INFLUENCE OF APPLICATION VARIABLES ON SPRAY DEPOSITION, QUALITY, CANOPY PENETRATION AND PESTICIDE EFFICACY IN PEANUT

by

MADAN SAPKOTA

(Under the Direction of Simerjeet S. Virk)

ABSTRACT

These studies investigated the impact of application variables i.e. ground speed, carrier volume, and droplet size on pesticide spray deposition, quality, canopy penetration, and efficacy in peanut. Increasing ground speed significantly reduced deposition and impacted spray quality for the conventional sprayer without a rate controller whereas utilizing a rate controller resulted in more consistent spray deposition and quality. Both carrier volume and droplet size influenced spray deposition, droplet density, and canopy penetration in peanut. The higher carrier volumes of 140 to 187 L ha^{-1} and medium to coarse spray droplets increased droplet density, thereby improving spray deposition for both herbicide and fungicide applications in peanut. They enhanced deposition up to the middle of peanut canopies, while deposition at bottom remained consistent regardless of carrier volumes and droplet sizes. The higher carrier volume and medium droplet showed improved disease control in some cases but neither variable affected weed control and yield.

INDEX WORDS: Ground speed, carrier volume, nozzle selection, droplet size, rate controller, spray coverage, spray quality, canopy penetration, efficacy, pesticides, peanut

INFLUENCE OF APPLICATION VARIABLES ON SPRAY DEPOSITION, QUALITY, CANOPY PENETRATION AND PESTICIDE EFFICACY IN PEANUT

by

MADAN SAPKOTA

B.S., Agriculture and Forestry University, Nepal, 2019

A Thesis Submitted to the Graduate Faculty of The University of Georgia in Partial Fulfillment of the Requirements for the Degree

MASTER OF SCIENCE

ATHENS, GEORGIA

2023

INFLUENCE OF APPLICATION VARIABLES ON SPRAY DEPOSITION, QUALITY, CANOPY PENETRATION AND PESTICIDE EFFICACY IN PEANUT

by

MADAN SAPKOTA

Major Professor:	Simerjeet S Virk
Committee:	Eric P Prostko Robert C Kemerait Glen C Rains

Electronic Version Approved:

Ron Walcott
Vice Provost for Graduate Education and Dean of the Graduate School
The University of Georgia
August 2023

DEDICATION

For my parents (Ganga Ram Sharma and Tahali Sharma), beloved wife (Sarita Chapagain), brother (Mahendra Sapkota), and my sisters (Juna and Maya Sapkota) – thank you all for your love, support, and encouragement over the years.

ACKNOWLEDGEMENTS

First of all, I would like to thank the Georgia Peanut Commission, the National Peanut Board, and the University of Georgia for the financial and material support of this research. I am grateful to my major advisor Dr. Simerjeet S. Virk for his supervision and guidance throughout my master’s program. I would also like to thank my committee members: Dr. Eric P. Prostko, Robert C. Kemerait, and Glen C. Rains for their guidance, support, and suggestions. I am thankful to the amazing team of UGA Digital Ag lab: Coleman Byers, Matt Tucker, Ravi Meena, and Michael Goodnight for their support in data collection and lab work. Finally, I would like to thank my family for giving me the strength and encouragement to face all challenges in life.

TABLE OF CONTENTS

Page

CHAPTER

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION AND LITERATURE REVIEW

1.1 INTRODUCTION

Peanut (*Arachis hypogea* L.) is an important oilseed crop and a major source of economy in the United States, especially in the Southeast region. However, peanut production in the Southeast region is threatened by diseases and pests supported by climatic conditions (long spells of warm and humid). During the late vegetative growth stages, the middle and bottom portions of the peanut canopy become dense and prone to disease development and insect infestation (Plaut and Berger 1980). Thus, timely and effective pesticide applications are critical during this stage for successful pest management. Use of precision spray technologies on a boom sprayer can help improve application accuracy and spray drift management.

Adequate spray coverage and canopy penetration are important for pesticides to be effective. To achieve consistent spray coverage that is evenly distributed throughout the canopy, the selection of adequate spray volume and optimal droplet size are important considerations during pesticide applications. Some studies recommend using finer droplet size (Feng et al. 2003; Ferguson et al. 2018) and higher carrier volume (Derksen et al. 2008) for adequate coverage and canopy penetration. On the other hand, Reed and Smith (2001) suggest the cotton growers to use lower carrier volume and finer droplets to improve coverage and pest control.

Although spray technology has advanced considerably in recent years, many growers still utilize a traditional boom sprayer without a rate controller where the target application rate is achieved by maintaining a consistent ground speed. However, ground speed variations are common in the field during pesticide application resulting in the actual applied rate being different from the target rate. Past research indicates that changes in sprayer ground speed of the sprayer can alter the application rate which can affect coverage and drift (Nuyttens et al. 2007). However, relatively little information is available on how ground speed variations impact spray quality.

Limited research is available on evaluating the influence of application variables during pesticide application in peanuts. Therefore, this research project aims at understanding how those parameters influence spray coverage, quality, canopy penetration, and pesticide efficacy in peanut.

1.2 LITERATURE REVIEW

1.2.1 Peanut Production in US

Peanut is an important oilseed crop that is grown around the world in tropical, sub-tropical and warm temperate climates (Stalker 1997). China is the largest producer of peanuts in the world followed by India, Nigeria, and United States. Based on a USDA survey report, the total production of peanuts worldwide is 50,436,000 MT (USDA 2022b). The United States accounts for 6 % of the worldwide peanut production. The total area of peanuts planted and harvested in the U.S. in 2022 are 586,916 ha and 560,651 ha respectively. Similarly, the peanut production and yield for 2022 are 2,525,670,355 kg and 4505 kg per ha (USDA 2022a). Peanut production is highly concentrated in the Southeast region of the United States. Georgia is the leading producer of peanuts followed by Florida, Alabama and Texas. Georgia accounts for 44 % of the total US peanut production. The total area of peanuts planted and harvested in Georgia are 307,561 ha and 303,514 ha respectively (USDA-NASS 2022). Peanut growers in the US grow four types of peanuts; Runner, Virginia, Spanish and Valencia. Runner have a prostrate growth habit, spreading along the ground. Virginia peanuts have a semi-erect growth habit, with some stems growing above the ground. Spanish peanuts have a semi-erect growth habit as well, while Valencia peanuts have an upright growth habit. Among them, runner type is widely grown in the southeast and makes up 80% of the total planted acreage of the U.S. (APC 2020).

1.2.2 Use of Pesticide in Agriculture

Over the past few decades, there has been a dramatic increase in the use of pesticides in the United States. A study by Fernandez-Cornejo et al. (2014) reported that herbicides are the most commonly used pesticide in the United States followed by insecticides and fungicides. Based on the report, the trends of applying pesticide changed considerably from 1960 to 2008. The amount of herbicide used in 1960 was 18% of the total amount of pesticide applied, and the use of herbicide increased to 76 % by 2008. However, the use of insecticides was 58% of the total amount of pesticide applied in 1960 but decreased to only 6 % by 2008. Interestingly, the trend of fungicide use remained stable (7%) over the years. Row crops like field corn, soybean, and cotton were the crops where herbicides and insecticides were heavily applied whereas fruits and vegetables were greatly influenced by the impact of fungicides application (Ridgway et al. 1978). Among all the pesticides used, the widespread use of herbicides has been a major concern for growers and researchers. In recent years, due to the increased occurrences of herbicide-resistant weeds, producers are applying more herbicides without considering their effects on plant communities and the environment which has prompted a large number of spray drift complaints, especially in row crops like field corn, soybean, cotton, and peanut (Dill et al. 2008).

Peanut production in the United States, especially in the southeastern region, is greatly affected by diseases and pests. Extended warm and humid weather conditions and the potential for high rainfall and thunderstorms during the growing season creates a favorable environment for the development of diseases, especially fungal diseases (Kemerait et al. 2015). The most important peanut diseases in the southeastern U.S. are tomato spotted wilt virus (TSWV), leaf spots (both early and late), and southern stem rot (white mold). Corn earworm (*Helicoverpa virescens*), tobacco budworm (*Heliothis virescens*), three-cornered alfalfa hopper (*Spissistilus festinus*), and burrower bug (*Pangaeus bilineatus*) were the most important insect pest on peanuts. Likewise, Palmer amaranth (*Amaranthus palmeri*), Florida pusley (*Richardia scabra L.*), Tropical spiderwort (*Commelina benghalensis*), Florida beggarweed (*Desmodium tortuosum*) and sicklepod (*Senna obtusifolia*) are among the most troublesome weeds in peanut production at Georgia (Monfort et al. 2022) .

Based on a USDA survey, herbicides, fungicides, and insecticides are the major pesticides sprayed in peanuts. Among the pesticides, herbicides were applied most extensively in the field (94% of planted acres) followed by fungicides (88% of planted acres) and insecticides (37% of planted acres) (USDA, 2018). Flumioxazin was the most widely used herbicide which is applied to 65% of planted acres. Similarly, chlorothalonil (solely or in combination with other fungicides) is one of the most widely used fungicides for foliar disease management in peanut. Organophosphates are the most commonly used insecticides in row crops including peanuts.

1.2.3 Spray Application Parameters

During the late vegetative growth stage, for row crops like peanut, there are remarkable increases in the number of branches, leaf area, main stem nodes, and plant height (Tewolde et al. 2002). Over the course of canopy development, the middle and bottom portions of the canopy become prone to the diseases and pest infestation (Plaut and Berger 1980). Therefore, growers need to make wise decisions in proper selection of application parameters such as nozzle type, droplet size, spray volume, spray pressure, boom height, and ground speed to improve coverage, quality, canopy penetration and efficacy of pesticide application (Bode et al. 1976; Nordby and

Skuterud 1974). Moreover, environmental factors like wind speed, air temperature, and relative humidity (Byass and Lake 1977; Maybank et al. 1978) as well as the canopy shape and structure of targeted plants (Hall 1991) have a significant influence on the accuracy and efficacy of pesticides.

1.2.3.1 Carrier Volume

Carrier volume is one of the significant factors affecting pesticide coverage and performance (Butts et al. 2018). The amount of carrier volume depends upon the pesticide mode of action. As stated in the review by Knoche (1994), there was a significant interaction between herbicide type and carrier volume, and it was reported that the plant response consistently increased as carrier volume decreased for glyphosate (systemic herbicide). However, a decrease in carrier volume for the contact herbicides resulted in the decrease of herbicide performance. It was also found that decreasing carrier volume for systemic herbicides was more effective for herbicide performance on difficult-to-wet plants than easy-to-wet plants.

Spraying higher volume is the one of the most effective ways of increasing canopy penetration through the production of a greater number of spray droplets that help in penetration of upper canopy and coverage of middle and bottom canopy (Derksen et al. 2008). Higher volume also helps in reducing the spray drift potential. Sharpe et al. (2018) observed the effects of carrier volume and nozzle type on spray penetration into a strawberry canopy and found that the carrier volume had a significant impact on penetration. Penetration increased with increasing carrier volume; however, the nozzle types used in this experiment made no impact on penetration. Legleiter and Johnson (2016) also reported similar results where carrier volume showed a significant influence on herbicide coverage in narrow row soybean. Higher carrier volume (140 L ha^{-1}) aided in better coverage of spray in the bottom of soybean canopies compared to a lower volume (94 L ha^{-1}). However, nozzle types had no significant influence in coverage at the lower canopy of the plant. Creech et al. (2018) suggested that the proper selection of nozzle and increasing the career volume can result in better canopy penetration of soybean and corn plant.

Most often, across the herbicides, using large droplet sizes decrease the efficacy of application; however, increasing carrier volume nullifies the effects of using large droplet size and aids in better coverage and penetration with minimum drift (Bretthauer et al., 2008; Butts et al., 2018). Bretthauer et al. (2008) experimented with the influence of carrier volumes (47 L ha^{-1} and 94 L ha^{-1}) and droplet sizes (medium and very coarse) on the control of soybean rust, and the results from the finding showed that very coarse droplets at higher volume (140 L ha^{-1}) provided better canopy coverage and penetration than any other combination of droplet size and volumes.

Some studies have also shown that using a higher carrier volume had minimal effect on deposition, coverage, and pest control. Reed and Smith (2001) indicated that spray deposition decreased with an increase in carrier volume and droplet size; therefore, growers were recommended to use low spray volume and smaller droplets for improved deposition and mortality of *Heliothine* larvae in cotton. Fritz et al. (2007) also reported that lower carrier volume with larger droplet sizes resulted in better residue deposition in wheat heads for aerial fungicides application. A study by Derksen et al. (2008) also observed less impact of carrier volume on the amount of fungicide residue on the bottom canopies of soybean.

Carrier volume affects the concentration of solution which in herbicide applications ultimately affects the toxicity to the plants. The lower the volume, the higher is the concentration of the solution. At the same dosage rate, concentrated solution is more phytotoxic than diluted solutions (Cranmer and Linscott 1991; McKinlay et al. 1974). Different studies have been conducted in row crops looking at influence of carrier volume in spray deposition, quality, canopy penetration and pest control. However, research evaluating the influence of carrier volume in peanut is limited.

1.2.3.2 Nozzle Types/Droplet Size

An important decision growers must make is which nozzle size and type to use for pesticide application. Apart from determining the spray volume, nozzle selection influences droplet size which further affects spray uniformity, canopy coverage, and drift potential. Droplet size distribution is the main basis for nozzle selection where droplet size is measured in microns (µm). The American Society of Agricultural and Biological Engineers (ASABE) developed a droplet size classification system and classified nozzles as very fine (450 µm), fine (100-175 µm), medium (175-250 µm), coarse (250-375 µm), very coarse (375-450 µm), or extremely coarse (>450 µm) (ASABE/ANSI 2020).

The impact of droplet size on the efficacy of pesticides depends upon the pesticide's mode of action. Generally, nozzles producing finer droplets are mainly used for postemergence contact application because of their excellent coverage on leaf surfaces whereas nozzles producing coarser droplets are used for systemic pesticides (Hanna et al. 2009a). However, some of the experiments concluded that there was no impact of droplet size on the efficacy of systemic herbicides (Feng et al. 2003; Prokop and Veverka 2006), but for contact herbicides, fine droplets were found to be more efficient than coarse droplets (Feng et al. 2003; Ferguson et al. 2018; Jones et al. 2002; Prokop and Veverka 2006; Wolf 2000; Wolf et al. 1992).

Limited research is available on the impact of droplet size on insecticide efficacy. Most of the studies suggest that spraying with larger droplets will have a significant impact on the bottom of the canopies. Sumner et al. (2007) reported better performance of low-drift nozzles (which produces large droplets ranging from 496-587 µm) over hollow-cone type against stinkbug control in cotton. However, Reed and Smith (2001) indicated that there was a decrease in larval mortality with the increase in droplet size in cotton. Therefore, a balance of better coverage with increased canopy penetration can be achieved by using nozzles that produce medium-sized droplets.

Fungicide applications should provide good coverage and penetration into the canopy to provide effective control of fungal pathogens. Most of the research findings suggest using a nozzle that produces medium-sized droplets to balance the need for good coverage and penetration into the canopy (Garcerá et al. 2020; Hanna et al. 2009b; Ozkan et al. 2006). Prokop and Veverka (2006) found that the efficacy of contact fungicides increased for finer droplets without using a surfactant in potato. Derksen et al. (2008) observed that the fungicide applied with the medium-quality XR8004 flat-fan nozzle showed significantly more fungicide residue than coarse-quality XR8005 in bottom canopies of soybean. Similarly, Wolf and Daggupati (2009) reported improved canopy penetration into dense soybean canopy from nozzles producing fine and medium droplets. However, Bretthauer et al. (2008) observed that the use of very coarse droplets in the presence of higher spray volume resulted in better coverage and deposition in the plant canopy than medium droplets. Zhu et al. (2004) also studied the impact of different hydraulic nozzles on spray penetration into peanut canopies with single- and twin-row planting systems. They used four different types of hydraulic nozzle tips; flat fan, hollow cone, twin jet and air-induction to determine spray coverage at the top, middle and bottom of canopies with a spray mixture containing water and a fluorescent tracer. They found that the nozzles producing coarse droplets had higher spray penetration performance than finer droplet producing nozzles. Unlike other researchers, Derksen et al. (1998) reported no significant effects of droplet size on efficacy of fungicide application on tomato diseases management.

Pesticide drift associated with the finer droplet became a major issue for the growers of different crops. Therefore, in most cases, optimum selection of droplet size using appropriate nozzle helps to minimize spray drift potential. (Bouse et al. 1990; Hanna et al. 2009a; Taylor et al. 2004; Yates et al. 1985). The concerns of growers towards drift led to the introduction of Venturi nozzles (Air induction nozzles) which aim to minimize drift, increase coverage on the specific part of crops, and improve crop canopy penetration (Fietsam et al. 2004).

Virk et al. (2021) conducted seven on-farm trials in peanut fields using a commercial sprayer to compare the spray performance of air induction (AI) nozzles with non-AI (conventional flat fan) nozzles. They reported that there was variation in spray coverage among the nozzle types; however, nozzle type had no influence on pest control and yield. Therefore, they suggested that the peanut growers having fields from low to average pest pressure can utilize coarser droplet-producing AI nozzles. Similarly, Carter et al. (2017) compared the influence of auxin nozzle types (AIXR 11002 and TTI 11002) with conventional drift-guard nozzles (DG 11002) which produced coarse, ultra-coarse and medium droplets respectively. They observed no significant impact of nozzle types in pest control and peanut yield in non-crop test, but the result from in-crop test showed no influence of nozzle type in Palmer amaranth control and yield whereas the control of annual grass was 5% to 6% lower when using TTI nozzle compared to other nozzles. Creech et al. (2018) also studied the glyphosate spray penetration into corn and soybean canopies using four nozzle types (XR11005, AIXR11005, AITTJ11005, AND TTI11005) and a drift control adjuvant. They found that the TTI11005 nozzle (air-induction nozzle) had the greatest amount of spray penetration in soybean.

Spray pressure affects nozzle performance and droplet size that ultimately impacts the efficacy and drift potential of pesticides (Ferguson et al. 2016). As the pressure increases, nozzle flow rate increases, ultimately resulting in production of a larger number of finer droplets (Teejet 2013). A greater percentage of small droplets increases herbicide efficiency on one side, but on the other side increases off-target drift. Therefore, McMullan (1995) suggested selecting appropriate spray pressure for achieving efficacy while keeping drift to a minimum.

In reality, it is challenging to cover all the surfaces of leaves and stems of plants with the sprayed pesticides. Therefore, it is better to utilize angled spray to overcome this problem by making a suitable decision while selecting nozzle types (single vs twin fan). When pesticides are applied with a single fan nozzle, the droplets emitting from the nozzle orifice are most likely to strike non-vertical to plant surface resulting large proportion of them bouncing off the surface othe nto soil surface (Jensen 2007). This problem can be improved by changing the spray angle from vertical to non-vertical using twin fan nozzles (Okzan et al. 2012). Previous research has reported the better performance of twin flat-fan nozzle in contrast to single flat-fan. Aliverdi (2020) found that the twin symmetrical flat fan nozzle with a smaller size worked better than single and twin asymmetrical flat fan nozzle. Moreover, Aliverdi and Karami (2019) studied the effects of increasing the number of nozzle orifices (single, twin, and triplet fan nozzle) and concluded that increasing the orifice number of each nozzle can lead to improved penetration of spray droplets into the canopy.

1.2.3.3 Ground Speed

Proper selection of application rate is an important consideration for achieving adequate coverage, efficacy and pest control in peanut. Since many of the peanut growers in Southeast United states are still utilizing a conventional boom sprayer without rate controller, target application rate is achieved by maintaining a consistent ground speed – selected during sprayer calibration – for the given nozzle size and pressure. However, ground speed variations are common in the field during pesticide applications that result in reductions of carrier volume and ultimately effects on spray deposition and quality.

Most of the research has been carried out to study the impact of ground speed on pesticide spray drift, but only limited literature can be found studying its impact on the coverage, quality and efficacy of application. Carroll (2017) used different nozzle types; Teejet AI, XR, AIXR, and TTI to achieve medium, very coarse, and ultra-coarse droplet sizes and operated sprayer at three spray speeds; 11 km h^{-1}, 19 km h^{-1}, and 29 km h^{-1} to evaluate their effects on herbicide efficiency at 3, 7 and 15 days after treatment (DAT). Carroll observed that a travel speed of 11 km h^{-1} and a medium droplet size had a highest mean percent control of weeds at 3 DAT, and a travel speed of 29 km h^{-1} and a very coarse droplet size were found to have highest mean percent weed control at 7 DAT. They suggested that both droplet size and travel speed should be taken into due consideration to reduce potential drift along with maximizing herbicide efficiency.

When speed increases, it increases the nozzle flow rate to achieve desired application rate (ASABE 2016). Moreover, higher speed results in higher pressure at the nozzle orifice, which produces smaller droplets that escape out into the atmosphere (Miller and Smith 1997; Nuyttens et al. 2007). Several studies have reported pesticide drift issues with the increase in speeds (Miller and Smith 1997; Nuyttens et al. 2007; Taylor et al. 1989). Miller and Smith (1997) measured an increase in spray drift by approximately 51% when speed increased from 4 km h^{-1} to 8 km h^{-1}. Moreover, the drift increased to 144% when the speed was further increased to 16 km h^{-1}. Taylor et al. (1989) also reported a 4% increase in drift potential value from the boom sprayers on increasing speeds from 4 to 7 km h^{-1}, and a 90% increase in drift value on increasing speed from 7 to 10 kmh^{-1}.

1.2.3.4 Boom Height

Boom height plays an important role in improving accuracy of pesticide application and reducing drift. The height of a boom needs to be adjusted in such a way so as to provide adequate coverage and minimize drift potential. Generally, lower boom heights are usually better when there is proper overlapping of nozzles (Nuyttens et al. 2007); however, if boom height is too low, an uneven spray pattern may occur. If the spray boom is too high above the crop or target, the potential of off-target movement of spray droplets increases (Jong et al. 2000; Nuyttens et al. 2007; Teske and Thistle 1999).

Balsari et al. (2017) found that the use of air-induction (AI) nozzles became more effective than standard nozzles in reducing potential drift (between 56% and 91%) at the same boom height. However, the drift potential value was reduced by 55% and 36% in standard and AI nozzles respectively on reducing boom height from 70 to 50 cm. Jong et al. (2000) and Nordby and Skuterud (1974) also found that lowering boom height resulted in less drift than higher boom heights.

1.2.3.5 Environmental Factors

Wind speed is the most critical environmental factor affecting spray drift. Fritz (2006) also concluded that wind speed was the most influential meteorological factor on deposition and drift of aerially applied sprays. Speed of wind is highly responsible for the off-target movement of spray droplets (Berg et al. 1999; Craig et al. 1998). Though applicators have no complete control over wind speed, they can limit its effect by following specific label instructions before, during, and after the application.

