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ARTICLE

Carrier Volume and Nozzle Type Effects on Spray Coverage, Droplet Density and Weed Control in Peanut

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ABSTRACT

Recent trends in herbicide applications show a preference among peanut growers for using lower carrier volumes and coarser-droplet nozzles. Field-scale studies using commercial application equipment were conducted in 2021 and 2022 to investigate the influence of carrier volume and nozzle type on spray coverage, droplet density, and weed control in peanut. The study treatments consisted of target carrier volumes of 94, 117, and 140 L ha^{-1}, with each volume applied using three different nozzles – XRC, AIXR and TTI – to attain different droplet sizes. Spray coverage and droplet density data were collected during herbicide applications. Weed control was recorded after herbicide applications and peanut yield was measured at harvest. Spray coverage improved with an increase in carrier volume from 94 to 140 L ha^{-1}. The AIXR nozzles provided comparable (2021) or improved (2022) coverage than the XRC nozzle while reduced coverage was observed for the TTI nozzle during both years. Droplet density was greatest for the XRC nozzle followed by the AIXR and TTI nozzles but was not impacted by carrier volume. Despite noticeable differences in spray coverage and/or droplet density, weed control and peanut yield were not affected by carrier volume and nozzle type. Overall, these findings suggest that peanut growers may observe reduced spray coverage for herbicide applications at low carrier volumes and/or when using nozzles that produce large (Ultra Coarse) droplets, but this effect may not directly translate into reduced herbicide efficacy or peanut yield in most fields with low to moderate weed pressure. Future studies should investigate the influence of spray parameters (carrier volume, nozzle type, etc.) on weed management in fields with varying weed pressures and different weed sizes.

INTRODUCTION

Peanut (*Arachis hypogea* L.) is one of the major row crops grown in the southeastern United States. In 2023, 2.7 million metric tons of peanuts were produced on 647,420 ha in the US (USDA-NASS, 2023). Weeds can cause great competition with peanut plants for moisture, sunlight, and nutrients during the growing season (Wilcut *et al.* 1994), and affect crop yield, quality, and economic value (Everman *et al.* 2008). Effective weed management is critical for growers to produce high peanut yields and quality. According to an Agricultural Chemical Use Survey conducted in 2018, herbicides were the most widely used pesticides in peanut production, applied to more than 90% of the planted acreage in the US (USDA-NASS 2019). Consequently, effective applications through proper selection of a herbicide program, application parameters and timing are important for effective weed control in peanut.

Previous research suggests that spray coverage and efficacy of herbicide applications are influenced by several application parameters such as carrier volume (Borger *et al.* 2013; Butts *et* *al.* 2018), nozzle type/droplet size (Etheridge *et al.* 2001; Carter *et al.* 2017), ground speed (Sapkota *et al.* 2023), boom height (Balsari *et al.* 2017), and environmental conditions such as wind speed and direction (Alves *et al.* 2017). While environmental conditions can vary and cannot be controlled during applications, spray parameters can be properly selected and optimized to improve the effectiveness of herbicide applications. Among these parameters, proper selection of carrier volume and droplet size is an important consideration as it helps in attaining adequate coverage and mitigating drift concerns while also maintaining the efficacy of applications (Butts *et al.* 2018; Legleiter and Johnson, 2016). Generally, higher carrier volume provides better coverage and improves efficacy due to increased spray deposits on the surface of targets (Knoche, 1994). Legleiter and Johnson (2016) reported that a higher carrier volume of 140 L ha^{-1} provided improved coverage at the bottom of soybean canopies compared to a lower volume of 94 L ha^{-1}. Similarly, Borger *et al.* (2013) reported that an increase in preemergence herbicide carrier volume from 30 to 150 L ha^{-1} increased spray coverage, resulting in improved weed control in wheat. Conversely, few studies have reported minimal to no reduction (Etheridge *et al.* 2001; Ramsdale and Messersmith, 2001) in pesticide efficacy at lower carrier volumes.

Besides carrier volume, proper selection of nozzle type also plays an important role in attaining desired coverage and efficacy (Guler *et al.* 2012). Nozzle type affects droplet size, which further impacts spray uniformity, coverage, and the amount of spray particle drift (Taylor *et al.* 2004; Nuyttens *et al.* 2007). Conventional flat-fan nozzles that produce a higher amount of finer spray droplets tend to improve coverage and efficacy compared to nozzles producing larger droplets (Etheridge *et al.* 2001) but smaller spray droplets are also more susceptible to particle drift. Due to increased concerns about pesticide drift, air induction/venturi nozzles (AI) were developed, that produce coarser spray droplets and help in minimizing particle drift (Etheridge *et al.* 2001; Lund 2000; Ramsdale and Messersmith 2001). However, one of the main concerns with AI nozzles is the possible reduction in spray coverage and efficacy due to larger droplet sizes. Few researchers have compared the performance of AI nozzles to conventional flat-fan (non-AI) nozzles in peanut and reported no influence of nozzle type on pesticide efficacy with respect to pest management despite varied coverage between these nozzle types (Berger *et al.* 2014; Carter *et al.* 2017; Virk *et al.* 2021).

