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Spray Characterization of an Unmanned Aerial Vehicle for Agricultural Spraying

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Sustainability and higher efficiency in crop production are possible with the use of new technologies. The use of unmanned aerial vehicles brings many advantages both in terms of monitoring agricultural areas and pesticide applications. This technology allows us to detect diseases and damages in an early manner and apply them in areas that are not accessible by conventional sprayers. However, a lack of knowledge on how to use UAVs and what parameters need to be considered prevent the widespread use of drone technology in agriculture. This study established parameters for spraying with clean water using a DJI Agras 14 MG-1P (RTK) Unmanned Aerial Vehicle. Droplet distribution and droplet analyses were examined in the studies carried out at different heights (1.5, 2.0, and 2.5 m) and flow rates (10, 15, 20, 25, and 30 L/ha). Droplets were analysed using DepositScan. Coefficients of variation of droplet distribution tend to decrease with the increasing spray rate. The trials with the closest values to uniformity are spraying applications made with a flight height of 2 m. When we evaluate pesticide efficacy according to the number of droplets per unit area, insecticides and all herbicides can be effective at applications with flight heights of 1.5 and 2 m and spray rate of 20 L/ha. While all spraying is done with flight heights of 1.5 and 2 m and spray rates of 25 L/ha, fungicides are ineffective when applied from 2.5 m height. As a result, this study found the measurements made at 2 m altitude and 20 L/ha spray rate have the highest coverage rate and lowest drift potential.

Keywords: aerial spraying, drift, drone, droplet, spraying, surface coverage

INTRODUCTION

The rapid increase in the world's population causes people to worry about food sources. Increasing the yield per unit area will be possible to supply enough food sources for the world's population. Many researchers are focusing on new technologies to increase efficiency. Drones are one of the latest products of this technology. In addition, drone technology can be used effectively in farms, paddy fields, orchards and steep hillside fields that are hard to reach with conventional machinery (Yallappa 2017). Drone technology has found its place in many areas of agriculture. That has also strengthened over the years (Urbahs and Jonaite 2013; Celen et al. 2020).

Each add-on that is installed on drones expands their areas of use. While drone technology was costly for agricultural applications in its early years, more and more companies join the market every year. Due to their competition, drone technology has become affordable for farmers (Stehr 2015). That cost reduction can be between 20% and 90% by saving pesticides and reducing water use. (Garre and Harish 2018). Traditional remote sensing methods for monitoring agricultural pests are not effective in agriculture due to slow detection, high cost and low accuracy. Based on studies, drones can be used for remote detection and long-term monitoring of pests and their control.

There are significant losses in agricultural production due to pests and plant diseases. Pesticides and chemical fertilizers are used to increase the quality and yield of crop production and reduce losses. Drone technology is widely used in agriculture for applying pesticides. It is shown by many researchers that drone technology will be better than classical applications (Su et al. 2018). According to the World Health Organization, one million cases of poisoning occurred due to manual spraying applications. These health problems can be avoided using unmanned aerial vehicles (Mogili et al. 2018). Pharne et al. (2018) showed that pesticide-related diseases can be prevented by using autonomous drones for spraying chemicals. More areas could also be sprayed per unit time compared to conventional spraying methods. In a similar study, Spoorthi et al. (2017) showed that farmers could control a drone using an Android app; autonomous spraying operations could be done without human contact with the pesticide.

A visible problem when using the drone is the downward airflow generated by the propellers when spraying, which can disperse the liquid from the spray nozzles in the air and cause the pesticide to drift. For this reason, the propellers on the drone must be positioned in a drag-blocking manner (Sarghini and De Vivo 2017). The droplets sprayed from unmanned aerial vehicles are affected by a downward airflow (downwash effect) due to rotor movement (Tang et al. 2017).

Moreover, Zhang (2002) reported that the proportion of farmers using remote sensing technology in their operations did not reach even 1%. In addition, it has been determined that the farmers who adapt and use remote sensing use these technologies for yield monitoring of grains such as corn, wheat and barley. It is stated that innovative agricultural applications such as spraying planning are used extensively by farmers who produce fruits, vegetables and nuts. However, there are difficulties in using and developing drone technology since remote sensing is quite expensive, especially for developing countries.

