Uluslararası Tarım Araştırmalarında Yenilikçi Yaklaşımlar Dergisi
International Journal of Innovative Approaches in Agricultural Research 2025, Vol. 9 (2), 110-126
https://doi.org/10.29329/ijiaar.2025.1321.5

Original article

Evaluation of Spray Drift in Agricultural Spraying Using Unmanned Aerial Vehicles

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Abstract

The use of unmanned aerial vehicles, especially in agricultural pesticide applications, has increased significantly. Under constant conditions of UAV operating parameters such as altitude, velocity, and spray fluid type, droplet drift is mainly affected by meteorological conditions. When spraying applications made from the ground and air are compared, the differences in the drift models revealed that this issue should be examined. In this study, the subject of drift in comprehensive project studies has been emphasised. For this purpose, drifts that occurred in the spraying application with clean water using a DJI Agras MG-1P (RTK) model agricultural spraying drone at different heights (1.5-2.0-2.5 m) and spray rates (10-30 l/ha) were evaluated. When the results of drift studies are examined, the effect of the wind created by the propellers increases the drift when the drone approaches the ground. Around the application area (20 m), residue and droplet distributions were detected almost close to the application area (40 droplets/cm2 at 0 m, 35 droplets/cm2 at 20 m around). The droplet size (VMD) was approximately 355 µm at the optimal conditions. Spray droplets have been observed to be carried up to a distance of 40 meters with the effect of the wind. As the height of flight increased in the applications, there were deteriorations in the distribution as the wetting area of the spray expanded. In general, in the application at a height of 2.0 m, the droplet distribution was uniform and the risk of spray drift was low.

Keywords: Spraying, Spray Drift, Drone, Droplet Coverage, Unmanned Aerial Vehicle.

Received: 03 November 2024 * **Accepted:** 08 June 2025 * **DOI:** https://doi.org/10.29329/ijiaar.2025.1321.5

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INTRODUCTION

The growing world population and decreasing agricultural land reveal the need to increase yield values per unit area. To achieve this, many studies have been published to find new technologies that can improve efficiency. Drones have developed rapidly in the last 20 years and are now being used in agricultural applications (Urbahs and Jonaite, 2013; Celen et al., 2020), such as in paddy fields, orchards, and steep slopes where it is difficult for humans to reach (Yallappa, 2017; Onler et al., 2023). Drones can also have add-ons that expand their usage area. Although drone technology is initially costly for agricultural applications, more companies are entering the market every year, making it less costly for farmers through competition (Stehr, 2015).

One of the main areas where drone technology is used in agriculture is the use of pesticides and chemical fertilisers to increase crop production and reduce losses. According to reports from the World Health Organisation, manual spraying of plants has resulted in one million poisoning cases. These health problems can be prevented by using unmanned aerial vehicles (UAVs) (Mogili et al., 2018). Pharne et al. (2018) conducted research showing that drones can prevent pesticide-related diseases in humans and save time by spraying more areas in a unit of time. Drones have also become popular among farmers who grow crops such as corn, wheat, and barley. Smart agricultural practices, such as spray planning, are used by farmers producing fruits, vegetables, and nuts (Zhang, 2002; Spoorthi et al., 2017).

The most important problem encountered in agricultural spraying using drones is the downward airflow created by drone propellers that can disperse the liquid and cause pesticide drift (Tang et al., 2017). To prevent drift, the position of the propellers on the drone should be placed in a way that prevents this (Sarghini and De Vivo; 2017). The flight speed, flight height, vertical distance of the spray boom to the rotors, horizontal distance between the spray nozzles, and their effects on residue and drift are studied. Researchers reported that drone spraying is greatly affected by application parameters such as droplet size, layout of nozzles, number of propellers flying speed, flying height and environmental conditions such as wind, temperature and humidity (Chen et al., 2022). Dengeru et al. (2022) reported concluded that larger droplets generated by the nozzles reduces the risk of drift. Wang et al. (2020), investigated the drift data under three different droplet sizes and different wind speeds, and formulated the relationship between the wind speed, droplet size and the drift distance. They stated that the formulation can be used to perform drift risk assessments.

Plants in contact with the soil are vulnerable to pests and diseases. Although chemical treatments are necessary, entering the field during humid and rainy weather can increase contamination. In these conditions, unmanned aerial vehicles (UAVs) are advantageous because they can spray without causing contamination and prevent damage to plants.

Many operators use UAVs in agriculture without proper knowledge, believing that simply flying the drone is enough. However, improper applications can lead to time and financial losses, as well as environmental pollution. Proper UAV applications can reduce chemical waste, complete jobs faster, and reduce field traffic. This project aims to enable the successful and efficient implementation of pesticides and chemical applications using UAVs.

This study aimed to characterise the risks of drift, droplet size, and droplet distribution under three different flight heights and two different spray rates in agricultural spraying using a drone equipped with flat fan nozzles and to conclude the most suitable application parameters for drone spraying applications.

MATERIALS and METHODS

Spraying Drone

Agras MG-1P RTK (Dà-Jiāng Innovation Science and Technology Co., Ltd.) agricultural drone (Figure 1) was used in the experiments, with its technical specifications detailed in Table 1.

