# Influence of some Operational Parameters on Boom Spray Drift

Firozeh Solimani, Majid Rahnama*, Mohammad Amin Asoodar, Mahmoud Ghasemi Nejad Raini, Mohammad Ali Hormozi

*( Faculty of Agricultural Engineering and Rural Development, Department of Agricultural Machinery Engineering, Agriculture Sciences and Natural Resources University of Khuzestan, Iran )*

**Abstract:** Reduction in nozzle drift can be considered as one of the main factors in preventing the risk of environmental pollution because of using pesticides. For this aim, three types of air-assisted nozzles, namely, air-liquid-air(ALA), liquid-air(LA), liquid-air-liquid(LAL), and at four levels of air-assisted velocity (0, 2, 4, and 7.5 m/s$^{-1}$)were used; They were also examined at four levels of wind velocity (0, 2, 3, and 4 m/s$^{-1}$).A spectrophotometry device, MATLAB, SAS 9.1, and IBM SPSS statistical software were used for measurement. The results showed that the effects of the nozzle type, air-assisted velocity, and wind velocity on the drift, deposition, unified spraying, volume median diameters of 50% and 90%, and spraying quality indicators were significant ($\alpha \leqslant 0.01$).Also in this study, the third nozzle (LAL) with wind and air-assisted velocity of 4 m/s-1 as the best nozzle was obtained in order to the maximum of the deposition, the minimum of the drift, and the highest spraying uniformity. Therefore, it is recommended to use the third nozzle (air-liquid-air) for better deposition and less drift to protect the solution against different environmental conditions.

**Keywords**: Air-Assisted, Drift, Droplet Volume Diameter, deposition, Spraying Quality Indicator, Nozzle

**Citation:** F. Solimani, M. Rahnama, M. A. Asoodar, M. Ghasemi Nejad Raini, and M. A. Hormozi 2022. Influence of some operational parameters on boom spray drift. Agricultural Engineering International: CIGR Journal, 24 (2):70-82

## 1 Introduction

Pesticide spraying is a task that significantly improves the productivity of crops, especially in orchards, where pest control is essential for increasing yield (Gao et al., 2018). However, spraying control requires a large amount of spraying because of the probability of occurrence of pests and irregularities of occurrence (Seol et al., 2022).

Drift is one of the key factors that affect the control of pesticides and increases the pesticides losses and off-target depositions from 50% to 70%. Spray drift is defined as a physical movement of droplets of the target crop to any off-target location during the spray operation or for a short time thereafter due to complex environmental factors in the field (Nuyttens et al., 2006). Drift droplets and environmental exposure can damage sensitive crops, affect natural enemies of pests, reduce pollinator populations, cause environmental contamination, and threaten human and animal health (Langkamp-Wedde et al., 2020). Since the advent of agricultural spraying, spray drift occurs and has always been an important, challenging, and complex topic (Wang et al., 2017). However, there are two internal and external conditions affecting the drift of the droplets: the internal conditions are mainly droplet size (Balsari et al., 2017), spray device, and spray technology (Al Heidary et al., 2014), whereas the external conditions are mainly meteorological parameters (Dorr et al., 2008), wind speed (Nuyttens et al., 2006), and release height (Teske et al., 2018).

Nozzles provide the primary means of controlling three factors that affect any application and possible off-target movement of the pesticide: the application volume,

**Received date:** 2020-10-30 **Accepted date:** 2021-07-22

***Corresponding author: Majid Rahnama,** Faculty of Agricultural Engineering and Rural Development, Department of Agricultural Machinery Engineering, Agriculture Sciences and Natural Resources University of Khuzestan, Iran. E-mail: rahnamam2002@asnrukh.ac.ir.

droplet size, and spray pattern (Chen et al., 2020). Nozzle size and design selection are the most critical parameters in spraying because they determine the spray droplet size and characteristics of the droplet velocity delivered to the target species (Fox et al., 2008). Several technical solutions have been developed to help increase droplet sizes and reduce the degree of the drift of the spread liquid (Nuyttens et al., 2007b), there by moderating the burden on the environment.

A way of increasing droplet sizes is using a twin fluid system in which air is actively pumped into the nozzle by a compressor during system operation, and droplet sizes created by the nozzles can be changed by altering the operating pressure of the liquid and air flowing into the nozzles from the hydraulic spray system (Jamar et al., 2010). (Tsay et al. 2004), the research on boom sprayer equipped with a blower unit in a simulated environment showed that an air-assisted sprayer is a good strategy to the reduce drift; the results of their investigation also showed that in the air-speeds of 20 to 30 meters per second, relative drift index was reduced by 50 to 80 percent for the wind-wise distribution and by 5 to 22 percent for the counter-wind-wise distribution, which represents more drift potential. In another research, Sayinci and Bastaban (2011), examined spray distribution uniformity of different types of nozzles and their spray deposition on potato plants. The test results showed that the best value for spray unified distribution (CV) was for the air induction nozzle (AL) with 16.4% and the highest CV was for air assisted rotary atomizer nozzle (AR), hollow cone pattern nozzle (HC), and spinning disc nozzle ( SD) at means of 43.9%, 40.4%, and 46.5%, respectively.

These studies prove that the nozzle type has a direct connection with drift rate reduction, unified distribution of spray, amount of deposition spray, and saving solution spray liquid. The aim of this research is to the effect of the nozzle type, air-assisted velocity, and wind velocity on boom sprayer performance indicators.

## 2 Materials and methods

This research was conducted in 2016 on the educational and research workshop of from agriculture sciences and natural resources university of Khuzestan – Iran, located 36 km northeast of Ahvaz and on the eastern beach of the Karun with a latitude of 31 degrees and 36 minutes and a longitude of 48 degrees and 53 minutes, was carried out at a height of 51 meters above sea level. Repetitive field trials were conducted while keeping all the other sprayer working parameters (forward velocity, working pressure, and boom height) constant. The experiments of the research were carried out with three replications in a completely randomized design.

### 2.1 Different levels of the tested factors

There are three types of the air-assisted nozzle (N1 [Air-liquid-air, ALA], N2 [Liquid- air, AL], and N3 [Liquid-air-liquid, LAL]) with varied patterns of air and liquid, four levels of air-assisted velocity (0, 2, 4, and 7.5 m $s^{-1}$) (Al Heidary et al., 2014), four levels of wind velocity (0, 2, 3 and 4 m $s^{-1}$) which are based upon the statistics provided by the meteorological organization in Ahwaz, Iran. The liquid flow rate was (0.77 L $min^{-1}$) because the nozzles have the same output diameter (nozzles outlet diameter (1.2 mm)), the working pressure was (3.0 bar), and the sprayer forward velocity (6 km $h^{-1}$) (Gil et al., 2015).

### 2.2 Characteristics of tractor boom sprayer used during field trials

This sprayer is commonly known by the name tractor boom sprayer and also by four hundred liter sprayers. The boom sprayer used in this study was equipped with 20 nozzles, a boom of 10 meters wide, a nozzles distance of 0.5 meters from each other, and a tank capacity of 400 liters. John Deer 3140 tractor (210 HP) was used as a source of hydraulic power. Moreover, the air compressor (2 HP, 50 L, 8 Bar, and 220 V) was utilized for the production of the sprayer’s air-assisted flow.

