Spray Deposition and Efficacy of Pesticide Applications with Spray Drones in Row Crops in the Southeastern US

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Abstract. *The use of spray drones for pesticide applications is expanding rapidly in agriculture, with one of the top uses currently being in row crop production. Several research studies were undertaken in 2023 to measure and assess spray deposition and efficacy of pesticides applied with spray drones in the major row crops (maize, cotton, and peanuts) grown in the southeastern US. These studies also evaluated and compared the deposition and pesticide efficacy of spray drones with traditional ground-based application methods, commonly used for applications in these crops. The specific studies included fungicide applications in maize and peanut with a DJI Agras T30 spray drone, and harvest-aid applications with a DJI Agras T40 spray drone. In each study, spray deposition was assessed for both spray drones and ground applications using water-sensitive paper placed across the full spray swath (varying from 5.4 to 10.0 m) at different positions (top, middle, and bottom) within the crop canopies and using water as a spray solution. For assessing efficacy, fungicide, and harvest-aid products were applied at nominal application rates for both aerial and ground applications. Efficacy ratings were conducted within two to three weeks after each application. The results from the study showed a highly variable (CV = 40% to 69%) spray deposition across the spray swath for spray drone applications in all crops whereas ground-based applications showed more uniform in-swath deposition (CV = 6% to 22%). Regardless of the crop and application method, the coverage was greatest at the top of the crop canopy with a decreasing coverage towards the bottom of the canopy. In contrast to coverage exhibited by the spray drones, the coverage was greater for ground sprayer applications due to the higher nominal rates (93.5 to 140.3 L ha^{-1}) commonly used for pesticide applications. Despite differences in spray deposition and uniformity, both spray drone and ground-based sprayer applications exhibited similar efficacy and yield for fungicide and harvest-aid applications in all three crops. Overall, the results from these studies suggest the potential of spray drones to be viable application tools for pesticide applications in row crops in the southeastern US.*

Keywords. *Spray Drones, Pesticides, Spray Deposition, Uniformity, Efficacy, Yield*

Introduction

The use of spray drones for pesticide applications in agriculture has garnered increased attention lately in the United States with multiple spray drone platforms (varying in size and capabilities) available through different manufacturers. In row crops such as maize and soybean, the most common uses of spray drones include spot or selective spraying of herbicides, especially post-emergence, and fungicide applications late in the season when the crop canopy is tall and inaccessible to low-clearance ground equipment (Chen et al. 2021). In the southeastern US, cotton and peanut are prevalent row crops grown along with maize and soybean so the expansion of spray drones for pesticide applications in these crops was quite natural and expected. Particularly, spray drones have been used for fungicide applications in peanut and harvest-aid applications in cotton (Cavalaris et al. 2022). As the interest rises in the use of these technologies for pesticide applications, it is important to understand the spray deposition characteristics and efficacy of products being applied with spray drones.

While spray drones are not new to agriculture, their use for pesticide applications in the US was limited to non-existent due to strict rules and regulations around their use (Anonymous, 2024). The smaller tank and limited battery life on most of the earlier models also made them a better fit for smaller and irregular fields. However, the availability of modern spray drone models with increased tank capacities and improved battery life has changed that trend recently, thus contributing to their increased usage in the US. While there is considerable research available on investigating the effect of flight parameters, platform design, and other factors on spray performance of some of the earlier or even custom-built spray drone models (Huang et al. 2009; Qin et al. 2014; Giles and Billing, 2015), the information on most of the new spray drones currently utilized by applicators and growers is limited. The spray drone technology is also advancing rapidly with newer models with varying characteristics (Carvalho et al. 2020) being introduced into the market every year.

Most pesticide applications with spray drones are currently being performed using low rates of 18.7 to 28.1 L ha^{-1} (2 to 3 gallons per acre) while the selection of other parameters such as application height and speed is also up to the operator with no specific recommendations from drone manufacturers based on the type of application or crop. Thus, characterizing spray deposition across the swath in different crops is important to understand and optimize the operational parameters that can improve application accuracy and efficiency. Further, applying commonly used pesticide products with spray drones is necessary to understand their efficacy and/or any implications on pest control so appropriate best management practices can be informed for crop-specific applications. Therefore, the goal of this study was to assess spray deposition within the crop canopy and the efficacy of pesticides applied with a spray drone to evaluate their feasibility as a valid application tool for pesticide applications in the prevalent row crops grown in the southeastern US.