Flight speed, flight height, the vertical distance of the spraying boom with rotors of UAV, the horizontal distance between the spray nozzles and the effects of these variables on residue and drift are studied. They concluded that two main parameters that affect drift are flight speed and altitude of the drone (Wen et al. 2019).

The modern agricultural spraying practices that we have seen frequently encourage farmers recently. This enthusiasm is crucial as it improves the farmers' perspective of technological developments. However, the spraying characteristics that must be set in drone applications are unknown. This unclarity raises doubts about drone spraying applications. The applications made without the knowledge also cause several legal cases. Studies focused on the advantages of aerial spraying applications are supporting drones. In addition, it should be determined which parameters should be used during the application. In this study, the droplet size and distribution of the spraying applications performed on different flight heights and spray rates were examined, then optimum values were determined.

Table 1. Trial planning.

Trial no.	Group	Height(m)	Rate (l/ha)	Code
1	A	1.5	10	A1
2	A	1.5	15	A2
3	A	1.5	20	A3
4	A	1.5	25	A4
5	A	1.5	30	A5
6	B	2.0	10	B1
7	B	2.0	15	B2
8	B	2.0	20	B3
9	B	2.0	25	B4
10	B	2.0	30	B5
11	C	2.5	10	C1
12	C	2.5	15	C2
13	C	2.5	20	C3
14	C	2.5	25	C4
15	C	2.5	30	C5

MATERIALS AND METHODS

This study was carried out in the trial fields of Tekirdag Namik Kemal University Faculty of Agriculture, Turkey, in November 2020. All trials were conducted at different times and in suitable weather types by checking meteorological conditions. Temperature and humidity were measured with Testo 605-H1 thermo-hygrometer, then wind speed values were measured with Lutron AM 4202 anemometer. All the measured values were recorded during applications. Sampling surfaces are placed in the area to be used for this purpose. Clean water was sprayed on sampling surfaces by the drone at three different flight heights (1.5, 2.0, and 2.5 m) and five different flow rates (10, 15, 20, 25, and 30 L/ha) (Fig. 1). All spraying trials were repeated three times. All sampling surfaces (water-sensitive papers) were collected, then droplet analysis was conducted. Trials are planned and encoded shown in Table 1.

Spraying Drone

The DJI Agras MG-1P (RTK- Real Time Kinematics) agricultural spraying drone was used during the trials. Specifications of the Agras MG1P drone are shown in Table 2. The spraying drone has 4 Teejet XR11001VS (Spraying Systems Co.) flat fan spraying nozzles with a beam angle of 110° installed on it (Fig. 2). After the field boundaries are set using the RC controller, the DJI software creates the route, then the drone flights autonomously follow the planned route. Following this route, the drone can apply 10 L of the chemical-water mixture to a 1 ha area in 10 min as long as there are

Fig. 1. DJI brand Agras MG-1P Drone.

Table 2. DJI brand Agras model agricultural drone specifications.

Properties	Parameters
Total Weight (kg)	9.7
Dimensions (m)	1460 × 1460 × 578 mm (arms unfolded, without propeller) 780 × 780 × 578 mm (arms folded)
Max Power Consumption (W)	6400
Cruise time (minutes)	20
Min Height On the Plant (cm)	150
Type and Number of Spray Nozzle	XR11001VS 4 pcs
Spray Nozzle Flow Rate (l/sec)	0.379
Load Weight (liters)	10
Spray Width (m)	4
Max Operating Speed (m/s)	7
Max Flight Speed (m/s)	12
Battery Capacity (mAh)	12000
Battery Weight (kg)	4

sufficient reserve batteries and a charging unit. The drone can adjust the flight speed and height while spraying even on uneven terrain with the help of the GPS and radar system. In addition, two pumps provide accurately and even spraying pressure for each spraying nozzle.

