant; *: the means indicated with different letters in the same column (a-e) are significantly different at 5% level; **: the means indicated with different letters in the same row (x-y) are significantly different at 5% level.

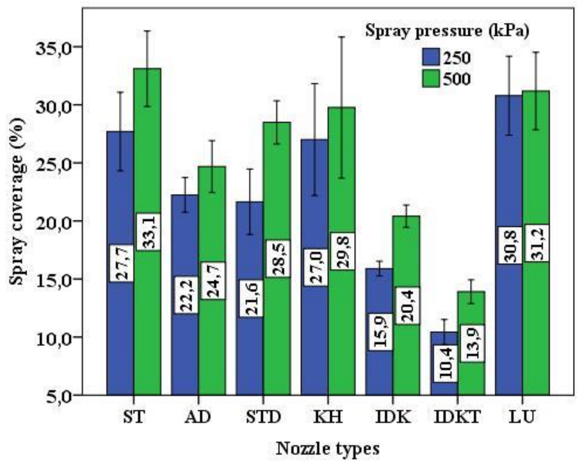


Figure 5. Effects of operational pressures on spray transfer at horizontal plane (means were indicated with ±2SE)

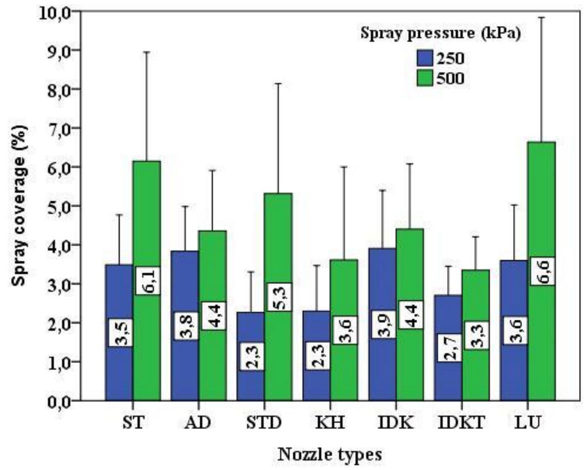


Figure 6. Effects of operational pressure on spray transfer at vertical plane (means were indicated with ±2SE)

In Table 3, spray coverage ratios of the drops transferred to horizontal plane were compared. The greatest spray coverages were obtained from LU and ST nozzles and the lowest ratios were obtained from KH and IDKT nozzles. When the nozzle position angle was set as 45°, significant increases were observed in spray transfer efficiency of LU, ST, IDK and AD nozzles at vertical plane. In Figure 6, increasing spray transfers are presented at vertical plane under high-pressure conditions. Positive effects of pressure on spray transfer at vertical plane varied with the nozzles, but increasing values were observed in all nozzles.

Spray Penetration into Plant Canopy at Horizontal and Vertical Plane

It was observed according to general means provided in Table 4 that spray drop penetration into plant canopy at horizontal plane decreased with increasing nozzle position angle. The greatest penetrations were respectively obtained from ST, LU and AD nozzles and the differences in penetration ratios of the other nozzles were not found to be significant. As presented in Figure 7, drop penetration ratios increased at high operating pressures. It was observed that KH nozzles had greater penetration ratios at low pressure.

Table 4. Spray transfer into plant canopy at horizontal and vertical plane

Nozzle type	Nozzle position angle		*Mean±SD
	0˚	45˚	(F=19,5; p<0,01)
ST110015	12,5±2,6	7,0±1,9	9,8±3,6 a
LU120015	10,0±4,2	7,2±2,0	8,6±3,4 a
AD120015	5,1±0,4	6,8±1,1	6,0±1,2 b
STD80015	4,9±1,4	3,8±1,2	4,3±1,3 c
KHØ1,2	5,8±2,8	2,8±0,9	4,3±2,5 c
IDK120015	5,3±3,2	3,1±0,5	4,2±2,5 c
IDKT120015	2,1±0,4	4,8±0,7	3,4±1,5 c
Mean±SD (F=11,9; p<0,01)	6,5±4,0^{x}	5,1±2,2^{y}	

p<0,01: highly significant; *: the means indicated with different letters in the same column (a-e) are significantly different at 5% level; **: the means indicated with different letters in the same row (x-y) are significantly different at 5% level.