### 2.3 Air-assisted nozzle designing and fabrication

In this study, three types of nozzles were designed: the first nozzle (ALA) is one that injects liquid through the middle and air from around the nozzle; this nozzle has four airflow outlets that have been designed and fabricated to help unify the distribution. The second nozzle (LA) is one in which fluid and air are sprayed separately; and the third nozzle (LAL) is a nozzle through which liquid is injected from around and air through the middle (This nozzle has six liquid outlets; for this reason and to reach two liquid outlets of 1.2 mm, this logic was postulated: using circle diameter and making six outlets of 0.5 mm each). The three nozzles were designed in a hollow cone-shape that was done using SolidWorks Software (SP3-32bit- premium 2013). Figure 1 shows a schematic of the nozzle structure and the shape of the explosive components using SolidWorks software.

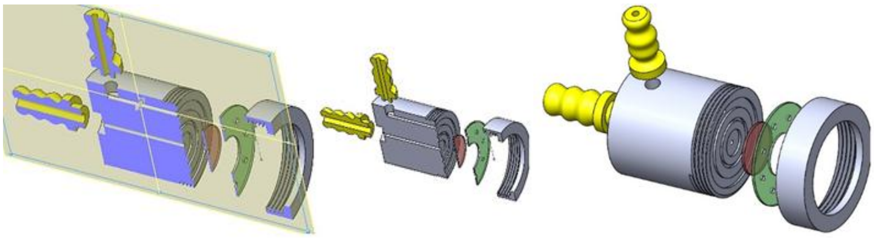


Figure 1 Schematic of the nozzle structure and shape of explosive components using SolidWorks software

For fabrication of nozzles, a piece of aluminum (two patches with an accuracy of 0.05 mm), 50 mm in diameter and, length of 5 and 10 cm (to arrange for the trunk and the nozzle warheads) was used. Figure 2 shows an image of air-assisted nozzles.

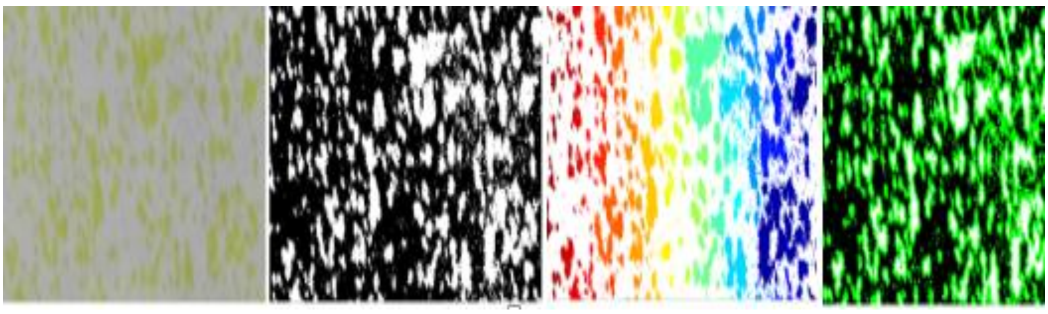
Figure 2 Image of air-assisted nozzles

**2.4 The tracker used in the experiment to simulate the liquid**

Tracker (color) used in the sprayer tank in this experiment was mixed with water as soluble to simulate the liquid in real conditions; the soluble toxin contains TARTRAZINE yellow color with code E102. This color is a food coloring with an amount of 5-6 g $L^{-1}$ soluble in water (Gil et al., 2012; Balsari et al., 2014).

**2.5 Measurement of droplet sizes**

To record spray droplets and determine their size, water-sensitive cards (Gil et al., 2013) with dimensions of 7 cm× 3 cm were used. Photos of each card were taken using a digital camera. Then the cards were labeled with numbers and stored in a dark, dry place. After that, the cards were cut with the MATLAB R2013a Image Processing Toolbox and the droplet sizes were calculated by using Image Tool 1-QR. The diameter and the number of sprayed droplets were obtained using MATLAB software and the resulting data were replaced in the corresponding formulas to achieve the median volume diameter of 50 and 90, as well as the numerical median diameter. Figure 3 shows water-sensitive cards as the original image, binary image of the water-sensitive card, labeled image, and isolated image design.



(a) Original Image, (b) Binary Image of the Water-sensitive Card, (c) Labeled Image, (d) Isolated Image Design

Figure 3 water-sensitive cardsTo measure the velocity of the wind simulated (by a fan and the compressor), and the ambient temperature and humidity, Extech-instruments was used.

## 2.6 The measured factors

In order to measure the amount of the sprayed solution deposition, the petri dishes with a diameter of 9 cm were used. For reading and drawing graphs' standard wavelength, a spectrophotometer with wavelength 427nm (Jenna Analytics, model spicules, 2000) was utilized. The depositions in each petri dish were calculated according to the following equation (Gil et al., 2013):

$$D_i = \frac{(\rho_{smpl} - \rho_{blk}) \times V_{dil}}{\rho_{spray} \times A_{col}} \quad (1)$$

Where: $D_i$ is the amount of the solution deposition in each petri dish (μL cm$^{-2}$), $\rho_{smp}$ denote the amount of the sample absorbance, $\rho_{blk}$ defines the amount of the sample witness (water), $\rho_{spray}$ is the amount of the concentration of the solution in the samples, $V_{dil}$ refers to the liquid volume of the distilled water (μL) and $A_{col}$ represents the area petri dish for the solution collection (cm$^2$).

The amount of the spraying potential was calculated according to the following equation (Gil et al., 2015):

$$DPV = \sum_{i=1}^{n} \frac{D_i}{RSD} \times 100 \quad (2)$$

Where: *DPV* is the amount of the drift potential, *RSD* shows the witness deposition, *n* is the Petri dish number, and $D_i$ refers to the amount of the deposition in each petri dish (μLcm$^{-2}$).

The quality spray index was calculated according to the following equation (Safari et al., 2013):

$$q = \frac{VMD}{NMD} \quad (3)$$

Where: *q* is the quality spray index, *VMD* goes to the volume median diameter (mm) and *NMD* represents the numerical median diameter (mm).

## 2.7 Statistical Analysis of Experiment Data

Data analysis and drawings of graphs were done using Excel 2013 and SAS 9.1 software, and IBM SPSS Statistics 20; also, Duncan test at the level of (0.01) and LS-means test for cutting interaction between data, analysis of variance (ANOVA test), and regression analysis were done. The Image processing (MATLAB software R2013a) was used for the analysis of water-sensitive cards.

