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Evaluation of DJI AGRAS T30, Airplane, and Ground Sprayer Spray Deposition on Tassel-Stage Corn

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Abstract

Mid- to late-season crop protection in tall crops like corn often relies on aerial spraying, including with unmanned aerial vehicles (UAVs). However, information on UAV spray consistency remains limited. This study compared spray depositions from a DJI Agras T30 UAV, airplane, and ground sprayer on tassel-stage corn to simulate fungicide applications, while assessing the influences of key UAV operational parameters and the use of drift reducing agent (DRA). At the Alabama site, UAV applications without DRA increased spray dye concentration by 145.8% on upper leaves and 51.1% on ear leaves compared with airplane applications at 18.7 L ha^{-1}. DRA 1 reduced upper leaf deposition, but both DRAs improved ear leaf deposition relative to no DRA and airplane treatments. UAVs without DRA and airplanes showed similar variability in dye concentration, while DRA use enhanced deposition uniformity. At the Georgia site, no treatment differences were found on ear leaves, but UAV and ground sprayer treatments produced higher upper leaf deposits than airplane application. Increasing UAV swath by 1.5 m at 2.4 m height reduced deposition, while a 4.6 m swath increased it, regardless of altitude. Overall, results suggest that downwash from UAV propellers enhances spray deposition within the crop canopy, and DRAs further improve this effect and influence spray uniformity. Additional studies on UAV spray parameters and droplet size are needed to better understand downdraft influence.

Keywords: DJI Agras T30; airplane; ground sprayer; drift reducing agent (DRA); spray parameters

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1. Introduction

Corn (*Zea mays* L.) is the leading agricultural commodity in the United States, accounting for 32% of total global production [1]. Effective management of fungal diseases in corn is critical for ensuring food security and maintaining high crop yields. Diseases such as gray leaf spot, southern rust, fusarium ear rot, and diplodia ear rot can cause yield losses up to $18.99 per acre in the Southern U.S. [2]. These pathogens predominantly infect lower and mid-canopy leaves or other structures within the ear zone, where complex canopy architecture can limit fungicide active ingredients to these infection sites. Consequently,

effective disease suppression relies not only on application timing, but also on sufficient spray droplet coverage within the upper canopy and at the ear leaf level. Previous studies have shown that applying fungicides during the corn tasseling stage is one of the most effective timings, resulting in an average increase of seven bushels per acre compared to non-treated fields [3,4]. At this growth stage, corn plants have reached considerable height. As a result, pesticide applications using conventional ground-based spray methods may physically damage the plants [5].

To address this challenge, aerial application is one of the solutions for mid- to late-season fungicide application in corn. With advancements in technology, sprayer unmanned aerial vehicles (UAVs) have emerged as a promising solution. This technology offers several advantages, such as higher efficiency, adaptability, and maneuverability across diverse terrain conditions, as well as reduced water and chemical usage [5–7]. Prior studies demonstrated that the use of UAVs can enhance spray deposition and coverage on wheat compared to ground sprayers, possibly due to the downwash force generated by UAV propellers [8]. The downwash effect is generated when the propellers are spinning, created by the difference in pressure between the propellers' blades [9]. This airflow promotes the opening of the upper canopy, thereby facilitating droplet penetration into lower canopy layers, which are often difficult to reach with standard ground-based applications operating at higher spray volumes [9–12].

Despite the benefits, fungicide application by this technique is significantly influenced by several operational spray parameters, such as spray height, speed, droplet size, tank size, etc. [9,13]. Previous studies have demonstrated that flight altitude and speed can affect spray performance and the intensity of the downwash airflow; specifically, increased flight altitude prolongs droplet fall time, weakens downwash effect, and reduces product penetration within the canopy [14,15]. Additionally, droplet size and canopy structure also play critical roles in spray deposition. Previous studies have shown that coarse droplets are more affected by dense canopy structures, resulting in lower depositions in the lower parts of the canopy [15,16]. These responses illustrate how individual operational spray parameters can affect spray performance, both independently and through interaction with other parameters, making it challenging to understand their effects on droplet deposition within the upper canopy and at the ear leaf level.

