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DETERMINATION OF SOME SPRAYING CHARACTERISTICS OF DIFFERENT AIR INDUCTION NOZZLES

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Abstract: Although there are alternative methods of struggle against diseases, pests and weeds in agricultural production, chemical control method is widely preferred. The ability of the pesticide to show sufficient effect on the target surfaces depends on the correct functioning of the nozzles. In plant protection applications, it is necessary to make the pesticide in the appropriate nozzle type, spraying height, spraying pressure, forward speed and norm values. This study was carried out to determine the surface coverage, droplet frequency and volume median diameter of different air induction nozzles at different spraying heights and spray pressures. In the study; four different nozzles, three with air induction (ID 90-03 C, IDK 120-03, AITX B 8003) and one with hollow cone nozzle (TR 80-03), were used. This study conducted in field conditions. Two different spray heights (50 cm, 70 cm) and three different spray pressures (2 bar, 4 bar, 6 bar) were applied. As a result of the applications, the volume median diameter, droplet frequency and surface coverage were examined. Water sensitive papers and Image Tool for Windows V3 image processing program were used to determine the volume median diameter and surface coverage. The excel program was used to calculate the droplet frequency values. According to the results of the research, the highest surface coverage rate was achieved with 37.29% at IDK 120-03 nozzle at 70 cm spraying height and 6 bar spray pressure. The lowest surface coverage was obtained with the TR 80-03 nozzle at a spray height of 70 cm and pressure of 6 bar with 9.33%. The largest volume median diameter was 547.01 µm in AITX B 8003 nozzle and 256.60 µm in the smallest volume median diameter TR 80-03 nozzle. The highest droplet frequency is 74 (pcs / cm^2) at TR 80-03 nozzle with 50 cm spraying height and 2 bar spray pressure, while the lowest droplet frequency is 8 (pcs / cm^2) at 50 cm spray height and 2 bar spray pressure at AITX B 8003 nozzle was obtained.

Keywords: Air induction nozzle, Surface coverage, Volume median diameter, Water sensitive paper, Image processing

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1. Introduction

In recent years, there has been an increasing demand in the agricultural industries for precision agriculture and affordable tools and equipment to meet the demands of the current world population. It is important for farmers to increase productivity in agriculture and reduce production costs in order to minimize yield losses in crop production. For these purposes, the importance of agricultural mechanization is increasing day by day.

Despite the physico-mechanical, genetic, biological and biotechnical methods of controlling diseases, pests and weeds in agricultural production, chemical control is the most widely used method in the world and in our country. Pesticides are used in chemical control. Pesticide use is growing in Turkish agriculture, though it varies year to year. Due to the negative effects of pesticides on human health, environment and natural balance and increasing production costs, they should be applied more sensitively, carefully and with minimum pesticide loss (Dursun, 2000).

Both the safety and effectiveness of pesticide use are largely determined by the technical condition of the equipment used for application (Anonymous, 2020). Over the years, pesticides are becoming more specific in terms of application techniques by users in terms of the variability of environmental factors and adaptation to new technologies. Therefore, a higher standard in application technique is demanded. In pesticide applications, it is aimed to ensure homogeneous transport of the active substance to the target, retention on the target surface, minimization of variation in drug distribution and drift level, and maximum biological efficacy at the recommended dose. The design features and operating parameters of the sprayers used for this purpose affect the success of agricultural control (Çomaklı, 2017). Even in cases where spraying tools and equipment are selected correctly, the expected success cannot be achieved if spraying is not carried out with the correct pulverization characteristics (average drop diameters, drop frequency, surface coverage value) that will provide sufficient surface coverage. In spraying, it is necessary to minimize the damage to the natural balance while providing the highest effect of the pesticide on the target surface. This can be achieved by correctly selecting the pulverization characteristics that ensure that the pesticide is delivered to the target surface and placed there.