Table 1. DJI Agras model agricultural drone technical specifications

Dimensions (m)	1460 × 1460 × 578 mm (with arms extended, without propellers)		
Total weight (kg)	44.751,00	**Max power consumption (W)**	6400
Flight time (minutes)	20,00	**Height above plant (cm)**	150
Number of rotors	8,00	**Load weight (liter)**	10
Spray nozzle type and number	XR11001VS 4 units	**Spray nozzle flow rate (l/s)**	0.379
Battery weight (kg)	4,00	**Max flight speed (m/s)**	12
Max working speed (m/s)	7,00	**Battery capacity (mAh)**	12000

The drone spray system used four XR11001VS spray nozzles (Figure 2), which are designed to resist pesticide drift and are recommended for use under windy conditions. With a sufficient battery and charging unit, the drone can apply 10 litres of chemical to 1 hectare in 10 minutes by entering field parameters into the controller. The drone can automatically adjust its flight on uneven terrain and adapt its spray speeds to the flight speed, while GPS and/or radar provide precise positioning and avoid overlap. Two pumps accurately spray the four nozzles.

Figure 1. DJI Agras MG-1P Drone

Nozzle	bar	Drop size 80°	Drop size 110°	Capacity one nozzle in l/min	l/ha 50 cm 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

Figure 2. Spray nozzle specifications used in the drone (Teejet Technologies, 2021)

The Agras MG1-P model is equipped with high-sensitivity microwave radars that enable control over spray height, keeping it constant especially when working autonomously. Three radars are located at the front, rear, and below the spray tank of the drone, allowing the aircraft to detect changes in terrain and adjust its height accordingly. In this study, RTK GPS was also used to prevent position deviations.

To ensure the desired flight height was maintained, it was first set in the DJI software, and during the application, the height was measured approximately using a long wooden stick. The spray rate of the four nozzles was measured according to ASTM E641-85, Method of testing agricultural hydraulics and compared with the values read in the DJI software.

The drone spray system has three spray modes (forward spray, backward spray, and full spray) with a pump that controls the front and rear nozzle pairs separately. A pressure sensor and flow sensor monitor the spray rate in real-time and dynamically control the spray rate and quantity during operation, while extended spray boom nozzles are utilised to maximise downward airflow.

Experimental Design and Conditions

This study was conducted in November 2020 at the Faculty of Agriculture, Tekirdağ Namık Kemal University, Turkey, on a field covered with wheat stubble. The experiments were carried out at various times while continuously monitoring meteorological conditions. A Testo 605-H1 thermohygrometer was used to measure and record temperature and humidity values, while a Lutron AM 4202 anemometer was employed to measure wind speed.

The study included six different treatments based on combinations of three flight heights (1.5, 2.0, and 2.5 meters) and two spray rates (10 and 30 l/ha), coded as D1 to D6 (Table 2). Each treatment was repeated three times under slightly varying environmental conditions to ensure data reliability, resulting in a total of 18 experimental runs. The trial codes (e.g., D1.1, D1.2, D1.3) represent individual replications.

Environmental parameters such as wind speed (1.8–3.1 m/s), humidity (69–71%), and temperature (18–20°C) were carefully monitored and remained within acceptable ranges for drift analysis (Table 1). Minor variations were considered negligible, and data from the replications were pooled for analysis. The primary focus of the evaluation was on the effects of flight height and spray rate on spray drift and droplet distribution

Table 1. Trial Conditions and Numbers

Trial No	Code	Wind speed (m/s)	Humidity(%)	Temperature
1	D1.1	1,8	69	18
2	D1.2	3,1	69	18,5
3	D1.3	2,2	70	19
4	D2.1	1,9	69	19,4
5	D2.2	2,9	71	20
6	D2.3	2,7	70	20
7	D3.1	2,5	69	19,8
8	D3.2	2,4	69	19,8
9	D3.3	2,4	70	19,7
10	D4.1	2,1	70	19,6
11	D4.2	1,9	71	19,6
12	D4.3	2	69	19,4
13	D5.1	3,1	70	19,5
14	D5.2	1,9	70	19,6
15	D5.3	2,6	70	19,8
16	D6.1	2,4	70	19,8
17	D6.2	2,3	71	19,7
18	D6.3	2,1	71	19,7

Table 2. Trial planning

Trial Number	*Height (m)*	*Spray rate (l/ha)*
D1	1,50	10.0
D2	1,50	30.0
D3	2,00	10.0
D4	2,00	30.0
D5	2,50	10.0
D6	2,50	30.0

Application Area

Sampling areas were selected by identifying an empty region as the application area (20 m x 20 m) (Figure 3). In addition, water-sensitive papers were placed outside the application area in a single row (100 m) with 20 m intervals from the border on the right, left, bottom, and top. The papers were fixed on 20×20 cm boards to prevent them from being affected by soil moisture. (Figure 3).