UAV-based spraying differs from traditional spraying methods due to its reliance on specific operational and aerodynamic factors that influence the behavior of the spray within the crop canopy. Therefore, understanding the influences of swath and flight height combinations, addition of drift-reducing agents (DRAs), and the downwash force on corn within the upper canopy and at the ear leaf level compared to traditional methods is essential for optimizing UAVs use in corn mid-to-late season applications. The objective of this study was to compare spray depositions of DJI Agras T30, airplane, and ground sprayer on tassel-stage corn (VT), under varying application parameters: swath, height, row direction, and use of DRA.

2. Materials and Methods

2.1. Trial Descriptions

Two field trials were conducted during the summer of 2022 to evaluate spray deposition in tassel-stage corn (*Zea mays* L.) using different application methods. At both the Alabama and Georgia sites, applications were conducted at the VT growth stage in conventionally prepared fields with a planting density of 22,000 plants per acre and 30-inch row spacing. The first trial was established in Macon County, Alabama, and included only aerial applications, whereas the second trial was conducted in Early County, Georgia,

and included both aerial and ground applications. The specifications of the DJI Agras T30 (DJI®, Shenzhen, China) unmanned aerial vehicle are presented in Table 1.

Table 1. Unmanned aerial vehicle (UAV) specifications.

Model	Tank Size	Dimensions *	Nozzle Type	Weight Including Battery	Rotor Diameter	Droplet Spectrum	Max Payload Weight	Max Speed	Max Swath	Max Flow Rate
	L	mm		kg	mm	µm	L	m s^{-1}	m	L min^{-1}
DJI Agras T30	30	2858 × 2685 × 790	Hydraulic	38	2145	130–250 (XR 11001) 170–265 (XR 110015)	30	7	9	7.2 (XR 11001) 8 (XR 110015)

* Dimensions represented with arm and propellers unfolded. More details can be found at DJI's official website. Data previously reported in Ref. [17].

At the Alabama site, treatments consisted of applications using the DJI Agras T30 UAV and an airplane (Table 2).

Table 2. Spray method, drift reduction agent (DRA), swath width, height above the corn, flight direction, and wind speed and direction at the time of each spray application in Alabama trial *.

#	Spray Method	Spray Volume (L ha^{-1})	DRA	Swath (m)	Height (m)	Row Direction	Wind Speed (mph)	Wind Direction
1	DJI Agras T30	18.7	DRA 1	6	3.6	N-S	1	ESE
2	DJI Agras T30	18.7	DRA 2	6	3.6	N-S	1.6	ESE
3	DJI Agras T30	18.7	No DRA	6	3.6	N-S	3.4	ESE
4	Airplane	18.7	No DRA	21	3.6	N-S	2.7	ESE

* Data previously reported in Ref. [17].

At the Georgia site, treatments included UAV applications at different swath widths (4.5 and 6 m) and flight heights (2.4 and 3.6 m), an airplane application, and a ground sprayer application (Table 3).

Table 3. Spray method, spray volume, swath width, height above the corn, flight direction, and wind speed and direction at the time of each spray application in Georgia trial *.

#	Spray Method	Spray Volume (L ha^{-1})	Swath (m)	Height (m)	Row Direction	Wind Speed (mph)	Wind Direction
1	DJI Agras T30	18.7	4.6	2.4	N-S	0.5	NE
2	DJI Agras T30	18.7	6	2.4	N-S	1.3	NE
3	DJI Agras T30	18.7	4.6	3.6	N-S	1.5	NE
4	DJI Agras T30	18.7	6	3.6	N-S	1	NE
5	Airplane	18.7	21	3.6	N-S	0	N
6	Ground sprayer	140.3	21	3.6	N-S	1.6	WSW

* Data previously reported in Ref. [17].

2.2. Treatments and Application Parameters

At both locations, a fluorescent dye (Rhodamine WT, Cole-Parmer®, Vernon Hills, IL, USA) was used as a tracer to quantify spray deposition. The dye concentration was adjusted according to the spray volume to achieve a final rate of 84 g ha^{-1}.