In general, spray application is a complex process, and interactions among different spray application parameters such as carrier volume and droplet size (nozzle type) are not uncommon (Reichard, 1988). An extensive review of the effects of droplet size and spray volume on herbicide performance by Knoche (1994) reported that the effects of droplet size were most prominent when applying lower carrier volumes, whereas the effects of volume were most noticeable at larger droplet sizes. Similarly, Butts *et al.* (2018) stated that an increase in carrier volume from 47 to 187 L ha^{-1} diminished the effect of larger droplet size (900 µm), and resulted in better weed control for a systemic herbicide (dicamba) used in their study. However, the authors also reported that the optimal droplet size across different carrier volumes used in the study was lower (310 µm) for contact herbicides (glufosinate). The interaction between spray volume and droplet size can also be influenced by the herbicide mode of action, weed species (Sikkema *et al.* 2008), and weed stage at the time of application (Berger *et al.* 2014).

Peanut is an important rotational crop with cotton in the southeastern US. To mitigate spray drift concerns, cotton growers are required to utilize drift-reducing nozzles that produce coarser droplets when spraying auxin herbicides. As changing nozzles between crops is uncommon for growers, the same nozzles also get utilized for most pesticide applications in peanut including herbicides, insecticides, and fungicides. Moreover, there is also a rising trend among growers towards utilizing lower carrier volumes to cover more acreage per tank load and reduce the total number of refills. As noted earlier, the effect of nozzle type can vary depending on carrier volume and research investigating the nozzle type effects at different carrier volumes, especially the interaction between these two application variables, for weed control in peanut has not been conducted. Additionally, most previous research on the spray performance of different nozzles in peanut is conducted in small plots with herbicide applications using a CO_2-powered backpack sprayer. The authors believe these conditions often cannot adequately represent the field-scale environment and applications performed with large-scale, commercial equipment. Therefore, the objective of this study was to assess spray coverage, droplet density, and weed control in peanut at varying carrier volumes and nozzle types (to target different droplet sizes) in large-scale fields using a commercial agricultural sprayer. The study aimed to provide information on the implications of utilizing lower carrier volumes and/or nozzles producing coarser droplets on spray deposition and/or weed management in peanut.

MATERIALS AND METHODS

Location and Application Equipment

Field experiments were conducted at the Sunbelt Ag Expo farm in Moultrie, Georgia, USA in 2021 (31^0 08' N, 83^0 43' W) and 2022 (31^0 08' N, 83^0 42' W). During both years, herbicide applications were made using a commercial LMC agricultural boom sprayer (LMC Manufacturing, Albany, GA) (Figure 1). The study treatments consisted of three carrier volumes of 94, 117, and 140 L ha^{-1} with each volume applied using three different nozzle types [Extended Range, XRC; Air Induction Extended Range, AIXR; Turbo-TeeJet Induction TTI, (TeeJet Technologies, Springfield, IL)] to target different droplet sizes of Medium, Very Coarse, and Ultra Coarse, respectively (ASABE/ANSI, 2020). These carrier volumes and nozzle types were selected based on the nominal volumes and nozzle types used by peanut growers across the southeastern US, especially in Georgia. The target carrier volumes were attained by varying the nozzle orifice size while keeping the constant spray pressure at 344.7 kPa and the ground speed of 16.1 km h^{-1}. The sprayer boom width was 18.3 m with nozzles spaced equidistantly at 0.46 m. The sprayer boom was split evenly among the selected nozzle types (XRC, AIXR, and TTI; Figure 2). However, this arrangement prevented randomization of the nozzle types across the boom during the testing and can, therefore, be considered as a limitation of the experimental design employed in this study. During each year, the plots measured 6.1 m wide by approximately 150 to 200 m (equal to the length of the field) in length. The study followed a split-plot design where carrier volume was treated as the main plot factor and nozzle type served as the sub-plot factor. Before each application, the sprayer was calibrated (using each nozzle size) to deliver the target spray volumes at the selected spray pressure (344.7 kPa) and the ground speed (16.1 km h^{-1}). During calibration, the applied volume was measured and verified for each boom section to ensure flow rate consistency among the different nozzle types installed on the sprayer boom. Since spray pressure affects carrier volume and droplet size, it was kept constant across all the study treatments and verified across different boom sections during calibration. For all applications, the sprayer boom height was maintained at approx. 0.76 m from the ground surface. Table 1 provides detailed information on the treatments and other application parameters used in this study.

Figure 1. The commercial LMC boom sprayer used for herbicide applications in the peanut spray studies conducted in 2021 and 2022.