The Agras MG1-P model is equipped with microwave radars to adjust and control the flight height. This feature allows the spray height to be controlled. It keeps the spray height constant, especially when working in autonomous mode. Three high-precision microwave radars are placed on the front, under the rear shield and in the spray tank. Radars on the front and rear detect terrain and enable the aircraft to adjust its height approximately. The radar under the tank then provides high-precision flight height. When scanning radars, MG1-P can detect a land change, adjust its flight height and keep it constant on the plants. An external RTK system was also used to provide precise positioning since the trial area is relatively small.

The spraying system has three spraying modes in the form of forward spraying, backward spraying and complete spraying, with the pump that separately controls the front and rear nozzle pairs. The pressure and flow sensors monitor the spray speed in real-time, dynamically controlling the spray speed and rate during operation. Extended spray boom nozzles are preferred to take better advantage of downward airflows.

Desired flight height was first set on the DJI software. Also, during applications, the flight height of the drone was measured approximately using a wooden stick with 2.5 m length as a measuring tool. The flow rate of all four nozzles was measured according to ASTM E641-85, Method of Testing Agricultural Hydraulic and compared with the values read on the DJI software. In order to calibrate the spray nozzles, the drone was sprayed at 1.5 bar and 2.5 bar pressures, as can be seen in the Fig. 2, then the flow rates were measured. As a result of the measurements, approximately 1% differences were observed. As stated by Matthews (2008) and Celen (2012), spray nozzles are considered faulty when there is more than +/- 5% difference. As can be seen from the Fig. 2, there was no significant change in the flow rates of the spray nozzles.

For each parameter, a single pass was made by determining the drone route in the trial area. The drone started spraying 10 m before reaching the target area and stopped 10 m after the application had finished. In addition, the drone movement was planned to start 10 m from outside the area where the sampling surfaces are placed in the x-y direction (Fig. 3).

Application Area

The trials were conducted in the trial areas of Tekirdağ Namık Kemal University on the coordinates 40° 59''22' N 27° 34''54' E (Fig. 1). Sampling surfaces were placed on the 20 x 20 m² application area and clear tap water was used as a spraying solution. Spraying started from 10 m outside around the flight area and was completed 10 m away from the site (Fig. 3).

Droplet Size and Distribution

A total of 20 sampling surfaces were placed at equal intervals (5 m) in the trial area, then samples were collected for droplet analysis. Water-sensitive papers (WSP, 26 × 76 mm, Novartis, Syngenta Crop Protection, Basel, CH) were used for droplet analysis. They were scanned with a scanner at 1176 x 1176 pixel resolution, 600 dpi and transferred to the computer. Droplet analysis was carried out using DepositScan software, as described by Zhu et al. (2011).

	bar	DROP SIZE 80°	DROP SIZE 110°	CAPACITY ONE NOZZLE IN l/min	l/ha 50cm 4 km/h	5 km/h	6 km/h	7 km/h	8 km/h	10 km/h	12 km/h	16 km/h	18 km/h	20 km/h	25 km/h	30 km/h	35 km/h
XR8001 XR11001 (100)	1.0	F	F	0.23	69.0	55.2	46.0	39.4	34.5	27.6	23.0	17.3	15.3	13.8	11.0	9.2	7.9
	1.5	F	F	0.28	84.0	67.2	56.0	48.0	42.0	33.6	28.0	21.0	18.7	16.8	13.4	11.2	9.6
	2.0	F	F	0.32	96.0	76.8	64.0	54.9	48.0	38.4	32.0	24.0	21.3	19.2	15.4	12.8	11.0
	2.5	F	F	0.36	108	86.4	72.0	61.7	54.0	43.2	36.0	27.0	24.0	21.6	17.3	14.4	12.3
	3.0	F	F	0.39	117	93.6	78.0	66.9	58.5	46.8	39.0	29.3	26.0	23.4	18.7	15.6	13.4
	4.0	F	VF	0.45	135	108	90.0	77.1	67.5	54.0	45.0	33.8	30.0	27.0	21.6	18.0	15.4

Fig. 2. Properties of the spray nozzle used in drone (Teejet catalog 51 M).