At the Alabama site, DJI Agras T30 treatments were applied at 18.7 L ha^{-1} using Greenleaf AIRMIX 11001 nozzles (Greenleaf Technologies®, Covington, LA, USA), with a medium droplet size, 6 m swath, 3.6 m flight height, and 25.1 km/h flight speed. Treatments were applied with and without a drift-reducing agent (DRA). The DRAs evaluated were proprietary, pre-commercial formulations that are referred to as DRA 1 and DRA 2;

therefore, specific composition and mixing rate information cannot be disclosed due to confidentiality restrictions.

The airplane treatments were applied at 18.7 L ha^{-1} using TeeJet AITTJ60-11010VP (TeeJet® Technologies, Glendale Heights, IL, USA) nozzles with a medium to coarse droplet size, 21 m swath, 3.6 m height, and 255 km/h spray speed.

At the Georgia site, aerial treatments were applied at 18.7 L ha^{-1}, and ground applications at 140.3 L ha^{-1}, using Greenleaf AIRMIX 11001 nozzles with a medium to coarse droplet size, 6 m swath, 3.6 m flight height, and speeds of 255 km/h for airplane and 9 km/h for ground sprayer. Airplane and ground sprayer applications used a 21 m swath and 3.6 m height, while DJI Agras T30 UAVs operated at 4.5 or 6 m swaths and 2.4 or 3.6 m heights. The difference in spray volume between aerial applications and ground sprayer application was selected to reflect standard field application conditions.

2.3. Experimental Design and Sampling

Each treatment block included three sampling transects, true replications that were 15 m apart from each other, positioned perpendicular to the flight direction (Figure 1). Each replication was 22.9 m long, and 25 corn plants were sampled per replication, totaling 150 leaves per treatment block, and one pass per equipment type over each replication. A buffer of at least 15 m was left between blocks.

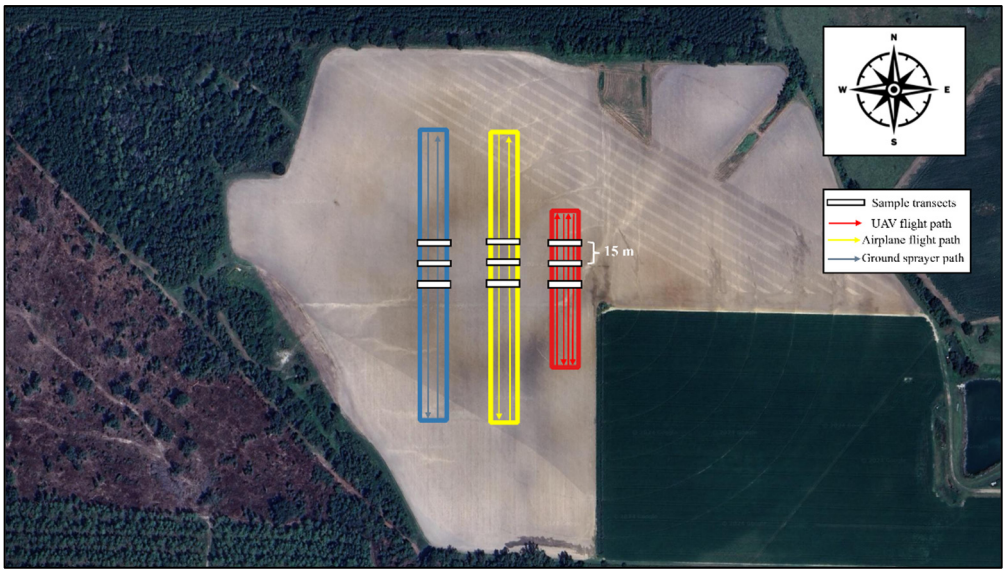


Figure 1. Illustration of the data collection setup for ground sprayer, airplane, and DJI Agras T30 treatments (three sample collection transects were used to collect replicated data over multiple passes at 15 m apart from each other. The airplane and ground sprayer blocks were 3.2 ha and UAV block 0.81 ha. Reprinted from Ref. [17].