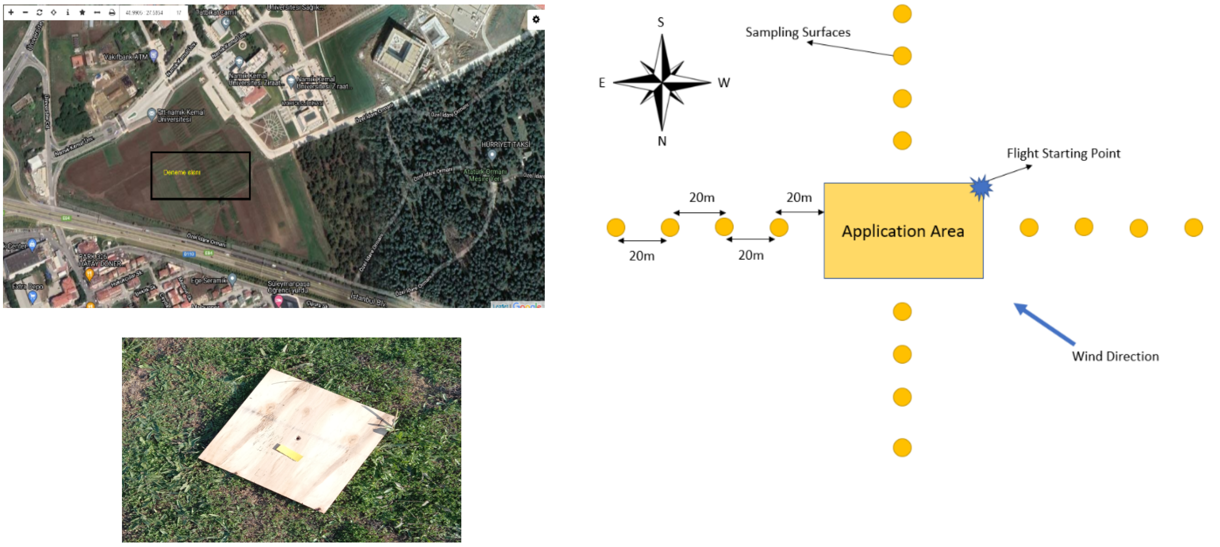

Figure 3. Trial area and trial map

Droplet Size Distribution

For droplet analysis, 20 sampling areas were evenly positioned outside the experimental region. Water-sensitive papers (WSP, 26 × 76 mm, Novartis, Syngenta Crop Protection, Basel, CH) were used for droplet analysis. The papers were scanned using a scanner with 1176 x 1176 pixel resolution and transferred to a computer. DepositScan software (Zhu et al., 2011) was used for droplet analysis. This software is capable of rapidly assessing the spray coverage distribution on water-sensitive paper and is suitable for on-site evaluation of spray quality, even under field operating conditions (Zhu and Sciarini, 2010). Before the measurements were performed, the software was calibrated with black and white paper as instructed in the user manual. Sample surfaces were scanned at 600 dpi resolution by adjusting the greyscale (Figure 4).

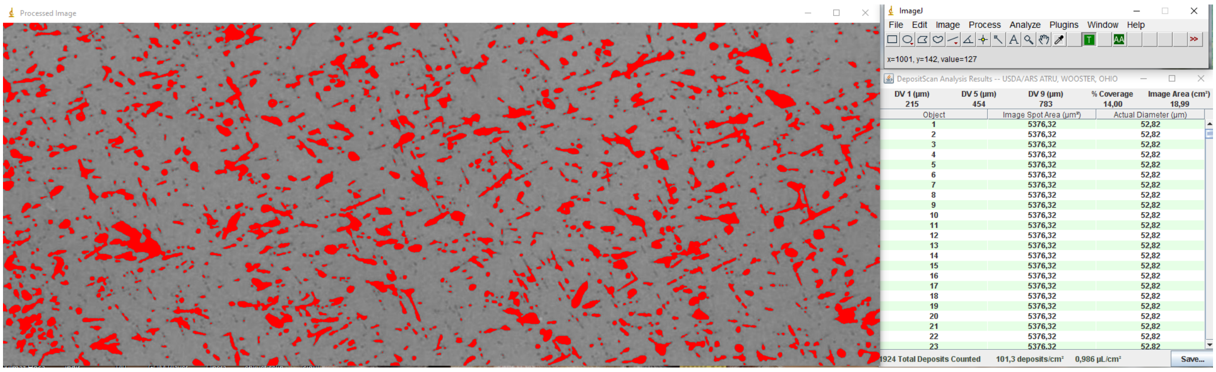

Figure 4. WSP analysis with DepositScan software

The droplet size distribution ($D_{v0.1}$, $D_{v0.5}$, and $D_{v0.9}$), the surface coverage of the selected area (%), the image area analysed (image spot area), individual droplet sizes (actual diameter), and the total droplet number were calculated. The software determined the threshold values in the shapefiles it created. The number of droplets on the paper and their diameter values were measured, and the coverage rates were calculated. It should be noted that the diameter values on water-sensitive papers are not actual diameter values, as the droplets spread on the paper. Therefore, the diffusion factor specified in the company's catalogue that produces water-sensitive papers, DepositScan, was taken into account during the analysis.

$$D_d = 1.06\ A_s^{0.455} \qquad (1)$$

D_d= original droplet diameter (µm)

A_s = Spot area (mm^2)