Methodology

Study Location and Crops

For this study, field experiments were conducted in 2023 in different row crops predominantly grown in the southeastern United States: maize, cotton, and peanut. The spray drone deposition studies in maize, cotton, and peanut were conducted at the University of Georgia Research Farms located in Tifton (31.47544, -83.53076) and Midville, GA (32.88015, -82.21073). Further, two different spray drone models were used in the studies: a DJI T30 equipped with traditional hydraulic spray nozzles and a DJI T40 with rotary atomizers (Figure 1). The DJI T30 spray drone was used for spray deposition studies in maize and peanut whereas the DJI T40 spray drone was used for defoliating cotton.

Figure 1. DJI T30 and T40 spray drones used for deposition and efficacy evaluation studies.

Spray Deposition and Efficacy Assessment

Spray deposition was assessed by placing water-sensitive paper at three different locations (top, middle, and bottom) of the crop canopy prior to the actual fungicide application (Figure 2). In maize, the water-sensitive paper was placed directly on the leaves whereas in cotton and peanut, it was placed on card holders that were adjusted to different heights (top, middle, and bottom) within the canopy. In maize, the ear leaf represented the middle canopy position while the leaf two leaves above and below the ear leaf represented the top and bottom positions within the canopy. In each crop, spray deposition was also assessed within each crop row (0.91 m apart) across the whole swath, which varied in maize due to different spray heights whereas it was 5.5 m for peanut and 7.3 m for cotton. The study treatments also varied by the crop and the type of application and are listed in Table 1.

Water was used as a spray solution for this assessment. For maize, the spray deposition data was collected on June 28, 2023, while similar data in cotton during defoliation was collected on Sept. 26, 2023. In peanuts, the fungicide applications are initiated 30-40 days after planting (DAP), and then regular applications at 14-day intervals were performed throughout the season. The deposition data in peanut was collected at 45, 60, 90 and 120 DAP. The exact date of data collection varied as it was dependent on weather and field conditions so the spray deposition data in peanut were collected on 19 July, August 2, September 1, and October 4, 2023. All spray drone passes consisted of a three-pass pattern to provide sufficient overlap within the swath from adjacent passes. Flight plans for all applications were created using the drone's controller and using an RTK base station to achieve high accuracy. Fungicide or defoliant products were applied in the crop using the same application parameters as used for deposition assessment either on the same day as spray deposition data collection or the following day. For maize, only certain treatments (18.7 and 46.8 L ha^{-1}) were used to apply the fungicides using a fixed height of 3.0 m.

Immediately after deposition data collection, the water-sensitive paper were transported to the laboratory and analyzed using a DropScope Instrument (SprayX, Sao Paulo, Brazil). The analysis provided the area covered by the spray droplets on the water-sensitive paper as coverage (%). In each crop, efficacy ratings were recorded to evaluate the effect of different treatments applied either using the spray drone or conventional application method i.e. a ground sprayer. In maize, disease ratings for Tar Spot (TS), Northern Corn Leaf Blight (NCLB), and Southern Corn Rust (SCR) were recorded approximately two weeks after the fungicide application. In cotton, efficacy ratings consisted of recording defoliation (%), open (%) and closed bolls (%), and regrowth (%) at 10 to 14 days after application. In Peanut, leaf spot using a Florida 1-10 scale was rated at 120 DAP, and white mold ratings were recorded when the peanuts were inverted before harvest at 140 DAP. Yield data was recorded by harvesting the middle two (for 4-row plots) or four (for 6-row plots) crop rows within each study.

Figure 2. Illustration of water-sensitive paper placement in different crop canopies used for spray deposition assessment in the studies conducted in 2023.

Table 1. Information on application parameters used for spray deposition and efficacy assessment studies.