**Table 1 Variance analyses influence of nozzle type, air-assisted velocity, and wind velocity for boom sprayers on measured parameters**

| Source | DF | Mean Square | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | deposition | Drift | C.V | $Dv_{0.5}$ | $Dv_{0.9}$ | DVN | Index Quality |
| Air-assisted velocity (b) | 3 | **6376.50 | **0.26 | **4.07 | **0.008 | **0.129 | **0.012 | **0.81 |
| Wind velocity (a) | 3 | * 155.77 | ns0.004 | **13.16 | **0.012 | **0.187 | **0.101 | **0.068 |
| Nozzle (n) | 2 | **9464.65 | **0.44 | **0.37 | **0.004 | **0.158 | ns 0.001 | **0.085 |
| (b*a) | 9 | **1467.40 | **0.05 | **0.56 | **0.018 | **0.045 | **0.019 | **0.074 |
| (b*n) | 6 | **6243.09 | **0.23 | **1.02 | **0.002 | **0.071 | **0.012 | *0.021 |
| (a*n) | 6 | **330.93 | **0.01 | **6.64 | **0.004 | **0.030 | **0.020 | ns 0.015 |
| (b*a*n) | 18 | **1062.16 | **0.04 | **0.161 | **0.002 | **0.027 | **0.009 | **0.021 |
| Residual | 96 | 42.29 | 0.002 | 0.007 | 0.0002 | 0.0003 | 0.0002 | 0.007 |
| C.V | | 7.23 | 11.59 | 5.04 | 7.69 | 3.60 | 2.59 | 19.37 |

*, ** and ns showed significant at 5%, 1% level, and no significant difference, respectively

**Table 2 Variance analyses of cutting of interactive effects (triple) on the drift, amount of the deposition, spray uniformity, volume media diameter 50% and 90%, numerical media diameter, and quality index**

| Source | DF | Mean Square | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | deposition | Drift | C.V | $Dv_{0.5}$ | $Dv_{0.9}$ | DVN | Index Quality |
| N1 | 15 | 914.72** | 0.03** | 4.23** | 0.007** | 0.072** | 0.011** | 0.039** |
| N2 | 15 | 1322.41** | 0.06** | 1.61** | 0.006** | 0.030** | 0.028** | 0.031** |
| N3 | 15 | 3853.97** | 0.14** | 1.20** | 0.007** | 0.061** | 0.018** | 0.048** |

*, ** and ns showed significant at 5%, 1% level, and no significant difference, respectively.

## 3 Results and discussion

### 3.1 Effect of nozzle type, air-assisted velocity, and wind velocity on boom sprayer performance indicators:

According to Table 1, there was a significant effect from the nozzle type, air-assisted velocity, and wind velocity on the drift, amount of the deposition, spray uniformity, median volume diameter of 50 and 90 percent, numerical media diameter, and quality index at the one percent level.According to Table 1, since the three interaction effects (nozzle type, air-assisted velocity, and wind velocity) are significantly effective at the level of one percent, the cutting method for comparing the average interaction (triple) effect of nozzle type, air-assisted velocity, and wind velocity on the drift, amount of the deposition, spray uniformity, median volume diameter of 50 and 90 percent, numerical media diameter and quality index were used. The variance results, the analyses of cutting of interactive effects (triple) by nozzle type are shown in Table 2 According to this table, the effects of nozzle type, air-assisted velocity, and wind velocity on the drift, amount of the deposition, spray uniformity, median volume diameter of 50 and 90 percent, numerical media diameter, and quality index were significant at 1% level.

### 3.2 Effect interaction of treatments on the drift amount:

Table 3 shows effect of the drift on the nozzle type. The ANOVA test to evaluate the recovery values obtained showed that there is a significant relationship between the amount of drift and the nozzle type, ($p$ <0.000) Particularly for the third type nozzle (Table 3).The average recovery value for all experiments with three types of nozzles was 62%, which indicates the higher performance of the boom spray distribution.

**Table 3 ANOVA test for statistical analysis of the relationship between Drift (dependent variable) and predictors (constant): wind velocity, nozzle type, air-assisted velocity**

| Model | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| Regression | 10.702 | 3 | 3.567 | 7.064 | $0.000^b$ |
| Residual | 161.604 | 320 | 0.505 | | |
| Total | 172.306 | 323 | | | |

Regression analysis of the drift, deposition, and droplet diameter was calculated as dependent variable on constant factors including nozzle type, air-assisted velocity, and wind velocity in order to influence the relationships and also the most influential factor on the drift and droplet diameter with SPSS software.

Table 4 shows the results of the drift regression analysis in terms of the independent variables of the nozzle type, air-assisted velocity, and wind velocity. These variables explain a significant total of 62% of the changes in the drift deflection at the one percent level. ($R^2$=62%, F=7.064, Sig=$0.000^*$).

**Table 4 Regression analysis table of the factors affecting drift by nozzle type, air-assisted velocity, and wind velocity**

| Variable | B | S.E.B | β | Sig.t |
|---|---|---|---|---|
| nozzle type | -0.228 | .0048 | -0.204 | 0.000 |
| wind velocity | -0.047 | 0.048 | -0.042 | 0.389 |
| Air-assisted velocity | -0.089 | 0.035 | -0.058 | 0.1010 |
| | Constants=3.090 | | F=7.064 | Sig=$0.000^*$ |

In other words, these three variables are able to explain the amount of the drift. The obtained Beta value shows that increasing a standard deviation in the above variables causes 0.089, 0.047, and 0.228, respectively, decreasing the standard deviation of the drift variable. Due to the significance of the T-test in the three variables, the role of these variables in explaining the amount of the drift is significant. As the table shows, the nozzle type variable is the most important variable in predicting drift. According to the results of Table 4 the regression equation for drift is as follows;

$$Y= 3.090 - 0.058\ x_1 - 0.042\ x_2 - 0.204\ x_3 \qquad (4)$$

According to Figure 4 the maximum and minimum amounts of the drift were related to the third nozzle (LAL), while the minimum amount of the drift in the third nozzle was related to the controlled air-assisted velocity, and wind velocity of 4 m $s^{-1}$ with the amount of 0.06 percent; and a maximum of 0.73 percent

According to results of Al Heidary et al. (2014), the influence of the nozzle type, nozzle arrangement, and side wind velocity on the spray drift as measured in a wind tunnel, and maximum drift percentage were for treatments TWIN AXI-CVIT at air-assisted velocities of 7.5 meters per second with 17 percent; and the minimum was for treatments AXI-CVIT TWIN at air-assisted velocity 2 meters per second with 5 percent. As such, the corresponded to no air-assisted velocity, and no wind velocity (Control treatment).

highest amount of the drift in the nozzles was for a treatment in which the wind velocity was more than 4 m_$s^{-1}$ and the lowest amount for the treatments in which wind velocity was less than 4 m_$s^{-1}$. Therefore, the findings of this investigation are compatible with those (Al Heidary et al., 2014) in using the most suitable air-assisted velocity.