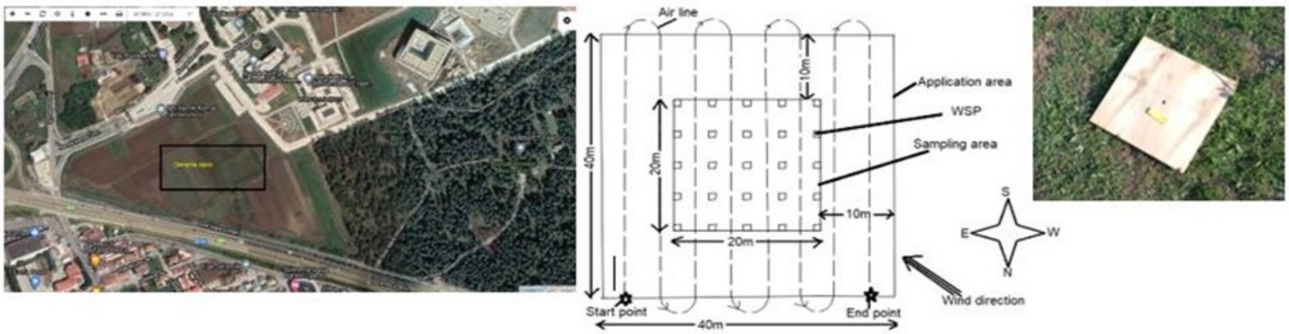

Fig. 3. The parcel where trials are conducted.

The results of droplet analysis were given in an MS Excel spreadsheet; the relative span value (NY) measures how varied the droplet sizes are in a given spray. It was computed using Eq. (1), where $D_{V0.9}$, $D_{V0.5}$, and $D_{V0.1}$ represent diameters that are larger by 90%, 50%, and 10% of all droplets, respectively. Only a single pass by the spraying drone was performed for all trials.

$$NY = (D_{V0.9}-D_{V0.1})/D_{V0.5} \qquad (1)$$

RESULTS AND DISCUSSION

A total of 15 trials were conducted (Table 1). Droplet analyses were performed in each trial. Trials were conducted under 18 - 20°C temperature, 69-71% humidity, and 1.8-3.1 m/s wind speed (Table 4). These meteorological conditions were deemed suitable for the application (Hanna and Schaefer 2008).

Spraying Characteristics Within The Application Area

While observing the change of the spray rate in applications made with a drone, droplet characteristics were examined. These analyses were evaluated separately. This study presents $D_{V0.1}$, $D_{V0.5}$, and $D_{V0.9}$ values, droplet count/cm^2 and coverage area values in flight height and spray rate changes.

The potential for drift depends on the volumetric median droplet size ($D_{V0.5}$) and the total spectrum of droplet sizes. The larger the $D_{V0.1}$ value, the less likely the droplets to drift. The larger the $D_{V0.9}$ value, the fewer droplets available to provide sufficient coverage (Chen 2020). The authors clearly stated that increasing droplet size could reduce droplet drift. These characteristics will give information about the size distribution of droplets. Table 5 shows the trial results for these values.

Table 4. Distribution of droplet size (μ) obtained in the applications.

Spray nozzle	$Dv_{0.1}$	$Dv_{0.5}$	$Dv_{0.9}$	Drop class
XR11001VS	180	355	616	Coarse (C)