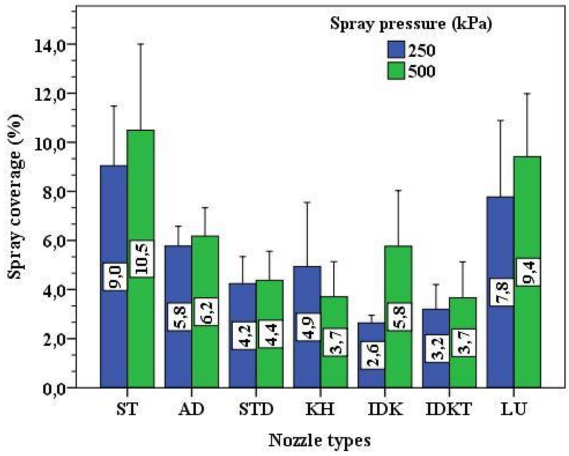


Figure 7. Effects of operational pressure on spray penetration into plant canopy at horizontal plane (means were indicated with ±2SE)

According to statistical assessments for spray penetration into plant canopy at vertical plane (Table 5), the greatest penetration values were obtained from IDK and AD nozzles and the lowest penetration values were obtained from KH and STD nozzles. The spray position angle of 45° along the forward movement direction of the spray increased penetration values. As can be seen in Figure 8, the greatest penetrations into the plant canopy at vertical plane were obtained from IDK and AD nozzles. General means revealed that penetrations increased at high pressures, but distinctively decreased in KH nozzles.

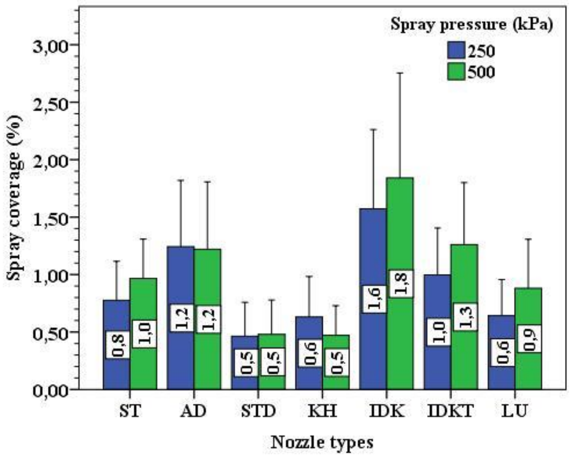


Figure 8. Effects of operating pressure on spray penetration into plant canopy at vertical plane (means were indicated with ±2)

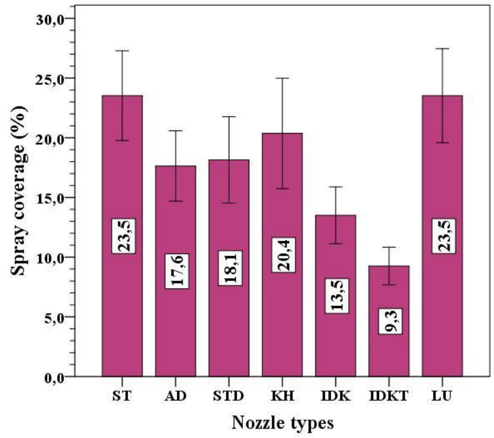
Table 5. Spray penetration into plant canopy at vertical plane

Nozzle type	Nozzle position angle		*Mean±SD (F=18,1; p<0,01)
	0˚	45˚	
IDK120015	1,51±1,71	1,90±1,71	1,71±1,70 a
AD120015	0,85±0,66	1,62±1,52	1,23±1,22 b
IDKT120015	1,10±0,98	1,16±1,07	1,13±1,01 bc
ST110015	0,67±0,59	1,07±0,79	0,87±0,72 cd
LU120015	0,72±0,76	0,80±0,84	0,76±0,79 de
KHØ1,2	0,32±0,34	0,78±0,81	0,55±0,65 e
STD80015	0,51±0,62	0,44±0,64	0,47±0,62 e
Mean±SD (F=15,3; p<0,01)	$0{,}81\pm0{,}96^{y}$	$1{,}11\pm1{,}19^{x}$	

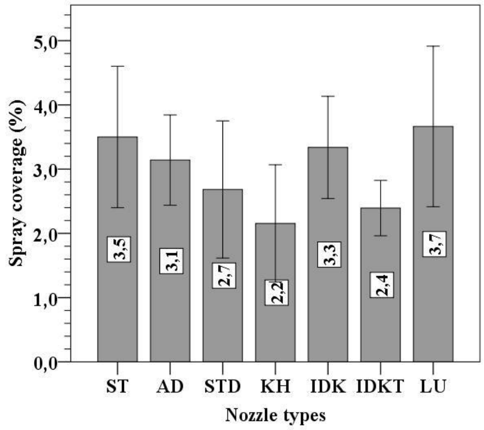
p<0,01: highly significant; *: the means indicated with different letters in the same column (a-e) are significantly different at 5% level; **: the means indicated with different letters in the same row (x-y) are significantly different at 5% level.