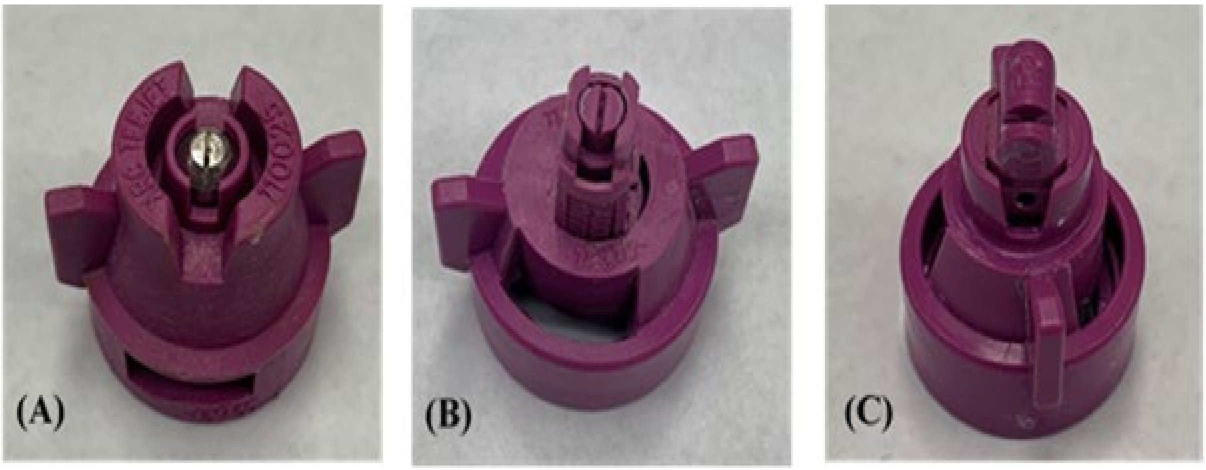

Figure 2. Different nozzle types: (A) XRC, (B) AIXR, (C) TTI (TeeJet® Technologies, Springfield, IL) used to target various droplet sizes in the peanut spray studies conducted in 2021 and 2022.

Table 1. Information on carrier volume and nozzle type treatments along with other application parameters used for the peanut spray studies conducted in 2021 and 2022.

Carrier Volume	Nozzle Type[a]	Spray Angle	Orifice Size	Spray Pressure	Speed	Boom Height
L/ha		degrees		kPa	km/h	m
94	XRC	110	025	344.7	16.1	0.76
94	AIXR	110	025	344.7	16.1	0.76
94	TTI	110	025	344.7	16.1	0.76
117	XRC	110	04	344.7	16.1	0.76
117	AIXR	110	04	344.7	16.1	0.76
117	TTI	110	04	344.7	16.1	0.76
140	XRC	110	05	344.7	16.1	0.76
140	AIXR	110	05	344.7	16.1	0.76
140	TTI	110	05	344.7	16.1	0.76

[a] XRC: Extended Range, AIXR: Air Induction Extended Range, TTI: Turbo-TeeJet Induction (TeeJet® Technologies, Springfield, IL)

Herbicide Applications and Data Collection

Each year, herbicide applications were made twice in the growing season: a preemergence (PRE) application at or right after planting, and a postemergence (POST) application at approximately 14 to 21 days after the PRE application. The specific herbicide formulations and their corresponding rates used for both herbicide applications are listed in Table 2. These products represent the most commonly used herbicide program by growers for weed control in peanut across the state of Georgia and were therefore selected for this study.

Table 2. Information on herbicide formulations and their rates used in the peanut spray studies conducted in 2021 and 2022.

Application	Trade Name	Active ingredient	Rate (kg ai/ha)
Preemergence	Prowl®	Pendimethalin	1.06
	Valor®	Flumioxazin	0.11
	Strongarm®	Diclosulam	0.01
Postemergence	Cadre®	Imazapic	0.07
	Dual Magnum®	S-metolachlor	0.90
	Butyrac®	2,4-dichloro-phenoxybutyric acid	0.90

During herbicide applications, environmental conditions including wind speed (m/s), wind direction, temperature (°C), relative humidity (%), and dew point (°C) were monitored and recorded at 1-min intervals by installing an on-site weather station (Model 6357 Vantage Vue^{TM}, Davis Instruments, CA). The meteorological data recorded during the herbicide applications for both years is presented in Table 3. The temperature and wind speed remained mostly consistent across the applications and study years. The wind speed was relatively low (0 to 1 m s^{-1}) whereas temperature ranged from 27.8 to 31.7 °C during applications. The only difference observed was in relative humidity, which varied by more than 9% and 30% between the PRE and POST applications in 2021 and 2022, respectively.

Table 3. Meteorological conditions recorded during pre- and postemergent herbicide applications in peanut studies conducted in 2021 and 2022. Values represent mean ± standard deviation.

Year	Application[a]	Temperature	Relative Humidity	Dew Point	Wind Speed	Wind Direction
		°C	%	°C	m/s	
2021	PRE	27.8 ± 0.8	60.0 ± 3.4	23.9 ± 0.5	0.7 ± 0.6	NNW
	POST	31.7 ± 1.5	51.5± 4.9	20.4 ± 1.9	0.0 ± 0.1	WSW
2022	PRE	29.8 ± 2.6	43.5 ± 7.6	15.8 ± 0.8	0.8 ± 0.7	WSW
	POST	28.9 ± 1.7	74.4 ± 5.2	23.8 ± 0.5	1.0 ± 0.7	WNW

[a] PRE and POST refer to preemergence and postemergence herbicide applications, respectively.