In the spraying trials with 1.5 m flight height, $D_{V0.1}$, $D_{V0.5}$, and $D_{V0.9}$ values increased as the spray rate increased. $D_{V0.1}$ had a minimum μ of 113 and a maximum of 247 μ. For $D_{V0.5}$, these values were μ 195-516, while $D_{V0.9}$ was 316-1062 μ. Coefficients of Variation (CV) of spray rate values for $D_{V0.1}$ at the same height were calculated as 20.54, 8.38, 14.12, 18.26 and 16.53, respectively. For $D_{V0.5}$, it was 16.00, 12.07, 14.44, 18.55, 18.89. For $D_{V0.9}$, 20.45, 16.17, 16.45, 20.01, 24.19 values were detected. In the spraying trials with 2 m flight height, similar increases were observed in $D_{V0.1}$, $D_{V0.5}$, and $D_{V0.9}$ values as the spray rate increased. $D_{V0.1}$ values were the lowest at 105 μ and the highest at 212 μ. For $D_{V0.5}$, these values were 172-398 μ, while $D_{V0.9}$ was 289-816 μ. Coefficients of Variation (CV) of spray rate values for $D_{V0.1}$ at the same height were calculated as 15.95-12.43-15.52-8.99-11.07, respectively. For $D_{V0.5}$, it was 18.89-18.20-9.22-18.47-11.05, while $D_{V0.9}$ had values of 24.15-8.76-21.63-14.39-16.27. Fang et al. (1988) stated in their studies that, when the effects of drift and droplet accumulation are taken into account, the drone's flight speed in the field environment should be less than 6 m/s and the flight height should be 2 m above the plant canopy (Fig. 4).

Table 5. Coverage area rate obtained as a result of spraying (%).

Trial Group	Min	Max	Average	Std. Deviation	CV
A1	0,76	9,56	2,81	2,05	73,08
A2	1,88	12,03	4,32	2,07	47,97
A3	2,99	9,22	5,70	1,91	33,45
A4	3,31	23,51	11,35	5,89	51,84
A5	3,68	21,69	12,79	5,37	41,99
B1	0,72	4,26	2,19	1,01	46,29
B2	2,29	8,00	4,93	1,65	33,36
B3	2,10	11,74	5,49	3,06	55,75
B4	4,85	14,78	7,84	2,64	33,72
B5	2,40	12,43	6,43	2,72	42,30
C1	0,22	5,54	2,15	1,72	80,12
C2	1,54	8,37	3,91	1,72	44,03
C3	2,17	19,53	7,65	4,65	60,88
C4	3,53	13,08	7,63	2,55	33,40
C5	1,16	14,44	7,95	5,45	68,57

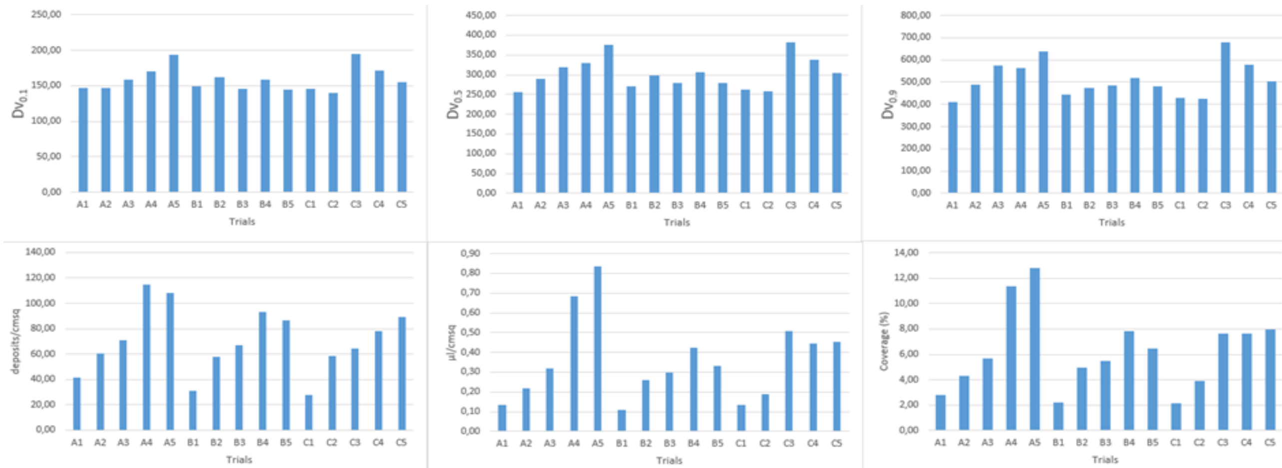

Fig. 4. Main analysis results on average spraying characteristics of research groups.