The application of pesticides at both high and low wind speeds decrease the efficacy of the application. While higher wind speeds will lead to potential drift loss, lower wind speeds (dead calm condition) increases the chance of temperature inversion. Growers are generally recommended to apply pesticides when wind speed range between 4.8 to 16.1 km h^{-1} to reduce the potential risk of drift. Alves et al. (2017) studied the effects of different nozzles (XR, TT, AIXR, and TTI) under varying wind speeds (3.2, 8.0, 12.9 and 17.7 km h^{-1}) on dicamba spray drift in a wind tunnel. When wind speed increased from 3.2 to 17.7 km h^{-1}, the spray drift from XR, TT and AIXR nozzles increased exponentially, but increased linearly in the case of TTI nozzle. The difference in the increase in drift among the nozzles is due to the variation in droplet size production by each nozzle. TTI nozzle produced the coarsest droplet size and was less susceptible to drift due to wind.

Apart from wind speed, temperature and relative humidity also affect the efficiency and drift of pesticides (Kirk et al. 1992). High temperature and low humidity increase the evaporation of spray droplets, decrease the droplet size, and reduce the volume of pesticides reaching the target. Losses through evaporation of droplets can be reduced through the application of pesticides in cool and damp conditions, especially in the morning and evening.

1.2.4 Plant Canopy Characteristics: Shape and Structure

The canopy structure and shape of targeted plants have a great influence on the efficiency of spray application (Hall 1991). In crops, when there is a dense canopy at the late vegetative stage, the canopy intercepts the spray particles and reduces the deposition of the active ingredient of pesticide within the targets (Wolf et al. 1993). For such crops, pesticide efficacy is directly related to the abilities of spray to penetrate crop canopy (Knoche 1994) and distribute evenly through the canopies (Uk and Courshee 1982; Wolf 2000). As the growing season proceeds, foliage density and Leaf Area Index (LAI) increase. However, after the plant reaches its peak vegetative stage, LAI starts to decrease very slightly. When LAI increases, spray deposition and penetration at the middle and bottom portion of the canopy (where the incidence of disease and insects is high) decreases. Zhu et al. (2004) studied on spray penetration into peanut canopies using four hydraulic nozzle tips (flat fan, hollow cone, twin jet, and air induction) and measured canopy height, width and leaf area index (LAI) to correlate them with spray deposit at middle and bottom of peanut canopies at 46, 75, and 104 days after planting. They reported that the spray deposition at the bottom of peanut canopy linearly decreased with an increase in LAI for each nozzle types as the growing season proceeded from 46 to 104 days after planting. Moreover, the plant shape and position of leaves influence the deposition of spray droplets (Tu et al. 1986). Leaf morphology and structures of targeted plants play an important role in determining optimal droplet size during application of pesticides. Leaf structures such as hairs, edges, cuticular wax, etc. also make a difference in spray deposition on targeted leaves (De Rutter et al. 1990).

1.2.5 Spray Technologies

Accuracy of pesticide application is very important to enhance crop yield and quality (Ozkan 1987). Both over-application and under-application of pesticides decrease the quality of the product and result in yield loss. Different precision spray technologies are available today which control over the different application parameters to enhance efficiency of application. Rate controller, Automatic Section Control (ASC), Pulse-Width Modulation (PWM), and Automatic Boom Height Control systems are some of the precision spray technologies available for the growers to make precise spray application.

Rate controller is one of the basic precision spray technologies available for the growers to improve the application accuracy of farm inputs. Most of the sprayer rate controllers that are used today work on flow rate control-based systems (Sharda et al. 2011). With a rate controller, application rate can be adjusted based on real-time speed and application width. When using a boom sprayer without rate controller, maintaining consistent application rate is difficult due to variations in ground speed. Therefore, integrating a rate controller in a boom sprayer minimizes application errors and reduces the mis-application of pesticides (Al-Gaadi and Ayers 1994; Ayers et al. 1990; Rockwell and Ayers 1996).

The adoption of spray controller with Automatic Section Control (ASC) is increasing which reduces the overlap and application into non-targeted areas (Sharda et al. 2010a). In irregular fields with obstacles, nozzle off-rate or non-uniformity that amplifies application errors is common (Sharda et al. 2010b). Instead of switching the boom section on and off manually, the ASC technology closes the boom/individual nozzle valves whenever the sprayer reaches already-covered areas or no-spray areas. Therefore, the use of ASC technology for controlling over individual or boom section reduces off-rate application, improves efficacy, minimizes overlap, and saves on time and inputs resources (Luck et al. 2010).

Recently, Pulse-Width Modulation (PWM) systems are becoming common on boom sprayers. PWM is a spraying system where the flow rate is controlled across a range of ground speeds by regulating application pressure and spray droplet size. Flow is controlled by pulsing a solenoid valve at each nozzle, and is changed by varying duty cycles (proportion of time that nozzle is open) (Butts et al. 2018).

Maintaining consistent boom height during pesticide application has been a great concern to most growers when operating in fields with uneven terrain and/or varying crop canopy heights (Herbst et al. 2018; Sartori et al. 2002). Therefore, automatic boom height control systems for sprayers have also become popular in recent years. These systems automatically set a boom height above the top of the crop canopy (based on ultrasonic sensor detection), and in the case of undulated terrain, the system aligns the position of the left and right arms of the boom with respect to terrain. This technology helps to solve issues of spray overlap, non-uniform spray, and spray drift (Herbst et al. 2018).

1.3 RATIONALE

Peanut, unlike other row crops, has well-developed and dense canopy growth as the growing season proceeds to late vegetative stage. In this stage, spray coverage and canopy penetration are important considerations when for attaining adequate pesticide efficacy, especially for the control of fungal pathogen. Though using finer spray droplets along with higher volumes could help to improve coverage and penetration into crop canopies, growing concerns about pesticide drift have led to the adoption of nozzles that produce coarser droplet sizes. Currently, limited research exists on which combination of application parameters (carrier volume and droplet size) can be used to maximize coverage and canopy penetration in peanut. Additionally, traditional boom sprayer without a rate controller are also being commonly used by peanut growers, where target application rate is achieved by maintaining consistent ground speed. However, it is very common to observe variations in ground speed in the field during pesticide applications which consequently decreased application rate and impacts on spray performance of applied pesticide. Past research indicates that change in ground speeds of sprayer can affect spray coverage and drift; however, limited research is available on how it impacts spray quality. Integrating a simple spray technology i.e a rate controller on peanut sprayers could help grower to maintain the target application rate and uniformity across field despite changes in ground speed. However, no substantial information is found on the evaluation and comparison of boom sprayers with and without a rate controller. Therefore, this project aims to understand the influence of spray application parameters on spray coverage, quality, penetration, and efficacy in peanut. Also, this project will evaluate and compare the effectiveness and efficacy of pesticide application using boom sprayer with and without a rate controller.

1.4 HYPOTHESES AND OBJECTIVES

1.4.1 Hypotheses

1. Ho1: Integrating rate controller on a boom sprayer will improve the spray coverage and quality of herbicide applications
2. Ho2: Proper selection of carrier volume and droplet size will influence the herbicide spray coverage, efficacy and peanut yield
3. Ho3: Proper selection of carrier volume and droplet size will influence fungicide spray coverage, canopy penetration and disease control in peanut

1.4.2 Objectives

1. To evaluate the influence of ground speed on spray coverage and quality for an agricultural sprayer with and without a rate controller
2. To study the influence of carrier volume and droplet size on coverage, droplet density, and efficacy of herbicide application
3. To determine the influence of carrier volume and droplet size on fungicide spray coverage, quality, canopy penetration, and disease control

CHAPTER 2

[1]SPRAY DEPOSITION AND QUALITY ASSESSMENT AT VARYING GROUND SPEEDS FOR AN AGRICULTURAL SPRAYER WITH AND WITHOUT A RATE CONTROLLER

Sapkota, M., Virk, S., and Rains, G (2023). AgriEngineering, 5(1), 506-519. https://doi.org/10.3390/agriengineering5010033. Reprinted here with the permission of publisher.

2.1 ABSTRACT

Ground speed variations are common and unavoidable during pesticide applications with agricultural sprayers. Field tests were conducted to evaluate the effect of varying ground speeds on spray deposition and quality with a commercial agricultural boom sprayer without a rate controller (CNS) in 2021 and equipped with a rate controller (SRC) in 2022. During each year, the sprayer boom was split evenly among three different nozzle types (XRC, AIXR, and TTI) to attain different droplet sizes (medium, very coarse, and ultra-coarse, respectively). Prior to testing, the sprayer was calibrated to deliver an application rate of 187 L ha^{-1} at a spray pressure of 207 kPa and ground speed of 9.7 km h^{-1}. For spray deposition and quality assessment, pesticide applications were made at five different ground speeds of 9.7, 12.9, 16.1, 19.3, and 22.5 km h^{-1}, and data were collected by placing water-sensitive paper at different locations across the sprayer boom and in the field. Results for CNS indicated that spray deposition reduced significantly ($P < 0.05$) with an increase in ground speed across all three nozzle types, primarily due to a decrease in the quantity of spray droplets applied per unit area. The quantity of spray droplets and spray deposition was more consistent among the ground speeds for SRC. Ground speed affected spray quality for both CNS and SRC; however, the spray quality variations were greater for SRC due to an increase in spray pressure with ground speed. Among nozzle types, the trends in spray deposition and quality were similar for the XRC and TTI nozzles as observed for CNS and SRC. However, the AIXR nozzle showed inconsistent spray deposition and quality as ground speed varied. The results of this study indicated agricultural sprayers equipped with a rate controller provide adequate and consistent spray deposition compared to conventional sprayers (no rate controller) when ground speed changes occur during pesticide applications. While spray quality is also affected when using a rate controller, best management practices including proper nozzle

selection and application at nominal ground speeds should be followed to minimize these effects and ensure effective technology utilization.

2.2 INTRODUCTION

Pesticide application has been an indispensable part of row crop production in the United States. The use of pesticides to manage weeds, insects, and diseases has increased steadily over the years (USDA-NASS 2022a). A comprehensive survey conducted by the USDA Economic Research Service on the pesticide use of 21 selected crops from 1960 to 2008 indicated that the use of pesticides dramatically increased by more than three folds in the first two decades, from 88.9 million kg of pesticide active ingredient in 1960 to 286.7 million kg in 1981, and then declined slightly to 234.1 million kg in 2008 (Fernandez-Cornejo et al., 2014). This trend of increasing pesticide use has continued until today and shows that pesticide application has been a major component of input costs for row crops production in the United States (USDA-NASS 2022b). Effective and judicious use of pesticides is important to extend the usefulness and longevity of pesticides in agriculture. Maintaining application accuracy while minimizing off-rate errors and off- target movement of pesticides is critical to ensure safe and efficient pesticide applications. Along with following the best management practices, one of the ways to achieve this is through effective utilization of available spray technologies such as rate controller (Al-Gaadi and Ayers 1994; Ayers et al. 1990), automatic boom section, individual nozzle control (Luck et al. 2010; Sharda et al. 2010), and PWM system (Butts et al. 2018;Virk and Meena 2022).

The spray coverage and efficacy of pesticide application can be influenced by many equipment and application-related factors. Among them, ground speed and nozzle type/droplet size are important parameters as they can influence spray coverage, quality, efficacy, and drift (Miller and Smith 1997; Taylor et al. 1989; Hofman and Solseng 2001; Nuyttens et al. 2007; Virk et al. 2021). Currently, there is an increasing trend of using agricultural sprayers with wider booms (application swaths 27.4 m) along with applications at faster ground speeds (19.3 km h^{-1}) in order to cover more acres and save time. However, a common concern with an increase in ground speed is the reduced application rate due to the overall decreased amount of total spray droplets reaching the target (Ozkan and Womac 2005). Ground speed variations during pesticide application also affect nozzle performance and droplet size distribution. An increase in ground speed results in increased production of finer droplets, thereby increasing the potential for spray drift. Several studies have reported greater pesticide drift and reduced coverage associated with the increase in application speed (Miller and Smith 1997; Nuyttens et al. 2007; Taylor et al. 1989).

The spray quality is an important spray characteristic that is used to classify nozzle type based on the droplet size (VMD). Spray quality also affects coverage and particle drift (ASABE/ANSI, 2020). Generally, conventional flat-fan nozzles (such as Teejet® XR or XRC) that produce fine spray droplets are used for applying contact pesticides because of the greater coverage required on soil or leaf surfaces. However, increased pesticide drift associated with finer droplets led to the introduction of venturi/AI nozzles (such as Teejet® AIXR or TTI). These AI nozzles produce coarser spray droplets which are more suited for applying systemic pesticides while minimizing the risk of spray particle drift (Ramsdale and Messersmith, 2001). The improved drift control performance of AI nozzles (Etheridge et al. 1999; Lund 2000) and comparable coverage (or improved coverage in some cases) and efficacy to the conventional flat nozzles (Carter et al. 2017; Virk et al. 2021) have been reported by several researchers. Therefore, the appropriate selection of nozzle type—to attain desired spray quality—is highly recommended to maintain a balance between spray coverage and drift during pesticide applications (Bouse et al. 1990; Hanna et al. 2009; Taylor et al. 2004; Yates et al. 1985).

Ground speed variations coupled with other operational errors make maintaining a target rate during pesticide applications, a challenging task. However, maintaining a target application rate (L ha^{-1}) is critical to apply the desired pesticide amount (kg ha^{-1}), and achieving adequate coverage and efficacy. Therefore, different precision spray technologies have been developed over the years and are available to be utilized on agricultural sprayers to maintain application accuracy. A rate controller is one of the common spray technologies that helps in addressing the issues of off-rate application errors associated with traditional sprayers, by controlling the flow rate and maintaining the desired rate despite changes in ground speed (Al-Gaadi and Ayers, 1994; Ayers et al. 1990; Ozkan and Womac 2005). However, these flow rate adjustments are accomplished by changes to the system spray pressure and any changes in spray pressure also affects spray quality. Therefore, for a nozzle with a fixed orifice, an increase in spray pressure results in the production of a large number of finer droplets (Teejet 2013). Thus, while the changes in spray pressure help in maintaining the target application rate and may improve coverage by increased production of finer droplets, it also greatly increases the drift potential (Ferguson et al. 2016). To overcome this issue, PWM systems are becoming more common on agricultural sprayers where the flow rate is controlled across a range of ground speeds by varying duty cycle (proportion of time that nozzle is open) while still maintaining a constant spray pressure and droplet size (Butts et al. 2018;Virk and Meena 2022).

A review of the literature suggested that most of the previous studies that investigated the influence of nozzle type and/or ground speed have been focused primarily on assessing spray coverage (Miller and Smith 1997; Taylor et al. 1989; Hofman and Solseng 2001; Nuyttens et al. 2007; Virk et al. 2021; Carter et al. 2017; Carroll 2017) or particle drift (Ramsdale and Messersmith 2001; Bouse et al. 1990; Hanna et al. 2009; Taylor et al. 2004; Yates et al. 1985;

Ferguson et al. 2016; Ozkan and Zhu 1998; Wolf et al. 1993; Van de Zande et al. 2005; AI Heidary et al. 2014). Spray quality has received minimal to no attention in these studies. Further, most of these studies have not investigated how some of the commonly available spray technologies such as a rate controller can influence spray quality during pesticide applications. Currently, a large number of traditional agricultural boom sprayers—both within and outside the United States—especially by small acreage or specialty crop growers, are used without a rate controller while most modern agricultural sprayers (especially self-propelled) come equipped with a rate controller today. To ensure efficient pesticide applications with both conventional and newer technology-equipped sprayers, it is important to assess and understand their spray performance at a varying range of ground speeds. Therefore, the objective of this study was to evaluate spray deposition and quality at varying ground speeds for an agricultural sprayer equipped with and without a rate controller.

2.3 MATERIALS AND METHODS

2.3.1 Site and Application Equipment

Field experiments in this study were conducted in 2021 and 2022 at the Southeast Georgia Research and Education Center in Midville, Georgia, USA (32◦49′ N, 82◦14′ W). A tractor-mounted commercial agricultural boom sprayer (Demco X-fold, Demco Manu- facturing Co., Boyden, IA, USA) was used for herbicide applications (Figure 2.1a) during both years. The sprayer had a boom length of 18.3 m with nozzles spaced equidistant (0.46 m) across the length of the boom. In 2021, the sprayer was used without a rate controller whereas a Micro-Trak MT-2405F II rate controller (Micro-Trak, Mankato, MN, USA) in conjunction with a TeeJet® 346BPR-2F-03 (TeeJet Technologies, Springfield, IL, USA) regulating valve was used on the same sprayer in 2022 (Figures 2.1b and 2.1c, respectively). During both years, all other application settings including boom height and nozzles on the sprayer were kept similar. The only difference was the applications without and with a rate controller between the study years. Thus, these sprayer setups utilized in 2021 and 2022 will be referred to as CNS and SRC, respectively, from here forward.

Figure 2.1 (a) The commercial Demco X-fold boom sprayer used for spray performance testing in 2021 and 2022. (b) The Micro-Trak MT-2405F II rate controller and (c) the TeeJet® 346BPR-2F-03 regulating valve used in 2022.

To evaluate and compare spray performance between CNS and SRC, herbicide applications were made using five different ground speeds of 9.7, 12.9, 16.1, 19.3, and 22.5 km h−1 in the selected field. These ground speeds were attained by selecting the appropriate gear ratio of the tractor. Further, three different nozzle types, XRC, AIXR, and TTI (Teejet® Technologies, Springfield, IL, USA) (Figures 2.2a, 2.2b and 2.2c, respectively) were used to produce medium, very coarse, and ultra-coarse droplets, respectively, as per the ASABE standard S572.1 (ASABE/ANSI 2020). All nozzles used in this study had a 110° spray angle and a 04-orifice size. The nozzles were split evenly across the sprayer boom (18.3 ml) in the following arrangement from left to right (Figure 1a): XRC, AIXR, and TTI. During testing, each nozzle sprayed six rows (row spacing 0.91 m) which constituted a sub-plot that measured 5.5 m wide and approximately 182 to 200 m in length, which was equivalent to the length of the field. Before testing each year, the sprayer was calibrated to deliver 187 L ha^{-1} of spray volume at 207 kPa and 9.7 km h^{-1} for a 04-nozzle size. During testing, the study treatments were attained by varying the ground speed while keeping the nozzle type and size constant throughout the whole testing period each year.

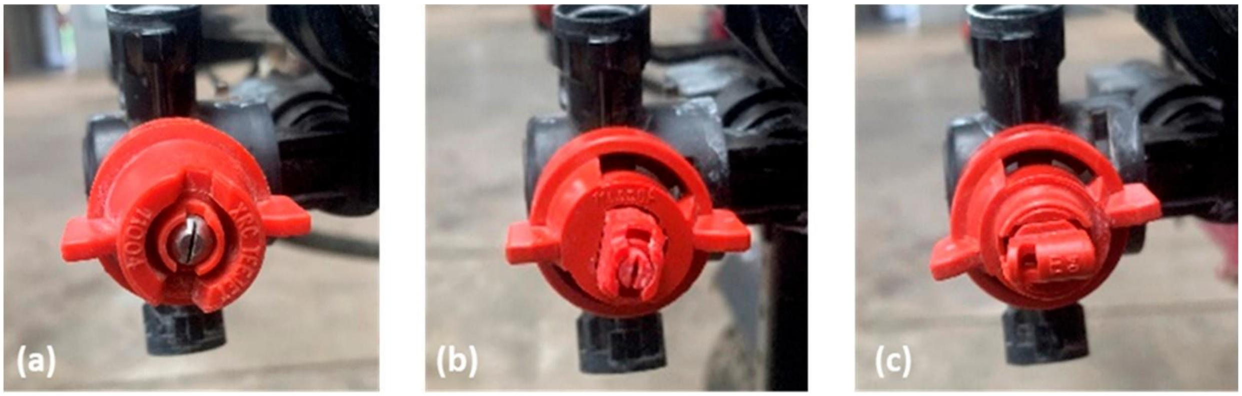

Figure 2.2 Three different nozzle types: TeeJet® (a) XRC 11004; (b) AIXR 11004; and (c) TTI 11,004. These nozzle types were used to attain medium, very coarse, and ultra-coarse spray droplets, respectively, (ASABE/ANSI, 2020) in this study.

2.3.2 Spray Applications and Data Collection

During both years, two herbicide applications—a preemergence and a postemergence—were made in the field planted with peanuts. Preemergence applications were made at or right after planting and before the emergence of peanut seedlings while the post-emergence spray applications were made approximately three to four weeks after the pre-emergence application. Details on the herbicide program used for pre-emergence and postemergence applications in these research trials conducted in 2021 and 2022 are shown in Table 2.1. In 2021, the preemergence and the postemergence herbicide applications were made on May 11 and June 16, respectively, whereas these applications were made on May 3 and June 1, respectively, in 2022.

Table 2.1 Information on different herbicides and their rates used during the spray testing conducted in 2021 and 2022.

Application	Herbicides	Active Ingredient	Rate (kg ha^{-1})
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

For data collection, nine wooden blocks—with a paper clip attached on the top of each block to hold a WSP (Figure 2.3a)—were placed on the ground in a grid pattern (5.5 x 15.2 m) prior to any herbicide applications in the field. Within each grid, the blocks were placed 15.2 m apart along the length of the spray pass (each row serving as a replication) and 1.8 m apart along the sprayer boom. Each 3 x 3 grid of blocks during application covered six rows and represented data collection for one nozzle type. WSP (26 x 76 mm) were placed on all the blocks prior to each sprayer pass. Herbicides were mixed with water as a carrier in their labeled concentration (Table 1) and spray applications were made implementing different ground speed treatments. After each sprayer pass, WSP were allowed to dry for few minutes and then collected in standard labeled envelopes to prevent further contamination due to moisture or humidity. At the end of the field testing, samples were carefully transported to the laboratory located in the Engineering building at the University of Georgia Tifton campus in Tifton, GA for further analysis.

During spray testing each year, meteorological 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 VueTM, Davis Instruments, Hayward, CA, USA). The averaged meteorological data for the entire application period for 2021 and 2022 are presented in Table 2.2. The meteorological conditions during both years remained consistent throughout the entire testing period including the wind speed, which was low (mean wind speed 1 ms^{-1}) during both years and did not have any significant effect on spray deposition during applications.

Table 2.2 Meteorological conditions recorded during the time of pre- and post-emergence applications in 2021 and 2022.

Year	Temperature (°C)	Relative Humidity (%)	Dew Point (°C)	Wind Speed (ms^{-1})	Wind Direction
2021	30.8 ± 1.3	56.4 ± 9.9	20.9 ± 1.7	0.6 ± 0.6	ESE
2022	28.8 ± 1.7	75.0 ± 0.9	23.9 ± 0.5	1.0 ± 0.7	NNW

2.3.3 Data Analysis

In the laboratory, WSP were scanned using a DropScope (SprayX, São Paulo, Brazil) instrument (Figure 2.3b) and a compatible SprayX software (SprayX, São Paulo, Brazil). The analysis provided spray coverage, droplet density, $D_{0.1}$, $D_{0.5}$/VMD, $D_{0.9}$, and spray quality. Spray coverage refers to the percentage of area covered by the spray droplets while droplet density refers to the quantity of spray droplets per unit area. $D_{0.5}$ (VMD) is the droplet diameter (µm) where 50% of the spray volume is in droplets smaller than this value. Similarly, $D_{0.1}$ and $D_{0.9}$ are the droplet diameters where 10% and 90%, respectively, of the spray volume is in droplets smaller than this value. Spray quality refers to the droplet size classification based on the VMD as per the ASABE S572.3 (ASABE/ANSI 2020). For each treatment, the WSP analysis also classified the overall spray quality in different droplet sizes based on their VMD as VF (61–105 µm), F (106–235 µm), M (236–340 µm), C (341–403 µm), VC(404–502 µm), EC (503–665 µm) and UC (>665 µm) (ASABE/ANSI 2020). The SprayX software utilized the spread factor and other related information as listed in the ASABE S572.1 to provide $D_{0.1}$, $D_{0.5}$, $D_{0.9}$, and spray quality (droplet size distribution) information for each treatment.