Achieving the desired success in terms of agricultural pest control application technique depends on the correct selection of equipment, pesticide, target surface and time. Although nozzles are one of the cheapest parts of sprayers, they have a very important effect in providing biological efficacy in the control of diseases, pests and weeds. The pesticide application efficiency varies depending on the nozzle type, drop diameter and pesticide distribution pattern. Diversity in sprayer can be achieved by selecting different nozzle types (Çelen, 2013) or pressure settings (Pearson and Reed, 1993).

Since 30% of the pesticide consumed cannot be delivered to the target surfaces, it causes economic losses and environmental pollution. Due to pesticide loses, the required homogeneity in spraying cannot be achieved. Studies show that there is an average of 25-30% crop loss in areas where plant protection procedures are not applied. In pesticide applications, the drop diameter values formed by the nozzles are known as important characteristics. Drop diameter has a direct effect on pulverization characteristics such as collection of drops on target surfaces, surface coverage and drop frequency. Image Processing Method is widely used to determine drop diameter values and surface coverage rate (Moor et al., 2000; Duran, 2012).

Image processing technique is used in many areas such as determination of drop size, drop frequency and surface coverage in pesticide applications. V3 Image Tool (UTHSCSA ImageTool) is used to determine drop diameters and surface coverage depending on spray pressure and spray height, which are effective parameters on drop diameter and surface coverage rate. Image analysis functions include dimensional (distance, angle, perimeter, area) and grey scale measurements (point, line and area histogram with statistics). The software has a multi-document interface (MDI) application that supports any number of windows (images) simultaneously (Anonymous, 2024a).

Water sensitive papers are used in image processing techniques, especially in the determination of volume median diameter and surface coverage. Water-sensitive papers are preferred because they are used in natural application conditions and allow their analyses to be performed later. Water-sensitive paper, which is a hard paper with a specially coated yellow surface, is coloured dark blue by liquid drops hitting it. Firstly, the papers are placed in the target area before spraying the liquid and collected after drying after the application. The collected water-sensitive papers are used to calculate volume median diameter and coverage rates (Anonymous, 2024b).

Nozzles working with air flow are more commonly known as pneumatic nozzles. This type of nozzles are used in air flow sprayers. The energy required for the disintegration of the liquid and the transport of the drops in air-flow nozzles is provided by the air flow (Yağcıoğlu, 2016).

Prevention of drift in pesticide applications is becoming more important day by day. For this purpose, as a result of research on different nozzle types, air suction nozzle types have become more preferred in recent years due to the advantages they provide in terms of drift. In these nozzle types, the liquid is mixed with the air sucked into the nozzle before leaving the nozzle. In this way, the drop diameter size increases and its drift by the wind (Çelen, 1998) can be significantly reduced. It should be known that nozzle types and spray height are the most important parameters that prevent entrainment and research on this subject is needed (Balsari et al., 2017). At the same time, the ability to form conical or fan beam is seen as the most important advantage of air suction nozzle types besides reducing drift (Çilingir and Dursun, 2010).

This study was conducted to determine the volume median diameter, surface coverage and drop iftfrequency of some nozzle types at different spray heights and spray pressures.

2. Materials and Methods

The field trials of the study were carried out in the trial areas of Bornova Agricultural Pest Control Research Institute of the Ministry of Agriculture and Forestry in 2020. The analyses and evaluations of the water-sensitive papers obtained from the trials were carried out at Ondokuz Mayıs University, Faculty of Agriculture, Department of Agricultural Machinery and Technologies Engineering. In the study; four different nozzles, three with air induction (ID 90-03 C, IDK 120-03, AITX B 8003) (Dafsari et al., 2021) and one with hollow cone nozzle (TR 80-03) were used for comparison. Water sensitive papers (WSP) (Syngenta) with dimensions of 26x76 mm were used as the sampling surface to determine the number of droplets, volume median diameter, and the surface coverage (Salyani et al., 2013; Açık, 2018). A Scanner device was used for scanning the water-sensitive papers. Lechler brand oil bath manometer was used to measure the spray pressures. The experiments were carried out with a suspended type field sprayer (Agrotek, Manisa-Türkiye) connected to a Massey Ferguson 3.050 model tractor (Figure 1). In addition, air velocity was measured with a digital thermo-anemometer with probe type during the trials.