For data collection related to assessing spray deposition, nine wooden blocks (8.9 x 8.9 x 5.1 cm) – with a paper clip attached on the top of each block to hold a water-sensitive paper (WSP) – were placed on the ground surface in a grid pattern (3.6 m × 15.2 m) under the boom (three blocks/data points per nozzle) during herbicide applications in the field. Within a grid, each row of blocks was placed 15.2 m apart along the length of the sprayer pass and served as a replication. Each 3x3 grid of blocks during application represented data collection for one nozzle type within the selected spray volume treatment. WSP (26 x 76 mm) was placed on all wooden blocks (Figure 3A) before each sprayer pass. Before any herbicide applications each year, an application using water only as a solution was also conducted to assess and verify the droplet sizes created by each nozzle type at the selected carrier volumes. Herbicides were mixed with water as a carrier in their labelled concentration (Table 2) and applications were made implementing different combinations of carrier volume and nozzle type. After each application, WSP was allowed to dry for a few minutes and then collected in pre-labelled envelopes to have minimum exposure to moisture and/or humidity. All samples were transported to the laboratory for analysis immediately after data collection.

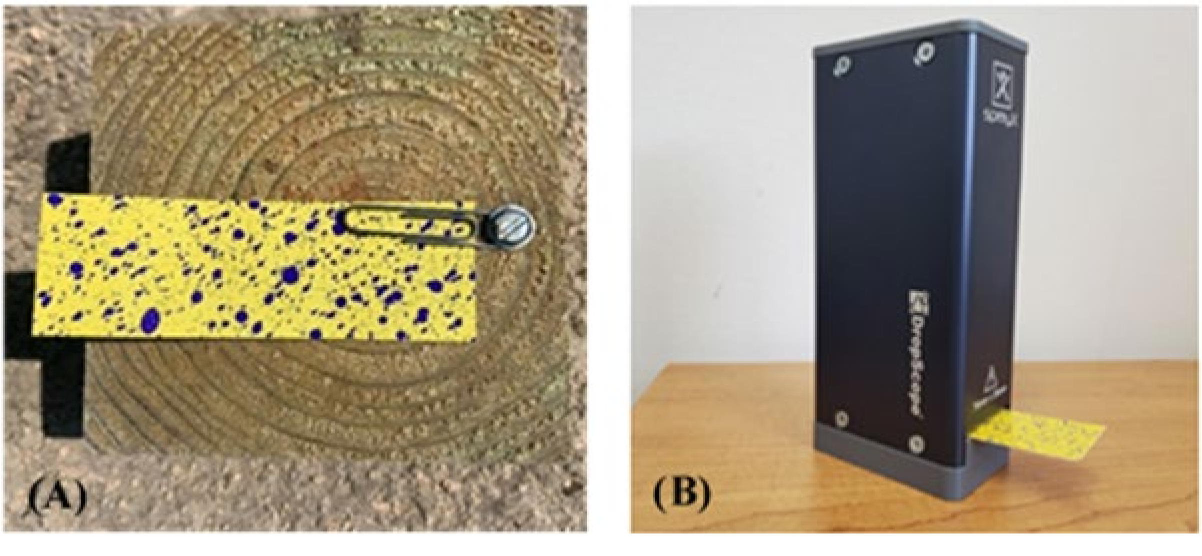

Figure 3. (A) Illustration of setup used for collecting spray deposition using water-sensitive paper, and (B) DropScope instrument (SprayX, São Paulo, Brazil) used for analyzing water-sensitive paper.

WSP was scanned using a DropScope instrument (Figure 3B) and SprayX software (SprayX, São Paulo, Brazil). The WSP analysis provided spray coverage, droplet density, and Volume Median Diameter (VMD). Spray coverage refers to the percentage of area covered by the spray droplets while droplet density refers to the quantity of droplets per unit area. VMD is the droplet diameter (µm) where 50% of the spray volume is in droplets smaller than this value. The SprayX software utilizes the appropriate spread factor for WSP and other related information as listed in ASABE S572.3 (ASABE, 2020) to provide VMD information. The VMD data was only used for applications made with water to assess if the desired droplet sizes were attained during applications. Table 4 presents this data and shows that the droplet sizes attained for different nozzles used in this study were within the corresponding VMD range and droplet size classification as specified in the ASABE 572.3 (ASABE, 2020).

Table 4. Droplet size information from spray assessment conducted with water only as a solution for different nozzle types and carrier volume treatments.

Carrier volume	Nozzle Type[a]	Droplet Size[b]	VMD Range[c]	Droplet Size Classification[c]
L/ha		µm	µm	
94	XRC110025	304	236-340	M
	AIXR110025	453	404-502	VC
	TTI110025	670	>665	UC
117	XRC11004	323	236-340	M
	AIXR11004	442	404-502	VC
	TTI11004	739	>665	UC
140	XRC11005	321	236-340	M
	AIXR11005	497	404-502	VC
	TTI11005	746	>665	UC
187	XRC11006	337	236-340	M
	AIXR11006	499	404-502	VC
	TTI11006	883	>665	UC

[a] XRC: Extended Range, AIXR: Air Induction Extended Range, TTI: Turbo-TeeJet Induction (TeeJet® Technologies, Springfield, IL)

[b] Droplet size represents the volume median diameter (VMD) of the spray droplets assessed using water only.