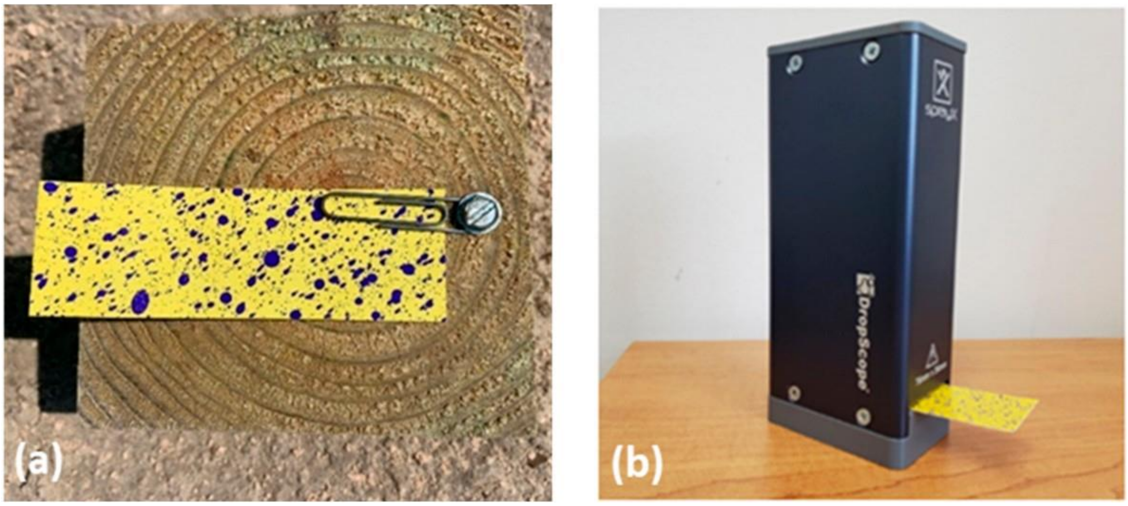

Figure 2.3 (a) Illustration of data collection setup (wooden block and water-sensitive paper) used in the field, and (b) the DropScope instrument used for analyzing water-sensitive paper.

All data were analyzed using JMP® Pro 16.0.0 (SAS, Cary, NC, USA). Statistical analysis indicated no significant interaction between the pre- and post-emergence applications for all the measured responses (P-values > 0.05); therefore, data were pooled across both applications for each year. Since the main goal of this study was to understand the influence of varying ground speed on spray deposition and quality for CNS and SRC, the spray performance data were analyzed separately for each nozzle to avoid any unnecessary interactions among the ground speed and nozzle types. Data were subjected to ANOVA with ground speed as the main effect for each nozzle type. For effects that were significant, treatment means were separated with a Student's t-test procedure using $\alpha = 0.05$.

2.4 RESULTS AND DISCUSSION

2.4.1 Spray Deposition

Table 2.3 ANOVA results (*P*-values) for spray coverage and quantity of spray droplets by nozzle type for CNS and SRC. CNS represents the sprayer without a rate controller and SRC represents the sprayer equipped with a rate controller used in this study.

Nozzle Type	Spray Coverage		Quantity of Spray Droplets	
	CNS	SRC	CNS	SRC
XRC	<.0001*	NS	0.0002*	NS
AIXR	<.0003*	0.016*	NS	0.0027*
TTI	<.0002*	NS	0.0042*	NS

* represents significant effects ($P<0.05$) and NS represents non-significant effects ($P>0.05$) XRC, AIXR and TTI denotes extended range, air induction extended range, and turbo-teejet induction nozzle types, respectively.

Table 2.3 presents the *P*-values from ANOVA analysis for spray deposition (spray coverage and quantity of spray droplets) for CNS and SRC for three different nozzle types used in this study. For CNS, ground speed affected spray coverage where a decrease in spray coverage was observed with an increase in ground speed (Table 2.4). This trend of reduced spray coverage was noticed across all three nozzle types (XRC, AIXR, and TTI) with an increase in ground speed from 9.7 km h^{-1} to 22.5 km h^{-1}. Among all nozzle types, the spray coverage was highest (40.1, 35.9, and 26.3% for XRC, AIXR, and TTI, respectively) at the slowest speed of 9.7 km h^{-1} (which was also the speed used for sprayer calibration prior to testing) whereas it was lowest (11.3, 18.0, and 9.4% for XRC, AIXR, and TTI, respectively) at the highest ground speed of 22.5 km h^{-1}. This reduction in spray coverage for CNS was somewhat expected as when ground speed increases, the number of spray droplets per unit area decreases due to the system pressure, and consequently the flow rate still being the same as selected during sprayer calibration. This is also evident from the reduction in the quantity of drops with an increase in ground speed, presented in Table 4. However, these results were only noticed across XRC and TTI nozzles. These findings differed for the AIXR nozzle where a reduction in spray coverage from 35.9% at 16.1 km h^{-1} to 18.0% at 22.5 km h^{-1} was observed; however, the quantity of spray droplets was comparable between the ground speeds. As mentioned earlier, a decrease in spray coverage is generally accompanied by a reduction in the number of spray droplets in the absence of a rate controller, so these findings for AIXR nozzles were unexpected.

Table 2.4 Influence of ground speed on spray coverage (%) and quantity of drops by nozzle type for CNS. CNS represents the sprayer without a rate controller used in this study.

Speed (km h^{-1})	Spray Coverage[a]			Quantity of Spray Droplets[a]		
	XRC	AIXR	TTI	XRC	AIXR	TTI
9.7	40.1 a	35.9 a	26.3 a	5746 a	2733	905 a
12.9	29.7 b	29.5 b	23.4 a	4933 ab	3089	601 c
16.1	23.5 c	22.0 c	17.0 b	4589 b	2074	404 bc
19.3	16.0 d	21.0 c	14.1 b	2819 c	2921	604 b
22.5	11.3 e	18.0 c	9.4 c	2363 c	2955	566 b

[a] values followed by the same letter within each column are not significantly different from each other ($P>0.05$).
XRC, AIXR and TTI denotes TeeJet® extended range, air induction extended range, and turbo-teejet induction nozzle, respectively.

Ozkan and Womac (2005) reported that ground speed is one of the most influential factors affecting application rate, and suggested determining an appropriate ground speed before any pesticide application. The results for CNS sprayers emphasize the importance of selecting and maintaining the appropriate ground speed during pesticide applications for agricultural sprayers without a rate controller. As observed for CNS, the reduction in spray coverage for the XRC and TTI nozzles was also expected due to the overall reduced applied rate at ground speeds higher than the speed (9.7 km h^{-1}) used for sprayer calibration. Ayers et al. (1990) also observed greater rate errors during applications at different ground speeds with a sprayer without a rate controller.

For SRC, the spray coverage for XRC and TTI nozzles was more consistent as ground speed increased from 9.7 km h^{-1} to 22.5 km h^{-1} (Table 5) as compared to CNS. While the quantity of spray droplets exhibited some variability among the ground speeds; however, the mean quantity of spray droplets was statistically similar (P>0.05) for both nozzle types. As for the AIXR nozzle, the increase in ground speed again provided inconsistent results for both spray coverage and quantity of spray droplets, where the spray coverage reduced at increased ground speeds and the quantity of spray droplets varied among the ground speeds.

Table 2.5 Influence of ground speed on spray coverage (%) and quantity of spray droplets by nozzle type for SRC. SRC represents the sprayer equipped with a rate controller used in this study.

Speed (km h^{-1})	Spray Coverage[a]			Quantity of Spray Droplets[a]		
	XRC	AIXR	TTI	XRC	AIXR	TTI
9.7	41.0	43.5 ab	37.5	6845	2441 b	1325
12.9	50.8	49.4 a	34.3	7893	5736 a	1677
16.1	46.9	37.9 bc	35.7	8626	3371 b	2263
19.3	34.5	25.2 d	31.2	7355	3366 b	2092
22.5	37.2	32.1 cd	28.0	8218	5970 a	2334

[a] value followed by the same letter within each column are not significantly different from each other (P>0.05).

XRC, AIXR and TTI denotes TeeJet® extended range, air induction extended range, and turbo-teejet induction nozzle, respectively.

With ground speed variations in the field during pesticide applications, a rate controller maintains the target application rate by adjusting spray pressure and consequently the nozzle flow rate (ASABE 2016). The results for XRC and TTI nozzles verified this where SRC showed consistent spray coverage over the range of ground speeds used in this study. Similar spray performance results with the use of a rate controller were shared by Al-Gaadi and Ayers (1994) and Ayers et al. (1990). These results suggest that the use of a sprayer controller resulted in a significant reduction of application errors, thus maintaining the desired application rate over a wide range of ground speeds. Fewer rate errors during application also mean more uniform spray coverage as noticed in the present study. Although it can be observed that the quantity of spray droplets increased with an increase in ground speed from 9.7 km h^{-1} to 22.5 km h^{-1} for both XRC and TTI nozzles (Table 5); however, this trend was not statistically significant ($P>0.05$). For a sprayer equipped with a rate controller, an increase in ground speed results in increased spray pressure at the nozzle orifice, thus producing finer spray droplets speeds (Miller and Smith, 1997; Nuyttens et al. 2007). Generally, finer spray droplets provide better coverage as compared to coarser droplets; however, they are also more prone to off-target movement, especially at higher ground speeds. The results for the AIXR nozzle for both CNS and SRC imply an inconsistent spray performance at varying ground speeds of this nozzle compared to XRC and TTI nozzles.

2.4.2 Spray Quality

Table 2.6 ANOVA results (*P*-values) for D0.1, D0.5, and D0.9 by nozzle type for CNS and SRC. D0.1, D0.5, and D0.9 are the droplet diameters (μm) where 10%, 50%, and 90%, respectively, of the spray volume is contained in the spray droplets smaller than this value. CNS represents the sprayer without a rate controller and SRC represents the sprayer equipped with a rate controller.

Effects	$D_{0.1}$		$D_{0.5}$		$D_{0.9}$	
	CNS	SRC	CNS	SRC	CNS	SRC
XRC	0.0101*	NS	NS	NS	NS	NS
AIXR	0.0115*	0.004*	0.0317*	0.0014*	NS	NS
TTI	0.0096*	NS	NS	NS	NS	NS

* represents significant effects ($P<0.05$) and NS represents non-significant effects ($p > 0.05$). XRC, AIXR, and TTI denote TeeJet® extended range, air induction extended range, and turbo-teejet induction nozzle types, respectively.

Table 2.7 Influence of ground speed on $D_{0.1}$, $D_{0.5}$, and $D_{0.9}$ by nozzle type for CNS. $D_{0.1}$, $D_{0.5}$, and $D_{0.9}$ are the droplet diameters (µm) where 10%, 50%, and 90%, respectively, of the spray volume is contained in the spray droplets smaller than this value. CNS represents the sprayer without a rate controller.

Nozzle type	Speed (km h^{-1})	$D_{0.1}$ (µm)	$D_{0.5}$ (µm)	$D_{0.9}$ (µm)
XRC	9.7	205.8 a	420.4	719.3
	12.9	180.2 b	350.6	687.5
	16.1	174.4 bc	374.4	713.0
	19.3	178.4 bc	374.5	697.0
	22.5	164.6 c	399.5	774.1
AIXR	9.7	338.0 a	822.6 a	1385.3
	12.9	330.0 a	841.8 a	1410.7
	16.1	329.4 a	818.3 a	1435.3
	19.3	271.1 b	719.1 b	1561.4
	22.5	244.5 b	692.1 b	1405.0
TTI	9.7	617.1 ab	1396.5	1975.0
	12.9	663.0 a	1319.7	2397.0
	16.1	659.5 a	1486.7	2467.0
	19.3	556.3 b	1229.3	2019.3
	22.5	412.1 c	985.7	1607.2

[a] values followed by the same letter within each column and for each nozzle type are not significantly different from each other (P>0.05). XRC, AIXR and TTI denotes TeeJet® extended range, air induction ex-tended range, and turbo-teejet induction nozzle, respectively.

Table 2.6 presents the *P*-values from ANOVA analysis for spray quality ($D_{0.1}$, $D_{0.5}$, and $D_{0.9}$) for CNS and SRC for three different nozzle types used in this study. $D_{0.1}$, $D_{0.5}$, and $D_{0.9}$ are the droplet diameters (µm) where 10%, 50%, and 90%, respectively, of the spray volume is contained in the spray droplets smaller than this value. For CNS, ground speed affected $D_{0.1}$ across all nozzle types whereas no effect of ground speed on $D_{0.5}$ and $D_{0.9}$ was observed with the exception of $D_{0.5}$ for the AIXR nozzle (Table 2.7). The observed trend was that $D_{0.1}$ decreased with an increase in ground speed regardless of the nozzle type. For the AIXR nozzle, $D_{0.5}$ decreased with an increase in the ground speed.

A graphical illustration of spray quality i.e., droplet size classification based on VMD for XRC, AIXR, and TTI nozzles at different ground speeds used in this study is presented in Figure 2.4 for CNS. Observing the graphs, a change in spray quality with an increase in ground speed can be noticed across all nozzle types. For the XRC nozzle, the largest variations with ground speed increase were observed in the VF and F spray droplets where the percentage of F and VF droplets increased from 2.5% to 5.8% and 12.6% to 19.0%, respectively, as ground speed increased from 9.7 km h^{-1} to 22.5 km h^{-1}. Similarly, the AIXR and TTI nozzles exhibited the greatest variation in UC droplets followed by F, VF, and M. As ground speed increased from 9.7 to 22.5 km h^{-1}, the UC droplets decreased by 12.8% for the AIXR nozzle and by 14.5% for the TTI nozzle. Since the spray pressure remained constant for CNS during herbicide applications as ground speed varied, the observed changes in the spray quality (different droplet sizes) can be attributed to the overall lower number of spray droplets applied per unit area with an increase in ground speed, which is also evident from the data presented in Table 2.4. A review of the literature shows limited information on the influence of varying ground speed on the overall spray quality, especially on different droplet sizes ranging from VF to UC. Thus, these findings cannot be compared to any of the previous work conducted on ground speed influence on spray deposition. Though, it will be useful to provide data for comparison and verification of results with similar spray performance studies conducted in the future.

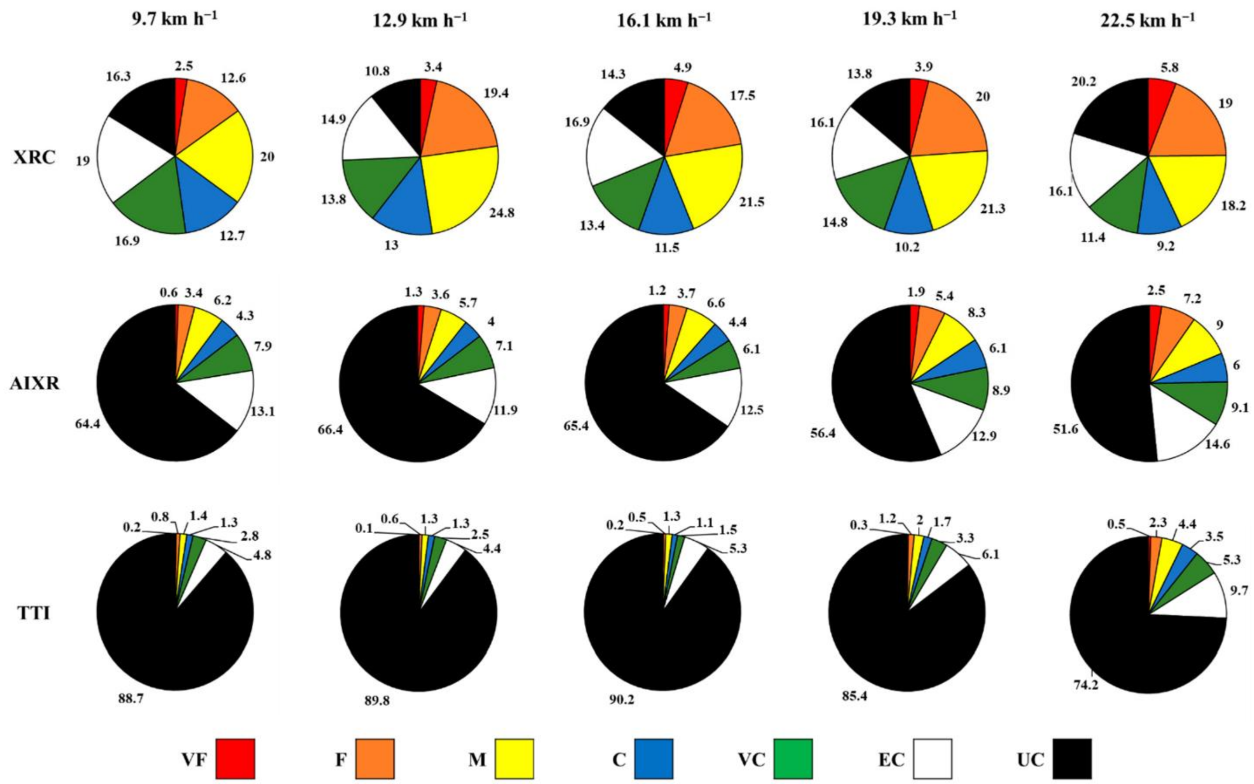

Figure 2.4 Spray quality (droplet size classification based on volume median diameter) for XRC, AIXR, and TTI nozzles at varying ground speeds for CNS. CNS represents the sprayer without a rate controller while XRC, AIXR, and TTI represent TeeJet® extended range, air induction extended range, and turbo-teejet induction nozzle types, respectively, used in this study. VF, F, M, C, VC, EC, and UC represents the very fine, fine, medium, coarse, very coarse, extremely coarse, and ultra-coarse spray droplets, respectively, as defined by the ASABE S572.3 (ASABE/ANSI, 2020).

For SRC, no effect of ground speed on $D_{0.1}$, $D_{0.5}$, and $D_{0.9}$ was observed for XRC and TTI nozzles (Table 2.6); however, it had a significant effect on $D_{0.1}$ and $D_{0.5}$ for the AIXR nozzle. The $D_{0.1}$ and $D_{0.5}$ for the AIXR nozzle decreased with an increase in the ground speed from 9.7 to 22.5 km h^{-1} (Table 2.8). A similar trend was also observed in the $D_{0.1}$, $D_{0.5}$, and $D_{0.9}$ values for the XRC and TTI nozzles but it was not statistically valid ($P>0.05$). Figure 2.5 illustrates spray quality in terms of droplet size classification based on VMD by nozzle type at different ground speeds for SRC. The XRC nozzle exhibited a considerable increase in the quantity of F and VF spray droplets from 12.0% to 19.8% and 19.3% to 29.8%, respectively, with an increase in ground speed from

9.7 to 22.5 km h^{-1}. Conversely, the quantity of UC and EC spray droplets decreased by 14.8% and 9.9%, respectively, with an increase in ground speed. A similar trend for VF, F, EC, and UC spray droplets was noticed for the AIXR and TTI nozzles, where the amount of finer (VF and F) spray droplets increased and the coarser spray droplets (EC and UC) decreased as ground speed increased.

Since a rate controller was used on SRC during applications, these results were expected as the target application rate with increasing ground speed is maintained by an increase in spray pressure, which also affects spray quality. A higher spray pressure at the same nozzle orifice results in the production of more finer spray droplets (Miller and Smith 1997; Nuyttens et al. 2007), which was noticed here across all three nozzle types. These data also suggest a degradation in spray quality at higher ground speeds compared to the ground speed of 9.7 km h^{-1} at which the sprayer was calibrated to deliver a target rate (GPA) and the desired spray quality.

Though the effect of ground speed on spray quality was observed for both CNS and SRC, the variations in spray quality were greater for SRC due to the change in spray pressure with an increase in ground speed. Besides an overall degradation in spray quality, the increase in ground speed for SRC is also increasing the potential for off-target movement of spray particles, as finer spray droplets are highly susceptible to pesticide drift (Miller and Smith 1997; Nuyttens et al. 2007). As evident from the data provided in Figure 2.5, this is more concerning for the XRC nozzles due to the greatest quantity of finer spray droplets (VF and F) produced at higher ground speeds among all the nozzles used in this study.

Table 2.8 Influence of ground speed on $D_{0.1}$, $D_{0.5}$, and $D_{0.9}$ by nozzle type for SRC. $D_{0.1}$, $D_{0.5}$, and $D_{0.9}$ are the droplet diameters (µm) where 10%, 50%, and 90%, respectively, of the spray volume is contained in the spray droplets smaller than this value. SRC represents the sprayer equipped with a rate controller used in this study.

Nozzle type	Speed (km h^{-1})	$D_{0.1}$ (µm)	$D_{0.5}$ (µm)	$D_{0.9}$ (µm)
XRC	9.7	195.5	385.3	693.1
	12.9	200.7	382.5	680.4
	16.1	189.0	388.8	667.0
	19.3	175.0	331.3	583.7
	22.5	175.0	323.3	548.9
AIXR	9.7	350.5 a	818.2 a	1320.8
	12.9	282.5 b	693.9 b	1281.3
	16.1	279.3 b	608.3 c	1099.5
	19.3	251.2 bc	571.9 c	1152.6
	22.5	224.4 c	550.3 c	1040.0
TTI	9.7	572.9	1236.0	1897.6
	12.9	416.0	944.0	1602.2
	16.1	385.6	916.0	1584.3
	19.3	397.4	877.2	1452.9
	22.5	333.0	756.4	1601.7

[a] values followed by the same letter within each column and for each nozzle type are not significantly different from each other ($P>0.05$). XRC, AIXR and TTI denotes TeeJet® extended range, air induction extended range, and turbo-teejet induction nozzle, respectively.