Crop	Application Method	Spray Drone	Application Rate (L ha^{-1})	Application Height (m)	Application Speed (m s^{-1})
Maize	Spray Drone	DJI T30	18.7	1.5, 3.0, 2.3, 3.8	3.7
			46.8	1.5, 3.0, 2.3, 3.8	3.7
Peanut	Spray Drone	DJI T30	46.8	3.0	3.7
	Ground Sprayer		140.3	0.6	2.2
Cotton	Spray Drone	DJI T40	28.1	3.0	3.7
	Spray Drone	DJI T40	46.8	3.0	3.7
	Ground Sprayer		46.8	0.5	3.6
	Ground Sprayer		93.5	0.5	3.6

Data Analysis

Mean deposition in terms of spray coverage (%) was calculated for each treatment and a coefficient of variation (CV; %) was computed to assess uniformity across the respective swaths used for maize, cotton, and peanut. Spray deposition was plotted across the respective swath used for each crop to visualize coverage and uniformity associated with different study treatments. For each crop, an analysis of variance (ANOVA) was conducted using study treatments (application method and rate) as explanatory variables and spray deposition, efficacy, and yield as response variables. All statistical analysis was conducted in JMP Pro 17 using an alpha value of 0.05. Where treatments were significant, means were separated using a Student's T-test ($p \leq 0.05$).

Results and Discussion

Maize Fungicide – Spray Deposition and Efficacy

The spray deposition pattern across the swath at different heights at the two application rates of 18.7 and 46.8 L ha^{-1} are presented in Figure 3 (a & b, respectively) while Figure 4 shows in-swath deposition at different positions within the canopy at these rates. The coverage pattern (for the DJI T30 spray drone) shows a heavy peak in the center of the swath (directly under the spray drone) for 46.8 L ha^{-1} and decreased coverage towards the end of the swath. This bell-shaped deposition is characteristic of the spray drones, especially at higher volumes (≥18.7 L ha^{-1}) where the nozzles are placed directly under the rotors and the propeller downwash pushes most of the spray directly beneath the spray drone. The 18.7 L ha^{-1} rate had a much lower deposition in the center of the swath compared to 46.8 L ha^{-1} but was more uniform across the swath. For both application rates (18.7 and 46.8 L ha^{-1}) and all four heights (1.5, 2.3, 3.0, and 3.8 m), a similar trend was observed where spray deposition was highest at the top of the canopy with decreasing coverage towards the bottom of the canopy (Figure 4). The increase in height increased the effective spray swath but all three application heights of 2.3, 3.0, and 3.8 m showed a similar response for spray deposition as shown in Figure 4. The application height of 1.5 m from the crop canopy showed high variability in the deposition as well as presented problems during applications due to proximity to the canopy and the spray drone's obstacle avoidance feature constantly turning on and halting the drone mid-application. Therefore, lower heights of ≤1.5 m are not recommended.

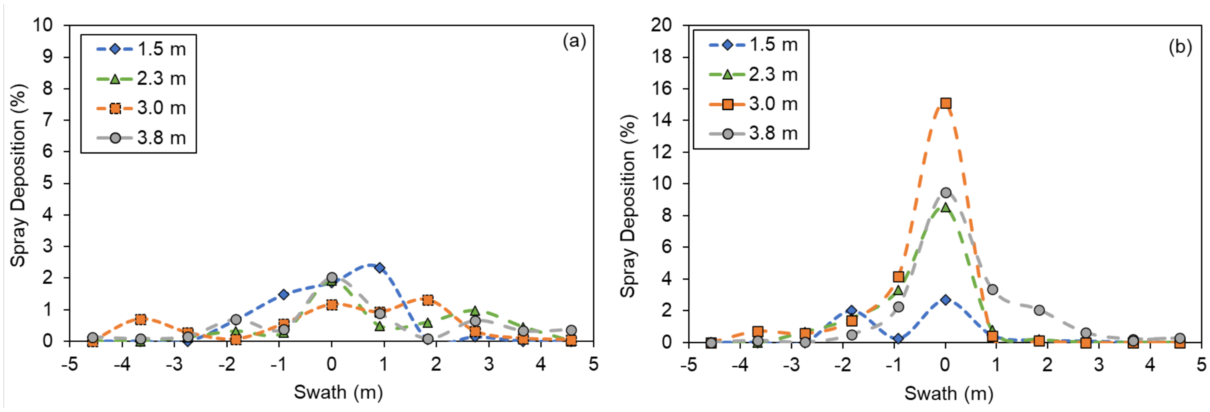

Figure 3. In-swath deposition measured at different heights for application rate of (a) 18.7 L ha^{-1} and (2) 46.8 L ha^{-1} in maize canopy.