The image spot areas were converted to the actual diameter of the drop using Equation (1), which takes into account the spread factor calculated by the programme. The volumetric mean diameter values were then calculated from the corrected diameter values using Equation (2) in Microsoft Excel. Water-sensitive papers with more than 40% coverage were excluded from the calculation, as the image analysis programme loses sensitivity at higher coverage rates (Fox et al., 2003). The resulting volumetric median diameter ($D_{v0.5}$) values were used for the analysis. The droplets were classified according to the diameter range and the mean diameter values (di) for each range were calculated along with the number of droplets (ni) falling into each range.

$$D_{v0,5} = \sqrt[3]{\frac{\Sigma(n_i.d_i)^3}{n}} \qquad (2)$$

$D_{V0.5}$= volumetric median diameter (µm)

n_i = number of droplets in the diameter group

d_i = mean value of the diameter group (µm)

n = total number of droplets

Furthermore, the relative spread value (RS) was calculated using Equation (3) and reported along with the other measurements. It should be noted that all tests were conducted with a single pass of the drone.

$$RS: (D_{V0.9}-D_{V0.1})/D_{V0.5} \tag{3}$$

RESULTS and DISCUSSION

The study involved six trials (Table 2) and droplet analysis was performed in each trial.

The drift potential depends on the median droplet size (Dv0.5) and the distribution of the droplets. A higher value of $D_{v0.1}$ value reduces the probability of drift, whereas a higher value of $D_{v0.9}$ value results in fewer droplets for sufficient coverage (Celen, 2012). The test results for these values are shown in Table 4, which provides information on the pulverization structure.

Table 4. The droplet size (μ) distribution obtained in the applications (Özyurt et al. 2022)

Spray Nozzle	$Dv_{0.1}$	$Dv_{0.5}$	$Dv_{0.9}$	Droplet Class
XR11001VS	180	355	616	Coarse (C)

Spray drift measurements were made for each height and at min-max spray rates to determine the recommended height and flow rate parameters in practice. The largest droplet diameter value was found in $D_{v0.9}$ diameters in all areas, as is usually the case during spray drift measurements. Similar droplet sizes were determined at a distance of 20 meters from the last flight line parallel to the values obtained in the application area. This is because half of the 4.0 m wetting area of the drone is outside the application area. No traces were found on the sampling surfaces located at 40-60 and 80 meters, except for a single application (D1).

In the first application (D1), made at 1.5 m height and 10 l/ha spraying rate, the values of $D_{v0.1}$, $D_{v0.5}$, $D_{v0.9}$ values within the application area were measured as 119-215-359 μ, respectively (Figure 5). With the sampling surface placed at 20 meters, droplet sizes of 130-228-356 μ and 157-276-336 μ were measured in the NE direction, respectively. The wind was found to be effective in the N-S direction. The results showed that the droplets decrease with drift and some large droplets are formed because of overlapping. The surface coverage value in the application area was 2.5%, while the number of droplets per unit area was 41.3 droplets/cm^2. The surface coverage values at the 20th meter were 2.3% in the E-W direction and 0.48-2.81% in the N-S direction, respectively. At the 40th meter, 0.3-0.06% surface coverage was obtained in the N-S direction.

Figure 5. Charts showing results for the D1 trial (EW: East-West; NS: North-South)

In the second application (D2), made at a height of 1.5 m and a spray rate of 30 l / ha, the values of $D_{v0.1}$, $D_{v0.5}$, $D_{v0.9}$ values within the application area were measured as 141-290-474 µ, respectively. On the sample surface placed at 20 meters, droplets of 169-325-556 µ and 155-293-475 µ were measured in the N-S direction, respectively (Figure 6.). The wind was found to be ineffective in the N-S direction. The surface coverage value in the application area was 3.53%, while the number of droplets per unit area was 50.9 droplets/cm^2. Surface coverage values at the 20th meter were 0.11-3.9% in the E-W direction and 5.86-20.15% in the N-S direction, respectively. When the number of droplets per unit area was examined, it was 3.4-44.0 droplets/cm^2 in the E-W direction and 64.5-118.6 droplets/cm^2 in the N-S direction, respectively.