Leaf samples were collected from two positions on each target plant: the ear leaf and the upper leaf (two leaves above the ear). Samples were always cut from the edge of the leaf, placed in labeled plastic containers, and stored in the dark to minimize photodegradation (Figure 2A). At the end of each application day, containers were transported to Auburn University for laboratory analysis.

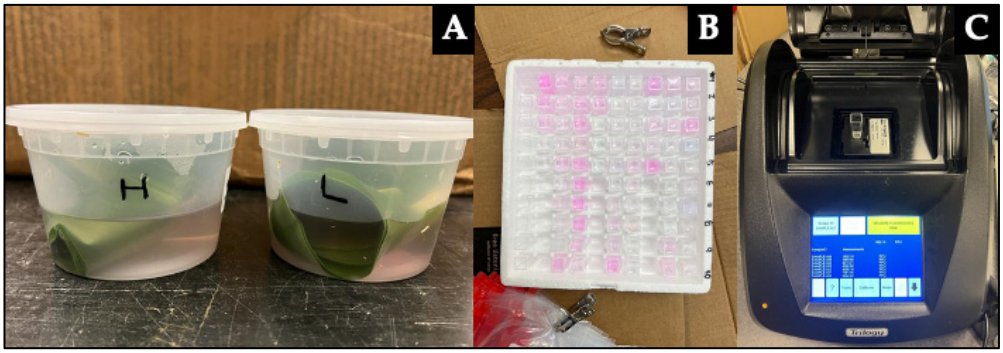


Figure 2. Corn leaf samples in containers with distilled water (**A**), extracted fluorescence dye on glass cuvettes ready for analysis (**B**), and fluorimeter used for dye analysis (**C**); detection limit was 1 ppb. H indicates leaves collected from the upper canopy, whereas L indicates leaves collected from the ear leaf position in corn. Reprinted from Ref. [17].

2.4. Dye Extraction and Fluorescence Measurement

Spray deposition was quantified through dye extraction from the collected leaf samples. Each leaf was rinsed after being collected at the field with 20 mL of distilled water, and 2 mL subsamples were taken using a pipette, transferred to glass cuvettes, and analyzed using a high-sensitivity fluorimeter (Turner Designs, Sunnyvale, CA, USA) (Figure 2B,C).

Cuvettes were cleaned with a 10% isopropyl alcohol solution after each measurement to prevent cross-contamination. Fluorescence readings were converted to dye concentration (ppb) using a calibration curve developed from an 800 ppb Rhodamine WT stock solution diluted to 0–800 ppb ($y = 1.0113x - 0.9909$; $R^2 = 0.9956$).

2.5. Baseline and Supporting Measurements

Tank samples were collected from each treatment to ensure that all measurements were referenced to a consistent baseline. Leaf area index (LAI) for each sample was measured using a LI-3100 leaf area meter (LI-COR Inc., Lincoln, NE, USA) to standardize dye concentration per unit leaf area prior to statistical analysis.

A weather station (WatchDog 2000 series, Spectrum Technologies®, Plainfield, IL, USA) was installed at each site, around 15 m from each block, to record air temperature, relative humidity, and wind speed during applications. Spray deposition uniformity was evaluated using the coefficient of variation (CV) among replicates.

2.6. Statistical Analysis

All data were analyzed using SAS 9.4 (SAS Institute Inc., Cary, NC, USA). Model residuals were visually evaluated and met assumptions of normality and homoscedasticity, so no data transformation was required. A generalized linear mixed model (PROC GLIMMIX) was used, with treatment considered a fixed effect and replication a random effect. Mean separations were performed using Tukey's honestly significant difference test at $\alpha = 0.05$.

3. Results

3.1. Alabama Trial

Analysis of spray dye deposition ($ng.cm^{-2}$) indicated significant treatment effects at the $p = 0.05$ level for both upper and ear leaf positions (Table 4). In Table 4, means followed by the same letter within a column are not significantly different, CV values represent the coefficient of variation, and DRA denotes a drift-reducing agent.