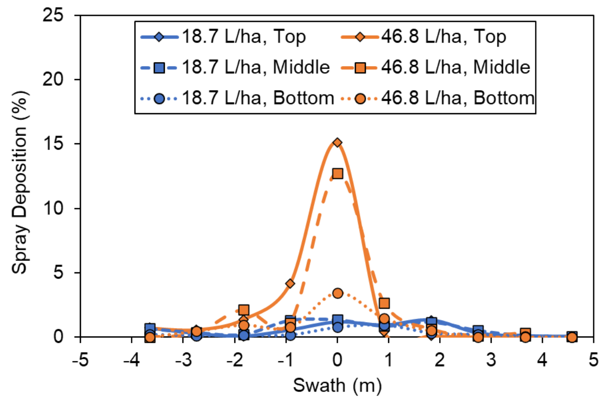

Figure 4. In-swath deposition measured at different positions (top, middle and bottom) within the maize canopy at application rates of 18.7 and 46.8 L ha^{-1}.

The disease ratings for the spray drone fungicide applications at 18.7 and 46.8 L ha^{-1} showed similar effectiveness at both application rates (Table 2) while the untreated control (no fungicide application) had greater disease ratings (Northern Corn Leaf Blight and Southern Corn Rust were significant). Corn yields were similar between the untreated and in plots where fungicides were applied with spray drones.

Table 2. Disease ratings and yield for fungicide applications with a spray drone at two different rates and an untreated control in maize.

Application Rate (L ha^{-1})	Tar Spot (%)	Northern Leaf Blight (%)	Southern Corn Rust (%)	Yield (kg ha^{-1})
18.7	0.0685	1.97 b	0.0351 b	12,679
46.8	0.0000	0.03 b	0.0067 b	11,926
Untreated Control	0.0074	6.70 a	0.4345 a	11,675

Peanut Fungicide – Spray Deposition and Efficacy

The spray deposition comparison between the spray drone and ground sprayer (Figure 5) showed that coverage was greater and more uniform for the ground sprayer (28 – 35%) than the spray drone (0 – 15%) within the spray swath regardless of the application timing. The higher coverage for the ground sprayer was mainly due to the higher carrier volume of 140.3 L ha^{-1} compared to the 46.8 L ha^{-1} used with the spray drone. Across all application periods (Table 3), the coverage for the spray drone had greater variability (CV=55-69%) within the swath than the ground sprayer

(CV=6-16%). This deposition behavior is typical of spray drone applications as coverage is highly concentrated and localized directly under the drone whereas the coverage decreases towards the end of the swath. Despite high variability in coverage, fungicide efficacy was comparable between both application methods indicating that the fungicide applications with spray drone were as effective as ground sprayer and therefore they can be another valid application technology for timely and effective fungicide applications in peanut.