[c] VMD range and droplet size classification according to ASABE S572.3.

The authors understand the limitations of using WSP to assess droplet size and that herbicide products can also impact droplet size; hence the presentation and discussion of results in this paper are focused on specific nozzle types used in this study instead of droplet sizes.

Weed density counts were performed in each plot by sampling six randomly selected locations in the center two rows, approximately two weeks after PRE and POST applications during both years. The total number of weeds per square meter was counted in each sampled location. An untreated check (no herbicide applied) was also included in the field each year to compare and evaluate weed control among the study treatments. After herbicide applications, peanut was managed following the standard agronomic recommendations outlined in the University of Georgia Peanut Production Guide (Monfort *et al.* 2022). Peanut yield was recorded by harvesting each plot using a commercial 6-row KMC peanut harvester (KMC Equipment, Tifton, GA) and weighing the harvested peanuts using a weigh wagon. Table 5 provides a timeline of the field operations and data collection including peanut planting, spray deposition assessment, weed density, inversion, and harvest for the peanut spray studies conducted in 2021 and 2022.

Table 5. Information on cultivar, planting, herbicide application, weed count, peanut inversion and harvest dates for peanut spray studies conducted in 2021 and 2022.

Year	Cultivar	Planting	PRE[a]	Weed Density[b]	POST[a]	Weed Density[b]	Peanut Inversion	Harvest
2021	GA-06G	May 04	May 06	May 21	June 04	June 14	Sept. 29	Oct. 05
2022	GA-06G	May 16	May 18	June 03	June 17	June 31	Sept. 30	Oct. 04

[a] PRE and POST refer to preemergence and postemergence applications, respectively.

[b] Weed density = weed counts performed approximately 14 days after each application.

Data Analysis

Data were analyzed using JMP® Pro 16.0.0 (SAS Institute Inc., Cary, NC) for any significant interactions between year, application timing (PRE and POST) and study treatments. Statistical analysis indicated no significant interaction for any of the measured response variables ($p>0.05$) between the applications. Therefore, data were pooled across both applications for each year. Considering the experimental design used in this study, where the nozzle type arrangement (sub-plot factor) was fixed across the sprayer boom, data were subjected to a mixed-effects model with carrier volume and nozzle type as explanatory variables, and spray coverage, droplet density, weed density, and yield as response variables. For analysis of variance, the main effects of carrier volume, nozzle type, and volume × nozzle type were used as fixed effects whereas rep and rep x nozzle type were considered random effects. An alpha value of 0.05 was used to determine the significance of the main and interaction effects. Treatment means were separated for significant effects with the Tukey HSD test ($p\leq0.05$).

RESULTS AND DISCUSSION

Spray Coverage

Both carrier volume and nozzle type were significant for spray coverage ($p<0.0001$) while their interaction was non-significant ($p=0.1064$). Additionally, there was no significant interaction of carrier volume with year ($p=0.1729$), therefore data were pooled together. The spray coverage increased with an increase in carrier volume, with the lowest coverage provided by the 94 L ha^{-1} and the highest coverage observed for the 140 L ha^{-1} (Table 6) across all nozzle types. The carrier volume of 117 and 140 L ha^{-1} exhibited 22% and 46%, respectively greater spray coverage than the 94 L ha^{-1} volume. Similarly, the increase in carrier volume from 117 to 140 L ha^{-1} resulted in a 20% increase in spray coverage indicating a linear trend that each 23 L ha^{-1} volume increased coverage by approx. 20% to 22%. In contrast to carrier volume, the effect of nozzle type varied among the study years. In 2021, both XRC and AIXR nozzles exhibited similar coverage (Figure 4A) whereas the AIXR nozzle showed greater coverage than the XRC nozzle in 2022 (Figure 4B). The TTI nozzle demonstrated the lowest coverage across all nozzle types during both years. In 2021, the XRC and AIXR nozzles provided approximately 23% to 33% higher coverage than the TTI nozzle while spray coverage was approximately 36% and 67% greater for the XRC and AIXR nozzles, respectively than the TTI nozzle in 2022.

These results were comparable with the findings of other recent studies that investigated the effect of carrier volume and/or nozzle type on herbicide spray coverage in other crops (Ferguson *et al.* 2016; Legleiter and Johnson, 2016; Ferguson *et al.* 2020). Using similar carrier volumes and nozzle types (as used in this study) for post-emergent herbicides, Legleiter and Johnson (2016) reported greater coverage with the 140 L ha^{-1} volume than the 94 L ha^{-1} in soybean for all nozzles. However, the coverage for nozzle types was inconsistent where both the XR and AIXR nozzles provided better coverage than the TTI nozzle in one year, and no difference in coverage among the nozzle types was observed in another. Similarly, Ferguson *et al.* (2016) indicated an 18% gain in coverage with an increase in spray volume from 50 to 100 L ha^{-1} in oat canopy across different nozzle types including XR, AIXR and TTI, used in their study. Herbicide coverage was similar between the XR and AIXR nozzles, and between the AIXR and TTI nozzles at the top of the oat canopy. In another study by Ferguson *et al.* (2020) evaluating different spray deposition assessment methods, a 56% increase in coverage was attained by increasing the spray volume to 100 to 200 L ha^{-1} for spray deposition assessed using water-sensitive paper.