Figure 1. Sprayer used in the trials

2.1. Statistical Analysis

Three different air suction nozzle types (ID 90-03 C, IDK 120-03, AITX B 8003) and TR 80-03 hallow cone nozzle type were used for comparison (Caner, 2007). The experiments were carried out with 4 replications at two different spray heights (50 cm, 70 cm) and three different spray pressure (2 bar, 4 bar, 6 bar) (Turgut, 2021). The water-sensitive papers used as sampling surface in the applications were placed on wooden wedges (Figure 2). These wedges were placed 3 metres apart, one at each nozzle level (Figure 3).

Figure 2. Wedges for WSP.

Figure 3. Placement of WSP on the wedges in the trial area.

The stain diameters (Figure 4) formed by the painted drops on water-sensitive papers (Çelen and Aktaş, 2000; Özyurt et al., 2022) were determined by analysing them with an image processing software (Fox et al., 2003). In addition, Fox et al., (2001) stated in their study that although there are many methods for determining the surface coverage, the most easily applicable method is the analysis with water-sensitive papers. Water sensitive papers were scanned with a scanner at 600 dpi and transferred to computer (Figure 5) in JPEG format (Jeon et al., 2011). They were analysed in computer environment with UTHSCSA Image Tool for Windows V3 image processing software. Stain diameters analysed on water-sensitive papers (Duran et al., 2013) were calculated by using the spread factor coefficients and volume median diameter (μm) (VMD) were calculated in excel computer program (Duran, 2012). Surface coverage (%) and droplet number (pcs/cm^2) values of the drops deposited on the water-sensitive papers scanned and saved in Tiff format in the image processing software (Zhu et al., 2011) were calculated.

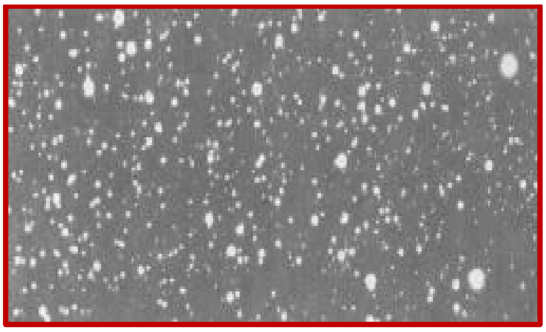

Figure 4. After the spraying WSP

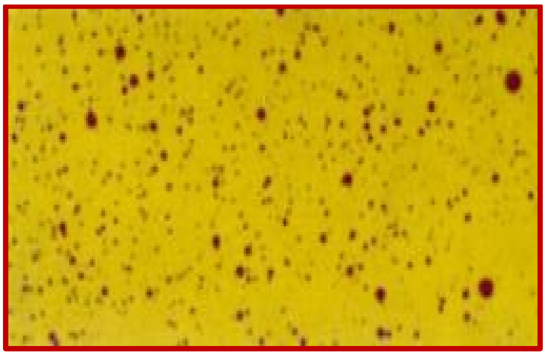

Figure 5. WSP on computer for analysis.

3. Results and Discussion

The nozzle types used in the experiments were applied at different spray heights and spray pressures at the constant forward speed and pesticide application rate. As a result of the applications, volume median diameter (VMD), droplet number (DS) and surface coverage (CR) values were reported (Güler et al., 2006).

3.1. Volume Median Diameter

The VMD values obtained as a result of the experiments are given in table 1. The largest VMD value of 547.01 μm was obtained with the AITX B 8003 nozzle. The smallest VMD value was obtained as 256.60 μm with TR 80-03 nozzle type.