Table 4. Spray dye deposition on corn leaves at two positions as influenced by treatment in Alabama trial *.

#	Spray Method	DRA	Swath	Height	Spray Dye Deposition	
					Upper Leaf	Ear Leaf
			m	m	ng/cm^2	
1	DJI Agras T30	DRA 1	6	3.6	47.5 b	50 a
2	DJI Agras T30	DRA 2	6	3.6	51 ab	48 a
3	DJI Agras T30	No DRA	6	3.6	63.8 a	34 b
4	Airplane	No DRA	21	3.6	26 c	22.5 c
ANOVA results					*p*-value	
Treatment					<0.0001	<0.0001

Means followed by the same letter in the same column do not differ significantly based on analysis of variance of a randomized complete block (p = 0.05). DRA—drift-reducing agent. * Data previously reported in Ref. [17].

In the upper leaf position, DJI Agras T30 treatments with or without DRA provided higher spray dye depositions (63.8–47.5 ng/cm^2) than airplane treatment (26 ng/cm^2). DJI Agras T30 without DRA resulted in 34% higher spray dye deposition on upper leaf (63.8 ng/cm^2) compared to the same spray method with DRA 1 (47.5 ng/cm^2).

For ear leaf samples, DJI Agras T30 treatments with or without DRA resulted in spray dye concentrations that were 51 to 122% higher than the airplane treatment (22.5 ng cm^{-2}). Addition of both types of DRAs significantly increased spray dye concentrations on the ear leaf, resulting in 113 to 122% higher deposition (48 and 50 ng cm^{-2}) compared to DJI Agras T30 without DRA (22.5 ng cm^{-2}). Notably, DJI Agras T30 treatment without DRA yielded a 145.8% increase in spray dye concentration on upper leaf and 51.1% on ear leaf compared to the airplane treatment.

On the upper leaf, spray uniformity (% CV) did not decrease with DRA addition (Table 5). However, airplane application resulted in approximately 24% increase in spray variation than all DJI Agras T30 applications. At the ear leaf, spray dye variation was similar across all treatments, but showed an approximately 12% increase in variation for treatments without DRA, regardless of the spray method.

Table 5. Spray dye variation on corn leaves at two positions by treatment in Alabama trial *.

#	Spray Method	DRA	Swath	Height	Coefficient of Variation	
					Upper Leaf	Ear Leaf
			m	m	%	
1	DJI Agras T30	DRA 1	6	3.6	55	55.2
2	DJI Agras T30	DRA 2	6	3.6	61	54.7
3	DJI Agras T30	No DRA	6	3.6	61	67
4	Airplane	No DRA	21	3.6	85.94	66.6

DRA—drift-reducing agent. * Data previously reported in Ref. [17].

3.2. Georgia Trial

Analysis of spray dye deposition presented significant treatment differences at the upper leaf position, but no significant differences at the ear leaf position at p = 0.05 level (Table 6).

Table 6. Spray dye deposition on corn leaves at two positions as influenced by treatment in Georgia trial *.

#	Spray Method	Spray Volume	Swath	Height	Spray Dye Deposition	
					Upper Leaf	Ear Leaf
		L ha^{-1}	m	m	ng/cm^2	
1	DJI Agras T30	18.7	4.6	2.4	63.5 a	42.4 a
2	DJI Agras T30	18.7	6	2.4	44 b	41.6 a
3	DJI Agras T30	18.7	4.6	3.6	59.4 a	40 a
4	DJI Agras T30	18.7	6	3.6	52.4 ab	37 a
5	Airplane	18.7	21	3.6	27.9 c	43.2 a
6	Ground sprayer	140.3	21	3.6	43.9 b	43.2 a
ANOVA results					*p*-value	
Treatment					<0.0001	0.8599

Means followed by the same letter in the same column do not differ significantly based on analysis of variance of a randomized complete block ($p = 0.05$). * Data previously reported in Ref. [17].