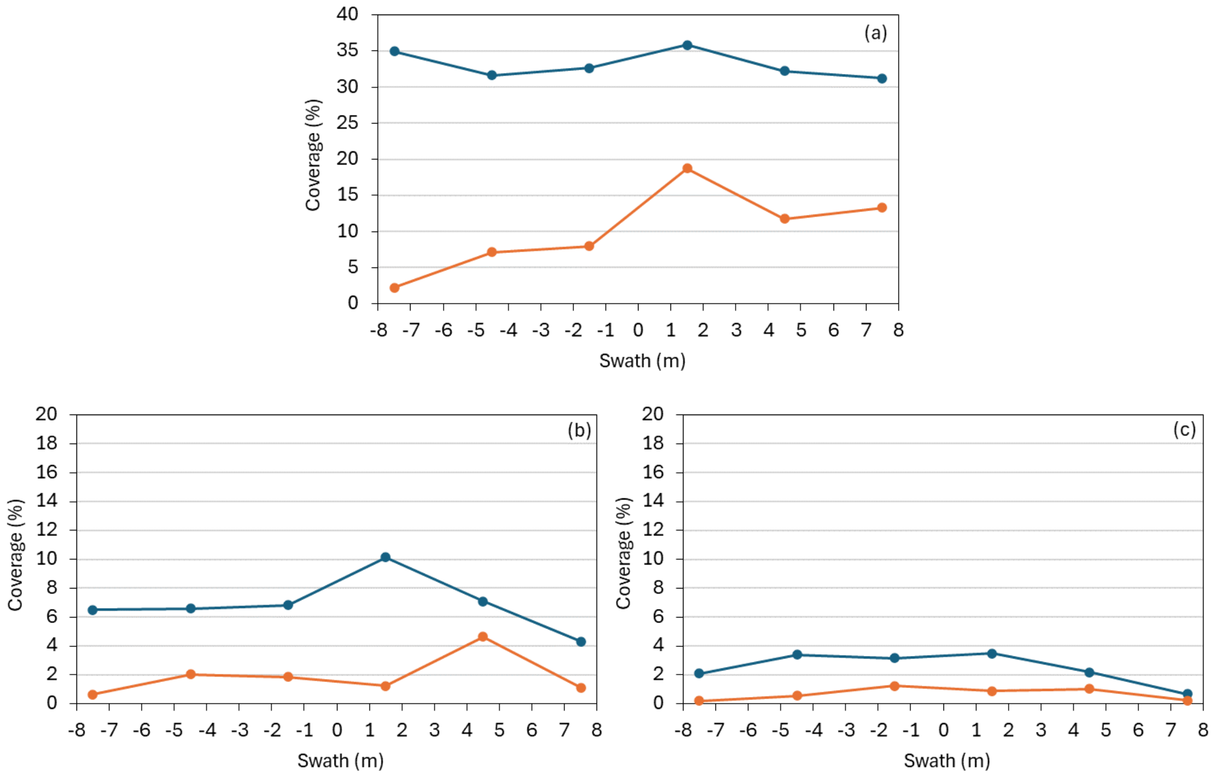

Figure 5. In-swath deposition measured at different canopy positions (a- top, b- middle & c- bottom) in peanut for fungicide applications with a ground sprayer (solid blue line) and spray drone (solid orange line).

Table 3. Mean deposition and uniformity across the swath, represented as CV (%), for fungicide applications performed with a ground sprayer and a spray drone at different days after planting (DAP) in peanut.

Application Method	Application Rate (L ha^{-1})	45 DAP		60 DAP		90 DAP		120 DAP	
		Mean (%)	CV (%)	Mean (%)	CV (%)	Mean (%)	CV (%)	Mean (%)	CV (%)
Ground Sprayer	140.3	29.0	15.5	31.6	11.2	33.1	6.0	28.6	14.1
Drone Sprayer	46.8	7.9	61.5	6.7	68.5	10.2	55.8	5.7	54.7

Table 4. Disease ratings and yield for fungicide applications performed with a ground sprayer and a spray drone versus an untreated control in peanut.

Application Method	Application Rate (L ha^{-1})	Leaf Spot (1-10)	Yield (kg ha^{-1})
Ground Sprayer	140.3	3.4 b	12,679
Drone Sprayer	46.8	3.3 b	11,926
Untreated Control	-	6.4 a	11,675

Cotton Defoliation - Spray Deposition and Efficacy

Table 1 below presents the mean deposition and uniformity (represented as CV) across the swath for different positions within the cotton canopy (top, middle, and bottom) for the 28.1 and 46.8 L ha^{-1} rates applied with the spray drone, and the 46.8 and 93.5 L ha^{-1} applied with the ground sprayer. A similar trend for spray deposition as observed in the other crops was noted where spray deposition was greatest at the top of the canopy and decreased thereafter towards the middle and bottom of the canopy, regardless of the application method and rates used. The amount of spray deposits received at the bottom of the canopy was also considerably lower than at the top of the canopy. When comparing the application methods and volumes, the ground sprayer at 93.5 L ha^{-1} exhibited the greatest spray deposition followed by the 46.8 L ha^{-1} with both ground sprayer and spray drone. The lowest deposition was observed for the 28.1 L ha^{-1} rate applied with the spray drone. The observed difference in spray deposition between 93.5 L ha^{-1} applied with the ground sprayer and 28.1 L ha^{-1} applied with the spray drone is mainly due to the difference in the water volume and was expected.