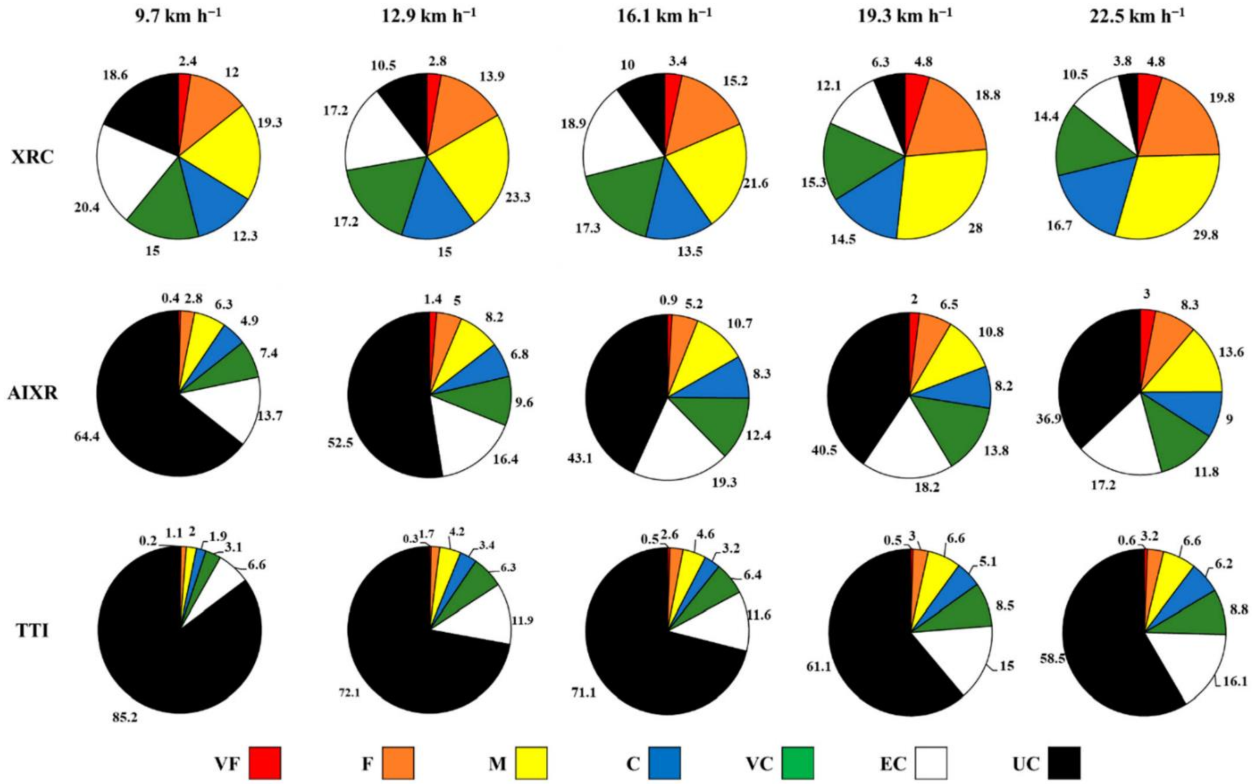

Figure 2.5 Spray quality (droplet size classification based on volume median diameter) for XRC, AIXR, and TTI nozzles at varying ground speeds for SRC. SRC represents the sprayer equipped with a rate controller while XRC, AIXR, and TTI represent TeeJet® extended range, air induction extended range, and turbo-teejet induction nozzle type, respectively, used in this study. VF, F, M, C, VC, EC, and UC represents the very fine, fine, medium, coarse, very coarse, extremely coarse, and ultra-coarse spray droplets, respectively, as defined by the ASABE S572.3 (ASABE/ANSI, 2020).

2.5 CONCLUSIONS

The spray performance of two different sprayer setups (CNS and SRC) was evaluated at varying ground speeds by assessing spray deposition and quality across three nozzle types (XRC, AIXR, and TTI). The following conclusions can be drawn from the results obtained in the study:

1. For CNS, an increase in the ground speed decreased the quantity of spray droplets applied per unit area and consequently reduced the spray deposition;

2. For SRC, the quality of spray droplets and the spray deposition was more consistent among the ground speeds due to the flow rate adjustments (and accordingly spray pressure changes) by the rate controller as ground speed increased;
3. Spray quality variations (difference in droplet size distributions) with an increase in the ground speed were observed for both CNS and SRC. However, these variations were greater for SRC because of the changes in spray pressure with ground speed;
4. Among nozzle types, the trends in spray deposition and quality were similar for the XRC and TTI nozzles as observed within each sprayer setup (CNS and SRC). The AIXR nozzle exhibited inconsistent spray deposition and quality as ground speed varied.

2.5 IMPLICATIONS AND FUTURE RESEARCH

Ground speed variations during pesticide applications are common and can considerably affect both spray deposition and quality as shown by the results of this study. Inadequate coverage can further result in reduced pesticide efficacy, thereby leading to poor pest control. The findings from this study suggest that agricultural sprayers equipped with a rate controller can provide adequate and consistent spray deposition when ground speed variations occur during pesticide applications. The study also highlights one of the limitations associated with a rate controller, which is the degradation of spray quality and production of greater drift-susceptible finer sprayer droplets, due to an increase in spray pressure with ground speed. This is more concerning for pesticide applications that require using a certain droplet size(s) to attain adequate coverage, such as fine-to-medium spray droplets for fungicide applications, or to mitigate spray drift such as ultra-coarse droplets for auxin herbicide applications. Minimizing spray drift while maintaining adequate spray coverage is challenging, yet an important consideration for effective pesticide applications. Therefore, best management practices including proper nozzle selection and application within the nominal ground speed range should always be followed for effective technology utilization. Additionally, since advanced spray technologies such as PWM systems (that maintains a constant spray pressure while also regulating flow to achieve target application rate) are available today to utilize on agricultural sprayers, future research efforts need to investigate the effect of PWM system on spray deposition and quality during pesticide applications. These studies should also consider spray performance assessment for conventional and PWM-compatible nozzles at varying duty cycles.

CHAPTER 3

[2] EFFECT OF CARRIER VOLUME AND DROPLET SIZE ON COVERAGE, DROPLET DENSITY AND HERBICIDE EFFICACY IN PEANUT

Sapkota, M., Virk, S.S., Prostko, E.P., and Kemerait, R.C. Submitted to Weed Technology.

3.1 ABSTRACT

Recent trends in herbicide applications have shown a preference among growers for using lower carrier volumes and coarser-droplet nozzles. Field-scale studies were conducted in 2021 and 2022 to understand the effect of carrier volume and droplet size on spray coverage, droplet density, and herbicide efficacy in peanut. Treatments consisted of three carrier volumes of 94, 117, and 140 L ha^{-1}, with each volume applied using nozzles to target three different droplet sizes: medium (M), very coarse (VC), and ultra coarse (UC). In 2022, an additional carrier volume of 187 L ha^{-1} was also tested. Spray coverage and droplet density data were collected using water-sensitive paper during preemergence and postemergence applications. Weed densities were recorded after each herbicide application and peanut yield was recorded at harvest. Results indicated spray coverage increased by 31% to 64% with an increase in the carrier volume from 94 to 140 L ha^{-1}. However, increasing carrier volume beyond 140 L ha^{-1} showed no additional improvement in coverage. VC droplet size provided comparable (in 2021) or better coverage (in 2022) than M droplet size while UC droplet size exhibited the least coverage during both years. In 2021, droplet density was not influenced by carrier volume but was reduced with an increase in droplet size from M to UC. During both years, carrier volume and droplet size did not influence weed control and peanut yield despite the differences observed in coverage and droplet density between the treatments. These findings suggest that while peanut growers may observe reduced coverage or droplet density for herbicide applications at low carrier volumes and/or when using nozzles that produce coarser droplets, this effect may not directly translate into reduced herbicide efficacy and yield, especially in fields with low to moderate weed pressure.

3.2 INTRODUCTION

Peanut (*Arachis hypogea* L.) is one of the major row crops grown in the southeastern United States. In 2022, 2,525 M kg of peanuts were produced on 607,028 ha in the US (USDA-NASS, 2022). 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 peanut growers to produce higher crop yields and quality. Herbicides are the most widely used pesticide in peanuts and are applied to more than 90% of the planted acres in the US (USDA-NASS 2019). Thus, effective herbicide applications through proper selection of active ingredients, application parameters, and timing are important in peanut production.

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; Etheridge et al. 2001; Legleiter and Johnson 2016; Ramsdale and Messersmith 2001), nozzle type/droplet size (Carter et al. 2017; Etheridge et al. 2001; Virk et al. 2021), 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 cannot be controlled by an applicator, application parameters can be 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 (PRE) herbicide carrier volume from 30 to 150 L ha^{-1} improved spray coverage by 5 to 32%, which also resulted in improved weed control in wheat. Contrarily, some of the previous studies have also reported minimal to no reduction (Etheridge et al. 2001; Ramsdale and Messersmith 2001) in efficacy when applying 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). Conventional flat-fan nozzles produce a higher amount of finer spray droplets, which tend to improve coverage and efficacy compared to larger droplets (Etheridge et al. 2001) but 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). One of the main concerns regarding the use of AI nozzles is the possible reduction in spray coverage and efficacy due to larger droplet sizes. Many studies have reported on the spray performance of AI nozzles compared to conventional flat-fan nozzles (Berger et al. 2014; Carter et al. 2017; Virk et al. 2021) but the information on their effect on herbicide efficacy is limited. Berger et al. (2014) reported no influence of nozzle type on herbicide (lactofen) efficacy on weed management in peanuts despite reduced coverage for AI nozzle. Similarly, Virk et al. (2021) reported no difference in pesticide efficacy on pest management in peanuts despite varied coverage between the AI and non-AI nozzles.

In general, spray application is a complex process, and interactions among different spray application parameters such as carrier volume and droplet size are not uncommon (Brazes et al.

1991; Reichard 1988). An extensive review on the effects of droplet size and spray volume on herbicide performance by Knoche (1994) reported the existence of interaction between two parameters in different crops. Overall, the review concluded 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. A study by Butts et al. (2018) also reported 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). Several studies have reported that the interaction between spray volume and droplet size is also affected by the nature of the herbicide, weed species (Brown et al. 2007; Ramsdale and Messersmith 2001; 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 and soybean growers are required to utilize drift-reducing nozzles that produce coarser droplets when spraying auxin herbicides. As changing nozzles between crops is uncommon for some growers, the same nozzles also get utilized for most pesticide applications in peanut. Similarly, there is also a rising trend towards utilizing lower carrier volumes in an effort to cover more acreage per tank load and reduce the total number of refills (Etheridge 1999). While few studies have investigated the influence of different nozzle types on coverage and weed control in peanut, information on the effect of carrier volume and especially the interaction of carrier volume and droplet size on herbicide coverage and efficacy in peanut is limited. Additionally, most previous research was conducted in small plots with herbicide applications using a CO_2-powered backpack sprayer. Thus, it is also important to verify the findings of these studies in large-scale trials with herbicide applications performed using commercial application equipment. Therefore, the objective of this study was to assess the influence of carrier volume, droplet size, and their interaction on coverage, droplet density, and efficacy of weed control in peanuts in large-scale field studies using a commercial agricultural sprayer.

3.3 MATERIALS AND METHODS

3.3.1 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 3.1). In 2021, the study treatments consisted of three carrier volumes of 94, 117, and 140 L ha^{-1} with each volume applied using three different droplet sizes – medium (M), very coarse (VC), and ultra coarse (UC) (ASABE/ANSI, 2020). In 2022, an additional spray volume of 187 L ha^{-1} was also included in the treatments. The target carrier volumes were attained by varying the nozzle size while the desired droplet sizes were obtained by varying the nozzle type i.e. Extended Range (XRC), Air Induction Extended Range (AIXR), and Turbo-TeeJet Induction (TTI) (TeeJet Technologies, Springfield, IL) for M, VC, and UC, droplet sizes respectively (Figure 3.2). The sprayer boom width was 18.3 m with nozzles spaced equidistantly at 0.46 m. The sprayer boom covered 18 total peanut rows (0.91 m row spacing) and was split evenly among the selected nozzle types (XRC, AIXR, and TTI) where each nozzle type sprayed six rows and constituted a sub-plot that measured 5.5 m wide by approximately 150 to 200 m (equal to the length of the field) in length. The treatments were arranged in a split-plot design where carrier volume served as the main plot factor and droplet size served as the sub-plot factor. Before any applications were made, the sprayer was calibrated using each nozzle size to deliver the target spray volumes at 344.7 kPa and the ground speed of 16.1 km h^{-1}. During testing, the sprayer boom height was maintained at approximately 0.76 m from the ground surface or crop canopy. Table 3.1 provides detailed information on the treatments and other application parameters used in this study.

Table 3.1 Information on spray volume and droplet size treatments along with other application parameters used for the spray studies conducted in 2021 and 2022.

Year	Carrier Volume (L ha^{-1})	Nozzle Type[a]	Droplet Size[b]	Spray Angle (^{0})	Orifice Size	Spray Pressure (kPa)	Speed (km h^{-1})	Boom Height (m)
2021-2022	94	XRC	M	110	025	344.7	16.1	0.76
	94	AIXR	VC	110	025	344.7	16.1	0.76
	94	TTI	UC	110	025	344.7	16.1	0.76
2021-2022	117	XRC	M	110	04	344.7	16.1	0.76
	117	AIXR	VC	110	04	344.7	16.1	0.76
	117	TTI	UC	110	04	344.7	16.1	0.76
2021-2022	140	XRC	M	110	05	344.7	16.1	0.76
	140	AIXR	VC	110	05	344.7	16.1	0.76
	140	TTI	UC	110	05	344.7	16.1	0.76
2022	187	XRC	M	110	06	344.7	16.1	0.76
	187	AIXR	VC	110	06	344.7	16.1	0.76
	187	TTI	UC	110	06	344.7	16.1	0.76

[a] XRC, AIXR, and TTI represent TeeJet® extended range, air induction extended range, and turbo-teejet induction nozzle, respectively used in this study.

[b] M, VC, and UC represent medium, very coarse, and ultra coarse spray droplets, respectively as defined in the ASABE S572.3 (ASABE/ANSI, 2020).

Figure 3.1 The commercial LMC boom sprayer used for making herbicide applications and spray assessment in the field studies conducted in 2021 and 2022

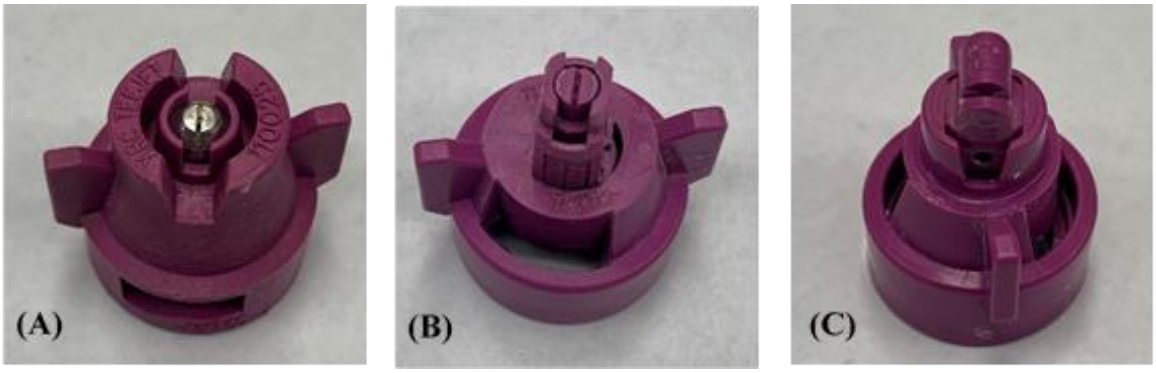

Figure 3.2 Three different nozzle types: (A) XRC, (B) AIXR, (C) TTI used to attain medium, very coarse, and ultra coarse droplet sizes (ASABE, 2020), respectively in the spray studies conducted in 2021 and 2022.

3.3.2 Spray 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 before the emergence of peanut seedlings, and postemergence (POST) application at approximately 14 to 21 days after the PRE. Table 3.2 presents information on the herbicide products and their corresponding rates used for herbicide applications in 2021 and 2022. Before the PRE-application each year, an additional spray application was also conducted only with water for collecting data to verify the droplet sizes created by each nozzle type at the selected carrier volumes.

Table 3.2 Information on herbicides and their rates used in the spray studies conducted in 2021 and 2022.

Application	Trade Name	Active ingredient	Rate (kg ai ha^{-1})
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

Table 3.3 Meteorological conditions recorded during pre- and postemergence herbicide applications in 2021 and 2022. Values are averaged across the applications for each year and represent mean ± standard deviation.

Year	Application[a]	Temperature (°C)	Relative Humidity (%)	Dew Point (°C)	Wind Speed (m s^{-1})	Wind Direction
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.

During herbicide applications, meteorological 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 averaged meteorological data for the entire PRE and POST application period for 2021 and 2022 are presented in Table 3.3. The meteorological conditions during both years remained consistent throughout the entire application period including the wind speed, which ranged between 0 to 1 m s^{-1} during both years and did not cause any significant effect on spray deposition data collection during the applications.

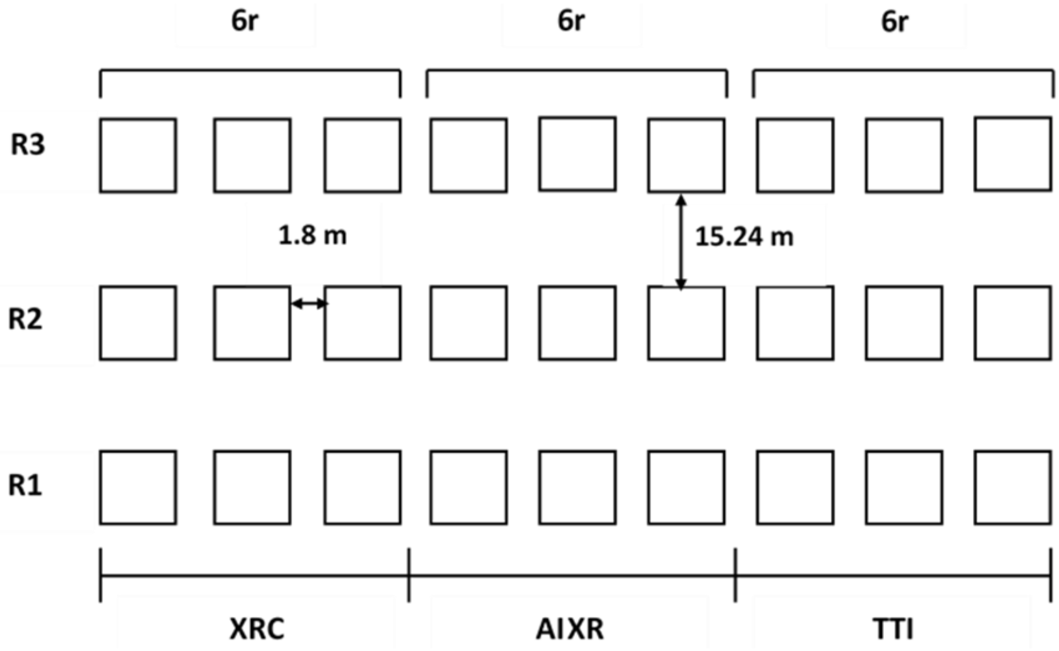

Figure 3.3 Experimental setup illustrating the arrangement of wooden blocks in the field for spray deposition data collection during the studies conducted in 2021 and 2022.

For data collection, 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 (5.5 x 15.2 m) during herbicide applications in the field (Figure 3.3). Within each grid, the blocks were placed 15.2 m apart along the length of the sprayer pass (each row served as a replication) and 1.8 m apart along the sprayer boom. Each 3x3 grid of blocks during application covered six crop rows and 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 3.4A) before each sprayer pass. Herbicides were mixed with water as a carrier in their labeled concentration (Table 3.2) and applications were made implementing different combinations of carrier volume and droplet size. After each application, WSP was allowed to dry for a few minutes and then collected in pre-labeled envelopes to provide minimum exposure to moisture and/or humidity. All samples were transported to the laboratory for analysis.

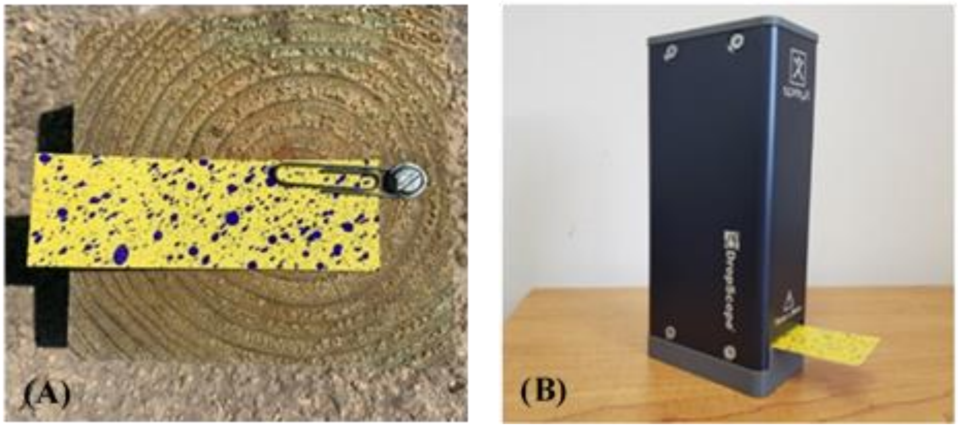

Figure 3.4 (A) Illustration of spray deposition on a water-sensitive paper for one of the study treatments, and (B) the water-sensitive paper being analyzed using the DropScope instrument.

In the laboratory, WSP was scanned using a DropScope instrument (SprayX, São Paulo, Brazil) (Figure 3.4B) and a compatible 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 S572.1 (ASABE, 2020) to provide VMD information. The VMD data was only used for applications made with water (prior to the herbicide applications) to determine if the desired droplet sizes were attained during applications. Table 3.4 presents these data and shows that the droplet sizes attained for different nozzles used in this study were within the VMD range and droplet size classification as specified in the ASABE 572.1 (ASABE, 2020).

Table 3.4 Droplet size information from spray assessment conducted with water for different nozzle types and carrier volumes used in the spray studies conducted in 2021 and 2022.

Carrier volume (L ha^{-1})	Nozzle Type	Droplet Size[a] (µm)	VMD Range[b] (µm)	Droplet Size Classification
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] Droplet size represents the volume median diameter (VMD) of the spray solution (water only).
[b] Droplet size classification according to ASABE S572.1.

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. An untreated check (no herbicide applied) was also included in the field each year to compare and evaluate the weed densities for the study treatments. The total number of weeds per square meter was counted in each sampled location for both untreated and treated plots. After PRE and POST applications, peanut were managed following the standard agronomic recommendations outlined in the University of Georgia Peanut Production Guide (Monfort et al. 2022). At the end of the season, peanut yield was recorded by harvesting all six rows and the full length of each plot using a commercial 6-row KMC peanut harvester (KMC Equipment, Tifton, GA) and peanut weigh wagon. Table 3.5 provides a timeline of the field operations and data collection including peanut planting, spray assessment, weed density, peanut inversion, and harvest for the research studies conducted in 2021 and 2022.

Table 3.5 Information on cultivar, planting, herbicide application, weed count, peanut inversion and harvest dates for spray studies conducted in 2021 and 2022.

Year	Cultivars	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/m^2 performed approximately 14 days after application.

3.2.3 Data Analysis

All data were analyzed using JMP® Pro 16.0.0 (SAS, Cary, NC). Statistical analysis indicated no significant interaction for any of the measured responses (P>0.05) between the PRE and POST applications, therefore data were pooled across both applications for each year. Data were analyzed separately for each year due to the additional spray volume in the 2022 study. Data were subjected to a two-factor mixed-model ANOVA where spray volume and droplet size served as explanatory variables, and spray coverage, droplet density, weed density, and yield served as the response variables. A p-value of 0.05 was used to determine the significance of the main and interaction effects. For significant effects, treatment means were separated with a Students t-test using $\alpha = 0.05$.

3.4 RESULTS AND DISCUSSION

3.4.1 Spray Coverage

Table 3.6 *P*-values from ANOVA analysis for spray coverage for carrier volume, droplet size, and their interaction effect in the spray studies conducted in 2021 and 2022.