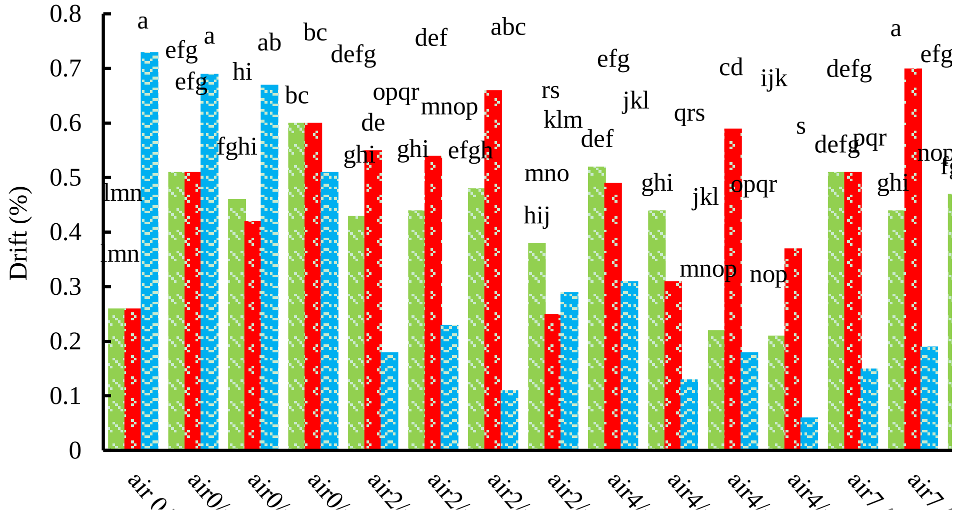



Figure 4 Effect of the interaction of the treatments on the amount of the drift (b0a0=without wind and without air-assisted)

**Table 5 ANOVA test for statistical analysis of the relationship between Di (dependent variable) and predictors (constant): wind velocity, nozzle type, air-assisted velocity**

| Model | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| Regression | 9.375 | 1 | 9.375 | 20.456 | 0.000[b] |
| Residual | 147.576 | 322 | 0.458 | | |
| Total | 156.951 | 323 | | | |

Also, Table 6 shows the results of the deposition regression analysis in the terms of the independent variables of the nozzle type, air-assisted velocity, and wind velocity. These variables explain a significant total of 74% of the changes in the drift deflection at the one percent level. ($R^2$=74%, F=8.544, Sig=0.000*).

**Table 6 Regression analysis table of the factors affecting deposition by nozzle type, air-assisted velocity, and wind velocity**

| Variable | B | S.E.B | β | Sig.t |
|---|---|---|---|---|
| nozzle type | 0.208 | .0046 | 0.244 | 0.000 |
| wind velocity | 0.014 | 0.046 | 0.016 | 0.762 |
| Air-assisted velocity | 0.074 | 0.033 | 0.119 | 0.027 |
| | Constants=0.159 | | F=8.544 | Sig=0.000* |

### 3.3 Effect of the interaction of the treatments on the amount of the deposition:

Table 5 shows the effect of the deposition on the nozzle type. The ANOVA test to evaluate the recovery values obtained showed that there is a significant relationship between the amount of the deposition and the nozzle type, (*p* <0.000), particularly nations for the third nozzle (Table 5).

The obtained Beta value shows that increasing a standard deviation in the above variables causes 0.074, 0.014, 0.208, respectively, decreasing the standard deviation of the deposition deflection variable. As the table shows, the nozzle type variable is the most important variable in predicting deposition. According to the results of Table 6, the regression equation for deposition is as follows;

$$Y= 0.159 + 0.119\, x_1 + 0.016\, x_2 + 0.244\, x_3 \quad (5)$$

Figure 5 shows the comparison of the means of interactive effects (Triple) and the amount of the deposition according to nozzle type. According to this diagram, in all treatments, the maximum amount of the deposition according to nozzle type was related to the third nozzle (LAL) with the treatment of air-assisted velocity, and wind velocity of 4 m $s^{-1}$ and the amount of 144.87 Li $ha^{-1}$. This indicates that for the third nozzle, using the air-assisted treatment had the most significant impact on the amount of the deposition solution compared to the other nozzles in the treatment with no air-assisted velocity, and no wind velocity (Control treatment). Moreover, the minimum rate of the deposition of the solution pertaining to the third nozzle in the treatment of no air-assisted, wind velocity of 2 m $s^{-1}$, and the amount of 31.16 Li $ha^{-1}$. The reason for the low amount of deposition in this nozzle while in the no air-assisted treatment is the small size of the droplets, which results from its unique design (the liquid is sprayed from six nozzles surrounding the air nozzle). Speaking in broad terms, the third nozzle could have protected the liquid at different velocities of the wind and has outperformed the other two nozzles in terms of the deposition.

Therefore, the third nozzle was able to perform the protection of the solution at different wind velocities and it is better in the deposition than the other two nozzles.

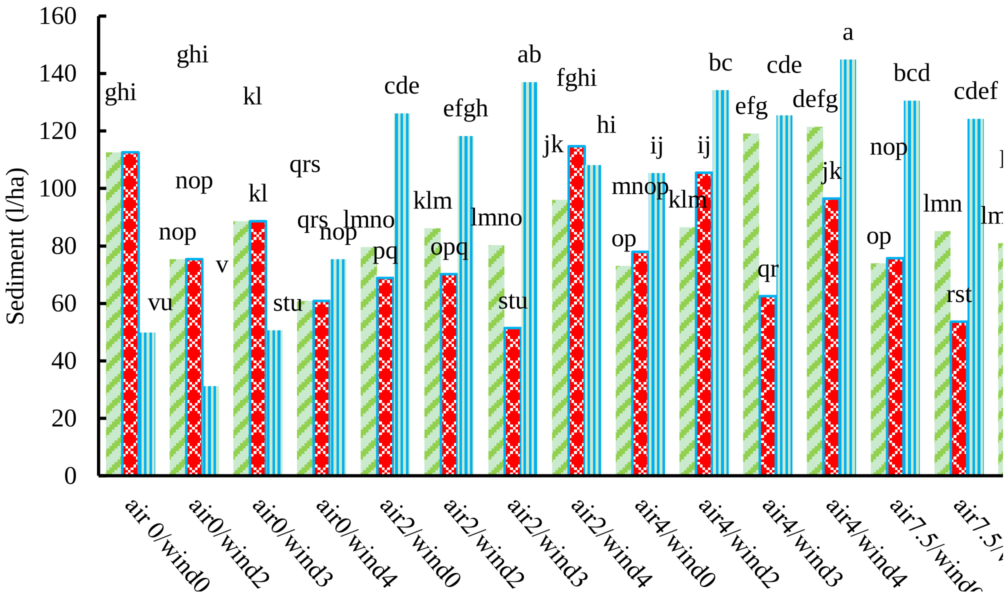



Figure 5 Effect of the interaction of the treatments on the amount of the deposition (b0a0=without wind and without air-assisted)

**Table 7 ANOVA test for statistical analysis of the relationship between $DV_{50}$ (dependent variable) and predictors (constant): wind velocity, nozzle type, air-assisted velocity**

| Model | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| Regression | 7.347 | 1 | 7.347 | 20.226 | .000[b] |
| Residual | 38.505 | 106 | .363 | | |
| Total | 45.852 | 107 | | | |

**Table 8 ANOVA test for statistical analysis of the relationship between DV90 (dependent variable) and predictors (constant): wind velocity, nozzle type, air-assisted velocity**

| Model | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| Regression | 3.125 | 1 | 3.125 | 10.076 | .002[b] |
| Residual | 32.875 | 106 | .310 | | |
| Total | 36.000 | 107 | | | |

According to results in a study conducted by Gil et al. (2014) on the assessment of the distribution of hand sprayer nozzles used in greenhouse tomato crops, with two spray nozzles (flat fan and hollow cone) and an air-assisted system in two different greenhouses (Coverage density up and down), the use of an air-assisted flat fan nozzle without an air-assisted flat fan nozzle, increased the amount of deposition from 1.98 to 2.95 percent. As such, in the present study, the ratio of the highest amount of the solution deposition to the lowest amount in using a nozzle with and without air-assisted treatments was 72% to 78%. Furthermore, the performance of solution deposition has an increase from 1.98 to 2.61. Therefore, the results of this study are in line with those of (Gil et al., 2014) in that both showed that the most suitable amount of the deposition in solution was related to the utility of the air-assisted nozzle.