Generally, a higher carrier volume and smaller spray droplets are likely to improve coverage due to a greater number of finer spray particles reaching the target. Similarly, a lower volume and larger droplet sizes are expected to reduce coverage because of a small number of large spray droplets reaching the target. For the nozzle types used in this study, the XRC nozzle produces finer spray droplets whereas both the AIXR and TTI nozzles generate coarser droplets (Very Coarse and Ultra Coarse, respectively) (TeeJet Technologies, Springfield, IL; Table 4). In this study, the spray coverage increased with carrier volume and the TTI nozzle (larger droplets) reduced spray coverage; however, the spray coverage results for the XRC and AIXR nozzles were different than expected. A comparable or improved coverage from the AIXR nozzles than the XRC nozzles can be possibly explained by the fact that the finer spray droplets produced by the XRC nozzles are also highly susceptible to off-target movement or even evaporation before reaching the target and can therefore exhibit reduced deposition. Additionally, the authors believe that the WSP and/or analysis method used to assess spray deposition does not have the high resolution generally required to detect very fine spray particles produced by the XRC nozzles.

Droplet Density

Contrary to spray coverage, droplet density was only significant for nozzle type ($p<0.0001$) but not for carrier volume ($p=0.0796$). The carrier volume × nozzle type interaction for droplet density was also non-significant ($p=0.0971$), and so was the year × carrier volume interaction ($p=0.5488$). The droplet density ranged from 90 to 111 droplets per cm^{-2} across the carrier volumes with considerable variability observed at each volume as indicated by relatively large standard deviation values (Table 6). Similar to spray coverage, the effect of nozzle type on droplet density varied between the study years (Table 7). In 2021, the XRC nozzle had the highest droplet density followed by the AIXR and TTI nozzles while in 2022, the AIXR nozzle had the greatest droplet density followed by the XRC and TTI nozzles. Both the XRC and AIXR nozzles had approximately 3.8 to 4.8x more droplets per unit area than the TTI nozzle whereas the droplet density differed by 1.3 to 1.6x droplets per unit area between the XRC and AIXR nozzles. These droplet density variations can be mainly attributed to the difference in size of spray droplets among these nozzles.