Effect	Spray coverage	
	2021	2022
Carrier volume	<0.0001*	<0.0001*
Droplet size	<0.0001*	<0.0001*
Carrier volume x Droplet size	NS	NS

*represents significant effect ($P<0.05$) whereas NS represents non-significant effect ($P>0.05$).

The results from the ANOVA analysis showed that both carrier volume and droplet size had a significant effect on spray coverage in 2021 and 2022 (Table 3.6), while their interaction was not significant during both years ($P>0.05$). In 2021, spray coverage increased with an increase in carrier volume (Figure 3.5A). The highest coverage of 23.2% was achieved at a carrier volume of 140 L ha^{-1} followed by 19.9 % at 117 L ha^{-1} and 17.7% at 94 L ha^{-1}. A similar trend of increased spray coverage with carrier volume was noticed in 2022; however, it was only statistically significant up to the carrier volume of 140 L ha^{-1} (Figure 3.5B) as both 140 and 187 L ha^{-1} provided comparable coverage. In 2022, the highest coverage of 23.6% and 24.4 % was attained at the carrier volumes of 140 and 187 L ha^{-1}, respectively followed by 19.1% coverage at 117 L ha^{-1} and 14.4% at 94 L ha^{-1}. Overall, the spray coverage increased by 31 to 64% with an increase in carrier volume from 94 to 140 L ha^{-1} and by 17 to 24% with an increase in carrier volume from 117 to 140 L ha^{-1} whereas it was observed in 2022 that increasing carrier volume beyond 140 L ha^{-1} did not improve coverage. A similar effect of carrier volume on spray coverage has been reported by previous studies (Ferguson et al. 2016; Ferguson et al. 2020; Knoche 1994; Legleiter and Johnson

2016). Legleiter and Johnson (2016) evaluated the herbicide spray coverage at 94 and 140 L ha^{-1} and reported that a higher carrier volume of 140 L ha^{-1} provided better coverage compared to a lower volume of 94 L ha^{-1} in soybean. Ferguson et al. (2020) observed a 56% increase in spray coverage as the carrier volume increased from 100 L ha^{-1} to 200 L ha^{-1}. Similarly, Ferguson et al. (2016) indicated a coverage increase of 18% when the carrier volume increased from 50 L ha^{-1} to 100 L ha^{-1} in the oat canopy.

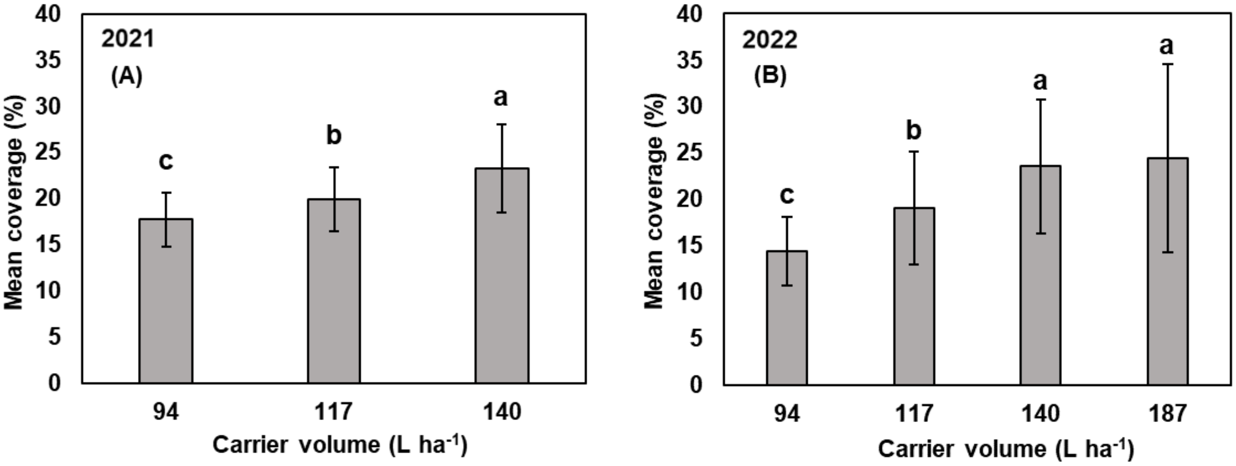

Figure 3.5 Influence of carrier volume on spray coverage (%) for spray tests conducted in (A) 2021 and (B) 2022. Error bars represent mean ± standard deviation. Bars sharing the same letters are not significantly different from each other ($P>0.05$). M, VC, and UC represent the medium, very coarse, and ultra coarse spray droplets, respectively as defined by the ASABE S572.3 (ASABE/ANSI, 2020).

The influence of droplet size on spray coverage varied among the study years (Figure 3.6, A and B). In 2021, both M and VC droplet sizes provided similar coverage (21.0% and 22.8%, respectively) but it was greater than the coverage exhibited by the UC droplet size (17.1%). Interestingly, in 2022, the VC droplet size had the highest spray coverage (26.1%) followed by the M (19.8%) and UC (15.2%) droplet sizes (Figure 3.6B). Generally, smaller droplets (fine to medium) provide better coverage (Etheridge et al. 2001; Ferguson et al. 2020) than the larger droplets (very coarse to ultra coarse) but their propensity to off-target movement is also greater

(Nuyttens et al. 2007). During data collection, the wind speed and relative humidity in 2022, especially for POST application were slightly higher than in 2021 (Table 3.3), thus, it is possible that for M droplet size, the off-target movement of finer spray particles (<236 µm) was slightly greater in 2022 than in 2021 resulting in fewer spray droplets to reach the target. The results attained in this study indicated that VC droplet size can provide comparable or greater coverage than the M droplet size but UC droplet size reduced coverage by 19 to 42% compared to M and VC droplet sizes.

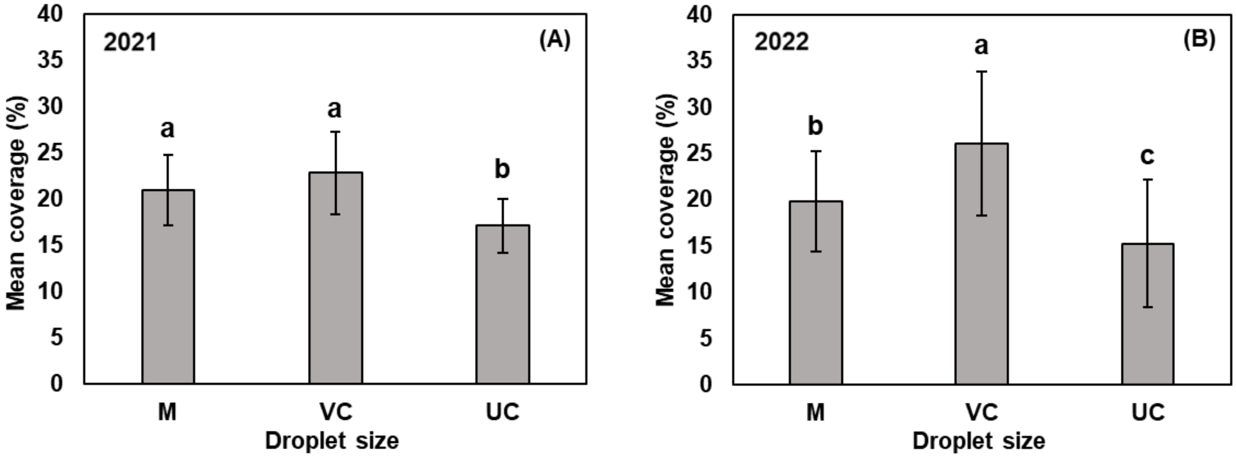

Figure 3.6 Influence of droplet size on spray coverage (%) for spray tests conducted in (A) 2021 and (B) 2022. Error bars represent mean ± standard deviation. Bars sharing the same letters are not significantly different from each other ($P>0.05$). M, VC, and UC represent the medium, very coarse, and ultra coarse spray droplets, respectively as defined by the ASABE S572.3 (ASABE/ANSI, 2020).

Past research indicates a varying effect of droplet size on spray coverage (Ferguson et al. 2020; Legleiter and Johnson, 2016; Virk et al. 2021). Virk et al. (2021) observed varied coverage across different nozzle types, where the coarser droplets produced from air induction (AI) nozzles provided better coverage than the finer droplets from the standard flat-fan (non-AI) nozzles in three of the seven on-farm locations in their study and an opposite effect was observed at one of the locations. Similarly, Ferguson et al. (2020) reported that the XR nozzles producing finer droplets provided better coverage than the TTI nozzles that produce coarser droplets but another similar study conducted by Legleiter and Johnson (2016) indicated that the TTI nozzles resulted in better coverage to the XR nozzles during one year, and comparable coverage in the following year.

3.4.2 Droplet Density

Table 3.7 *P*-values from ANOVA analysis for droplet density for carrier volume, droplet size, and their interaction effect in the spray studies conducted in 2021 and 2022.

Effect	Droplet Density	
	2021	2022
Carrier volume	NS	0.0125*
Droplet size	<.0001*	<0.0001*
Carrier volume x Droplet size	NS	0.0101*

*represents significant effect ($P<0.05$) whereas NS represents non-significant effect ($P>0.05$).

Droplet density was only affected by droplet size in 2021 while a significant interaction between carrier volume and droplet size for droplet density existed in 2022 (Table 3.7). In general, the number of spray droplets per unit area are expected to increase with an increase in carrier volume. In 2021, an increase in carrier volume from 94 to 140 L ha^{-1} showed a numerical increase in droplet density from 93 to 107 droplets cm^{-2}, but these values were not statistically different from each other (Table 3.8). Though a significant interaction between carrier volume and droplet density was present in 2022, the effect of spray volume on droplet density for the M and UC droplet sizes was similar to as observed in 2021. The droplet density for M droplet size ranged between 118 and 126 droplets cm^{-2} across all the carrier volumes. For UC droplet size, the droplet density increased from 19 to 42 droplets cm^{-2} as carrier volume increased from 94 to 187 L ha^{-1} but again this increase only represented a numerical trend and was not statistically valid (Table 3.9). These results could be possibly attributed to two different reasons. The first reason being 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 studies (Cunha et al. 2013; Fox et al. 2003; Zhu et al. 2011). The second reason is that the herbicide chemicals used in this study might have affected the droplet spectrum and ultimately the droplet density. Previous studies have reported droplet density can be influenced by the type of herbicides being used (Creech et al. 2015; Legleiter and Johnson 2016; Miller and Ellis 2000). 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. However, the extent of these effects depends on the specific formulation of herbicides (Legleiter and Johnson, 2016).

For droplet size, droplet density is expected to decrease with an increase in the size of the spray droplets (VMD). This trend was observed in 2021 where droplet density for the M droplet size (164 droplets cm^{-2}) was greater than the VC (104 droplets cm^{-2}) and UC droplet sizes (36 droplets cm^{-2}) across all three carrier volumes. In 2022, the effect of droplet size on droplet density varied among the carrier volumes. For carrier volumes of 94 and 117 L ha^{-1}, the droplet density for both M and VC droplet sizes (123 to 141 droplets cm^{-2}) was similar but greater than the droplet density for the UC droplet size (19 and 25 droplets cm^{-2}, respectively). For 140 and 187 L ha^{-1}, the VC droplet size had the highest droplet density (193 and 218 droplets cm^{-2}, respectively) followed by the M (104 and 118 droplets cm^{-2}, respectively) and UC droplet sizes (49 and 42 droplets cm^{-2}, respectively). Similar to the results attained here, the varied effect of droplet size on droplet density has also been reported by previous studies. Ferguson et al. (2020) reported that the XR nozzles (finer droplets) exhibited the highest droplet density, followed by AIXR (coarse to very coarse droplets), and TTI (ultra coarse droplets) had the lowest droplet density determined using a similar WSP method. As mentioned earlier, droplet density can be influenced by many factors, and as suggested by Creech et al. (2015), the highest effect on droplet size characteristics including droplet density is of nozzle type (droplet size), followed by the pesticide (herbicides), and carrier volume.

Table 3.8 Influence of carrier volume and droplet size on droplet density in the spray study conducted in 2021.

Effect	Levels[a]	Droplet Density[b] (quantity of droplets per $cm^{2)}$
	94	93
Carrier volume	117	103
	140	107
	M	164 a
Droplet size	VC	104 b
	UC	36 c

[a]M, VC, and UC represent the medium, very coarse, and ultra coarse spray droplets, respectively as defined by the ASABE S572.3 (ASABE/ANSI, 2020)
[b]Means in the same column with the same letter are not significantly different according to Student’s t-test (*P*=0.05).

As spray coverage is influenced by droplet density, these droplet density data supported the coverage results presented earlier for both study years. These results were also consistent with the findings of an extensive review by Knoche (1994), which stated that the droplet size effect is less pronounced at higher carrier volumes. In the present study, the effect of the smaller spray droplets (M droplet size) at 94 L ha^{-1} on droplet density (and ultimately on spray coverage) was highest compared to the larger droplets (VC and UC droplet sizes) for the same volume. As carrier volume increased from 94 L ha^{-1} to 187 L ha^{-1}, the effect of smaller droplet size (M) diminished, and the VC droplet size provided the higher droplet density (Table 3.9), and ultimately increased spray coverage (Figure 3.6B). Similarly, Knoche (1994) mentioned that the effects of carrier volume were greater for larger droplet sizes and reduces as the droplet size decreased.

Table 3.9 Influence of the interaction between carrier volume and droplet size on droplet density in the spray study conducted in 2022.

Carrier Volume (L ha^{-1})	Droplet Size[a]	Droplet Density[b] (quantity of droplets per cm^2)
94	M	123 b
	VC	119 b
	UC	19 c
117	M	126 b
	VC	141 b
	UC	25 c
140	M	104 b
	VC	193 a
	UC	49 c
187	M	118 b
	VC	218 a
	UC	42 c

[a] M, VC, and UC represent the medium, very coarse, and ultra coarse spray droplets, respectively as defined by the ASABE S572.3 (ASABE/ANSI, 2020).
[b] Means in the same column with the same letter are not significantly different according to Student's t-test (*P*=0.05).

3.4.3 Herbicide Efficacy

Both carrier volume and droplet size had no significant impact on weed control during both years (Table 3.11). Higher carrier volume and smaller droplet sizes are expected to provide better efficacy for non-systemic herbicides due to greater spray coverage (Ennis et al. 1963). Consequently, improved weed control is also anticipated at higher carrier volumes (140 L ha^{-1} and 187 L ha^{-1}) and with smaller droplet sizes (M). Though spray coverage differed among the carrier volumes and droplet sizes in the present study, the results showed similar weed control across all study treatments, thus indicating comparable herbicide efficacy regardless of the carrier volume and droplet size used for spray applications. Herbicide efficacy can be influenced by different 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). Past research on the effect of carrier volume and/or droplet size on herbicide efficacy (Berger et al. 2014, Carter et al. 2017 and Virk et al. 2021) shared similar findings where noticeable differences in spray coverage were observed between different carrier volumes or droplet sizes but no effect on weed control was observed in all these studies.

Table 3.10 *P*-values from ANOVA results for weed density and yield for spray volume, droplet size, and their interaction for spray studies conducted in 2021 and 2022.

Effect	Weed Density		Yield	
	2021	2022	2021	2022
Carrier volume	0.5841	0.1873	0.5196	0.1310
Droplet size	0.6147	0.2146	0.6953	0.6532
Carrier volume x Droplet size	0.3887	0.6983	0.6647	0.4589

Peanut yield was also not affected by carrier volume and droplet size during both years (Table 3.11). This was somewhat expected due to the non-significant differences observed for herbicide efficacy between the treatments during both years. Though limited studies have investigated and reported the influence of carrier volume or droplet size on crop yield, these results were analogous to the findings of the studies conducted by Carter et al. (2017) and Virk et al. (2021) in peanut. In both studies, the authors reported no differences in peanut yield between non-AI (medium to coarse droplets) and AI nozzles (very coarse to ultra coarse droplets) despite varied spray coverage and droplet sizes among these nozzle types.

Table 3.11 Weed density and yield for the different carrier volume and droplet size treatments in the spray studies conducted in 2021 and 2022.

Carrier Volume	Droplet Size[a]	Weed Density[b,c]		Peanut Yield (kg ha^{-1})	
		2021	2022	2021	2022
94	M	1.1 b	0.2 b	6299	6186
	VC	0.5 b	0.3 b	6008	5540
	UC	1.6 b	0.4 b	5791	6700
117	M	1.8 b	0.1 b	6089	6077
	VC	2.1 b	0.1 b	6017	6458
	UC	0.6 b	0.3 b	5868	5842
140	M	1.3 b	0.2 b	5939	5633
	VC	1.1 b	0.1 b	6793	5566
	UC	0.6 b	0.2 b	6304	5328
187	M	-	0.1 b	-	6512
	VC	-	0.4 b	-	5874
	UC	-	0.4 b	-	6513
Check		14.9 a	19.2 a		

[a] M, VC, and UC represent the medium, very coarse, and ultra coarse spray droplets, respectively as defined by the ASABE S572.3 (ASABE/ANSI, 2020).

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

[c] Means in the same column with the same letter are not significantly different according to Student's t-test (*P*=0.05).

3.5 CONCLUSIONS

Effective weed management is important in peanut production. With an increasing trend among peanut growers towards lower carrier volumes and nozzles that produce coarser droplets, understanding the influence of reduced volume and larger spray droplets on spray coverage, droplet density, and ultimately herbicide efficacy is imperative to provide informed, research-based recommendations to the growers. The results attained in this study demonstrated that both applicator-controlled variables, carrier volume and droplet size, can influence spray coverage and droplet density during herbicide applications. Specifically, it was noticed that increasing carrier volume from 94 to 140 L ha^{-1} can help in improving spray coverage whereas increasing it beyond 140 L ha^{-1} do not provide any additional improvement in coverage. Further, the droplet size results revealed that both M and VC droplet sizes provide comparable spray coverage and droplet density but spray coverage from M droplet size can be reduced in some cases. Despite significant differences in spray coverage and droplet density among some of the study treatments, carrier volume and droplet size did not affect weed control and peanut yield during both years.

Though the findings of this study suggest that similar herbicide efficacy and peanut yield can be attained using lower carrier volumes and coarser droplet size, it should be noted that these experiments were conducted in fields with low to moderate weed pressure and these results would likely differ in fields with high weed pressure. Thus, peanut growers should consider this along with the type and the amount of weeds present in their fields if planning to utilize lower than nominal carrier volumes and/or nozzles that produce coarser droplets for herbicide applications. Additionally, when selecting optimal application parameters for herbicide applications, a combination of carrier volume and nozzle type (droplet size) should be preferred that provides sufficient coverage while also minimizing the off-target movement of spray particles. Among factors that can influence herbicide efficacy and/or weed control, application timing is also one of the most important considerations in all crops including peanut and should be thoroughly investigated in the future studies focused on evaluation of spray application parameters in peanut.

CHAPTER 4

[3] ASSESSING FUNGICIDE DEPOSITION INTO PEANUT CANOPIES AT DIFFERENT CARRIER VOLUMES AND DROPLET SIZES

Sapkota, M., Virk, S., Kemerait, R.C., and Prostko, E.P. To be submitted to Pest Management Science.

4.1 ABSTRACT

Effective management of diseases and pests in peanut requires adequate spray deposition and penetration into the dense canopy, especially at the lower canopies of the plants. Limited information is available on how carrier volume and droplet size affect deposition within peanut canopies. Therefore, a study was conducted in 2021 and 2022 to assess spray deposition within the peanut canopies at three carrier volumes i.e. 94, 140, and 187 L ha^{-1} and three different droplet sizes (medium, very coarse, and ultra-coarse droplets). The study was organized as a factorial arrangement of spray volume by droplet size and was implemented in 4-row plots that measured 24.4 m long and 3.7 m wide. Spray deposition was assessed by placing water-sensitive paper at three different positions (upper, middle and lower) within the peanut canopies during fungicide applications. Applications were performed every two weeks from 30 to 120 days after planting (DAP). Spray deposition data were collected during applications at 45, 60, 90, and 120 DAP. Visual disease ratings (for leaf spot and southern stem rot) were recorded at pre-determined intervals while yield was collected by harvesting the center two rows in each plot. The results showed that both carrier volume and droplet size significantly influenced spray deposition within the canopies throughout the growing season. Spray deposition decreased from upper to bottom position of the canopies, with a higher carrier volume of 187 L ha^{-1} consistently providing the highest deposition in the upper and middle canopies followed by 140 L ha^{-1} and 94 L ha^{-1} respectively, whereas both the carrier volume of 140 and 187 L ha^{-1} showed similar deposition in lower canopies. For droplet size, M spray droplets had the highest deposition at the upper position, followed by VC and UC spray droplets. In the middle position, both M and VC had similar deposition, while at the lower canopies, all droplet sizes had comparable deposition except at 90 DAP. Lower carrier volume (94 L ha^{-1}) and M spray droplet resulted in an increased incidence of

leaf spot and southern stem rot in some cases of 2022. However, both carrier volume and droplet size had no effect on peanut yield during both years, despite significant differences in spray deposition within peanut canopies. These findings suggest that reduced spray deposition in peanut canopies may not necessarily lead to reduced fungicide efficacy and/or yield, especially in fields with low to moderate disease pressure and dense canopy growth at the mid-late vegetative stage.

4.2 INTRODUCTION

Peanut (*Arachis hypogea* L.) is one of the major row crops grown in the southeastern US. The average peanut yield in the US is 4504 kg ha^{-1} with Georgia accounting for 40 to 55% of the total production as a top producer of peanut in the US (USDA-NASS, 2022). The long spells of warm and humid climate conditions in this region contribute to the growth of diseases and pests that threaten peanut production (Kemerait et al. 2015; Woodward et al. 2013). Diseases such as leaf spot, rust, and southern stem rot significantly impact peanut yields (Anco et al. 2020; Branch and Culbreath 2013; Smith 1980), and therefore, they need to be managed by fungicide applications throughout the season. Fungicides are traditionally applied to peanuts 5 to 10 times during the growing season to control and reduce the impact of foliar and soilborne diseases on peanut yield. The dependence and frequency of fungicide applications make them a major component of peanut production as well as of the production costs incurred in peanut production in the southeastern US (Woodward 2006). Therefore, timely and efficient fungicide applications are critical throughout the growing season to sustain high peanut yields and maintain profitability in peanut production.

Besides choice of a good fungicide program, appropriate selection of application parameters used to apply fungicides such as carrier volume (Derksen et al. 2008; Chechi et al. 2020; Creech et al. 2018), droplet size (Ferguson et al. 2016; Wolf and Daggupati 2009; Derksen et al. 2008), ground speed (Sapkota et al. 2023), boom height (Balsari et al. 2017) is considered crucial to ensure adequate spray coverage, canopy penetration and product efficacy. As the peanut growing season proceeds, canopy growth and development can significantly affect fungicide spray penetration and deposition (Hall 1991; Wolf et al. 1993; Zhu et al. 2002)). Peanut canopies become denser during the late vegetative stage during which the upper canopy starts to intercept more spray particles, hindering their ability to reach the lower canopy where disease and pest incidence are higher (Wolf et al. 1993; Zhu et al. 2002; Zhu et al. 2004). Thus, the selection of adequate application parameters including carrier volume and nozzle type to achieve droplet size that improves application efficiency of fungicide applications are important for effective disease and pest control in peanut.