Therefore, the nozzle type is directly related to the deposition solution, and nozzle configuration is affected by the length of the failure and spray angle, and thus the formation of droplets of different sizes.

### 3.4 Effect of the interaction of treatments on volume 50 and 90 percent media diameter

Tables 7 and 8 show the effect of volume 50 and 90 percent media diameter on the nozzle type. The ANOVA test to evaluate the recovery values obtained showed that there is a significant relationship between volume 50 and 90 percent media diameter and nozzle type. ($p$ <0.000).

Also tables 9 and 10 show the results of volume 50 and 90 percent media diameter regression analysis in terms of independent variables by nozzle type, air-assisted velocity, and wind velocity.

**Table 9 Regression analysis table of factors affecting volume 50 percent media diameter by nozzle type, air-assisted velocity, and wind velocity**

| Variable | B | S.E.B | β | Sig.t |
|---|---|---|---|---|
| nozzle type | -0.069 | .0067 | -0.087 | 0.299 |
| wind velocity | -0.319 | 0.067 | -0.400 | 0.000 |
| Air-assisted velocity | -0.193 | 0.049 | -0.330 | 0.000 |
| | Constants=3.296 | | F=13.283 | Sig=0.000* |

**Table 10 Regression analysis table of factors affecting volume 90 percent media diameter by nozzle type, air-assisted velocity, and wind velocity**

| Variable | B | S.E.B | β | Sig.t |
|---|---|---|---|---|
| nozzle type | -0.208 | .0064 | -0.087 | 0.002 |
| wind velocity | -0.167 | 0.064 | -0.236 | 0.011 |
| Air-assisted velocity | -0.022 | 0.047 | -0.295 | 0.636 |
| | Constants=2.139 | | F=5.842 | Sig=0.000* |

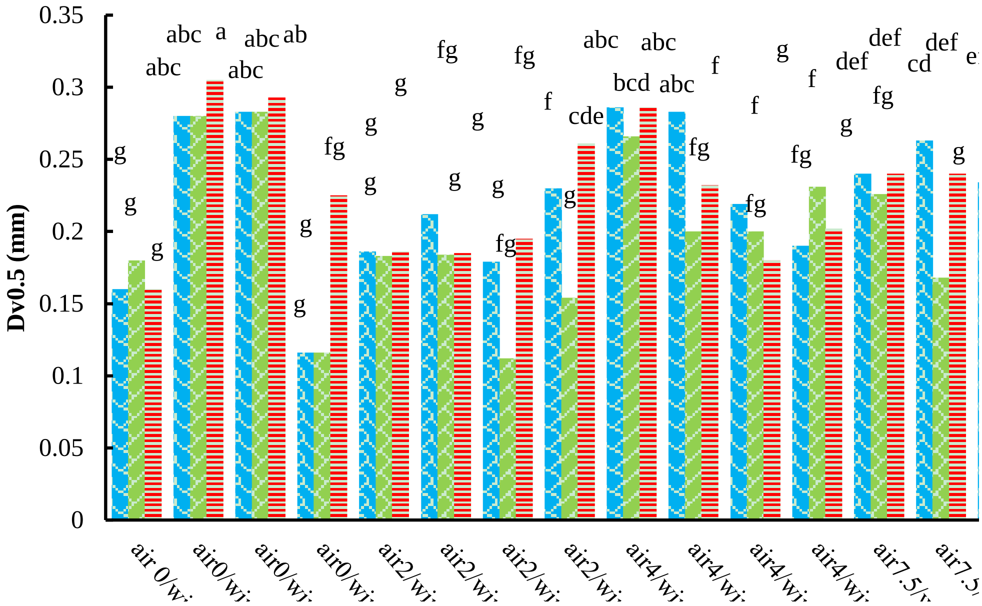



Figure 6 Effect of the interaction of the treatments on volume 50 percent median diameter (b0a0=without wind and without air-assisted)

Due to the significance of the T-test in the three variables, the effect of these variables in explaining the amount of volume 50 and 90 percent media diameter is significant. According to the results of Tables 9 and 10, the regression equation for volume 50 and 90 percent media diameter respectively is as follows;

$$Y= 3.296 - 0.330 x1 - 0.400 x2 - 0.087x3 \quad (6)$$

$$Y= 2.139 -0.022 x1 - 0.167 x2 - 0.208 x3 \quad (7)$$

According to the classification of spraying nozzles, and based on the standards of agricultural and biological engineering in America ((ASABE) standard S-572.1) by spectroscopic droplets, median volume diameter of 50 percent is between 177 to 218 µm , and a median volume diameter of 90 percent is between 257 to 360 µm. According to these experiments in figure 6 the most appropriate volume 50 percent median diameter grouped in this classification, was the second nozzle (LA) with a treated air-assisted velocity of 4 m $s^{-1}$ and wind velocity of 2 m $s^{-1}$ with 200 mm. Conversely, the most inappropriate was the first nozzle (ALA) with a treated air-assisted velocity of 4 m $s^{-1}$ and without a wind velocity of 286 µm. The maximum volume of 50 percent median diameter was obtained for the third nozzle (LAL) at no treated air-assisted velocity and wind velocity of 2 m $s^{-1}$ with 305 µm. Moreover, the minimum median diameters for the first and the second nozzles at no air-assisted velocity and wind velocity 4 m $s^{-1}$ were 116 µm.

According to these experiments in figure 7, the most effective median volume diameter of 90 percent in this classification was the third nozzle (LAL) at treated air-assisted velocity and wind velocity of 4 m $s^{-1}$ with 311 µm, and the least effective was for the first and second nozzles.

The maximum median volume diameter of 90 percent was for the second nozzle at the treated air-assisted velocity of 4 m s-$^{1}$ and no wind velocity with 713 µm and the minimum for the third nozzle at treated air-assisted velocity, and wind velocity of 2 m $s^{-1}$ with 305 µm.