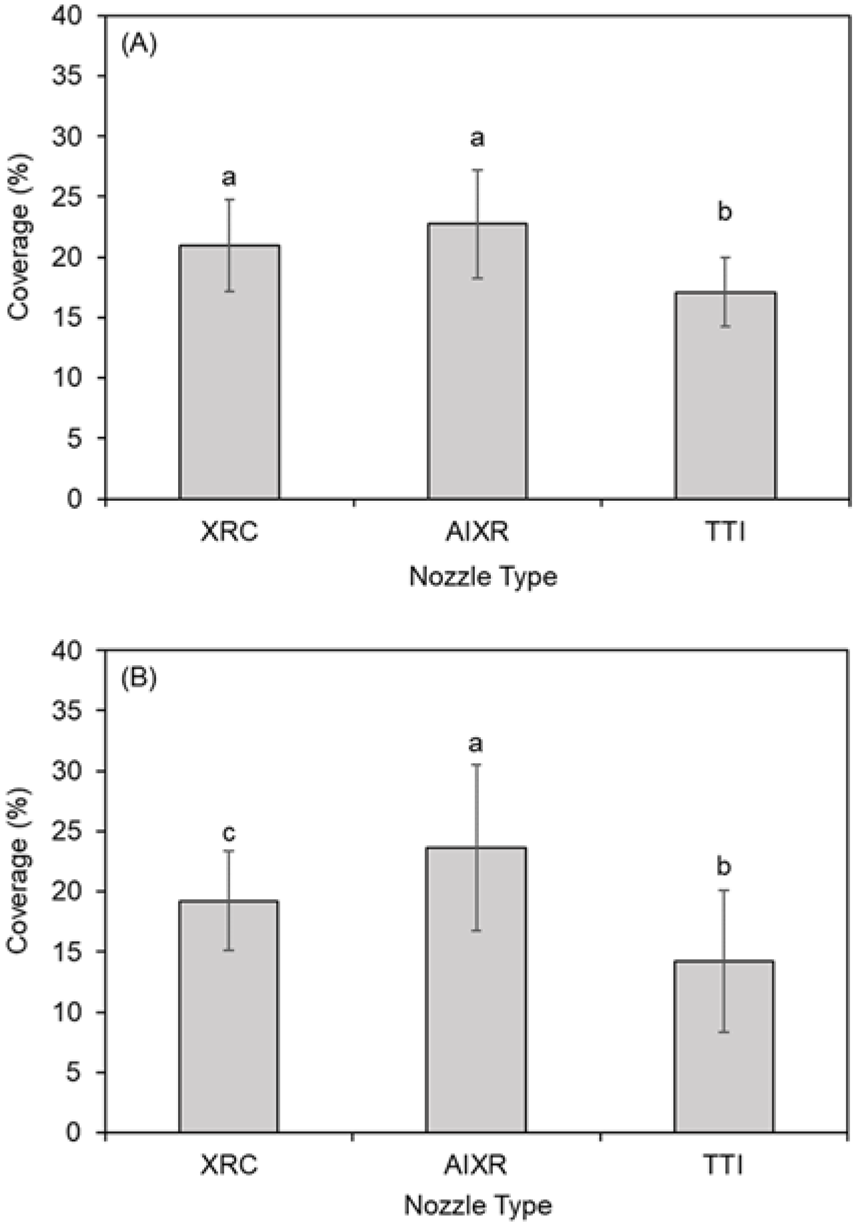

Figure 4. Spray coverage (%) as influenced by nozzle type in (A) 2021 and (B) 2022. Bars represent mean ± standard deviation. Values with the same letter are not significantly different from each other according to the Tukey HSD test ($p>0.05$). XRC: Extended Range, AIXR: Air Induction Extended Range, TTI: Turbo-TeeJet Induction (TeeJet® Technologies, Springfield, IL).

In general, droplet density is expected to increase with carrier volume and decrease with an increase in droplet size (VMD). Consequently, the XRC nozzles should exhibit higher droplet density followed by the AIXR and TTI nozzles. While the droplet density for the TTI nozzles was lowest as expected, the AIXR nozzle provided comparable or greater droplet density than the XRC nozzle. Similarly, an increase in carrier volume from 94 to 117 L ha^{-1} showed a numerical increase in droplet density but this trend was not statistically significant across the nozzle types. These results could be possibly attributed to two different reasons. The first is that the larger (coarser) droplets can overlap and/or shield the finer droplets on the water-sensitive paper, resulting in decreased droplet density. This limitation of using the water-sensitive paper method to determine droplet density has also been reported by other researchers (Cunha *et al.* 2013; Fox *et al.* 2003; Zhu *et al.* 2011). The second reason being that the herbicides used in this study could possibly have an effect on the droplet spectrum and ultimately the droplet density. Previous studies have also reported the influence of the herbicide product(s) on droplet density (Creech *et al.* 2015; Legleiter and Johnson, 2016; Miller and Ellis, 2000). In fact, Creech *et al.* (2015) found that the effect of herbicides was one of the most significant factors affecting the size of the droplet spectrum, either increasing or reducing it.

While the droplet density results for carrier volume did not correlate to spray coverage, the nozzle type effects on droplet density supported some of the spray coverage findings (Table 7). For example, the TTI nozzle had the lowest spray coverage and droplet density during both years. Similarly, the droplet density followed a similar trend as observed for spray coverage among the nozzle types in 2022 where the AIXR nozzle had the greatest droplet density (and spray coverage) followed by the XRC and TTI nozzles. In contrast, the XRC nozzle had the highest droplet density followed by the AIXR and TTI nozzles in 2021. Ferguson *et al.* (2020) shared similar findings in a study evaluating different deposition assessment methods where the authors reported that the XR nozzle (Fine droplets) exhibited the highest droplet density followed by the AIXR (Coarse to Very Coarse droplets) nozzle, and the TTI (Ultra Coarse droplets) nozzle had the lowest droplet density determined using a WSP method. The authors also noticed a similar volume effect (as observed in the present study) where there was no significant increase in droplet density with an increase in spray volume from 100 to 200 L ha^{-1} for the XR and AIXR nozzles, despite improved spray deposition observed from the increase in volume. In contrast, an increase in droplet density along with coverage was observed for the TTI nozzle in their study.

Table 6. Influence of carrier volume on spray coverage and droplet density.

Carrier Volume	Coverage[a]		Droplet Density	
	Mean	Std. Dev.	Mean	Std. Dev.
	%		quantity of droplets/cm^2	
94	16.6 c	3.7	90	59
117	19.5 b	4.9	100	59
140	23.4 a	6.0	111	67

[a] Means followed by the same letter are not significantly different from each other according to the Tukey HSD test (p>0.05).

Table 7. Influence of nozzle type on droplet density in 2021 and 2022.

Nozzle Type[a]	2021		2022	
	Mean[b]	Std. Dev.	Mean[b]	Std. Dev.
	quantity of droplets/cm^2		quantity of droplets/cm^2	
XRC	164 a	44	118 a	21
AIXR	104 b	28	151 b	60
TTI	36 c	11	31 c	15

[a] XRC: Extended Range, AIXR: Air Induction Extended Range, TTI: Turbo-TeeJet Induction (TeeJet® Technologies, Springfield, IL)

[b] Means followed by the same letter are not significantly different from each other according to the Tukey HSD test (p>0.05).