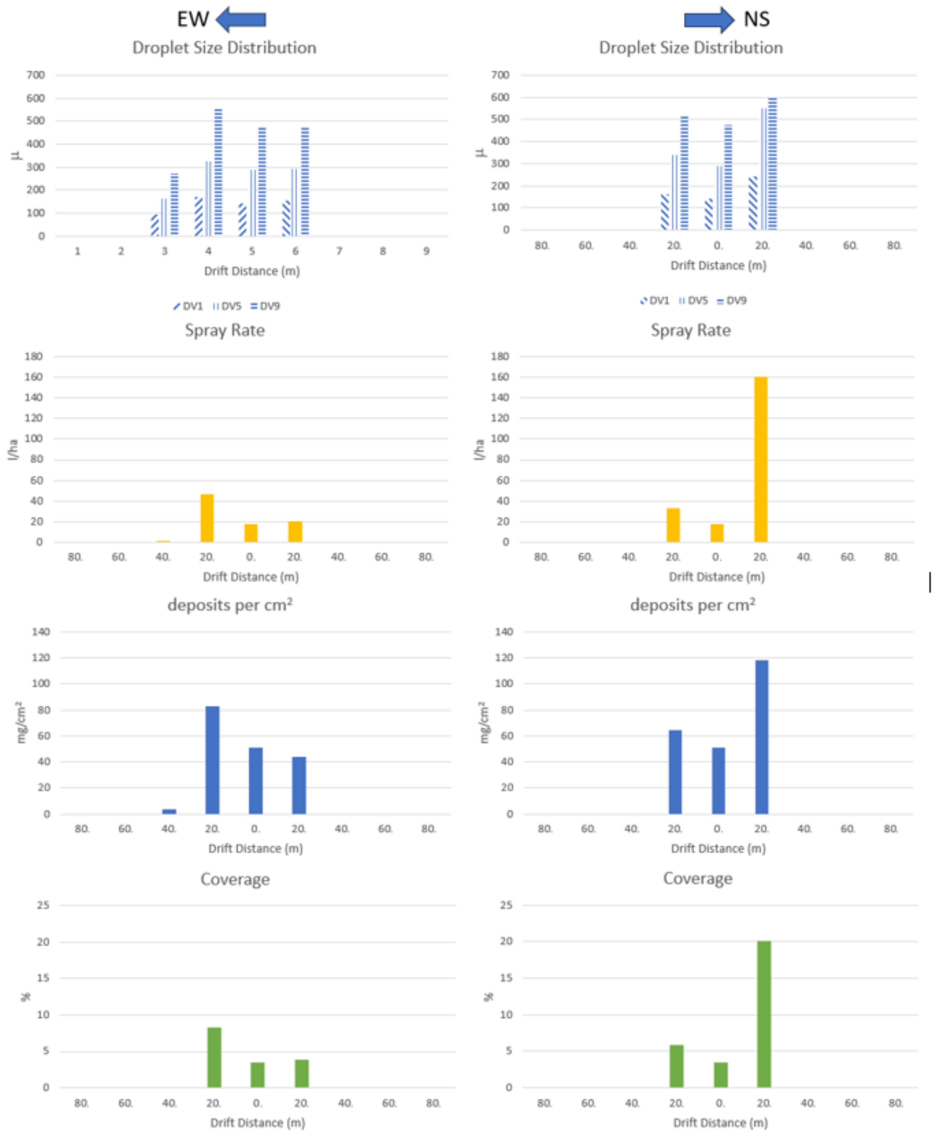

Figure 6. Graphs showing results for D2 trial (EW: East-West; NS: North-South)

It was observed that the propellers were more effective during low flight and instantaneous increases in wind speed affected the droplet drift. The size of the droplets increased with the spray rate, and the fact that the drone was close to the ground caused the propeller wind to be effective, resulting in droplets reaching up to 40 m away. Wind caused the droplets to collect on one side and overlap. Figures 5 and 6 provide detailed data for the D1 and D2 applications, respectively.

The carrying effect of the wind caused by drone propellers increases when the application is made at a height of 1.5 m. If the spray rate also increases along with the height, there is a higher risk of drifting the droplets to longer distances. When comparing the sample surfaces of both applications (D1-D2), there was a great overlap.

In the application of D3 (2.0 m height and spray rate of 10 l/ha spray rate), the droplet sizes ($D_{v0.1}$, $D_{v0.5}$, $D_{v0.9}$) were 130-240-416 µ, respectively, within the application area. On the sample surface placed at 20 meters, droplets of 155-324-575 µ and 150-287-496 µ were measured in the NE direction, respectively. In the N-S direction, droplet sizes of 188-354-645 µ and 157-301-440 µ were detected, respectively, at the 20th meter, and at the 40th meter, droplet sizes of 113-175-310 µ were determined in the N-S direction. It was observed that the wind had an effect in the N-S direction. The spray rate value in the D3 application was 8.6 l/ha in the application area, while 11.1-4.3 l/ha at 20 meters in the W direction. At the 40th meter, there were only detections in the N-S direction. The spray rate value, which was 81.4-13.9 l/ha on the 20th meter, decreased to 0.6 l/ha in the N-S direction on the 40th meter. The surface coverage value in the application area was 1.9%, and the number of droplets per unit area was 30.2 droplets/cm². When evaluated in terms of drift, the surface coverage values at the 20th meter were 1.99-0.83% in the NE direction and 13.55-2.69% in the N-S direction, respectively. At the 40th meter, 0.16% surface coverage was obtained in the N-S direction. When the number of droplets per unit area is examined, it is 23.6-10.0 droplets/cm² in the EW direction and 14.6-30.7 droplets/cm² in the N-S direction, respectively. At the 40th meter, 3.5 droplets/cm² were detected. According to the directional distribution shown in Figure 7, a greater spray drift was observed in the North-South (N-S) direction, which corresponds to the prevailing wind direction during the experiments. In contrast, the East-West (E-W) direction showed lower drift distances and droplet deposition values. These findings highlight the influence of wind direction on drift patterns and confirm the importance of accounting for meteorological conditions when planning UAV spraying operations.