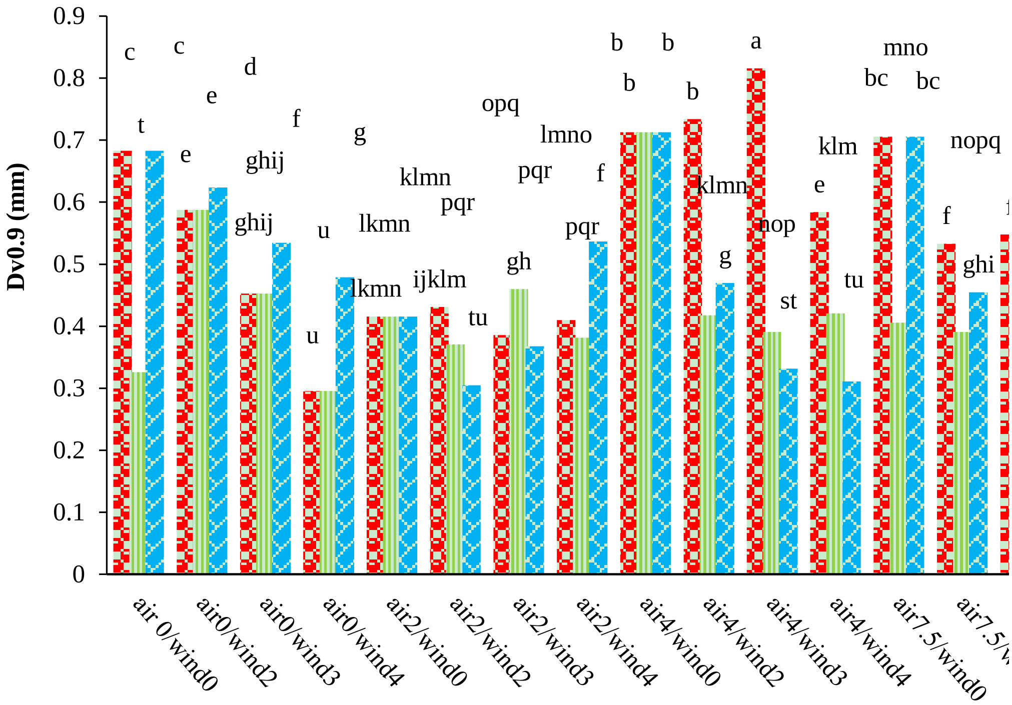



Figure 7 Effect of the interaction of the treatments on volume 90 percent median diameter (b0a0=without wind and without air-assisted)

According to results of Al Heidary et al. (2014), the influence of the nozzle type, nozzle arrangement, and side wind velocity on spray drift as measured in a wind tunnel, maximum median volume diameter of 50 and 90 percent was the CVI nozzle with 578 and 856 µm, and also the minimum for AXI nozzle was 226.5 and 353.5 µm.

In this study, the ratio of the largest to the smallest volumetric diameter of 50% in non-air-assisted and air-assisted nozzles was 61% to 54%. With the help of air-assisted treatment, the trend decreased from 1.62% to 1.18%. This indicates that with the air-assisted treatment, the mean volume of 50% will be standard. This means that in the air-assisted nozzle, there is a 50% reduction in the mean diameter and 50% in the standard volume to use the air-assisted treatment. Therefore, the results for the 50% mean-volume diameter are consistent with those of Al Heidary et al. (2014).

In this study, the ratio of the largest to the smallest 90% volumetric mean diameter in the non-air-assisted and air-assisted nozzles was 56% to 61%; and also the 90% mean volume efficiency in the non-air-assisted and air-assisted nozzles decreased from 1.30% to 1.62%. This indicates that with the aid of air, 90% of the mean diameter will be higher than non-air assisted treatment. According to the results of Al Heidary et al. (2014) in the study of the effect of the nozzle type, nozzle arrangement, and lateral wind velocity on the wind velocity in a wind tunnel, the maximum mean diameter of 50% and 90% at 2 m $s^{-1}$ air-assisted velocity were 578 and 856 µm, respectively and the lowest at the air-assisted velocity of 7.5 m $s^{-1}$ was 262.5 and 353.5 µm, respectively. By contrast, in this study, the maximum volumetric diameter of 50% and 90% was in the third nozzle with no air-assisted and wind velocity of 2 m $s^{-1}$ with 0.305 mm and in the first nozzle at the air-assisted velocity of 4 m $s^{-1}$ and velocity treatment. Moreover, the lowest mean volume of 50% and 90% in the third nozzle, with 0.131 mm, was obtained in the air-assisted treatment of 7.5 m $s^{-1}$ and a wind velocity of 3 m $s^{-1}$. Therefore, these results are consistent with those of Al Heidary et al. (2014).

### 3.5 Effect of the interaction of the treatments on the coefficient of variation (uniformity in spraying)

Figure 8 compares the means of the interactive effects of (Triple) cut shown by the coefficient of variation (spray uniformity) by type of nozzle. According to this diagram, the highest and the lowest coefficients of variation for nozzle types were obtained for the first (ALA) and the third (LAL), respectively. In contrast, the highest coefficient of variation (the lowest spray uniformity) was obtained in the first nozzle with a treatment of 7.5 and 4 m $s^{-1}$ without wind velocity with 4.08% and the lowest coefficient of variation was in the third nozzle related to 4 m $s^{-1}$ air and wind velocity treatment; it was calculated to be 0.42%. The treatment with the lowest coefficient of variation had a higher spray uniformity than the other treatments. This is because, in the third nozzle, the liquid and air injection are done in the most appropriate way, and the liquid solution is sprayed evenly on the target area.

The results of Hilz and Vermeer (2013) in liquid atomization and drift windscreen measurements in a wind tunnel for a twin system with a deflector showed that at TKSS 10-042 at 4 m $s^{-1}$ wind velocity, its relative coverage was 4 and 3 percent, respectively, while the same spray rate was reported to be at 2 m $s^{-1}$, 5 and 2.5 percent. The results showed that the ratio of the coefficient of variation in non-air-assisted and air-assisted nozzles decreased from 89% to 70%, respectively. As the coefficient of variation increases, the spray uniformity decreases, and the opposite trend is also true. Moreover, unified spraying efficiency in air-assisted and non-air-assisted sprayers increased from 2.42% to 8.71%, respectively. Therefore, the results of this study on the increasing uniformity in spraying using air-assisted spraying are consistent with the results of Hilz and Vermeer (2013).

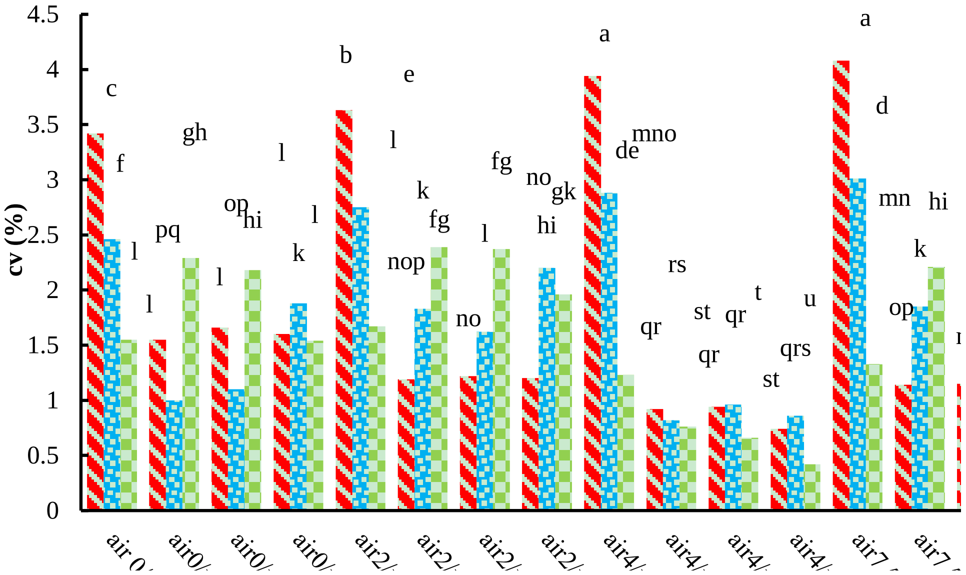



Figure 8 Effect of the interaction of the treatments on the coefficient of variation (uniformity in spraying) (b0a0=without wind and without air-assisted)