At the upper leaf position, all DJI Agras T30 treatments and ground sprayer treatment (ranging from 43.9 to 63.5 ng/cm^2) resulted in higher spray dye concentrations compared to airplane treatment (27.9 ng/cm^2). All T30 treatments provided statistically similar spray dye concentrations on the upper leaf. However, an increase of 1.5 m in swath when flying at 2.4 m above the corn resulted in significant decrease in spray dye deposition on the upper leaves (from 6.5 to 44 ng/cm^2), while no significant effect on spray dye concentration was observed when DJI Agras T30 was flying at 3.6 m above the corn (59.4 and 52.4 ng/cm^2). Both DJI Agras T30 treatments with 4.6 m swath (63.5 and 59.4 ng/cm^2), regardless of the spray height, provided statistically higher spray dye concentrations on upper leaves compared to ground sprayer treatment (43.9 ng/cm^2).

For ear leaf samples, no significant differences in spray dye concentration were observed among treatments. However, the airplane treatment at the Georgia site resulted in greater spray dye deposition on the ear leaf compared to the Alabama site. This difference is observational and is likely related to the terrain variations, as the Alabama site featured a downslope at the edge of the plots, requiring adjustments in the airplane application to achieve uniform height across the entire plot.

Airplane treatment resulted in the highest variation (% CV) on both leaf positions (68.5 and 85.5%) than any other treatment, followed by DJI Agras T30 flying at the higher swath and height (Table 7).

Table 7. Spray dye variation on corn leaves at two positions by treatment in Georgia trial *.

#	Spray Method	Spray Volume	Swath	Height	Coefficient of Variation (%)	
					Upper Leaf	Ear Leaf
			m	m	%	
1	DJI Agras T30	2	4.6	2.4	46.6	84
2	DJI Agras T30	2	6	2.4	52.6	74.8
3	DJI Agras T30	2	4.6	3.6	52.4	57
4	DJI Agras T30	2	6	3.6	60.7	67.7
5	Airplane	2	21	3.6	68.5	85.5
6	GS	15	21	3.6	48.2	57.4

* Data previously reported in Ref. [17].

The other DJI Agras T30 treatments presented similar spray dye variation as the ground sprayer, within a range of 46.6 to 52.6% on upper leaf. For ear leaf, the spray dye variation was higher for all treatments. The lowest variations for the ear leaf position were

observed with DJI Agras T30 with 4.6 m swath and 3.6 m height, and with ground sprayer, at 57 and 57.4% respectively.

4. Discussion

4.1. Alabama Trial

The results from the Alabama trial indicate that UAV applications improved spray deposition within dense corn canopies, consistent with previous studies attributing enhanced within-canopy deposition to propeller-induced downwash across a range of quantitative results [18–21]. This effect is particularly relevant at the tassel stage, when canopy density increases and achieving adequate fungicide deposition in lower canopy layers becomes more challenging [2].

In contrast, airplane applications resulted in lower droplet deposition in the lower canopy compared with UAV treatments, likely due to the absence of propeller-generated downwash and differences in operational parameters, such as flight height and forward speed. These factors may limit spray penetration and raise concerns regarding disease control efficacy for foliar diseases such as gray leaf spot (*Cercospora zeae maydis*) [16]. Additionally, airplane applications did not include a drift-reducing agent, and wind speeds during airplane treatments were higher than those observed during UAV applications. These environmental and operational differences likely contributed to the observed variation in deposition between application methods.

UAV applications further benefited from the inclusion of drift-reducing agents, which improved spray uniformity, as indicated by lower coefficients of variation. This response is likely associated with changes in spray solution surface tension and viscosity, resulting in more consistent droplet formation and deposition, particularly on the upper leaf surface, compared with UAV applications without DRAs [17,22,23]. Because DRAs typically increase droplet size [8,23], their inclusion promoted greater droplet mass and reduced fall time, facilitating deposition into lower canopy regions. Propeller-induced downwash may have further enhanced canopy opening, allowing droplets to move deeper into the canopy and accumulate at lower levels.