In the spraying trials with 2.5 m flight height, similar increases were observed in $D_{V0.1}$, $D_{V0.5}$, and $D_{V0.9}$ values as the spray rate increased. The lowest $D_{V0.1}$ obtained during the analysis was 116 µ, and the highest $D_{V0.1}$ was 240 µ. For $D_{V0.5}$, these values were 201-506 µ, respectively, while $D_{V0.9}$ was µ 288-944. Coefficients of variation (CV) of spray rate values for $D_{V0.1}$ at the same height were calculated as 20,45-16,17-16,45-20,01-24,19 respectively. For $D_{V0.5}$, it was 24.15-8.76-21,63-14.39-16.27. and for $D_{V0.9}$ 21.30-17.93-18.01 -19.88-13.95 (Fig. 3).

$D_{V0.1}$, $D_{V0.5}$, and $D_{V0.9}$ showed similar changes when looking at droplet sizes. There have been increases as the spray rate has increased. As the height increased, the value of $D_{V0.1}$ increased. When the changes were evaluated, the low variation coefficient was calculated in the trials with a flight height of 1.5 and 2.0 m. In addition, $D_{V0.9}$ was the highest in the spraying made at the flight height of 1.5 and 2.0 m. However, when looking at the variation coefficients, it can be said that the spraying application made at a flight height of 2.0 m provides a better-coverage area rate due to the low level of CV. Coefficients of Variation of $D_{V0.5}$ in all trials ranged from 9 - 18.5. The lower values indicate that the spraying performed is uniform. Furthermore, the decrease in $D_{V0.1}$ values as the flight height increased showed an increased risk of drift. In addition, the decrease in $D_{V0.9}$ values indicates that the number of droplets in cm² decreases for the adequate coverage area (Çelen 2012).

When the droplet size distributions were examined in the spraying area in all applications, it was generally observed that the size of $D_{V0.1}$ varies between 100-200 µ.

As the flight height decreased, there were areas with an increase towards 250 µ (A3-A4-A5) (at 1.5 m, 20 L/ha, 25 L/ha, and 30 L/ha spray rates). It was determined that drops up to 50 µ could shrink when the height increases (C1-C2) (at 2.5 m, 10 L/ha, 15 L/ha). Especially in the C4 application, drop sizes have shown very smooth distribution. The change in the droplet size distribution seen in both A5 and C3 applications was understood to be the effect of instantaneous winds.

When the $D_{V0.5}$ magnitude was examined in the trial area, different droplet sizes were determined at different heights. In the trials sprayed with 1.5 m flight height (A), droplet sizes ranged from 200 - 400 µ. A uniform distribution was generally observed in B applications (2 m height). In the trials sprayed with 2.5 m flight height and lower spray rate (C1), droplet sizes were between 200 and 400. There were differences in C2 and C3 applications due to unpredicted wind movements. Overlaps (overlapping droplets) were detected when the water-sensitive papers were observed. Since the DepositScan software cannot separate overlapping droplets, manual image processing was needed to eliminate droplets with overlap and these were not included in the analysis. In the C4 application, droplet sizes were detected in the 300-400 µ, then a homogeneous distribution was determined.

As the spray rate increased at an altitude of 1.5 m, the $D_{V0.9}$ drop size increased to 1000 µ. Low spray rate values were in the range of 400 - 600 µ. In some regions, there were overlapping droplets and droplet size increases due to the wind and the downwash effect of the drone. In C applications where height is increased, in other words, $D_{V0.9}$ drop sizes at an altitude of 2.5 m have fallen below 600 µ. Increases have occurred due to the impact of wind in C3.

C5 results are considered application failures because they do not give proper values. Not all trial results have been evaluated as they show that C% implementation will not matter.

The number of droplets/cm^2 has increased as the spray rate increases in volumetric soaking volume and surface coverage values. In addition, the height has increased and the number of drops falling on the ha unit area has decreased. In general, as the height increased, the wetting area expanded, but the lowest variation coefficient in residual homogeneity was detected at an altitude of 2 m. Volumetrically, the area soaked by droplets was higher at an altitude of 1.5 m.