Table 1. VMD values obtained in the trials

Nozzles		VMD (µm)
AITX B 8003	A	547.01
ID 90-03 C	B	461.68
IDK 120-03	B	446.89
TR 80-03	C	256.60

LSD= 27.89, CV = % 11.31, * The difference between values with different letters is significant (P < 0.05)

In general, for air suction nozzle types, larger VMD values were obtained at 50 cm spray height compared to 70 cm spray height applications (Table 2). Air induction nozzle types (ID 90-03 C and IDK 120-03) were classified as very coarse and AITX B 8003 nozzle type was classified as very coarse. In terms of VMD values obtained from air suction nozzle types, they were in the VMD class and in the group with the least risk of drift (ASABE, 2009). Hofman (1999) emphasised the importance of the correct selection of VMD for uniform spraying in his study to determine the drift and surface coverage relationships of drop diameters. In the hollow cone nozzle, the smallest VMD values were calculated as 277.57 µm for 50 cm and 235.63 µm for 70 cm at both spray heights compared to air suction nozzle types, respectively. Similarly, (Li et al., 2022) determined that the drop diameter decreased with increasing spray height, but not significantly.

Table 2. Spray height and VMD relationship

Nozzles	Spray height (cm)		VMD (µm)
AITX B 8003	50	A	568.15
AITX B 8003	70	B	525.86
ID 90-03 C	70	C	477.13
IDK 120-03	70	CD	457.09
ID 90-03 C	50	CD	446.23
IDK 120-03	50	D	436.70
TR 80-03	50	E	277.57
TR 80-03	70	F	235.63

LSD= 39.44, CV = % 11.31, * The difference between values with different letters is significant (P < 0.05)

3.2. Droplet Numbers

It was determined that the droplet frequency values obtained at different spray height and spray pressure applications were different depending on the nozzle types. When table 3 is analysed, the highest droplet frequency value of 74 (pcs/cm^2) was obtained at 50 cm spray height and 2 bar spray pressure value in TR 80-03 nozzle type. In air suction nozzle types, the highest droplet frequency values were generally obtained at 50 cm spray height and 2 bar spray pressure value. In this group, the highest droplet frequency values were obtained only in AITX B 8003 nozzle type at 50 cm spray height and 6 bar spray pressure.

In the applications where the spray height was 50 cm, the highest droplet frequency in air induction nozzles was 31 pieces/cm^2 in ID 90-03 C nozzle type in 2 bar spray pressure application and 31 pieces/cm^2 in IDK 120-03 nozzle type in the same application conditions. In the applications, it was determined that the droplet frequency values tended to decrease with the increase in spray pressure value when the spray height was 50 in ID 90-03 C and IDK 120-03 air induction nozzles. In the case where the spray height value was 70 cm, it was determined that the droplet frequency decreased with the increase in the pressure value. This situation was completely reversed in AITX B 8003 nozzle type. In air induction nozzle, 31 pieces/cm^2 droplet frequency was obtained in ID 90-03 C nozzle type. The same spray height and spray pressure values were obtained for the IDK 120-03 air induction nozzle. In AITX B 8003 nozzle, the highest droplet frequency value was obtained with 14 pieces/cm^2 at 50 cm spray height and 6 bar spray pressure applications.

Table 3. Spray height, Spray pressure and drop frequency relationship

Nozzless	Spray height (cm)	Spray pressure (bar)		Drop frequency (adet/cm^2)
TR 8003	50	2	A	74
TR 8003	50	4	B	60
TR 8003	70	2	B	60
TR 8003	50	6	C	43
TR 8003	70	6	CD	37
ID 90-03	50	2	DE	31
IDK 120-03	50	2	DF	31
IDK 120-03	70	6	EG	30
IDK 120-03	50	4	EG	27
IDK 120-03	50	6	EG	26
ID 90-03 C	50	6	EH	25
ID 90-03 C	50	4	EH	25
TR 8003	70	4	FH	24
ID 90-03 C	70	4	GI	23
IDK 120-03	70	4	HJ	18
IDK 120-03	70	2	HJ	18
ID 90-03 C	70	2	HJ	18
ID 90-03 C	70	6	IJ	17
AITX B 8003	50	6	JK	14
AITX B 8003	70	4	JK	14
AITX B 8003	50	4	JK	12
AITX B 8003	70	6	JK	12
AITX B 8003	70	2	K	9
AITX B 8003	50	2	K	8

LSD= 7.03, CV = % 18.01, * The difference between values with different letters is significant (P < 0.05)

3.3. Surface Coverage

As a result of the applications, it was determined that there were statistical differences between the surface coverage obtained according to the spray height and spray pressures in nozzle types. Similarly, spraying from the appropriate height affects the surface coverage as well as the uniformity of drop distribution. Lower spray height may cause uneven distribution uniformity (Dou et al., 2021). Wang et al. (1995) found that the effects of spray height on drop distribution uniformity were statistically significant.