Weed Control

The carrier volume, nozzle type and their interaction effects were not significant for weed control (*p=0.6513, p=0.7585,* and p=*0.0971,* respectively) indicating comparable efficacy of the herbicide program implemented using different carrier volumes and nozzle types (Table 8). However, all treatments exhibited better weed control than the untreated (no herbicide) plots. While attaining adequate and uniform coverage is important for all herbicides, it can be argued that the soil-applied residual and systemic herbicides are less sensitive to the effects of carrier volume and nozzle type (droplet size), and can often compensate for reduced spray coverage, which could also explain some of the results attained in the present study. Consequently, the selection of carrier volume and nozzle type is more important for improving the efficacy of contact (non-systemic) herbicides, mostly used for postemergence applications. This may also present an argument to evaluate the effect of carrier volume and nozzle type for contact (non-systemic) herbicides only; however, most peanut growers apply herbicide programs (including the one used in this study) utilizing the same volume and nozzle combination for both pre- and post-emergence applications. For this reason, this study aimed to evaluate the efficacy of the entire herbicide program at different carrier volumes and nozzle types than only for a few selected herbicides or for only postemergence herbicide applications.

Table 8. Effect of carrier volume and nozzle type on weed density and peanut yield.

Carrier Volume	Nozzle Type[a]	Weed Density[b,c]	Peanut Yield
L/ha			Kg/ha
94	XRC	0.6 b	6,243
	AIXR	0.4 b	5,774
	TTI	1.0 b	6,246
117	XRC	1.0 b	6,083
	AIXR	1.1 b	6,237
	TTI	0.4 b	5,855
140	XRC	0.8 b	5,786
	AIXR	0.6 b	6,180
	TTI	0.4 b	5,816
Untreated		16.7 a	-

[a] XRC: Extended Range, AIXR: Air Induction Extended Range, TTI: Turbo-TeeJet Induction (TeeJet® Technologies, Springfield, IL)

[b] Weed Density represents the total number of weeds per unit area (m^2)

[c] Means followed by the same letter are not significantly different from each other according to Tukey HSD test ($p>0.05$).

For herbicide efficacy, while the lower volume of 94 L ha^{-1} and the TTI nozzle (Ultra-Coarse droplets) significantly decreased coverage, these effects did not result in reduced weed control in this study. Berger *et al.* (2014) reported similar results where the spray coverage was reduced for the XR nozzles than the AI nozzles but showed no effect on the lactofen efficacy of Palmer amaranth. However, the authors did observe reduced control at 94 L ha^{-1} volume than 187 and 281 L ha^{-1} whereas this effect was not observed in the present study. One of the possible reasons for this could be the difference in weed pressures or weed sizes among the studies. Similarly, Carter *et al.* (2017) and Virk *et al.* (2021) reported noticeable differences in spray coverage between different non-AI (Medium to Coarse droplets) and AI nozzles (Very Coarse to Ultra Coarse droplets) but no effect on weed control in their studies. Herbicide efficacy can be influenced by many other factors including weed species (Brown *et al.* 2007; Sikkema *et al.* 2008), weed stage at the time of application (Berger *et al.* 2014), tillage and soil type (Franca *et al.* 2020), and pest pressure in the field (Zhang *et al.* 2000). Evaluation of these parameters was outside the scope of this study; therefore, the influence of these factors on weed control in peanut in conjunction with carrier volume and nozzle type needs to be investigated in future studies.

Carrier volume and nozzle type did not affect peanut yield (*p=0.7720* and *p=0.8681*, respectively; Table 8). This was mostly expected due to the non-significant differences observed in weed control between the study treatments. Though limited studies have investigated and reported the influence of nozzle type on crop yield, these results were analogous to the findings of Carter *et al.* (2017) and Virk *et al.* (2021) in peanut. In both studies, the authors reported no differences in peanut yield between different non-AI and AI nozzles used in their studies.

CONCLUSIONS

With an increasing trend among peanut growers in using lower carrier volumes and nozzles that produce larger (coarser) droplets, understanding the influence of these factors on spray coverage, droplet density, and weed control is imperative to provide informed, research-based recommendations to the growers. The results attained in this study indicated that both applicator-controlled variables, carrier volume and nozzle type, can influence spray coverage during herbicide applications. Specifically, it was noticed that increasing carrier volume from 94 to 140 L ha^{-1} improved spray coverage. Among nozzle types, the AIXR nozzle (Coarse droplets) demonstrated greater coverage than the TTI nozzle (Ultra Coarse droplets) and comparable or better coverage than the XRC nozzle (Medium droplets). However, these carrier volume and nozzle type effects did not have any significant impact on weed control and peanut yield. These findings suggest that growers who utilize lower spray volumes and coarser-droplet nozzles for weed management in peanut may not need to be concerned about reduced efficacy or yield in most fields with low to moderate weed pressure. However, it is also important to emphasize that both pre- and post-emergence herbicide applications in this study were timely and performed when weeds were smaller than 5 to 10 cm. Therefore, growers should consider these factors (timeliness, weed pressure and size) when making carrier volume and nozzle selection decisions for herbicide applications in peanut fields. In situations where weeds are taller or weed pressure is high, carrier volume and/or nozzle type may need to be adjusted accordingly for effective weed control. These types of weed management situations also necessitate conducting additional, similar studies in varying field conditions, especially with high weed pressures and/or different weed sizes.

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