Figure 7. Graphs showing the results for the D3 trial (EW: East-West; NS: North-South)

The D4 trial involved applying a 30 l/ha spray from a height of 2.0 m. When examining the drift, the values of $D_{v0.1}$, $D_{v0.5}$, and $D_{v0.9}$ values were found to be 150-285-587 µ within the application area. At the 20th meter in the E-W direction, 138-286-437 µ and 143-237-385 µ were determined, while in the N-S direction, 212-450-781 µ and 191-338-537 µ were found. The spray rate in the application area was 31.5 l/ha, with 6.6-5.9 l/ha in the E-N direction and 91.3-57.1 l/ha in the N-S direction at the 20th meter. It is believed that this increase in the N-S direction was caused by the wind. The size of the droplets increased with the spray rate. Surface coverage was 6.04% in the application area, with 78.8 droplets/cm^2. At the 20th meter, the surface coverage was 1.35-1.28% in the E-W direction and 13.02-74.4% in the N-S direction. The number of droplets per unit area was 19.4-17.3 droplets/cm^2 in the E-W direction and 97.6-74.4 droplets/cm^2 in the N-S direction. Accumulation and overlap were observed in the droplets in the drift direction. Data for the D4 application are given in Figure 8.

Figure 8. Graphs showing the results of the D4 trial (EW: East-West; NS: North-South)

The application of D5 was carried out at a height of 2.5 m with a spray rate of 10 l / ha. $D_{v0.1}$, $D_{v0.5}$, and $D_{v0.9}$ values were 138-244-369 µ within the application area. On the sample surface placed at 20 meters, droplets of 128-218-350 µ and 141-261-452 µ were measured in the E-W direction, while in the N-S direction, 187-343-500 µ and 133-211-381 µ were detected. The spray rate in the application area was 12.2 l/ha, with 8.1-5.8 l/ha in the E-W direction at the 20th meter, and 12.3-4.9 l/ha in the N-S direction. The surface coverage was 2.7% in the application area, with 39.2 droplets/cm^2. At the 20th meter, the surface coverage was 1.92-1.2% in the E-W direction and 2.07-1.17% in the N-S direction. The number of droplets per unit area was 31.2-16.5 droplets/cm^2 in the W direction and 17.3-19.1 droplets/cm^2 in the N-S direction. Data on the D5 application are given in Figure 9.

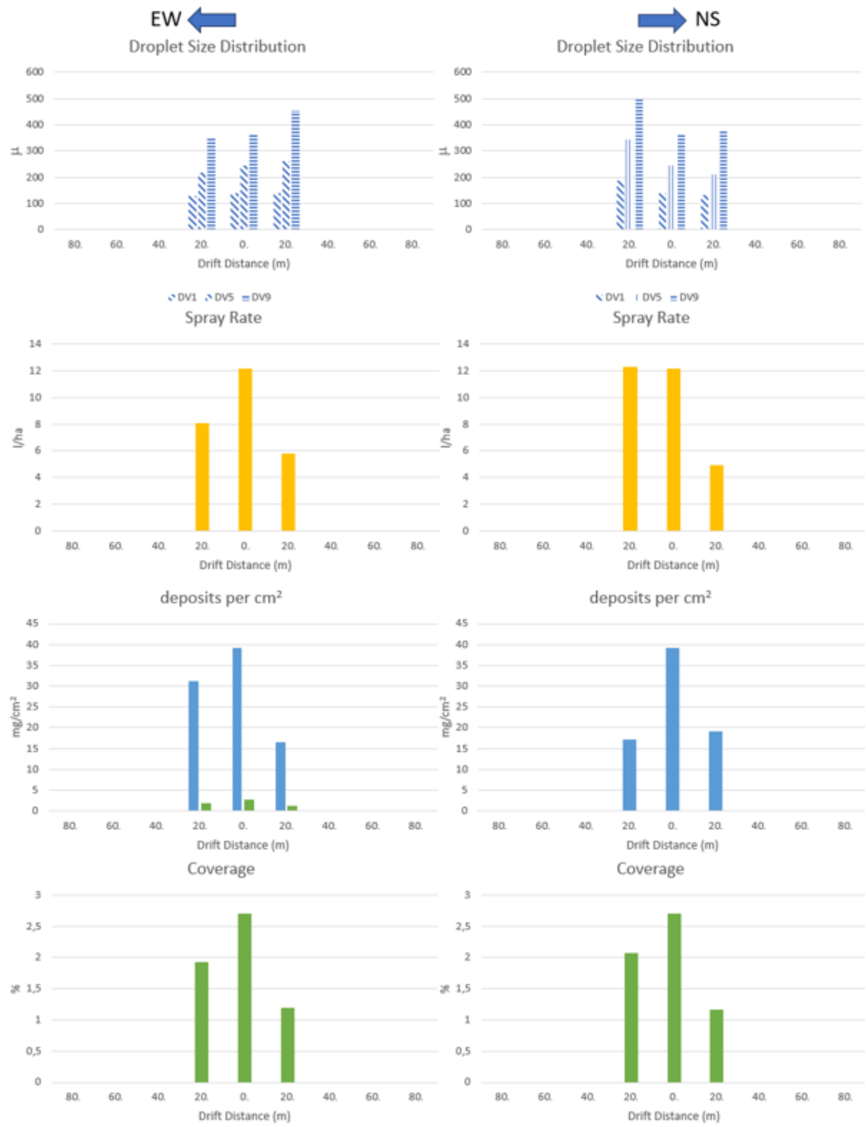

Figure 9. Graphs showing the results of the D5 trial (EW: East-West; NS: North-South)