When comparing the same volume (46.8 L ha^{-1}) applied with the ground sprayer and spray drone, a general expectation was that the spray drone would exhibit higher deposition, especially in the middle and bottom canopies due to significant propeller wash; however, the deposition was either comparable between the two application methods at the bottom of the canopies or ground sprayer had greater deposition than the spray drone at the top of the canopy. This can be caused and possibly attributed to the difference in application height between the two methods whereas the ground sprayer boom was operated approx. 0.51 m from the top of the canopy while the spray drone was 2.43 to 3.05 m from the canopy. It was also noticed during spray deposition testing and from in-swath data that the influence of propeller wash is only present directly under the spray drone (which is approx. 2.44 m wide) and not across the whole swath (7.32 m).

Table 5. Mean deposition and uniformity across the swath, represented as CV (%), at different positions within the cotton canopy for harvest-aid applications with a spray drone and ground sprayer at two different rates.

Application Method	Rate (L ha^{-1})	Top		Middle		Bottom	
		Mean (%)	CV (%)	Mean (%)	CV (%)	Mean (%)	CV (%)
Drone Sprayer	28.1	1.0 d	40	0.8 c	38	0.5 c	35
	46.8	2.0 c	43	1.6 c	34	1.1 bc	58
Ground Sprayer	46.8	5.7 b	22	3.5 b	47	1.8 ab	52
	93.5	13.0 a	19	8.1 a	40	4.5 a	41