In the applications made from 1.5 m altitude, it can be concluded that surface coverage percentages increased with the increasing spray rate (Table 6). Nevertheless, there were irregularities in the spray coverage rate for the applications made from 2 and 2.5 m altitudes. This irregularity can be associated with the increasing altitude, droplets were more exposed to wind effect and spray coverage rate decreased. In the same way, Coefficients of Variation have decreased along with the increasing spray rate. However, since the minimum variation coefficient is 33.45, it cannot be said that there is a uniform surface coverage ratio. In addition, the lowest Coefficients of Variation were obtained in the trials conducted at a flight height of 2 m. Wang et al. (2019) examined the effects of spray volume on UAV application efficiency and noted that better control of wheat diseases and insect pests was achieved when coarse droplet size and higher spray volume (> 16.8 L/ha) were used. The number of drops per square cm gives us the most important clue about the effectiveness of spraying. According to Syngenta Crop Protection AG, the minimum required drop densities according to pesticide varieties are given below in Table 7.

When Fig. 5 and 6 are examined, they show that $D_{V0.1}$ and $D_{V0.5}$ have values closer to their sum than $D_{V0.9}$. When the $D_{V0.9}$ average values are examined, the values spread over a broader scale between 410.15 and 677.61 are seen. The maximum value of CV was calculated on trial C1 and the minimum value of CV was calculated on trial B2. CV values ranged between 33% and 80%. Applications with 2 m have fewer CV values than the other altitudes (33 - 55%). These results show that the size range of the droplets tends to expand as the droplet diameter generated by the spray nozzles increases.

Table 8 compares the mean values of $D_{V0.1}$, $D_{V0.5}$, and $D_{V0.9}$ based on 15 trials. The relative span value had a range of 1.02 – 1.30 and a mean + SD of 1.16 + 0.08. When a very even distribution of spray is required, a lower relative span is generally desirable. The reason is that similarly sized droplets tend to behave similarly and follow similar trajectories. If there is a large spread in droplet sizes, particles can tend to group in certain areas depending on droplet size. This grouping is inevitable to a certain extent in all sprays, but with a larger relative span spray, the effect is more pronounced, resulting in less homogenous fluid distribution.

Table 6. Spray types according to the number of drops in the unit area (Syngenta Crop Protection AG).

Number of Drops/ cm^2	Spraying Application
20-30	Insecticide
20-30	Pre-Emergence Herbicide
30-40	Contact effective herbicide after emergence
50-70	Fungicide

Table 7. Relative propagation values calculated in all attempts.

Trial no.	$D_{V0.1}$	$D_{V0.5}$	$D_{V0.9}$	Relative Spread
1	147	256.8	410.15	1.02
2	146.85	290.3	487.45	1.17
3	158.1	318.15	573.15	1.3
4	169.9	329.4	564.25	1.2
5	193.32	376.68	637.63	1.18
6	149.05	270.16	442.74	1.09
7	161.79	297.05	473.26	1.05
8	146.26	278.74	485.26	1.22
9	158.53	305.63	518.68	1.18
10	144.53	278.89	480.11	1.2
11	145.45	262.3	430.35	1.09
12	139.63	257.37	423.32	1.1
13	194.17	381.33	677.61	1.27
14	171.05	336.89	578.95	1.21
15	155.2	304.2	504.4	1.15

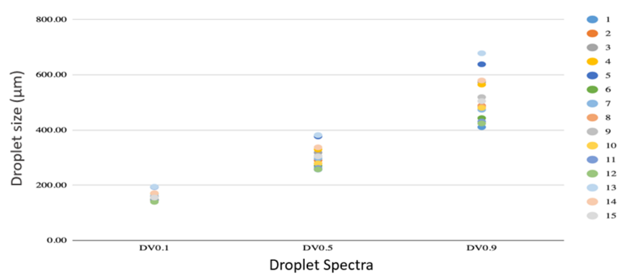

Fig. 5. Distribution of $D_{V0.1}$, $D_{V0.5}$, and $D_{V0.9}$.