In the application carried out at a spray height of 2.0 m, the values of $D_{v0.1}$, $D_{v0.5}$, and $D_{v0.9}$ values were found to be 165-338-661 µ, respectively, within the application area. On the sampling surfaces placed 20 meters apart in the E-W direction, droplet sizes of 152-300-497 µ and 150-265-422 µ were measured, respectively. In the N-S direction, droplet sizes of 184-385-660 µ and 163-320-570 µ were measured on the sampling surfaces placed 20 meters apart. While the spray rate was determined to be constant within the application area, the spray rate values on the 20th meter were found to be 31-14.8 l/ha and 71.2-35.4 l/ha in the EW and N-S directions, respectively. This increase in the N-S direction is believed to be due to increased drift caused by wind. Furthermore, as the flight height increases, the wetting area expands, resulting in higher spray rate values due to overlap. An increase in spray rate also leads to an increase in droplet size.

When examining the surface coverage values, the surface coverage value in the application area was found to be 10.82%, while the number of droplets per unit area was 115.5 droplets/cm^2. In terms of drift, the surface coverage values at the 20th meter were found to be 5.94-3.03% and 11.37-6.55% in the E-W and N-S directions, respectively. The number of droplets per unit area was found to be 69.2-38.4 droplets/cm^2 in the E-W direction and 99.8-72.9 droplets/cm^2 in the N-S direction. Figure 10 provides data on the D6 application.

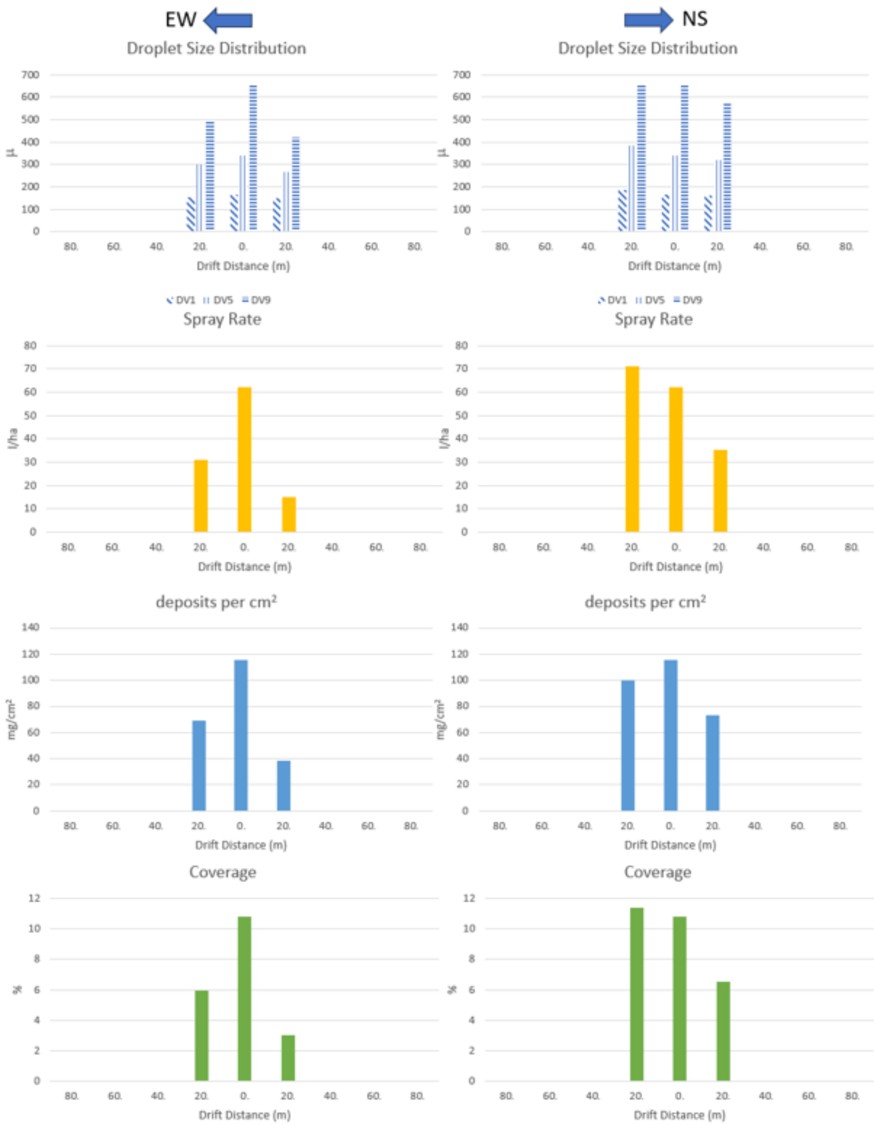

Figure 10. Graphs showing results for trial D6 (EW: East-West; NS: North-South)

CONCLUSION

This study characterises the factors that affect the risk of spray drift generated by spray UAVs, such as flight height and spray rate. The study evaluates the analysis of residues and droplets at different spray rates and heights to identify which parameters should be followed in specific applications.