Research investigating the impact of carrier volume and droplet size in peanut is limited. Most of the studies conducted thus far have been focused on other crops and suggested using higher carrier volume as one of the most effective ways to increase canopy penetration and improve coverage in the middle and bottom canopies (Chechi et al. 2020; Creech et al. 2018; Ferguson et al. 2016; Sharpe et al. 2018). Ferguson et al. (2016) reported that the higher carrier volume of 100 L ha^{-1} provided more spray deposition at the middle and bottom of the oat canopies compared to 50 and 75 L ha^{-1}. Similarly, Chechi et al. (2020) observed improved spray deposition into soybean canopies and enhanced Asian soybean rust control as carrier volume increased from 70 to 150 L ha^{-1}. Sharpe et al. (2018) observed the effects of carrier volume on spray penetration into a strawberry canopy and found that the spray penetration into the canopy increased with carrier volume. Creech et al. (2018) also suggested that increasing carrier volume can result in better canopy penetration into soybean and corn plants. Few studies have also reported no (Derksen et al. 2008) or negative effect (Fritz et al. 2007; Knoche 1994) of increased carrier volume on spray deposition and penetration into lower canopies.

For droplet size, most research findings have suggested using a nozzle that produces medium-sized droplets to balance the need for good coverage and penetration into the canopy (Garcerá et al. 2020; Hanna et al. 2009; Ozkan et al. 2006). Prokop and Veverka (2006) found that the efficacy of contact fungicides increased for finer droplets without using the surfactant in potato. Derksen et al. (2008) observed that the fungicide applied with the medium-sized droplets producing XR8004 flat-fan nozzle showed significantly more fungicide residue than coarse-droplets producing XR8005 nozzle in bottom canopies of soybean. Similarly, Wolf and Daggupati (2009) reported improved canopy penetration into dense soybean canopy from nozzles producing fine and medium droplets. However, some of the studies have also indicated the susceptibility of finer spray solution droplets (including fungicides) to drift and suggest utilizing coarser droplets (Bretthauer et al. 2008; Zhu et al. 2004). Bretthauer et al. (2008) observed that the use of very-coarse droplets in the presence of higher carrier volume resulted in better fungicide coverage and deposition in the soybean canopy than medium droplets. Zhu et al. (2004) also studied the impact of different hydraulic nozzles on spray penetration into peanut canopies with single- and twin-row planting systems. They used four different types of hydraulic nozzle tips; flat fan, hollow cone, twin jet, and air-induction to determine spray coverage at the top, middle and bottom of canopies with a spray mixture containing water and a fluorescent tracer. They found that the nozzles that produces coarse droplets (air-induction nozzle) had higher spray penetration performance than finer droplet producing nozzles. Unlike other researchers, Derksen et al. (1998) reported no significant effects of droplet size on efficacy of fungicide application on disease management in tomato.

Peanut is an important rotational crop with cotton in the southeastern US. To address concerns about spray drift, cotton and soybean growers are required to use nozzles that produce larger droplets when applying auxin herbicides to minimize drift. As changing nozzles between different crops (and even between different pesticide applications such as herbicides and fungicides) in peanut is uncommon, the same nozzles are get used for most pesticide applications in peanut throughout the season. Similarly, there is an increasing trend among growers towards using lower carrier volumes to cover more land per tank load and reduce the frequency of refills (Etheridge, 1999). While few studies have explored the impact of nozzle type on herbicide efficacy (Carter et al. 2017; Virk et al. 2021) in peanut, no recent studies have been conducted that have investigated the effect of application parameters on fungicide spray penetration and/or efficacy. Since the last study conducted by Zhu et al. (2004) in peanut, the design and type of nozzles used for pest management in row-crops including peanut have changed considerably to improve spray coverage and penetration into crop canopies while also keeping off-target movement of pesticides to a minimum. In recent years, many studies have evaluated the effect of carrier volume and/or nozzle type/droplet size in crops like soybean; however, this research has received minimal attention in peanut. Since peanut canopy growth and development also differ considerably from other crops, it is essential to investigate and verify the findings from other studies so appropriate recommendations regarding selection of application parameters can be provided to peanut growers for timely and efficient fungicide applications. Therefore, the main objective of this study was to assess the influence of carrier volume and droplet size on spray deposition into peanut canopies and efficacy of fungicide application in peanut.

4.3 MATERIALS AND METHODS

4.3.1 Study Location and Application Equipment

Figure 4.1 The 6-row UTV boom sprayer used for making fungicide applications and spray assessment in the field studies conducted in 2021 and 2022.

Field experiments were conducted at the Lang-Rigdon farm in Tifton, Georgia, USA in 2021 (31^0 31’ 05’’ N, 83^0 33’01’’ W) and 2022 (31^0 30’55’’ N, 83^0 32’ 59’’ W). During both years, fungicide applications were made using a 6-row UTV sprayer equipped with a rate controller and individual nozzle control capabilities (Figure 4.1). The study treatments consisted of three carrier volumes of 94, 140, and 187 L ha-1, with each volume applied using three different droplet sizes – medium (M), very coarse (VC), and ultra-coarse (UC) (ASABE/ANSI, 2020). The target carrier volumes were attained by varying the nozzle size while the desired droplet sizes were obtained by varying the nozzle type, i.e., Extended Range (XRC), Air Induction Extended Range (AIXR), and Turbo-TeeJet Induction (TTI) (Teejet Technologies, Springfield, IL) for M, VC, and UC droplet sizes, respectively (Figure 4.2). For this study, the sprayer boom sections were configured to cover four peanut rows (3.7 m) with nozzles that were placed equidistant at 0.46 m across the whole length of the boom. The study design consisted of a factorial combination of carrier volume by droplet size and was arranged as a randomized complete block design (RCBD). Each plot was approximately 24.4 m long and 3.7 m wide. Before any fungicide applications, the sprayer was calibrated using each nozzle type and size to verify the target carrier volumes. The sprayer boom height was maintained at approximately 0.46 m from the ground or crop surface for all applications in this study. Table 4.1 provides detailed information on the study treatments and other application parameters used for the fungicide applications in this study.

Table 4.1 Information on spray volume and droplet size treatments along with other application parameters used for the fungicide spray studies conducted in 2021 and 2022.

Carrier Volume (L ha^{-1})	Nozzle Type[a]	Droplet Size[b]	Spray Angle (^{0})	Orifice Size	Spray Pressure (kPa)	Speed (km h^{-1})	Boom Height (m)
94	XRC	M	110	025	206.8	11.3	0.46
94	AIXR	VC	110	025	206.8	11.3	0.46
94	TTI	UC	110	025	206.8	11.3	0.46
140	XRC	M	110	04	206.8	11.3	0.46
140	AIXR	VC	110	04	206.8	11.3	0.46
140	TTI	UC	110	04	206.8	11.3	0.46
187	XRC	M	110	05	206.8	11.3	0.46
187	AIXR	VC	110	05	206.8	11.3	0.46
187	TTI	UC	110	05	206.8	11.3	0.46

[a] XRC, AIXR, and TTI represent TeeJet® extended range, air induction extended range, and turbo-teejet induction nozzle, respectively used in this study.

[b] M, VC, and UC represent medium, very coarse, and ultra coarse spray droplets, respectively as defined in the ASABE S572.3 (ASABE, 2020).

4.3.2 Spray Application and Data Collection

Peanuts were planted on May 25 in both years. Each year, fungicides were applied seven times during the growing season starting at 30 days after planting (DAP) and then every two weeks thereafter at 45, 60, 75, 90, 105, and 120 DAP. The fungicide program included a combination of chlorothalonil and tebuconazole to control leaf spot, stem rot, and peanut rust, and was based on the standard recommendations outlined in the UGA Peanut Production Guide (Monfort et al. 2022). During both years, chlorothalonil (1.1 kg ai ha^{-1}) was applied throughout the fungicide application periods whereas tebuconazole (0.5 kg ai ha^{-1}) was applied along with chlorothalonil only at 45, 60, 90, and 120 DAP.

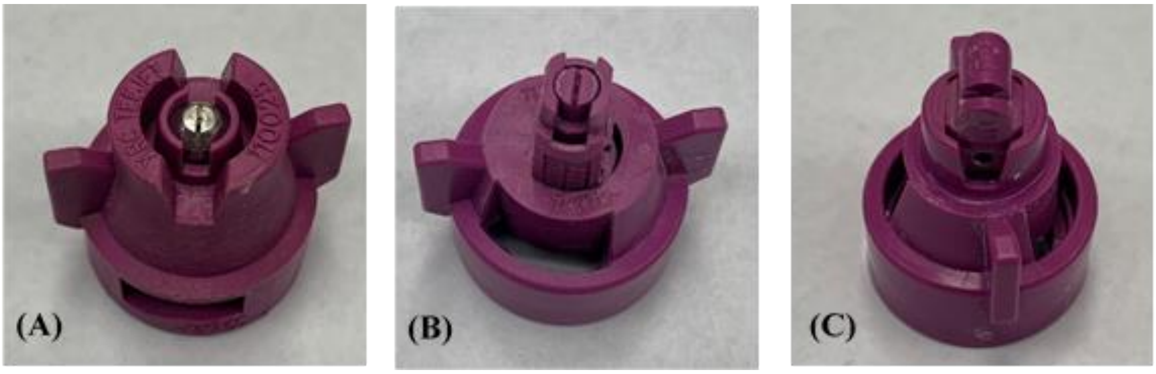

Figure 4.2 Three different nozzle types: (A) XRC, (B) AIXR, (C) TTI used to attain medium, very coarse, and ultra coarse droplet sizes (ASABE, 2020), respectively in the spray studies conducted in 2021 and 2022.

Spray deposition data were collected for fungicide applications at 45, 60, 90, and 120 DAP. For data collection, metal stands - with cardholders installed at the top to hold water-sensitive paper (WSP) – were placed at three different positions (upper, middle and lower) in the peanut canopies (as shown in Figure 4.3). Each canopy position was replicated three times. To maintain the consistency of spray deposition data collection between all applications, a field-length plot was selected in the field, and these metallic stands remained within that plot throughout the entire season. The height of the metal stands was adjusted during the season so that the stand at the upper position was right above the canopy, the stand in the middle was half of the plant/canopy height, and the stand at the lower position was 2 to 3 inches above the soil surface and at the bottom of the peanut canopies. During each fungicide application, spray deposition was collected by placing WSP in the cardholders at the respective positions in the canopies.

Figure 4.3 Illustration of water sensitive paper placed at different positions in the peanut canopies: (A) upper, (B) middle and (C) lower.

To reduce contamination during data collection, a team of three people was assigned for collecting WSP. Two people collected the WSP, and one person transported it to the dark cooler. For spray deposition data, applications were made only with water. After each spray application, WSP (three from each position in the canopy) were allowed to dry for a few minutes and then collected in pre-labeled envelopes to minimize exposure to moisture or humidity. All samples were carefully transported to the lab for further analysis at the end of the testing period.

In the lab, WSP was scanned using a DropScope instrument (SprayX, São Paulo, Brazil) (Figure 4.4B) and a compatible SprayX software (SprayX, São Paulo, Brazil). The WSP analysis provided spray coverage, droplet density, and other useful spray application information. 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. The SprayX software utilizes the appropriate spread factor for WSP and other related information as listed in ASABE S572.1 (ASABE, 2020) to provide that information.

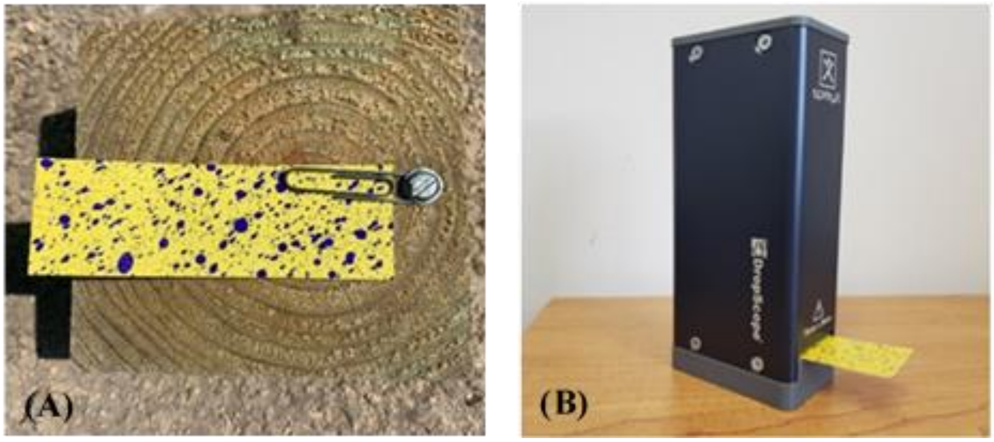

Figure 4.4 (A) Illustration of spray deposition on a water-sensitive paper for one of the study treatments, and (B) the water-sensitive paper being analyzed using the DropScope instrument.

Disease ratings were performed during both years for early/late leaf spot [*Passalora arachidicola* and *Nothopassalora personata* respectively], and southern stem rot/white mold [*Sclerotium rolfsii* (Sacc.)] which are economically important diseases for peanut. In 2021, leaf spot ratings were collected at 90 and 120 DAP. In 2022, the initial leaf spot rating was collected at 90 DAP, but no signs of leaf spot initiation were observed in both the treated and untreated plots (check). Therefore, the data was collected again after a week, at 97 DAP, when the leaf spot initiation was observed. Additionally, leaf spot ratings were collected at 120 and 140 DAP in 2022. Early and late leaf spots were rated together in the center two rows using the Florida 1-10 leaf spot severity scale, where 1 represents no disease, 0% defoliation, and 10 represents 100% defoliation, plants dead, killed by leaf spot (Chiteka et al. 1988). Similarly, a southern stem rot rating was collected at the time of digging in both 2021 and 2022. Southern stem rot severity was determined by counting the number of disease loci or hits per 18.3 m (per 60 feet) of row length in the center two rows and converting it to the percentage of infected rows. Untreated checks (no fungicide applied at all) were also left in the field each year to compare and evaluate disease ratings with the study treatments.

Immediately before or after each fungicide application, canopy measurements including height, width, and leaf area index (LAI), were collected to monitor the progress of the canopy throughout the growing season and to evaluate the impact of canopy growth on spray deposition and penetration into the peanut canopies as shown in table 4.2. In this study, Leaf Area Index (LAI), which represents the total leaf area per unit ground area, was determined using a ceptometer (AccuPAR LP-80, METER, Pullman, WA) in the field. The ceptometer measured the attenuation of diffuse sky radiation passing through the canopy, providing an estimate of the canopy cover.

Table 4.2 Canopy measurements and Leaf area index (LAI) measured on respective days after planting (DAP) during fungicide applications in 2021 and 2022.

Year	DAP	Height (cm)	Width (cm)	LAI
2021	45	23.9	42.9	0.6
	60	34.7	68.0	0.8
	90	45.8	83.5	4.5
	120	41.7	82.0	3.5
2022	45	29.7	59.9	0.92
	60	43.5	78.9	2.5
	90	49.9	80.6	3.4
	120	52.1	83.0	3.5

During all fungicide applications, meteorological conditions such as wind speed (m s^{-1}), wind direction, temperature (°C), relative humidity (%), and dew point (°C) were recorded at 1-min intervals by installing an on-site weather station (Model 6357 Vantage Vue^{TM}, Davis Instruments, CA). Table 4.3 presents the average meteorological data collected over the entire sampling dates for the years 2021 and 2022 during the fungicide application period.

During each year, peanuts were managed following the standard agronomic practices as outlined in the University of Georgia Peanut Production Guide (Monfort et al. 2022). Peanut yield was recorded at the end of each season by harvesting center two rows (1.8 m width and 18.3 m length) of each plot using a commercial 4-row peanut harvester and weighing the harvested peanuts. Table 4.4 provides a timeline of the field operations and data collection, including peanut planting, fungicide spray applications, disease rating, peanut inversion, and harvest, for the fungicide studies conducted in both years.

Table 4.3 Meteorological conditions recorded during fungicide application at different application dates in 2021 and 2022. Values are averaged across the applications for each date within a year and represent mean ± standard deviation.

Year	DAP[a]	Temperature (°C)	Humidity (%)	Dew Point (°C)	Wind Speed (m s^{-1})	Wind Direction
2021	45	32.2 ± 1.1	60.3 ± 4.4	74.4 ± 1.2	0.2 ± 0.3	WNW
	60	30.2 ± 0.5	67.9 ± 3.0	74.4 ± 0.9	1.5 ± 0.7	ESE
	90	29.0 ± 2.4	78.9 ± 7.4	77.2 ± 1.6	0.5 ± 0.5	NNW
	120	21.9± 3.0	63.9 ± 9.8	58.5 ± 1.3	1.5 ± 0.6	SE
2022	45	30.6 ± 1.8	74.6 ± 6.4	77.9 ± 0.9	0.5 ± 0.4	WNW
	60	31.1 ± 1.5	72.8 ± 7.1	78.1 ± 0.9	0.8 ± 0.5	WSW
	90	29.6 ± 1.3	63.6 ± 3.8	75.3 ± 1.0	0.7 ± 0.5	WNW
	120	24.8 ± 0.1	67.9 ± 6.5	62.3 ± 0.1	0.2 ± 0.2	NNW

[a] DAP refers to Days after planting

Table 4.4 Information on cultivar, planting, diseases rating, peanut inversion, and harvest dates for spray studies conducted in 2021 and 2022.

Year	Cultivars	Planting	Leaf spot rating	Southern stem rot rating	Peanut Inversion	Harvest
2021	GA-06G	May 25	Aug 23 and Sept 24	Oct 20	Oct 20	Oct 23
2022	GA-06G	May 25	Aug 23, Aug 30, Sept 21, Oct 12	Oct 19	Oct 20	Oct 24

4.3.3 Data Analysis

All data were analyzed using JMP® Pro 16.0.0 (SAS, Cary, NC). Statistical analysis indicated a significant treatment x fungicide application period interaction for spray coverage and droplet density ($p<0.0001$). However, there was no significant year x treatment interaction for any of the measured responses ($p=0.2838$ for spray coverage, $p=0.135$ for droplet density). Therefore, data were pooled across years and results are presented by each fungicide application period. Data were subjected to a two-way ANOVA by each fungicide application period and position in canopy where carrier volume and droplet size served as explanatory variables, and spray deposition and droplet density served as the response variables. For disease ratings and yield, since the onset of the disease (leaf spot) differed across two years, therefore data were analyzed separately for each year. A p-value of 0.05 was used to determine the significance of the main and interaction effects. For significant effects, treatment means were separated with a Students t-test using $\alpha = 0.05$.

4.4 RESULTS AND DISCUSSION

4.4.1 Spray deposition within the peanut canopies

The ANOVA analysis indicated that both carrier volume and droplet size had a significant impact on spray deposition at each position (upper, middle, and lower) within the peanut canopies (Table A.2-A.5) throughout the growing season. However, their interaction did not show any significant effect on spray deposition at any of the fungicide application periods and/or positions within the canopies ($p > 0.05$) so therefore, the results are presented separately for carrier volume and droplet size in the following sections.

4.4.1.1 Carrier Volume

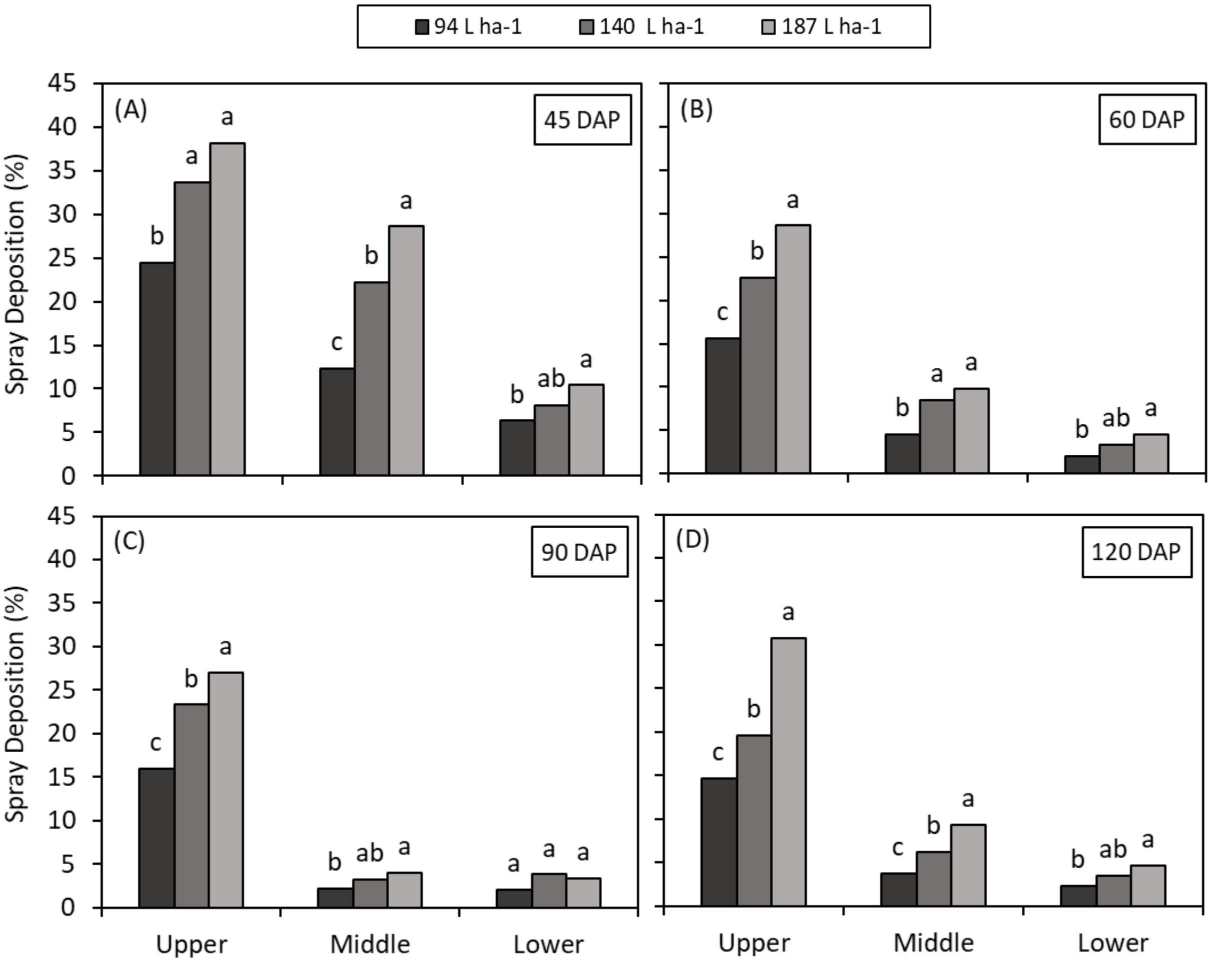

Figure 4.5 Effect of carrier volume (A, B, C and D) on spray deposition (%) at the upper, middle and lower positions in the peanut canopies during fungicide application at 45, 60, 90, and 120 days after planting (DAP). Bars sharing the same letter within or among the peanut canopy positions are not significantly different (P > 0.05).