In the applications where the spraying height was 50 cm and 70 cm in air induction nozzle types, the surface coverage were close to each other when the spray pressure were 6 bar. It was observed that surface coverage decreased with the decrease in spray pressure. Especially in 2 bar spray pressure applications, there was a decrease in the surface coverage in air induction nozzles (Table 4).

Table 4. Spray height, Spray pressure and surface coverage relationship

Nozzles	Spray height (cm)	Spray pressure (bar)		surface coverage (%)
IDK 120-03	70	6	A	37.29
IDK 120-03	50	4	AB	36.95
IDK 120-03	50	6	AC	36.19
ID 90-03 C	50	6	AD	35.64
ID 90-03 C	70	6	AE	35.39
AITX B 8003	50	6	AF	33.54
ID 90-03 C	50	4	AG	32.22
ID 90-03 C	70	4	AH	30.83
ID 90-03 C	50	2	BH	29.85
IDK 120-03	50	2	CH	29.47
AITX B 8003	70	4	DI	28.57
TR 8003	50	4	EI	28.16
TR 8003	50	2	EI	28.10
IDK 120-03	70	4	FI	26.66
AITX B 8003	50	4	GJ	25.92
AITX B 8003	70	6	GJ	25.67
IDK 120-03	70	2	HK	24.14
ID 90-03 C	70	2	IL	21.39
AIXT B 8003	50	2	IL	18.94
TR 8003	70	2	JL	18.87
AITX B 8003	70	2	KL	17.85
TR 8003	50	6	LM	15.81
TR 8003	70	4	M	9.74
TR 8003	70	6	M	9.33

LSD= 3.73, VK = % 19.87, * The difference between values with different letters is significant ($P < 0.05$)

Klotchkov et al. (1998) determined in their study that it is possible to reduce the losses in pesticide applications by 1.2-2.8% with the correct selection of spray height and spray pressure. In addition, Lardoux et al. (1998) investigated the effects of spray height, forward speed, nozzle type and nozzle position angles on surface coverage rate and found that these parameters were effective on surface coverage rate, evaporation and drift. (Pan et al., 2025) determined that drift increased with spray height in their study.

IDK 120-03 nozzle type, which is one of the air induction nozzle types, provided very close surface coverage at 4 and 6 bar spray pressure in 50 and 70 cm spray height applications. In this nozzle type, 36.95% surface coverage was obtained at 50 cm spray height and 4 bar spray pressure, while 36.19% surface coverage was obtained in 70 cm and 6 bar applications. The lowest surface coverage was obtained with 9.33 % at 70 cm spray height and 6 bar spray pressure at hollow cone nozzle (TR 8003). Chiu et al. (1999) reported that surface coverage could also be determined in their study in which they used water sensitive papers and image processing programme to determine pesticide losses. They also found that the surface coverage decreased when the spray height or forward speed was increased or the spray pressure was decreased.

In general, the highest surface coverage were obtained in applications where the spray height was 50 cm and the spray pressure was 6 bar for each nozzle type. In IDK 120-03 nozzle type, which is an air induction nozzle, 36.95 % at 4 bar spray pressure value at 50 cm spray height and higher surface coverage (36.19 %) was obtained compared to 6 bar (Table 4). There were cases where the spray pressure was low but the surface coverage was high. It can be said that these situations may be due to the fact that the trials were carried out under natural conditions during the trials and cannot be considered as a negative result since the values are close to each other. Açık (2018) conducted a study to determine the surface coverage and droplet distribution uniformity of some nozzle types at different spray heights and forward speed and determined that the surface coverage increased with the minimum level of spray height.