The number of droplets per unit area increases with the spray rate, and the coefficients of variation tend to decrease as the spray rate increases. Spraying from a height of 2 meters yields the closest values to uniformity. Residue and droplet distributions are detected around the application area of 20 meters. Spray droplets can be carried up to 40 meters by the wind. As the flight height increases, there are deteriorations in the distribution due to the expanding wetting area of the spray. In these application conditions, appropriate droplet diameter, surface coverage and droplet frequency values were obtained. At the same time, drift was at a minimum level. As a result suggested flight parameters for the spraying drone with 6 rotors and 4 flat fan nozzles are 2 meters flight height and 30 l/ha spray rate.

Acknowledgement

This work was supported by the Research Fund of Tekirdağ Namik Kemal University. Project Number: NKUBAP. 03.EÖAYP.20.255

REFERENCES

Celen, I. H. (2012). Tarımsal Mücadelede Püskürtme Memeleri (Spray Nozzles in Plant Protection Applications) (1st ed.). Toprak Ofset. ISBN: 978-605-86370-0-9. [in Turkish].

Celen, I. H., Onler, E., & Ozyurt, H. B. (2020). Drone technology in precision agriculture. In Academic Studies in Engineering Sciences (pp. 121–150). Livre de Lyon. ISBN: 978-2-38236-050-7.

Chen, P., Douzals, J. P., Lan, Y., Cotteux, E., Delpuech, X., Pouxviel, G., & Zhan, Y. (2022). Characteristics of unmanned aerial spraying systems and related spray drift: A review. Frontiers in Plant Science, 13, 870956.

Dengeru, Y., Ramasamy, K., Allimuthu, S., Balakrishnan, S., Kumar, A. P. M., Kannan, B., & Karuppasami, K. M. (2022). Study on spray deposition and drift characteristics of UAV agricultural sprayer for application of insecticide in redgram crop (Cajanus cajan L. Millsp.). Agronomy, 12(12), 3196.

Fox, R. D., Derksen, R. C., Cooper, J. A., Krause, C. R., & Ozkan, H. E. (2003). Visual and image system measurement of spray deposits using water-sensitive paper. Applied Engineering in Agriculture, 19, 549–552.

Hanna, M., & Schaefer, K. (2008). Factors influencing pesticide drift. Ames, IA: Iowa State University Extension and Outreach. Retrieved from https://store.extension.iastate.edu/product/Factors-Affecting-Pesticide-Drift

Mogili, U. R., & Deepak, B. B. V. L. (2018). Review on application of drone systems in precision agriculture. Procedia Computer Science, 133, 502–509. https://doi.org/10.1016/j.procs.2018.07.063

Onler, E., Özyurt, H. B., Şener, M., Arat, S., Eker, B., & Çelen, İ. H. (2023). Spray characterisation of an unmanned aerial vehicle for agricultural spraying. Philippine Agricultural Scientist, 106(1), 39–46.

Pharne, I. D., Kanase, S., Patwegar, S., Patil, P., Pore, A., & Kadam, Y. (2018). Agriculture drone sprayer. International Journal of Recent Trends in Engineering & Research, 4(3), 181–185.

Sarghini, F., & De Vivo, A. (2017). Interference analysis of a heavy-lift multirotor drone flow field and transport spraying system. Chemical Engineering Transactions, 58, 631–636.

Spoorthi, S., Shadaksharappa, B., Suraj, S., & Manasa, V. K. (2017). Freyr drone: Pesticide/fertilizer spraying drone—an agricultural approach. In 2017 IEEE 2nd International Conference on Computing and Communications Technologies (ICCCT) (pp. 252–255).

Stehr, N. J. (2015). Drones: The newest technology for precision agriculture. American Society of Agronomy, Natural Sciences, 44(1), 89–91.

Tang, Q., Zhang, R. R., Chen, L. P., Xu, M., Yi, T. C., & Zhang, B. (2017). Droplet movement and deposition of an eight-rotor agricultural UAV in downwash flow field. International Journal of Agricultural and Biological Engineering, 10(3), 47–56.

Urbahs, A., & Jonaite, I. (2013). Features of the use of unmanned aerial vehicles for agriculture applications. Aviation, 17(4), 170–175.

Wang, G., Han, Y., Li, X., Andaloro, J., Chen, P., Hoffmann, W. C., Xiaoqiang, H., Shengde, C., & Lan, Y. (2020). Field evaluation of spray drift and environmental impact using an agricultural unmanned aerial vehicle (UAV) sprayer. Science of the Total Environment, 737, 139793.

Yallappa, D., Veerangouda, M., Maski, D., Palled, V., & Bheemanna, M. (2017). Development and evaluation of drone mounted sprayer for pesticide applications to crops. In 2017 IEEE Global Humanitarian Technology Conference (GHTC) (pp. 1–7).

Zhang, N., Wang, M., & Wang, N. (2002). Precision agriculture—a worldwide overview. Computers and Electronics in Agriculture, 36(2), 113–132.

Zhu, H., & Sciarini, S. M. (2010). DepositScan manual: Portable scanning system for spray deposit qualification. USDA-ARS Application Technology Research Unit.

Zhu, H., Salyani, M., & Fox, R. D. (2011). A portable scanning system for evaluation of spray deposit distribution. Computers and Electronics in Agriculture, 76, 38–43.