Figure 4.5 (A-D) presents the effect of three different carrier volumes (94, 140, and 187 L ha^{-1}) on spray deposition (%) at the upper, middle, and lower positions within the peanut canopies at 45, 60, 90, and 120 DAP. Across each carrier volume, a general trend of significant reduction in spray deposition from the upper to the bottom of the canopies was observed throughout the growing season. For all four fungicide application periods when the spray deposition was assessed, the highest carrier volume of 187 L ha^{-1} consistently exhibited greatest spray deposition (27% to

38.2%) at the upper position of the peanut canopies followed by 140 L ha^{-}1 (19.6% to 33.7%) and 94 L ha^{-1} (14.7% to 24.4%) carrier volumes. A similar trend for spray deposition was observed in the middle of the peanut canopies, where the carrier volume of 187 L ha^{-1} provided the highest spray deposition. For fungicide applications at 60 and 90 DAP, the carrier volume of 140 L ha-1 provided a comparable spray deposition to 187 L ha^{-1} while the carrier volume of 94 L ha^{-1} had the lowest spray deposition in the middle of the canopies throughout the growing season (Figure 4.5B and 4.5C). At the lower position of the peanut canopies, the carrier volume showed a similar effect across at 45, 60, and 120 DAP where the carrier volumes of 140 L ha^{-1} and 180 L ha^{-1} provided a comparable spray deposition (Figure 4.5A, 4.5 B and 4.5D). For fungicide application at 90 DAP, all three carrier volumes had a similar deposition at the lower position of the peanut canopies (Figure 4.5C).

Table 4.5 presents the effect of carrier volume on droplet density within the peanut canopies for applications made at 45, 60, 90 and 120 DAP. The droplet density showed a similar trend as observed in the spray deposition due to the fact that the number of spray droplets are directly influenced by carrier volume. Earlier in the growing season, the peanut canopies are relatively smaller and open, and as the growing season proceeds, the canopies undergo significant development, characterized by the increase in foliage densities (Hall 1991; Wolf et al. 1993; Zhu et al. 2002). As the peanut canopies develop during the season, the upper position of the canopies started covering the lower portion of the canopies intercepting the portion of spray droplets (droplet density) reaching the target surface (which is the crown of the peanut plant) and eventully reducing the total number of spray droplets reaching the middle and lower position of the canopies. Similar observations were recorded for the effect of carrier volume on droplet density in this

Table 4.5 Effect of carrier volume on droplet density at different positions in the peanut canopies during fungicide application at 45, 60, 90 and 120 DAP.

Carrier volume (L ha^{-1})	Position within the canopy	Droplet Density (quantity of droplets cm^{-2})			
		45 DAP	60 DAP	90 DAP	120 DAP
94	Upper	143 b[a]	101 b	117 c	135 b
140		163 ab	157 a	142 b	158 b
187		170 a	197 a	185 a	207 a
94	Middle	81 b	28 b	15 b	31 b
140		127 a	54 a	26 a	39 b
187		145 a	64 a	34 a	59 a
94	Lower	48 b	11 b	14	16 b
140		52 b	20 a	28	22 b
187		76 a	25 a	22	33 a

[a] Means in the same column with the same letter are not significantly different according to Student's t-test (p = 0.05).

present study (table 4.5 and figure 4.5 A-D). The droplet density was highest at the upper position of the canopies (101 to 207 droplets cm^{-2}) (Table 4.5), thus contributing to the highest spray deposition at the upper position of the peanut canopies (Figure 4.5). The droplet density in the middle and lower position of the canopies were reduced (26 to 145 droplets cm^{-2} and 11 to 76 droplets cm^{-2}, respectively) due to interception by upper canopies. Both carrier volumes of 140 L ha^{-1} and 187 L ha^{-1} exhibited similar droplet densities in the lower canopies throughout the growing season with few exceptions where 187 L ha^{-1} provided slightly better deposition than the 140 L ha^{-1}. The lower carrier volume of 94 L ha^{-1} always resulted in less spray droplets delivered at the middle and lower position of the peanut canopies. Zhu et al. (2002) also reported similar results where the quantity of spray droplets and eventually spray deposition was improved at higher carrier volumes using larger nozzle orrifices from top upto the bottom of peanut canopies. Creech et al. (2018) also observed that a twofold increase in carrier volume from 94 to 187 L ha^{-1} resulted proportional increase in spray penetration within the corn canopies. Similarly, Derksen et al. (2008) found that the fungicide deposits increased into the leaf of middle canopies when spraying at higher carrier volume of 187 L ha^{-1} in narrow-row (18 cm) soybeans. These previous studies have also suggested to utilize higher carrier volume as it increases the quantity of droplets reaching the target and improves spray penetration deeper into canopies (Chechi et al. 2020; Ferguson et al. 2016; Sharpe et al. 2018).

4.4.1.2 Droplet Size

Figure 4.6 (A-D) presents the effect of different droplet sizes (M, VC, and UC) on spray deposition (%) at the upper, middle, and lower position of the peanut canopies at 45, 60, 90, and 120 DAP. Across all three droplet sizes, a general trend of reduced spray deposition from the upper to lower position of the canopies was observed throughout the growing season. Droplet size effect was observed upto the middle of the canopies whereas all the droplet size provided similar deposition in the lower canopies throughout the fungicide application periods except at 90 DAP. The highest spray deposition (27.3% to 37.3%) was observed consistently with the M spray droplets at the upper position of the peanut canopies followed by the VC (19.6% to 33.7%) and UC (14.7% to 24.4%) spray droplets for all fungicide application periods. In the middle of the peanut canopies, with the exception of application at 45 DAP where the M spray droplets again had highest deposition, both M and VC spray droplets provided comparable spray deposition while the UC spray droplets showed the lowest deposition as the peanut plant progressed from 60 to 120 DAP. In lower canopies, all three droplet sizes demonstrated the lowest (compared to upper and middle positions) and similar depositon at 45, 60, and 120 DAP (Figure 4.6A, 4.5 B and 4.5D).

For fungicide application at 90 DAP, M spray droplets had slightly better spray deposition (4.7%) than VC (2.1 %) and UC droplets (2.2 %) (Figure 4.6C).

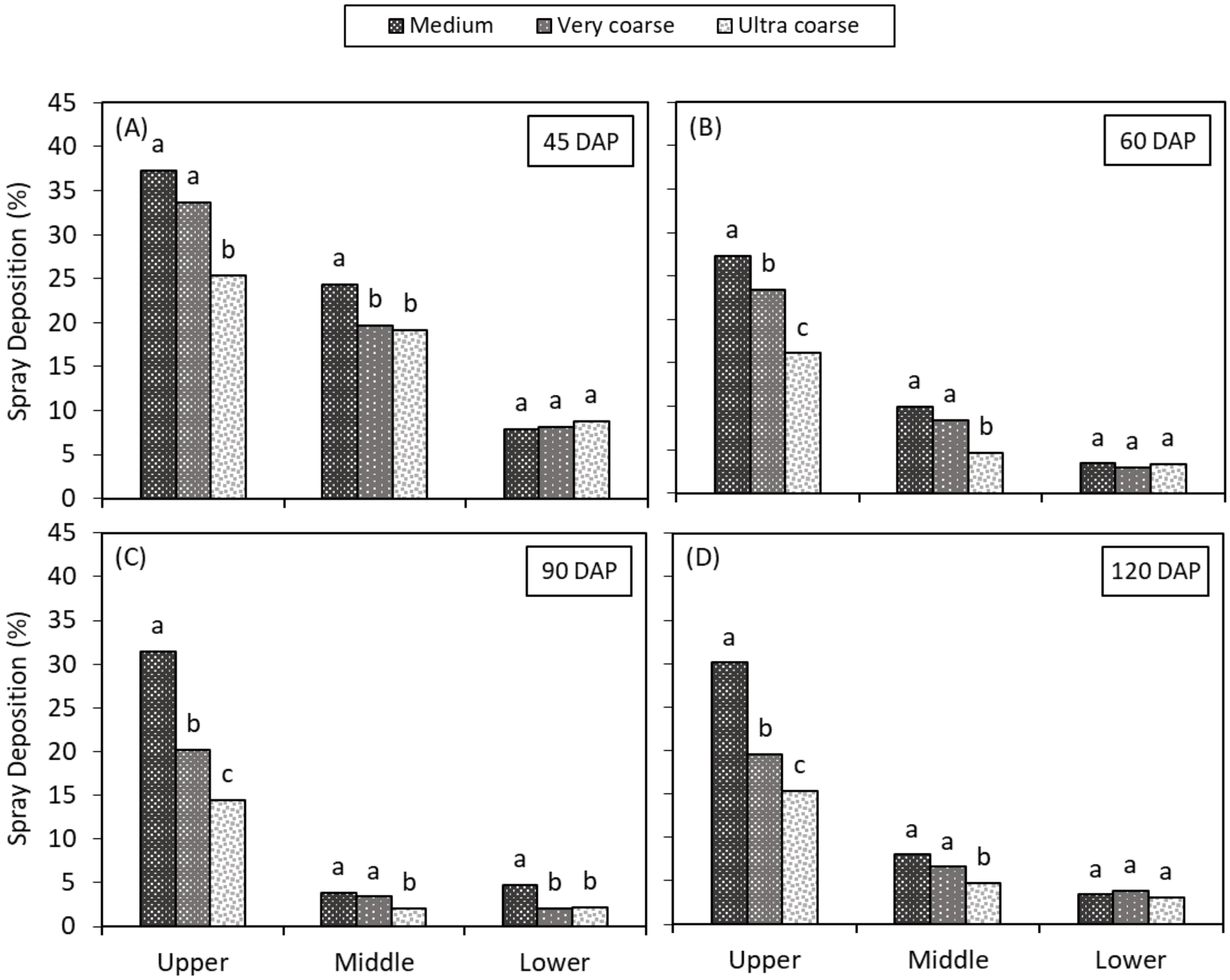

Figure 4.6 Effect of droplet size (A, B, C and D) on spray deposition (%) across three different positions in peanut canopies during spray application at 45, 60, 90, and 120 days after planting (DAP). Bars sharing the same letter within or among the peanut canopy positions are not significantly different (P > 0.05).

Table 4.6 presents the effect of droplet size on droplet density within the peanut canopies for applications made at 45, 60, 90 and 120 DAP. Throughout the growing season, the upper canopies received the highest quantiy of droplets followed by middle and lower canopies. As droplet density and consequesntly spray deposition is also influenced by droplet size, this trend was reflective of the observed spray deposition within the peanut canopies. Generally, droplet density is expected to decrease with an increase in the size of the spray droplets (VMD) (Ferguson et al., 2016). At the upper position of the peanut canopies, M spray droplets produced highest droplet density (256 to 289 droplets cm^{-2}) followed by VC (120 ot 144 droplets cm^{-2}) and UC (43 to 68 droplets cm^{-2}) spray droplets. In the middle and lower position of the canopies, a similar trend (M>VC>UC) but with reduced droplet density was observed (Table 4.6). The VC droplets provided comparable droplet densities to M spray droplets at 60 and 120 DAP at the bottom of the canopies. This reduction in droplet density from upper to lower canopies is again associated with the impact of upper canopies intercepting spray penetration into the lower canopies. Previous studies indicate that the influences of spray droplet size on canopy penetration varied depending on the crop. Derksen et al. (2014) found that the medium or coarse spray droplets showed better penetration into the soybean canopies compared to other droplet sizes. Zhu et al. (2004) observed that the air-induction nozzle that produces coarser droplets resulted in higher spray penetration performance than the finer droplet producing nozzles in peanut canopies. When very coarse droplets were applied in foliar bands to cotton, they resulted in the highest canopy penetration and deposition at the lower canopy positions (Womac et al. 2004). However, droplet classifications ranging from very fine to ultra coarse demonstrated similar levels of penetration (Ferguson et al. 2016) in oat canopy.

The efficacy of applied fungicides really depends on the extent to which the applied fungicides products penetrates the top canopy and deposited into the middle and lower canopies where the incidence of diseases such as leaf spot and southern stem rot is high (Wolf et al., 1993). At 45 DAP, the canopies were relatively open and smaller with height, width, and LAI ranging from 23.9 to 29.7 cm, 43.9 to 59.9 cm, and 0.56 to 0.92, respectively (Table 4.2). Therefore, a high quantity of spray droplets were observed into the middle of the peanut canopies at 45 DAP than at application dates later in the season. As peanut canopies developed, the reduction in spray deposition from the upper to the middle and lower positions of the canopies ranged from 25.1% to 72.8% at 187 L ha^{-1}, 34.1% to 75.9% at 140 L ha^{-1}, and 49.6% to 74.2% at 94 L ha^{-1}. Similar to the carrier volume effects at 45 DAP, the spray deposition reduction from the upper to the middle and lower canopies was the lowest and were 35.9% and 78.8% for M spray droplets, 41.5% and 41.5% for VC spray droplets, and 24.5% and 65.2% for UC spray droplets, respectively. At 60 DAP, the reduction in spray deposits from the top to the middle and lower positions was greater compared to 45 DAP for all carrier volumes and droplet sizes. At 90 DAP, the canopy cover was maximum (Table 4.2) and showed the highest measurements for canopy length (45.8-49.9 cm), width (80.5-83.6 cm), and LAI (3.39-4.45), leading to a significant reduction in spray deposition at the middle and lower positions of the canopies. Compared to the upper canopies, the spray deposition was reduced by 85.2% and 87.8% at 187 L ha^{-1}, 86.3% and 84.0% at 140 L ha^{-1}, and 86.2% and 87.4% at 94 L ha^{-1} at the middle and lower canopies, respectively. Similar patterns with reduced spray deposition in the middle and lower positions was observed across each droplet sizes. However, at 120 DAP, the spray deposition in the middle and lower canopies, for both carrier volumes and droplet sizes, was again higher compared to 90 DAP. Compared to the upper canopies, the reduction in spray deposits at the middle and lower positions were 70.0% and 85.1% at 187 L ha-1, 68.4% and 82.1% at 140 L ha-1, and 74.8% and 84.4% at 94 L ha-1, respectively, for carrier volumes. Regarding droplet size, the reduction in spray deposition was 73.4% and 88.7% for M, 66.3% and 80.1% for VC, and 69.5% and 79.9% for UC spray droplets, respectively. This could be attributed to the relative openness of canopies after 90 DAP, possibly due to natural defoliation or defoliation caused by leaf spot. Throughout the season, the highest percentage of spray deposition reaching the middle and lower peanut canopies was observed at 45 DAP which signifies the importance earlier fungicide applications with proper carrier volume to control the iniation of leaf spot problem that becomes sever later at 60 and 90 DAP when the canopies become dense.

Table 4.6 Effect of droplet size on droplet density across three positions in the peanut canopies during spray application at 45, 60, 90 and 120 DAP.

Droplet Size[a]	Position within the canopy	Droplet Density[b] (quantity of droplets cm^{-2})			
		45 DAP	60 DAP	90 DAP	120 DAP
M	Upper	273 a	256 a	281 a	289 a
VC		141 b	140 b	120 b	144 b
UC		61 c	58 c	43 c	68 c
M	Middle	193 a	80 a	41.9 a	73 a
VC		112 b	52 b	26.8 b	38 b
UC		50 c	15 c	6.2 c	18 c
M	Lower	91 a	25 a	38 a	33 a
VC		57 b	17 ab	18 b	27 a
UC		28 c	13 b	8 b	11 b

[a] M, VC, and UC represent the medium, very coarse, and ultra coarse spray droplets, respectively as defined by the ASABE S572.3 (ASABE/ANSI, 2020).

[b] Means in the same column with the same letter are not significantly different according to Student's t-test (p = 0.05).

4.4.2 Fungicide Efficacy

In 2021, no significant effects of carrier volume and droplet size were observed for leaf spot rating at 90 and 120 DAP, and southern stem rot at 148 DAP (Appendix A.6). Generally, higher carrier volumes and smaller droplet sizes tend to improve pesticide efficacy for contact applications due to increased spray deposition (Ennis et al. 1963). Therefore, it was expected that leaf spot and southern stem rot control would be better with higher carrier volumes and smaller droplet sizes (M). Although spray deposition varied within the peanut canopies for both carrier volume and droplet size during both years, all treatments showed similar disease control for both leaf spot and southern stem rot in 2021, indicating a comparable efficacy regardless of carrier volume and droplet size. However, every treatment combination performed better in disease control (leaf spot and southern stem rot) compared to the untreated check in 2021 (Table 4.7). The leaf spot rating progressed from 1.1 to 5.0 as the season advanced from 90 to 120 DAP which was significantly higher than both interval of disease ratings.

Table 4.7 Influence of the interaction between carrier volume and droplet size on leaf spot rating (90 and 120 DAP) and white mold (147 DAP) in the fungicide spray study conducted in 2021.

Carrier volume	Droplet size[a]	Leaf spot[b]		Southern stem rot[c]
		90 DAP	120 DAP	147 DAP
94	M	1.0 b	1.7 b	0.7 b
	VC	1.0 b	1.9 b	2.0 b
	UC	1.0 b	2.0 b	0.7 b
140	M	1.0 b	1.9 b	1.3 b
	VC	0.8 b	1.9 b	0.3 b
	UC	1.0 b	1.7 b	1.0 b
187	M	1.0 b	1.6 b	1.3 b
	VC	1.0 b	1.5 b	0.7 b
	UC	1.0 b	2.0 b	1.0 b
Check		1.1 a	5.0 a	6.7 a

[a] M, VC, and UC represent the medium, very coarse, and ultra coarse spray droplets, respectively as defined by the ASABE S572.3 (ASABE/ANSI, 2020).

[b] Leaf spot rating was based on Florida scale (1-10)

[c] White mold rating is expressed as the number of disease loci or hits per 18.3 m (60 feet) of row.

In 2022, a significant effect of carrier volume was observed for leaf spot and white mold ratings at 120 and 147 DAP, respectively (Appendix A.7). At 120 DAP, the lower carrier volume of 94 L ha^{-1} resulted in the highest leaf spot rating (2.3), while both higher carrier volumes of 140 and 187 L ha^{-1} showed a lower and similar ratings of leaf spot (1.9). Similar results were observed for white mold rating at 147 DAP, where the lowest carrier volume of 94 L ha^{-1} resulted in the highest leaf spot rating (5.3), while carrier volumes of 140 and 187 L ha^{-1} exhibited the lowest and similar ratings for leaf spot (Table 4.8). At 140 DAP, an interaction effect of carrier volume and droplet size was observed for leaf spot rating (Appendix A.7). As shown in Table 4.9, the combination of a lower carrier volume of 94 L ha^{-1} and M spray droplets resulted in the highest leaf spot rating (4.9) while all other carrier volume and droplet size combinations had a similar effect on leaf spot. However, all treatment combinations performed better than the untreated check for both leaf spot and southern stem rot in 2022 (Table 4.9). As presented in Figure 4.7, the leaf spot rating progressed from 1.2 to 7.9 as the season advanced from 97 to 140 DAP which was significantly higher than each disease ratings intervals.

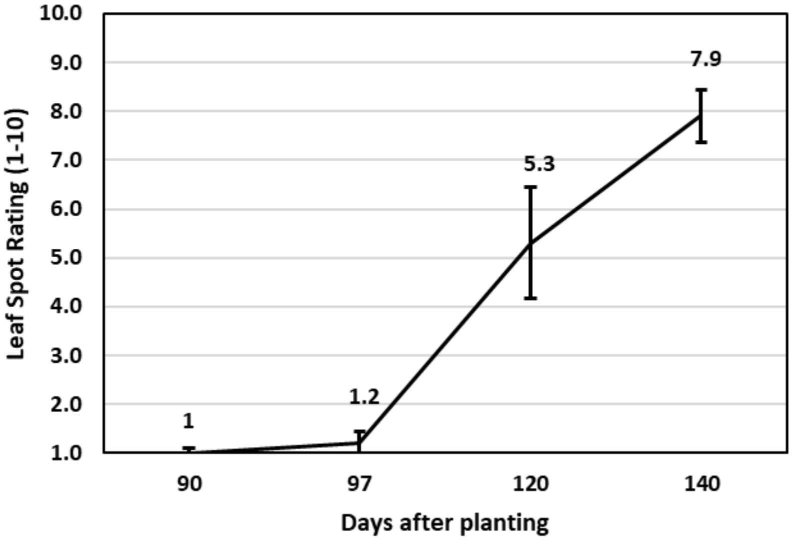

Figure 4.7 Graph showing the progress of leaf spot rating in the untreated plots (check) from 90 to 140 days after planting (DAP) for the fungicide study conducted in 2022.

During both years, at 90 DAP, the canopy reached its maximum progression (LAI ranged from 3.3 to 4.45), creating a favorable environment for the development of leaf spot and southern stem rot in the lower canopies. At 90 DAP, all carrier volumes provided similar and the lowest spray deposition in the lower canopies (Figure 4.5C). As the season progressed to 120 DAP, the use of a smaller volume (94 L ha^{-1}) resulted in lower droplet density and, consequently, reduced spray deposition in the lower canopies compared to other carrier volumes, as shown in Figure 4.5D. This may have created a more favorable environment for the development of leaf spot and southern stem rot, which were significantly higher in terms of rating, as presented in Table 4.8. Similarly, there was no significant droplet size effect observed in the lower canopies throughout the season (except at 90 DAP). Specifically, at 120 DAP, spray deposition was lowest for each droplet size, including M spray droplets. Therefore, the interaction of these treatment factors might have contributed resulting in increased leaf spot rating at 140 DAP, as shown in Table 4.9. The differences observed in disease ratings (leaf spot and southern stem rot) between the two years could possibly be attributed to the differences in disease pressure. In 2021, the results showed that disease pressure was likely low to moderate, whereas in 2022, it was likely high. Additionally, these differences may also be influenced by the variations in cropping histories as well as implementation of different management practices in each field and each year (Woodward et al., 2014).

Table 4.8 Influence of the carrier volume on leaf spot rating (120 DAP) and white mold (147 DAP) in the fungicide spray study conducted in 2022.

Volume (L ha-1)	Leaf spot @ 120 DAP[a]	Southern stem rot @ 147 DAP[b]
94	2.3 a	5.3 a
140	1.9 b	2.4 b
187	1.9 b	2.6 b

[a] Leaf spot rating was based on Florida scale (1-10)

[b] White mold rating is expressed as the number of disease loci or hits per 18.3 m (60 feet) of row.

Table 4.9 Influence of the interaction between carrier volume and droplet size on leaf spot rating (140 DAP) in the fungicide spray study conducted in 2022.

Carrier volume (L ha^{-1})	Droplet size[a]	Leaf spot[b]
94	M	4.8 b
	VC	3.8 c
	UC	3.6 c
140	M	3.4 c
	VC	3.4 c
	UC	3.5 c
187	M	3.6 c
	VC	3.9 c
	UC	3.4 c
Check		7.9 a

[a] M, VC, and UC represent the medium, very coarse, and ultra coarse spray droplets, respectively as defined by the ASABE S572.3 (ASABE/ANSI, 2020).

[b] Means in the same column with the same letter are not significantly different according to Student's t-test (p = 0.05).