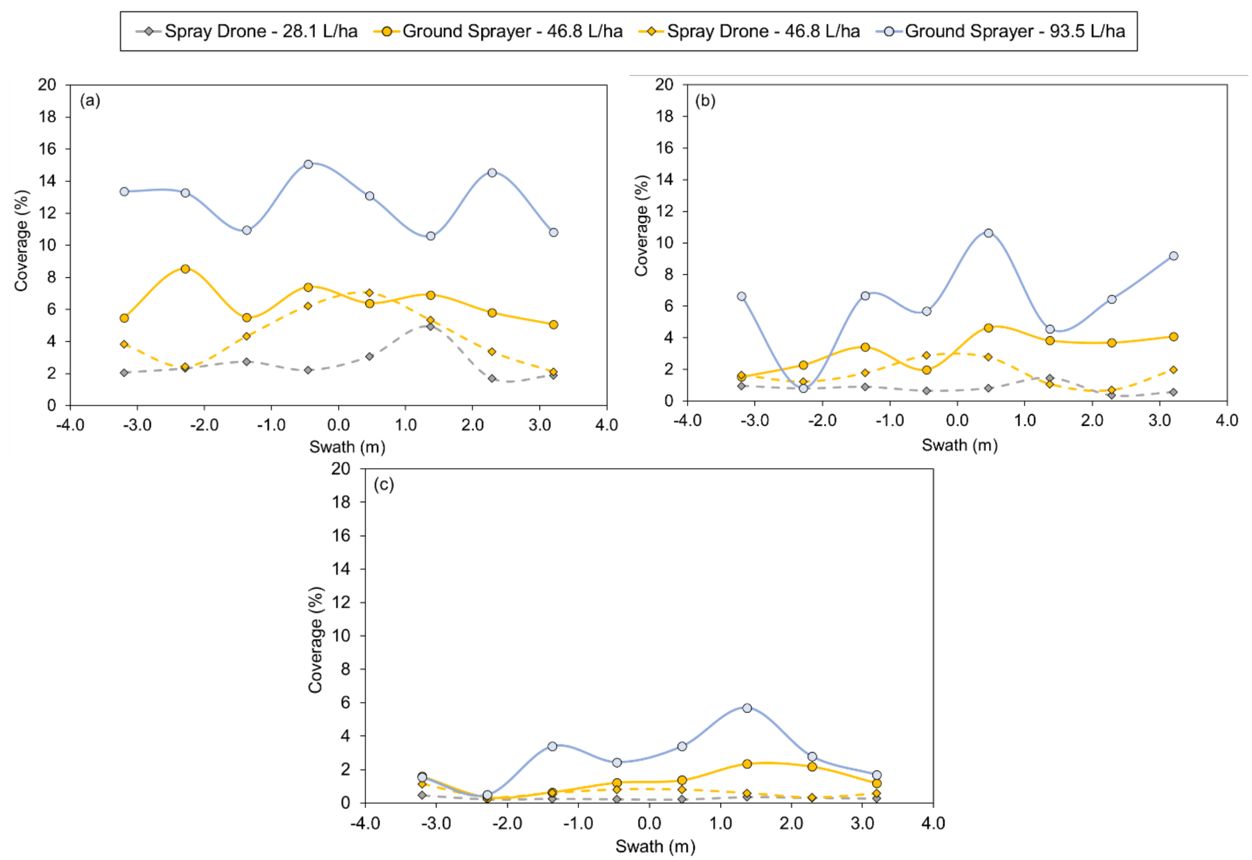

Figure 6. In-swath deposition measured at different canopy positions (a- top, b- middle & c- bottom) in cotton for harvest-aid applications with a ground sprayer and spray drone at different rates.

Figure 6 displays spray deposition assessed at different points within the swath (7.32 m, 8 rows) for different study treatments at various positions (a- top, b- middle & c- bottom) in the cotton canopy. It can be observed from Figure 6 and CV data provided in Table 5 that spray deposition was more uniform for ground sprayer (CV = 19% – 22%) at both rates than the spray drone (CV = 40 – 43 %) at the top of the canopy whereas the in-swath deposition uniformity was comparable (CV = 34 – 47 %) between the two application methods at the middle of the canopies. Interestingly, the spray drone exhibited slightly better uniformity than the ground sprayer (both rates) at the bottom of the canopies for 28.1 L ha^{-1} applied with the spray drone in Tifton. This result also agrees with the observations made in the field that a higher spray volume with a spray drone is likely causing more variability within the swath due to the majority of the spray deposition concentrated directly under the drone.

For efficacy, both the 28.1 L ha^{-1} with the spray drone and 93.5 L ha^{-1} with the ground sprayer had similar defoliation (~91%) and open bolls (95%) whereas the 46.8 L ha^{-1} with the spray drone had greater defoliation (82.5%) than the similar rate applied with the ground sprayer (75.8%) but the spray drone also showed higher desiccation (35%) and less open bolls (90%) than the ground sprayer at 46.8 L ha^{-1}. Comparing application rates within each method, the overall harvest-aid efficacy was better for 28.1 L ha^{-1} with the spray drone and 93.5 L ha^{-1} with the ground sprayer.

Table 6. Defoliation ratings and yield for harvest-aids applied with a ground sprayer and a spray drone at two different rates in cotton.

Application Method	Application Rate (L ha^{-1})	Defoliation (%)	Desiccation (%)	Regrowth (%)	Open Boll (%)	Yield (kg ha^{-1})
Drone Sprayer	28.1	91.2 a	25.8 c	0.8 b	95.0 a	1186
Drone Sprayer	46.8	82.5 b	35.0 a	2.5 b	90.0 b	1216
Ground Sprayer	46.8	75.8 c	19.3 b	8.3 a	93.8 a	1080
Ground Sprayer	93.5	90.8 a	10.8 c	4.0 b	95.0 a	1171

Summary

These studies evaluated in-swath spray deposition, uniformity, and efficacy of different pesticides (fungicides in maize and peanut, and harvest-aid products in cotton) applied with spray drones. Data suggested that applications with ground sprayers had higher deposition as well as uniformity across the swath compared to spray drone applications. For both the T30 and T40 spray drones used in these studies, the majority of the spray deposition was concentrated towards the middle of the swath. Efficacy data from the studies implied that the pesticide applications with the spray drones were equally effective as the traditional ground sprayer applications regardless of the considerable differences in spray deposition and uniformity among the application methods. Overall, these findings suggest that spray drones can be another viable application tool for timely and effective pesticide applications in row crops; however, further testing and evaluation should be conducted for the selection of optimal application parameters to improve deposition and uniformity.

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