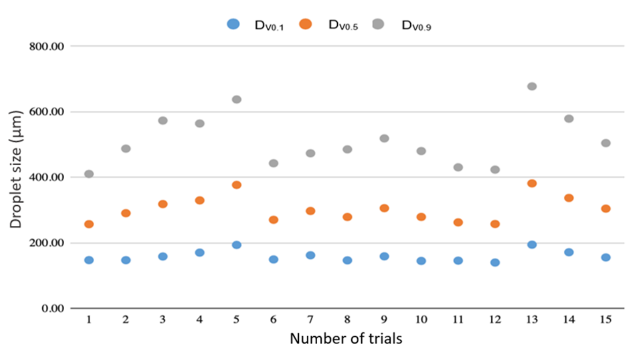

Fig. 6. Distribution of $D_{V0.1}$, $D_{V0.5}$, and $D_{V0.9}$ values by measurements.

CONCLUSION

Getting into the field with tractors for spraying operations during wet conditions can increase the risk of contamination via tractor tires. Spores of fungal diseases (fusarium, crown-rot disease) can stick to the tires and spread all over the field. Plants in contact with the soil contaminated by the tractor tires can cause an increased risk of pest attacks, thereby defeating the purpose of crop protection efforts. Chemical application using Unmanned Aerial Vehicles that will not contaminate the soil or cause damage to the crops compared to tractor spraying is more advantageous.

Many farmer operators do crop spraying using Unmanned Aerial Vehicles without proper knowledge or training. The success of the spraying application will depend on the operator's skill. Proper drone operation means less chemical use, less work time and reduced field traffic, but improper drone operation can cause time and material losses. This results ensured that pesticide applications using Unmanned Aerial Vehicles are carried out efficiently.

In this project, the relationship between the appropriate speed-flow rate-height of the drone and the plant and the pesticide applied in the sprayings was carried out using a spraying drone. How unmanned aerial vehicles should be used, in other words, how factors such as speed, height, residue distribution, drop size and distribution should be measured, was revealed as a result of the trial. In addition, droplet drift, an essential parameter in environmental pollution, is examined in applications with Spraying Drones. Residue and drop analyses at different flow rates and flight heights were evaluated separately. Thus, it was determined which parameters should be set in which application.

When the results were examined, the number of droplets in the unit area increased as the pesticide spray rate increased. Coefficients of Variation tend to decrease with the increasing pesticide spray rate. The trials with the closest values to uniformity are spraying applications made with a flight height of 2 m. When we evaluate drug effectiveness according to minimum drop densities, only insecticides can be effective in applications made at a 10 L/ha spray rate.

Insecticides and pre-emergence herbicides can be effective in applications at a 15 L/ha spray rate. Insecticides and all herbicides can be effective in applications with flight heights of 1.5 and 2 m and at a 20 L/ha spray rate. While all pesticides can be effective in applications with flight heights of 1.5 and 2m and at a 25 L/ha spray rate, fungicides are not effective in applications made at a flight height of 2.5 m. While all pesticides applied at 1.5 and 2m flight heights can be effective in applications made at a 30 L/ha spray rate, fungicides and contact-effective herbicides applied at a flight height of 2.5 m may not be effective. Due to the small volume of spray tanks, increasing the pesticide spray rate in drone applications will cause the pesticide to run out earlier. The drone will need extra energy with each take-off and landing. That leads the batteries to run out quickly. Therefore, it is necessary to determine a parameter in which all pesticides can be effective and maximum drone efficiency can be achieved.

Under these conditions, the lowest pesticide spray rate is sufficient for fungicide applications which require the most droplet density, determined as 20 L/ha. (Trials 3, 8, and 13) In applications performed at three different flight heights at a 20 L/ha pesticide spray rate, the highest homogeneity was observed at the flight height of 2 m regarding coverage area rates and average droplet diameters.

Results showed that the spraying application, which can achieve the highest homogeneity and effective results in all kinds of pesticides, is the spraying application with a flight height of 2 m and a spray rate of 20 L/ha. Future studies will be carried out using appropriate plant protection chemicals in agricultural plants to determine the effectiveness of plant protection.

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