With regard to spray transfer and penetration, greater volume of drops reached to horizontal plane than the vertical plane (Figure 9a, 9b). In general, the greatest spray coverages were obtained from LU and ST nozzles, but increasing coverages in IDK nozzles were observed only at vertical plane. Among the nozzle types, KH nozzles yielded the least coverage ratio. Of the drops transferred to open target at horizontal and vertical planes, only 25% reached to stem and root collar of the plant canopy (Figure 9c).

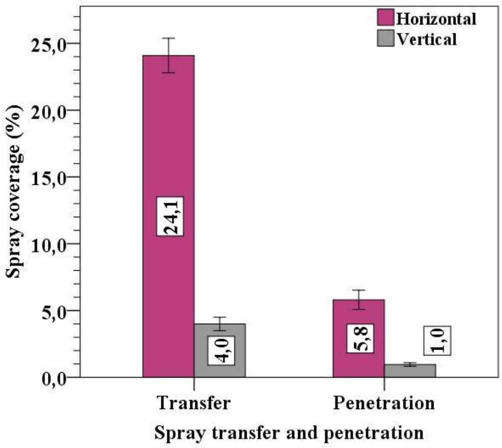
With increasing operating pressures, spray coverage ratios increased by 1.17 times at horizontal plane and 1.50 times at vertical plane (Figure 9d). While nozzle position angle did not have significant effects on spray transfer at horizontal plane, position angle yielded 40% increase in spray transfer at vertical plane. (Figure 9e). Along the forward motion of the device, the greatest coverage was achieved at front surfaces and quite low drop volumes were achieved in side and rear surfaces at vertical plane (Figure 9f).



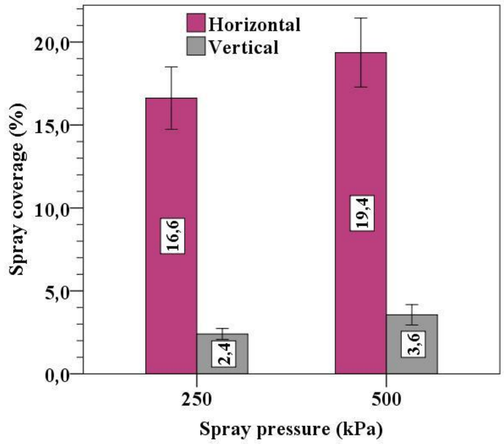
(a) Spray transfer of the nozzles at horizontal plane



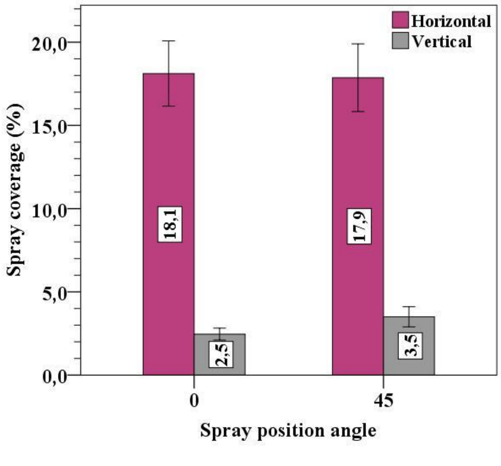
(b) Spray transfer of the nozzles at vertical plane



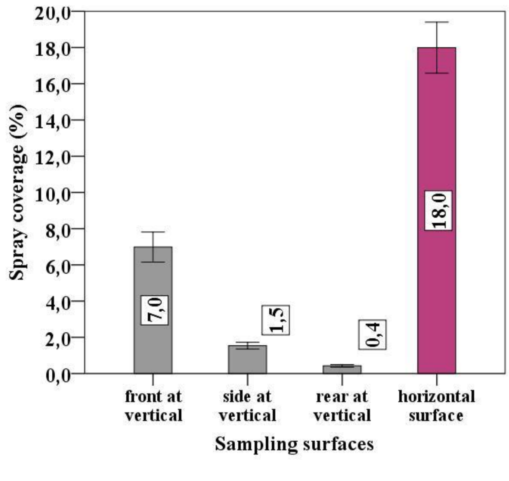
(c) Comparison of spray coverage ratios at target surface and plant canopy