The higher variability observed in airplane applications, particularly at the upper leaf level, is likely influenced by terrain-driven fluctuations in flight altitude during application. At the Alabama site, uneven terrain limited the aircraft's ability to maintain a constant flight height, introducing additional variability in spray distribution. This represents an important limitation of this study, as direct comparisons with UAV applications, which utilize terrain-following capabilities to maintain a more consistent operating height, may introduce bias. However, this constraint reflects real-world operational challenges commonly faced in manned aerial applications and, therefore, enhances the practical relevance of these findings. This limitation should be considered when interpreting differences between airplane and UAV deposition patterns.

4.2. Georgia Trial

The results from the Georgia trial further demonstrate the influences of application method and flight parameters on spray deposition and uniformity. Previous studies have shown that the higher spray volume used by ground sprayers results in greater coverage on the upper leaf portion of corn and wheat canopies compared with aerial applications, while still achieving equivalent disease control [12,24]. In addition, ground sprayers do not generate propeller-induced airflow, resulting in greater spray deposition on the upper leaf surface compared with other application methods, in part due to the higher spray volumes typically used in these applications. In UAV applications, airflow can disrupt the upper canopy layer, leading to slightly reduced deposition on the upper leaves.

Aerial applications have also been shown to provide disease control comparable to ground sprayers despite using lower spray volumes, due to the higher concentration of active ingredients in each droplet, which enhances efficacy [20].

In our study, both ground sprayer and all DJI Agras T30 treatments resulted in significantly higher spray dye concentrations on the upper leaf. This difference may be attributed to the higher spray volumes used by ground sprayers and the greater susceptibility of airplane applications to drift caused by wind interference when optimal flight altitude is not maintained [25]. In contrast, the downwash effect generated by UAV propellers likely improved droplet deposition accuracy [11,14,22]. Furthermore, spray distribution has been reported to become more uniform at higher flight altitudes, likely due to stabilized downwash airflow generated by UAV propellers [26–28].

Consistent with our findings, spray dye variation decreased with DJI Agras T30 applications at higher altitudes on the ear leaf compared with lower altitudes, regardless of the swath used. According to previous studies, at higher flight altitudes, the downwash airflow has more time to spread and stabilize before interacting with the canopy, thereby reducing uneven droplet displacement [5,14,26]. Additionally, no significant differences were observed in spray dye deposition on either leaf position when swath was increased at higher flight altitudes. However, it is important to note that the influence of flight height on effective swath varies depending on the specific characteristics of the UAV model [22,29].

5. Conclusions

The addition of DRAs proved beneficial for DJI Agras T30 applications, resulting in greater spray dye concentration and reduced spray variation on the ear leaf, which are critical for improving fungal disease control. Even without DRA, the DJI Agras T30 increased spray dye concentration by 145.8% on the upper leaf and 51.1% on the ear leaf compared with airplane applications. Higher spray volumes used by ground sprayers and the downwash effect generated by UAV propellers both contributed to greater dye depositions on the upper leaf than airplane treatments. Although similar dye concentrations were observed among the three application methods at the Georgia site, the airplane produced the lowest spray uniformity on both leaf positions. These findings highlight distinct differences in droplet deposition patterns among application methods in mid- to late-season corn canopies. Further research is needed to better characterize the mechanisms driving the observed differences in spray deposition. Studies incorporating measurements of propeller-induced airflow would improve understanding of droplet transport within corn canopies. Additional evaluations of UAV spray parameters and drift-reducing agents would help clarify their influences on deposition during tassel-stage applications. Field experiments assessing fungicide efficacy are also necessary to link deposition patterns with disease control outcomes. Because aerial and UAV field-scale studies are often constrained by operational and logistical limitations that restrict replication, future work conducted across multiple locations and a broader range of environmental conditions would enhance the robustness and generalizability of these findings.

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Conflicts of Interest: The authors declare no conflicts of interest.

Abbreviations

The following abbreviations are used in this manuscript:

UAV	Unmanned aerial vehicle
DRA	Drift-reducing agent
CV	Coefficient of variation (%)

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