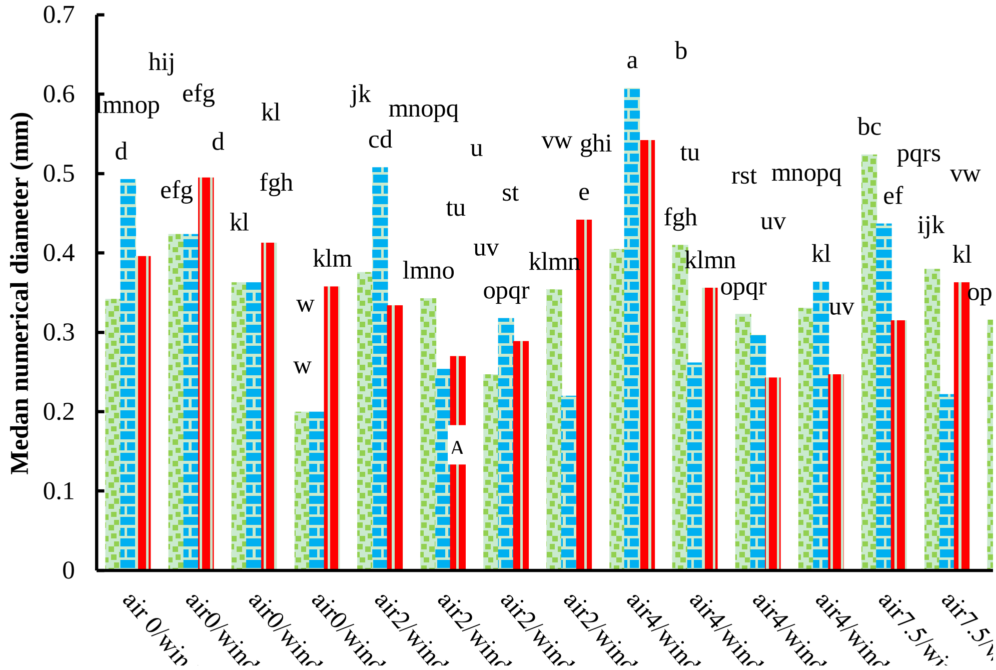



Figure 9 Effect of the interaction of the treatments on the median numerical diameter (b0a0=without wind and without air-assisted)

### 3.6 Effect of the interaction of the treatments on the median numerical diameter

Figure 9 showed effect of the interaction of the treatments on numerical mean diameter based on the nozzle type. According to this figure, the largest numerical mean diameter with 0.608 mm for air-assisted velocity treatment is 4 m $s^{-1}$ without wind velocity in the second nozzle (LA) and the smallest numerical mean diameter of the first and second nozzles was obtained in airless aids with a wind velocity of 4 m $s^{-1}$ with 0.200 mm. According to the results, the third nozzle (air-assisted velocity treatment and wind velocity of 4 meters per second) has the highest rate of subsidence and the lowest rate of wind. It has a suitable average numerical diameter of 0.247 mm. However, the treatment with the lowest amount of the solution has an average diameter of 0.495 mm.

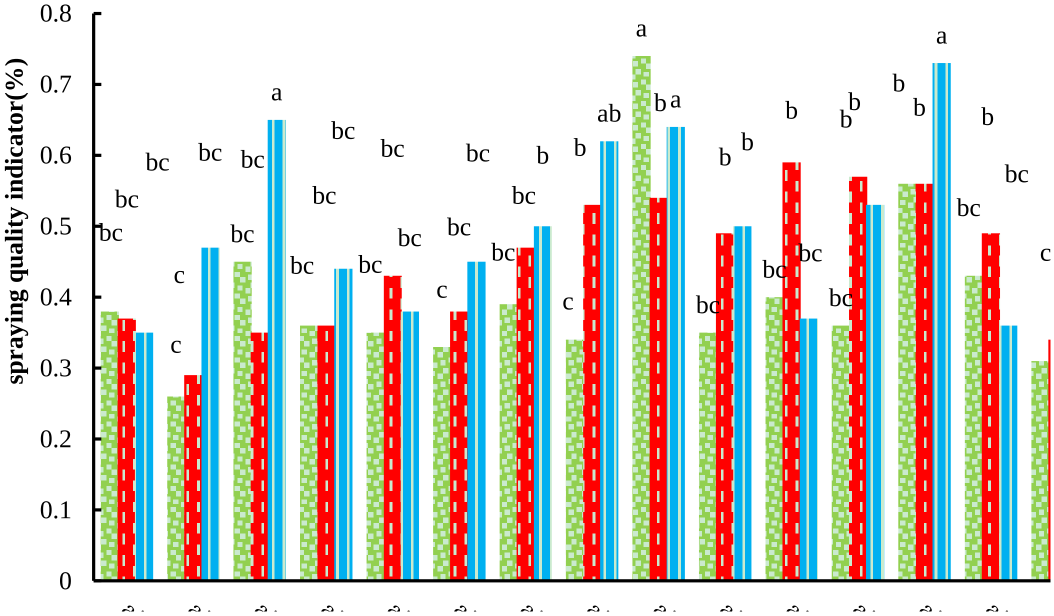



Figure 10 Effect of the interaction of the treatments on spraying quality indicator (b0a0=without wind and without air-assisted)

### 3.7 Effect of the interaction of the treatments on spraying quality indicator

Figure 10 showed effect of the interaction of the treatments on spraying quality indicators. According to this fig, the highest spraying quality indicator was with 0.74% related to the first nozzle (ALA) in the treatment of air-assisted velocity 4 m $s^{-1}$ without wind velocity and the third nozzle (LAL) 0.74% in the treatment of air-assisted velocity 7.5 m $s^{-1}$. But the first nozzle (ALA), with 0.26 percent related to the treatment of air-assisted velocity, and wind velocity of 2 m $s^{-1}$ was the lowest spraying quality indicator. Therefore, the spraying quality indicator in the third nozzle (treatment air-assisted velocity, and wind velocity of 4 m $s^{-1}$) with the highest and lowest amount of the solution and wind rate was 0.53%, but in the treatment of the lowest amount of the solution, the spraying quality indicator was obtained with 0.47%.

## 4 Conclusion

In the study of regression analysis with respect to explanatory coefficients above 60%, a small difference between the value predicted by the model and the actual value was found to indicate the desired regression models. Also in regression studies, among the three effective factors (nozzle type, air-assisted velocity, and wind velocity), the nozzle type with the highest coefficient of 0.62 (drift), 0.74 (deposition), 0.277(volume 50%), and 0.144(volume 90%), respectively, the most effective factor on the drift, the amount of the deposition and volume 50 and 90 percent media diameter were identified.