(d) Effects of operating pressure on spray coverage ratios



(e) Effects of nozzle position angle on spray coverage ratios



(f) Spray coverage ratios of different frontal surfaces at horizontal and vertical planes

Figure 9. Spray coverage ratios at horizontal and vertical planes

Discussion

Various qualitative and quantitative methods are used in spray treatments to determine drop adsorption of the target surface, coverage ratios, drop density and spray penetration (Sayıncı and Bastaban, 2009). Among these methods, water sensitive papers (WSPs) are commonly used in assessment of different parameters (Foqué and Nuyttens, 2011; Malneršič et al., 2016; Guler et al., 2006; Salyani et al., 2013). In sampling practices, papers (WSPs) are placed parallel to ground plane or placed over the leaf surfaces of the plant canopy. Following the spray treatments, the coverage ratio of the stains generated by spray drops is determined (Sayıncı and Bastaban, 2011). However, there are not any studies about spray transfer at horizontal and vertical planes. In present study, significant differences were observed in spray transfer at horizontal and vertical planes. Spray coverage ratios of the drops reached to vertical plane were quite lower than the drops reached to horizontal plane. Such a case clearly indicated that spray drops were not able to reach sufficiently to vertical root collars and stems of the plants.

In vertical plane, nozzle position angle relatively increased both spray transfer and penetration, but spray coverages were quite low. In all treatments made at constant volumes, drop diameters decrease, thus coverage ratios increase with increasing operating pressures (Sayıncı and Bastaban, 2011). Greater coverage ratios and penetrations were also achieved in this study with increasing operating pressures. However, spray coverage ratios were still at quite low levels as compared to horizontal plane.

Diameter-class of spray drops is a significant parameter influencing spray transfer and penetration into the target. At 300 kPa (3.0 bar) operational pressure, ST and LU nozzles produce fine drops (Serim and Özdemir, 2012; Lechler®, 2018); AD nozzles produce medium-size drops (Lechler®, 2018); IDK nozzles produce coarse drops (Lechler®, 2018) and IDKT nozzles produce extremely large drops (Lechler®, 2018). Since nozzle types produce different-size drops, terminal velocity and kinetic energy of the drops vary with the nozzle types. Fine drops have greater terminal velocities and thus have lower kinetic energy and greater drift potential (Sayıncı, 2016).

Conclusion

In horizontal and vertical planes, the greatest coverage ratios were achieved with LU and ST nozzles. The KH nozzles had the lowest spray coverage ratio and spray penetration at vertical plane and penetrations decreased with increasing operating pressures. Coverage ratio of IDK nozzles increased with increasing pressures and the greatest spray penetration into plant canopy was achieved at vertical plane. Despite the twin-flow, IDKT nozzles did not yield a significant advantage in spray transfer and penetration. Since IDKT nozzles have high spray transfer energy, spray penetration at vertical plane was greater than the nozzles producing fine spray drops. In STD nozzles with narrow beam angle, spray coverage ratios decreased with increasing position angles, thus this type of nozzles had the least spray penetration. AD nozzles have low drift potential, thus spray coverage ratios increased with increasing nozzle position angles. The second greatest spray penetration into the plant canopy was achieved with AD nozzles.

This study was conducted in a closed facility under controlled conditions, thus, there were not any drifts. Under present conditions, volume of drops transferred at vertical plane was quite lower than the volume of drops transferred at horizontal plane. Considering the negative impacts of potential drifts in practice, there is a need for alternative spray equipment able to better manage pests and diseases over the root collars and stems of the plants. In this case, the spray coverage rate at the spray pressure of 500 kPa increased compared to the low pressure levels. IDK and AD nozzles producing middle and coarse drops yielded greater spray penetration at vertical plane. However, at ideal weather conditions, ST and LU nozzles producing fine drops yielded greater spray coverage ratios, thus they were found to be more suitable for chemical treatments to plant leaves.

Acknowledgements

This study was supported by Scientific Research Projects Department of Atatürk University with the project number of FHD-2018-6643.