4. Conclusion

Although there are alternative control methods against harmful organisms (diseases, pests, weeds) in order to obtain the desired quality and quantity of products in agricultural production, chemical control method is widely preferred. In order to achieve the expected success in terms of agricultural pest control application technique, the pesticide, target surface and application time should be selected correctly together with the equipment to be used in the application. Nozzles used in sprayers have a significant effect on biological success when evaluated in terms of equipment.

In this study, volume median diameter (VMD), droplet frequency (DS) and surface coverage (SC) were analysed with four different nozzle types, three with air induction (ID 90-03 C, IDK 120-03, AITX B 8003) and one with hollow cone (TR 80-03), two different spray heights (50 and 70 cm) and three different spray pressure (2, 4, 6 bar).

The largest VMD was 547.01 μm for the AITX B 8003 nozzle with air induction. The smallest drop diameter was 256.60 μm in TR 80-03 nozzle with hollow cone nozzle. Considering the spray height, the largest VMD was 568.15 μm and 525.86 μm in AITX B 8003 nozzle at spray heights of 50 cm and 70 cm, respectively. In other air induction nozzles, 477.13 µm and 457.09 µm were obtained at 70 cm spray height in ID 90-03 C and IDK 120-03 nozzles, respectively. In TR 80-03 hollow cone, the highest VMD value was obtained with 277.63 µm at 50 cm spray height.

In both ID 90-03 C and IDK 120-03 nozzle types, the highest droplet frequency was 31 pieces/cm² in applications where the spray height was 50 cm and the spray pressure was 2 bar. In AITX B 8003 nozzle, the highest droplet frequency of 14 pieces/cm² was obtained in 50 cm spray height and 6 bar spray pressure applications. In TR 80-03 nozzle type, 31 pieces/cm² was obtained with a spray height of 50 cm and a spray pressure of 2 bar.

IDK 120-03 nozzle type provided the highest surface coverage rate with 37.29 % at 70 cm spray height and 6 bar spray pressure. For this nozzle type, 50 cm spray height and 4 bar spray pressure which provided 36.95% coverage rate, can be preferred. Air suction ID 90-03 C nozzle type provided the highest value with 35.64 % surface coverage at 50 cm spray height and 6 bar spray pressure applications. It can be said that this nozzle type can be preferred for 50 cm spray height and 4 bar spray pressure applications since it provided 32.22% surface coverage. AIXT B 8003 nozzle provided the highest surface coverage of 33.54 % in 50 cm spray height and 6 bar spray pressure applications.

The hollow cone nozzle (TR 80-03) used in the trials provided the highest surface coverage with 28.16 % at 50 cm spray height and 4 bar spray pressure.

During the trials, the tractor forward speed was selected as 3.85 km/h (=1.07 m/sec) and the average air temperature was 33 ^{0}C, relative humidity was 68% and wind speed was 3.24 km/h (=0.9 m/sec).

As a result, the most suitable values in terms of surface coverage, VMD and droplet frequency were obtained at different spray height and spray pressure applications. Considering the pesticide application quality and drift risk of air induction nozzle types in terms of VMD, surface coverage and droplet frequency, it is seen that the spray height is 50 cm and the spray pressure is 4 bar. In the hollow cone, it is concluded that when the spray height is 50 cm and the spray pressure is 4 bar, the appropriate value is reached in terms of surface coverage, VMD and droplet frequency.

Author Contributions

The percentages of the authors' contributions are presented below. All authors reviewed and approved the final version of the manuscript.

	H.D.	E.T.
C	70	30
D	80	20
S	90	10
DCP	60	40
DAI	70	30
L	50	50
W	70	30
CR	80	20
SR	80	20
PM	80	20
FA	60	40

C= concept, D= design, S= supervision, DCP= data collection and/or processing, DAI= data analysis and/or interpretation, L= literature search, W= writing, CR= critical review, SR= submission and revision, PM= project management, FA= funding acquisition.

Conflict of Interest

The authors declared that there is no conflict of interest.

Ethical Consideration

Ethics committee approval was not required for this study because there was no study on animals or humans.

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