According to the results in the first nozzle in which the liquid came out of the middle and the air through the sides (ALA), the highest solution saturation and the lowest wind velocity were associated with the air-assisted velocity and wind velocity of 4 m $s^{-1}$, 121.51 L $ha^{-1}$, and 0.21% with spraying uniformity of 0.74%. In the second nozzle (LA), in the treatment of air-assisted velocity 2 m $s^{-1}$ and wind velocity of 4 m $s^{-1}$ with 114.69 L $ha^{-1}$, and 0.25% and 2.20% the maximum and minimum solution of the saturation rates, drift, and uniformity were achieved. The maximum and minimum amount of the solution and drift was obtained in the third nozzle (LAL) with values of 144.87 L $ha^{-1}$, and 0.06%, and also, resulted in the highest spraying uniformity with 0.42% for air-assisted velocity and velocity treatment while the wind velocity was at 4 m $s^{-1}$.

The mean volume of 50 and 90 % diameters, numerical mean diameter, and quality index for the first, the second, and the third nozzles were 0.90, 0.864, 0.331 mm, and 0.31%, on the first one, the values of 0.154, 0.382, 0.22 mm and 0.53% for the second nozzle, and reported values of 0.220, 0.311, 0.224 mm, and 0.53% for the third nozzle. According to the comparison of means of the interactive effects on the (Triple) nozzle type, air-assisted velocity, and wind velocity, it can be stated that among the three air-assisted tested nozzles, the third one (LAL) with the treatment of the air-assisted velocity and wind velocity of 4 m_$s^{-1}$ had the maximum amount of the deposition, the minimum amount of the drift, and uniformity in spray with 144.87 L_$ha^{-1}$, 0.06 % and 0.42 %, respectively.

## References

Al Heidary, M., J. P. Douzals, C. Sinfort, and A. Vallet. 2014. Influence of nozzle type, nozzle arrangement and side wind speed on spray drift as measured in a wind tunnel. In *International Conference of Agricultural Engineering*, Ref 0385. Zurich, Switzerland, 6-10 July.

Balsari, P., E. Gil, P. Marucco, M. Gallart, C. Bozzer, J., C. Lleop, and M. Tamagnone. 2014. Study and development of a test methodology to assess potential drift generated by air-assisted sprayers. In *Aspects of Applied Biology 122, Internattional Advances in Pesticide Applications*, 339-346.

Balsari, P., E. Gil, P. Marucco, J.C. van de. Zande, D. Nuyttens, A. Herbst, and M. Gallart. 2017. Field-crop-sprayer potential drift measured using test bench, effects of boom height and nozzle type. *Biosystems. Engineering*. 154: 3–13.

Chen, H., B.K. Fritz, Y. Lan, Z. Zhou, and J. Zheng. 2020. Overview of spray nozzles for plant protection from manned aircrafts: present research and prospective, *International of Journal Precison Agricultural Aviation*. 3. 2:1-12.

Dorr, G., J. Hanan, S. Adkin, A. Hewitt, C. O'Donnell, and B. Noller. 2008. Spray deposition on plant surfaces: a modelling approach. *Functional Plant Biology*, 35(10): 988-996.

Fox, R. D., R.C. Derksen, H. Zhu, R.D. Brazee, and S.A.A. Svensson. 2008. History of air-blast sprayer development and future prospects. *Transactions of the ASABE*, 51(2): 405–410.

Gao, G., K. Xiao, and Y. Ma. 2018. A leaf-wall-to-spray-device distance and leaf-wall- density-based automatic route-planning spray algorithm for vineyards. *Crop Protection*. (111):33-41.

Gil, E., M. Gallart, J. Llorens, and J. Llop. 2012. Determination of drift potential value (DPV) for different flat fan nozzles using a horizontal drift test bench. In *Power and Machinery. International Conference of Agricultural Engineering-CIGR-AgEng 2012: Agricultural and Engineering for a Healthier Life,*Valencia, Spain, 8-12 July.

Gil, E., J. Llorens, J. Llop, X. Fàbregas, and M. Gallart. 2013. Use of a terrestrial lidar sensor for drift detection in vineyard spraying. *Sensors*, 13(1): 516-534.

Gil, E., P. Balsari, M. Gallart, J. Llorens, P. Marucco, P. G. Andersen, X. Fàbregas, and J. Llop. 2014. Determination of drift potential of different flat fan nozzles on a boom sprayer using a drift test bench. *Crop Protection*, 56: 58-68.

Gil, E., M. Gallart, P. Balsari, P. Marucco, M. P. Almajano, and J. Llop. 2015. Influence of wind velocity and wind direction on measurements of spray drift potential of boom sprayers using drift test bench. *Agricultural and Forest Meteorology*, 202: 94-101.

Hilz, E., and A. W. P. Vermeer. 2013. Spray drift review: the extent to which a formulation can contribute to spray drift reduction. *Crop Protection*, 44: 75-83.

Jamar, L., Mostade, O., Huyghebaert, B., Pigeon, O., & Lateur, M. (2010). Comparative performance of recycling tunnel and conventional sprayers using standard and drift-mitigating nozzles in dwarf apple orchards. *Crop Protection*, *29*(6), 561-566.

Langkamp-Wedde, T., D. Rautmann, D. von Hörsten, and J. K. Wegener. 2020. Comparison of the drift potential of two application methods for the control of oak processionary moths with biocidal products in an oak avenue. *Science of the Total Environment*, 704: 135313.

Nuyttens, D., K. Baetens, M. De Schampheleire, and B. Sonck. 2007b. Effect of nozzle type, size, and pressure on spray droplet characteristics. *Biosystems Engineering*, 97(3): 333-345.

Nuyttens, D., M. De Schampheleire, W. Steurbaut, K. Baetens, P. Verboven, B. Nicolaï, H. Ramon, and B. Sonck. 2006. Experimental study of factors influencing the risk of drift from field sprayers, part 1, meteorological conditions. *Aspects of Applied Biology*, 77(2).

Safari, M., Z. Shamabadi, and A. Sheikhi. 2013. Comparison of Tractor air-assisted boom sprayer with conventional sprayers to control sunn pests in wheat production. *International Journal of Agriculture and Crop Sciences*, 5(4): 433-444.

Sayinci, B., and S. Bastaban. 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.

Seol, J., J. Kim, and H. I. Son. 2022. Field evaluations of a deep learning-based intelligent spraying robot with flow control for pear orchards. *Precision Agriculture*, 23(2): 712-732.

Teske, M. E., D. A. Wachspress, and H. W. Thistle. 2018. Prediction of aerial spray release from UAVs. *Transaction of ASABE*, 61(3): 909-918.

Tsay, J. R., L. S. Liang, and L. H. Lu. 2004. Evaluation of an air-assisted boom spraying system under a no-canopy condition using CFD simulation. *Transactions of the ASAE*, 47(6): 1887-1897.

Wang, X., X. He, C. Wang, Z. Wang, L. Li, and S. Wang. 2017. Spray drift characteristics of fuel powered single-rotor UAV for plant protection. *Transactions of the Chinese Society of Agricultural Engineering (Transactions of the CSAE)*, 33(1): 117-123. (In Chinese).