References

Azimi A. H., Carpenter, T. G. and Reichard, D. L., 1985. Nozzle spray distribution for pesticide application. Transactions of the ASAE 28(5): 1410-1414

Bode, L. E., Butler, B. J., Pearson, S. L. and Bouse, L. F., 1983. Characteristics of the micromax rotary atomizer. Transactions of the ASAE 24(4): 999-1004

Coates, W. and Palumbo, J., 1997. Deposition, off-target movement, and efficacy of Capture™ and Thiodan™ applied to cantaloupes using five sprayers. Applied Engineering in Agriculture 13(2): 181-188

Foqué, D. and Nuyttens, D., 2011. Effect of air support and spray angle on coarse droplet sprays in ivy pot plants. Transactions of the ASABE 54(2): 409-416

Guler, H., Zhu, H., Ozkan, H. E., Derksen, R. C., Yu, Y., and Krause, C. R., 2006. Spray characteristics and wind tunnel evaluation of drift reduction potential with air induction and conventional flat fan nozzle. In 2006 ASAE Annual Meeting (p. 1). American Society of Agricultural and Biological Engineers

Hoffmann, W. C. and Salyani, M., 1996. Spray deposition on citrus canopies under different meteorological conditions. Transactions of the ASAE 39(1): 17-32

Lechler®, 2018. Agricultural Spray Nozzles, 2018 US Catalog. http://www.lechler.de (Available from: April 2018)

Malneršič, A., Dular, M., Širok, B., Oberti, R., and Hočevar, M., 2016. Close-range air-assisted precision spot-spraying for robotic applications: Aerodynamics and spray coverage analysis. Biosystems Engineering 146: 216-226

Piché, M., Panneton, B. and Thériault, R., 2000. Reduced drift from air-assisted spraying. Canadian Agricultural Engineering 43(3): 117-122

Reed, J. T. and Smith, D. B., 2001. Droplet size and spray volume effects on insecticide deposit and mortality of *Heliothine* (Lepidoptera: Noctuidae) larvae in cotton. Journal of Economic Entomology 94(3): 640-647

Salyani, M. and Whitney, J. D., 1988. Evaluation of methodologies for field studies of spray deposition. Transactions of the ASAE 31(2): 390-395

Salyani, M., Zhu, H., Sweeb, R. D. and Pai, N., 2013. Assessment of spray distribution with water-sensitive paper. Agric Eng Int: CIGR Journal 15(2): 101-111

Sanchez-Hermosilla, J. and Medina, R., 2004. Adaptive threshold for droplet spot analysis using water-sensitive paper. Applied Engineering in Agriculture 20(5): 547-551

Sayıncı, B. and Bastaban, S., 2009. İlaç uygulama performansının değerlendirilmesinde kalitatif ve kantitatif analiz yöntemlerinin değerlendirilmesi, Anadolu Tarım Bilimleri Dergisi 24(2): 133-140 (in Turkish)

Sayinci, B. and Bastaban, S., 2011. Spray distribution uniformity of different types of nozzles and its spray deposition in potato plant. African Journal of Agricultural Research 6(2): 352-362

Sayıncı, B., 2016. The influence of strainer types on the flow and droplet velocity characteristics of ceramic flat - fan nozzles. Turkish Journal of Agriculture and Forestry 40(1): 25-37

Serim, A. T. and Özdemir, Y. G., 2012. Herbisit uygulamalarında kullanılan pülverizatör memelerinin damla büyüklük dağılımlarının belirlenmesi. Tarım Bilimleri Araştırma Dergisi 5(2): 172-175 (in Turkish)

Whitney, J. D., Salyani, M., Churchill, D. B., Knapp, J. L., Whiteside, J. O. and Linell, R. C., 1989. A field investigation to examine the effects of spray type, ground speed, and volume rate on spray deposition in Florida citrus. Journal of Agricultural Research Engineering 42(4): 275-283

Wolf, R. E., 2005. Comparing downwind spray droplet deposits of four flat-fan nozzle types measured in a wind tunnel and analyzed using DropletScan™ software. Applied Engineering in Agriculture. 21(2): 173-177

Zhu, H., Dorner, J. W., Rowland, D. L., Derksen, R. C., Ozkan, H. E., 2004. Spray penetration into peanut canopies with hydraulic nozzle tips. Biosystems Engineering 87(3): 275-273

Zhu, H., Rowland, D. L., Dorner, J. W., Derksen, R. C. and Sorensen, R. B., 2002. Influence of plant structure, orifice size, and nozzle inclination on spray penetration into peanut canopy. Transactions of the ASAE 45(5): 1295-1301