[c] Leaf spot rating was based on Florida scale (1-10)

4.4.3 Yield

Peanut yield was not affected by carrier volume and droplet size during both years (Appendix A.8). As anticipated, in 2021, no significant differences in yield were observed, as the treatment had no impact on leaf spot and southern stem rot (Table 4.10). However, in 2022, with observed effects of both carrier volume and droplet size on leaf spot and white mold, it was expected that these treatment factors would translate into yield variations. However, no differences in peanut yield were observed among the study treatments in 2022 (Table 4.10). These findings were similar to the results of Bretthauer et al. (2008) where no significant differences in soybean yield were found among treatments varying in carrier volume and droplet size, despite variations in spray deposition within the canopies.

Table 4.10 Peanut yield for the different carrier volume and droplet size treatments in the spray studies conducted in 2021 and 2022.

Carrier volume (L ha^{-1})	Droplet size[a]	Peanut Yield (Kg ha^{-1})	
		2021	2022
94	M	4387	5771
	VC	5072	6734
	UC	4997	5923
140	M	5441	6690
	VC	5075	6507
	UC	5319	6764
187	M	5158	6666
	VC	6162	6506
	UC	5771	6571

[a] M, VC, and UC represent the medium, very coarse, and ultra coarse spray droplets, respectively as defined by the ASABE S572.3 (ASABE/ANSI, 2020).

4.5 CONCLUSIONS

The goal of this study was to assess the influence of carrier volume and droplet size on spray deposition within peanut canopies, fungicide efficacy, and peanut yield. Both carrier volume and droplet size affected the spray deposition within peanut canopies throughout the growing season. The highest carrier volume (187 L ha^{-1}) consistently provided the greatest spray deposition at the upper and middle position of peanut canopies. At the lower position of the canopies, the carrier volumes of 140 L ha^{-1} and 187 L ha^{-1} showed similar spray deposition, while the carrier volume of 94 L ha^{-1} had the lowest deposition throughout the season. Similarly, M spray droplets consistently provided the highest spray at the top of canopies, followed by VC and UC droplets. In the middle canopies, M and VC droplets showed similar deposition, while all three droplet sizes exhibited comparable and lowest deposition at the bottom canopies (except at 90 DAP). Disease control (leaf spot and southern stem rot) was not significantly affected by carrier volume and droplet size in 2021, but in 2022, lower carrier volume led to increased leaf spot and southern stem rot incidence. Additionally, an interaction effect was observed for leaf spot rating at 140 DAP, where the combination of lower carrier volume and M droplets resulted in the highest rating. Despite the observed differences in fungicide deposition or disease ratings for some of the study treatments, both carrier volume and droplet size did not impact peanut yield during both years. These study results showed that increasing carrier volume and using medium-sized droplets can improve fungicide deposition within peanut canopies. It is important to consider not only application parameters but also prevalent field conditions, crop growth, weather, and other factors that can impact disease severity, such as leaf spot and southern stem rot, in order to minimize their negative effects on peanut yield.

CHAPTER 5

CONCLUSIONS

Peanut production in the Southeastern United States faces significant threats from weeds, diseases, and other pests, which are exacerbated by the prevailing warm and humid weather conditions. Therefore, it is crucial to implement timely and effective pesticide applications to combat disease development and weed infestations. To ensure the efficacy of pesticides, it is essential to achieve adequate spray deposition, quality, and canopy penetration into the peanut canopies. The optimal selection of spray application parameters, including ground speed, carrier volume and droplet size is of vital importance during pesticide applications. Due to the limited research available on peanut crops regarding the influence of these application parameters on spray coverage, quality, canopy penetration, and pesticide efficacy, this study aimed to address these knowledge gaps and gain a comprehensive understanding of their effect on peanut pesticide applications.

For the first objective, the study evaluated the influence of five different ground speeds of 9.7, 12.9, 16.1, 19.3 and 22.5 km h^{-1} on spray deposition and quality using two different agricultural sprayer setups; a conventional sprayer without a rate controller (CNS) in 2021 and a sprayer equipped with a rate controller (SRC) in 2022 across three different nozzle types (XRC, AIXR and TTI). The study concluded that increasing ground speed in the CNS setup resulted in reduced spray deposition, while the SRC setup maintained more consistent deposition due to flow rate adjustments by rate controller. Both CNS and SRC exhibited variations in spray quality with higher ground speeds, with greater variations observed in the SRC due to changes in spray pressure. The XRC and TTI nozzles showed similar trends in spray deposition and quality within each setup, while the AIXR nozzle exhibited inconsistent performance. The study suggests that sprayers with rate controllers can achieve consistent spray deposition despite ground speed variations, but increased spray pressure may degrade the quality and lead to finer droplets prone to drift. Implementing best management practices, such as proper nozzle selection and application within a nominal ground speed range, is essential for effective pesticide applications.

For the second objective, field-scale studies were conducted in 2021 and 2022 to investigate the impact of carrier volume and droplet size on spray coverage, droplet density, and herbicide efficacy in peanut. The treatments included three carrier volumes (94, 117, and 140 L ha^{-1}) and three droplet sizes (M, VC, and UC) in 2021, with an additional carrier volume of 187 L ha^{-1} tested in 2022. The results from this study found that both carrier volume and droplet size significantly affected spray coverage and droplet density during herbicide applications. Increasing carrier volume from 94 to 140 L ha^{-1} improved spray coverage, but further increases did not provide additional improvement. The effect of spray volume on droplet density varied across years and was observed primarily at higher volumes of 140 L ha^{-1} or more. Regarding droplet size, both M and VC showed comparable spray coverage and droplet density, although M droplets exhibited reduced coverage in some cases, while UC droplets resulted in decreased coverage and density compared to M and VC droplets. However, neither carrier volume nor droplet size influenced weed control or peanut yield during both years. These findings suggest that lower carrier volumes and coarser droplet sizes can be used without compromising herbicide efficacy and peanut yield, but field conditions, including weed type, amount, and pressure should be considered during herbicide application. Moreover, peanut growers should carefully select optimal application parameters that provide sufficient coverage while minimizing off-target movement.

The final and third objective of this study was aimed at assessing spray deposition within the peanut canopies for fungicide applications at three carrier volumes i.e. 94, 140, and 187 L ha^{-1} and three different droplet sizes (medium, very coarse, and ultra-coarse droplets). The results showed a consistent reduction in spray deposition from upper to the middle position of the peanut canopies throughout the growing season. The highest carrier volume of 187 L ha^{-1} consistently provided the greatest deposition at the upper and middle canopies, while at the lower canopies, the volumes of 140 L ha^{-1} and 187 L ha^{-1} showed similar deposition. For droplet size effect, medium (M) droplets had the highest deposition at the upper canopies, followed by very coarse (VC) and ultra coarse (UC) droplets. In the middle canopies, M and VC droplets showed a similar deposition, while UC droplets had the lowest deposition. As the canopies developed, spray deposition gradually decreased, emphasizing the importance of early fungicide applications with proper selection of carrier volume and droplet size. However, carrier volume and droplet size had no significant effect on peanut yield during both years. The results of this study indicated that fungicide deposition into the peanut canopies can be improved by selecting higher carrier volume and/or nozzles that produce medium droplets. Beside application parameters, the prevalent field conditions during the growing season along with crop growth, weather and other factors that can influence disease severity should also be carefully evaluated to minimize the effect of diseases like leaf spot and while mold on peanut yield.

REFERENCES

Al-Gaadi K, Ayers P (1994) Monitoring controller-based field sprayer performance. Appl Eng Agric 10:205-208

Al Heidary M, Douzals JP, Sinfort C, Vallet A (2014) Influence of spray characteristics on potential spray drift of field crop sprayer: a literature review. Crop Prot 63:120-130. DOI: https://doi.org/10.1016/j.cropro.2014.05.006

Alves GS, Kruger GR, da Cunha JPA, de Santana DG, Pinto LAT, Guimarães F, Zaric M (2017) Dicamba spray drift as influenced by wind speed and nozzle type. Weed Technol 31:724-731

Aliverdi A, Karami S (2019) The effect of type and size of single, twin, and triplet flat fan nozzles on the activity of cycloxydim against wild barley (Hordeum spontaneum Koch.). Journal of Plant Protection (Mashhad) 33:465-474

Aliverdi A, Zarei M (2020) Forward angled spray: a method for improving the efficacy of herbicides. J Plant Prot Res 60:275-283

Anco DJ, Thomas JS, Jordan DL, Shew BB, Monfort WS, Mehl HL, Small IM, Wright DL, Tillman BL, Dufault NS (2020) Peanut yield loss in the presence of defoliation caused by late or early leaf spot. Plant Dis 104:1390-1399

APC (2020) The Peanut Industry. American Peanut Council. https://www.peanutsusa.com/about-apc/the-peanut-industry.html. Accessed: 29 September, 2021

ASABE (2016) Best Management Practices for Boom Spraying, ASABE Standard S592.1. St. Joseph, MI: American Society of Agricultural and Biological Engineers

ASABE (2020) Spray nozzle classification by droplet spectra, ASABE Standard S572.3. St. Joseph, MI: American Society of Agricultural and Biological Engineers

Ayers P, Rogowski S, Kimble B (1990) An investigation of factors affecting sprayer control system performance. Appl Eng Agric 6:701-706

Balsari P, Gil E, Marucco P, van de Zande JC, Nuyttens D, Herbst A, Gallart M (2017) Field-crop-sprayer potential drift measured using test bench: Effects of boom height and nozzle type. Biosyst Eng 154:3-13

Benbrook, CM (2012) Impacts of genetically engineered crops on pesticide use in the US-the first sixteen years. Environ Sci Eur 24:1-13

Berg F, Kubiak R, Benjey W, Majewski M, Yates S, Reeves G, Smelt J, van der Linden A (1999) Emission of pesticides into the air. Wat Air and Soil Poll 115:195-218. https://doi.org/https://doi.org/10.1023/A:1005234329622

Berger S, Dobrow M, Ferrell J, Webster T (2014) Influence of carrier volume and nozzle selection on Palmer amaranth control. Peanut Sci 41:120-123

Bode L, Butler B, Goering C (1976) Spray drift and recovery as affected by spray thickener, nozzle type, and nozzle pressure. Trans ASABE 19:213-0218

Borger CP, Riethmuller GP, Ashworth M, Minkey D, Hashem A, Powles SB (2013) Increased carrier volume improves preemergence control of rigid ryegrass (*Lolium rigidum*) in zero-tillage seeding systems. Weed Technol 27:649-55

Bouse L, Kirk I, Bode L (1990) Effect of spray mixture on droplet size. Trans ASAE 33:783-788

Branch W, Culbreath A (2013) Yield performance and pest resistance among peanut genotypes when grown without fungicides or insecticides. Crop Prot 52:22-25

Brazes R, Reichard D, Bukovac M, Fox R (1991) A partitioned energy transfer model for spray impaction on plants. J Agric Eng Res 50:11-24

Bretthauer SM, Mueller TA, Derksen RC, Zhu H, Bode LE (2008) The effects of spray application rate and droplet size on applications to control soybean rust. Pages 1 in Proceedings of the 2008 Providence, Rhode Island: American Society of Agricultural and Biological Engineers

Brown L, Soltani N, Shropshire C, Spieser H, Sikkema PH (2007) Efficacy of four corn (*Zea mays* L.) herbicides when applied with flat fan and air induction nozzles. Weed Biol Manag 7:55-61

Butts TR, Samples CA, Franca LX, Dodds DM, Reynolds DB, Adams JW, Zollinger RK, Howatt KA, Fritz BK, Hoffman WC (2018) Spray droplet size and carrier volume effect on dicamba and glufosinate efficacy. Pest Manag Sci 74:2020-2029

Byass JB, Lake JR (1977) Spray drift from a tractor-powered field sprayer. Pestic Sci 8:117-126

Carroll J (2017) The effects of sprayer speed and droplet size on herbicide burndown efficacy Master's Thesis. Fayetteville, AR: University of Arkansas. https://scholarworks.uark.edu/etd/2435

Carter O, Prostko E, Davis J (2017) The influence of nozzle type on peanut weed control programs. Peanut Sci 44:93-99

Chechi A, Roehrig R, Piton B, da Luz MR, Deuner CC, Forcelini CA, Boller W (2020) The combined use of spray volumes and droplet sizes in the chemical control of Asian soybean rust in cultivars with different leaf area indices. Crop Prot 136:105212

Craig I, Woods N, Dorr G (1998) A simple guide to predicting aircraft spray drift. Crop Prot 17:475-482

Cranmer JR, Linscott DL (1991) Effects of droplet composition on glyphosate absorption and translocation in velvetleaf (Abutilon theophrasti). Weed Sci 39:251-254

Creech CF, Henry RS, Fritz BK, Kruger GR (2015) Influence of herbicide active ingredient, nozzle type, orifice size, spray pressure, and carrier volume rate on spray droplet size characteristics. Weed Technol 29:298-310

Creech CF, Henry RS, Fritz BK, Kruger GR (2018). Herbicide spray penetration into corn and soybean canopies using air-induction nozzles and a drift control adjuvant. Weed Technol 32:72-79

Cunha JP, Farnese AC, Olivet JJ (2013) Computer programs for analysis of droplets sprayed on water sensitive papers. Planta Daninha 31:715-720

De Rutter H, Uffing AJ, Meinen E, Prins A (1990) Influence of surfactants and plant species on leaf retention of spray solutions. Weed Sci 567-572

Derksen R, Zhu H, Ozkan H, Hammond R, Dorrance A, Spongberg A (2008) Determining the influence of spray quality, nozzle type, spray volume, and air-assisted application strategies on deposition of pesticides in soybean canopy. Trans ASABE 51:1529-1537

Derksen RC, Miller SA, Ozkan HE, Fox RD (1998) Spray deposition characteristics on tomatoes and disease management as influenced by droplet size, spray volume, and air-assistance. Pages 1 in proceedings of the 2001 ASAE Annual Meeting. St. Josheph, Michigan: American Society of Agricultural and Biological Engineers

Dill GM, CaJacob CA, Padgette SR (2008) Glyphosate-resistant crops: adoption, use and future considerations. Pest Manag Sci 64:326-331

Ennis WB, Williamson RE (1963) Influence of droplet size on effectiveness of low-volume herbicidal sprays. Weeds 11:67-72

Etheridge RE, Hart WE, Hayes RM, Mueller TC (2001) Effect of venturi-type nozzles and application volume on postemergence herbicide efficacy. Weed Technol 15:75-80

Etheridge RE, Womac AR, Mueller TC (1999) Characterization of the spray droplet spectra and patterns of four venturi-type drift reduction nozzles. Weed Technol 13:765-770

Everman WJ, Clewis SB, Thomas WE, Burke IC, Wilcut JW (2008) Critical period of weed interference in peanut. Weed Technol 22:63-67

Feng PC, Chiu T, Sammons RD, Ryerse JS (2003) Droplet size affects glyphosate retention, absorption, and translocation in corn. Weed Sci 51:443-448

Franca LX, Dodds DM, Butts TR, Kruger GR, Reynolds DB, Mills JA, Bond JA, Catchot, AL, Peterson, DG (2020) Droplet size impact on lactofen and acifluorfen efficacy for Palmer amaranth (*Amaranthus palmeri*) control. Weed Technol 34:416-423

Ferguson JC, Chechetto RG, Adkins SW, Hewitt AJ, Chauhan BS, Kruger GR, O'Donnell CC (2018) Effect of spray droplet size on herbicide efficacy on four winter annual grasses. Crop Prot 112:118-124

Ferguson JC, Chechetto RG, O'Donnell CC, Fritz BK, Hoffmann WC, Coleman CE, Chauhan BS, Adkins SW, Kruger GR, Hewitt AJ (2016) Assessing a novel smartphone application–SnapCard, compared to five imaging systems to quantify droplet deposition on artificial collectors. Comput Electron Agric 128:193-198

Ferguson JC, Hewitt AJ, O'Donnell CC (2016) Pressure, droplet size classification, and nozzle arrangement effects on coverage and droplet number density using air-inclusion dual fan nozzles for pesticide applications. Crop Prot 89:231-238

Ferguson JC, Hewitt AJ, O'Donnell CC, Kruger GR (2020). Comparison of water-sensitive paper, Kromekote and Mylar collectors for droplet deposition with a visible fluorescent dye solution. J Plant Prot Res 60:98-105

Fernandez-Cornejo J, Nehring RF, Osteen C, Wechsler S, Martin A, Vialou A (2014) Pesticide use in US agriculture: 21 selected crops, 1960-2008. USDA-ERS Economic Information Bulletin(124).

Fietsam J, Young B, Steffen R (2004) Differential response of herbicide drift reduction nozzles to drift control agents with glyphosate. Trans ASABE 47:1405-1411

Fox RD, Derksen RC, Cooper JA, Krause CR, Ozkan HE (2003) Visual and image system measurement of spray deposits using water–sensitive paper. Appl Eng Agric 19:549-552

Franca LX, Dodds DM, Butts TR, Kruger GR, Reynolds DB, Mills JA, Bond JA, Catchot AL, Peterson DG (2020) Evaluation of optimal droplet size for control of Palmer amaranth (*Amaranthus palmeri*) with acifluorfen. Weed Technol 34:511-519

Fritz B (2006) Meteorological effects on deposition and drift of aerially applied sprays. Trans ASABE 49:1295-1301

Fritz BK, Hoffmann, WC, Martin DE, Thomson S (2007) Aerial application methods for increasing spray deposition on wheat heads. Appl Eng Agric 23:709-715

Gage KL, Krausz RF, Walters SA (2019) Emerging challenges for weed management in herbicide-resistant crops. Agric 9: 180

Garcerá C, Vicent A, Chueca P (2020) Effect of spray volume, application timing and droplet size on spray distribution and control efficacy of different fungicides against circular leaf spot of persimmon caused by Plurivorosphaerella nawae. Crop Prot 130:105072

Guler H, Zhu H, Ozkan HE, Ling P (2012) Characterization of hydraulic nozzles for droplet size and spray coverage. At Sprays 22:627-645

Hall F (1991) Influence of canopy geometry in spray deposition and IPM. HortScience 26:1012-1017

Hanna M, Kruckeberg J, Darr M, Steward B (2009) Nozzle and droplet size effects on pesticide performance and drift. Pages 49-52 in Proceeding of the 21st Annual Integrated Crop Management Conference. Ames, Iowa: Iowa State University

Herbst A, Osteroth HJ, Stendel H (2018) A novel method for testing automatic systems for controlling the spray boom height. Biosyst Eng 174:115-125

Hofman V, Solseng E (2001) Reducing spray drift. North Dakota State University Extension Service. Agricultural and Biosystems Engineering, Fargo, North Dakota. http://hdl.handle.net/10365/5111.

Jensen PK (2007) Nonvertical spray angles optimize graminicide efficacy. Weed Technol 21:1029-1034

Jones EJ, Hanks JE, Wills GD (2002) Effect of different nozzle types on drift and efficacy of Roundup Ultra (Vol. 1119). Office of Agricultural Communication, Division of Agriculture, Forestry, and Veterinary Medicine, Missisipi State University.

Jong Ad, Michielsen J, Stallinga H, Van de Zande J (2000) Effect of sprayer boom height on spray drift. Mededelingen-Faculteit Landbouwkundige en Toegepaste Biologische Wetenschappen, Universiteit Gent, 65:919-930

Kemerait R, Culbreath A, Brenneman T, Tubbs S, Srinivasan R, Abney M, Monfort S, Pilon C, Bag S, Brown N, LaForest J, Prostko E, Tillman B, Dufault N, Small I, Chen C, Jacobsen A, Balkcom K, Strayer-Scherer A, Graham S, Zerweller B, Anco Dan (2023) Minimizing disease of peanut in the southeastern United States. Peanut Rx. University of Georgia, University of Florida, Auburn University, Mississippi State University, Clemson University.

Kirk I, Bouse L, Carlton J, Franz E, Stermer R (1992) Aerial spray deposition in cotton. Trans ASABE 35:1393-1399

Knoche M (1994) Effect of droplet size and carrier volume on performance of foliage-applied herbicides. Crop Prot 13:163-178

Legleiter TR, Johnson WG (2016) Herbicide coverage in narrow row soybean as influenced by spray nozzle design and carrier volume. Crop Prot 83:1-8

Luck J, Zandonadi R, Luck B, Shearer S (2010) Reducing pesticide over-application with map-based automatic boom section control on agricultural sprayers. Trans ASABE 53:685-690

Lund I (2000) Nozzles for drift reduction. Asp Appl Biol 57:97-102 Pesticide application, University of Surrey, Guildford, UK, 17-18 January 2000

Maybank J, Yoshida K, Grover R (1978) Spray drift from agricultural pesticide applications. J Air Pollut Control Assoc 28:1009-1014

McKinlay K, Ashford R, Ford R (1974) Effects of drop size, spray volume, and dosage on paraquat toxicity. Weed Sci 22:31-34

McMullan P (1995) Effect of spray volume, spray pressure and adjuvant volume on efficacy of sethoxydim and fenoxaprop-p-ethyl. Crop Prot 14:549-554

Miller P, Smith R (1997). The effects of forward speed on the drift from boom sprayers. In Proceedings of the Brighton Crop Protection Conference: Weeds, Brighton, UK, 17-20 November 1997

Miller PC, Ellis MB (2000) Effects of formulation on spray nozzle performance for applications from ground-based boom sprayers. Crop Prot 19:609-15

Monfort WS, Knox P, Tubbs RS, Kvein CK, Holbrook CC, Ozias-Akins P, Pilon C, Culbreath AK, Brenneman TB, Porter WM, Prostko EP, Grey TL, Johnson III WC, Kemrait RC, Abney M, Rains GC, Vellidis G, Butts Chris, Kirk K, Warner A (2022) UGA Peanut Production Field Guide. University of Georgia, Athens, GA, USA, 2022, B-1146

Nordby A, Skuterud R (1974) The effects of boom height, working pressure and wind speed on spray drift. Weed Res 14:385-395

Nuyttens D, De Schampheleire M, Baetens K, Sonck B (2007) The influence of operator-controlled variables on spray drift from field crop sprayers. Trans ASABE 50:1129-1140

Ozkan H, Zhu H, Derksen R, Guler H, Krause C (2006) Evaluation of various spraying equipment for effective application of fungicides to control Asian soybean rust. Asp Appl Biol 77:1-8

Ozkan HE (1987) Sprayer performance evaluation with microcomputers. Appl Eng Agric 3:36-41.

Ozkan HE, Paul P, Derksen RC, Zhu H (2011) Influence of application equipment on deposition of spray droplets in wheat canopy. Asp Appl Biol 114:317-324

Ozkan H, Womac A (2005) Best management practices for boom spraying. Ohio State University Extension publication AEX-527-05. https://ohioline.osu.edu/factsheet/fabe-527. Accessed: January 22, 2023

Ozkan HE, Zhu H (1998) Effects of major variables on drift distances of spray droplets. Food Agric Biol Eng 525-598.

Plaut J, Berger R (1980) Development of *Cercosporidium personatum* in three peanut canopy layers. Peanut Sci 7:46-49

Phillips M, Bradford A, Harris P (1980) Effect on weed control of drop size, water volume and rate of a herbicide applied by spinning disc. In Proceedings of the 1980 British Crop Protection Conference-Weeds. Brighton, England: 15th British Weed Control Conference

Prokop M, Veverka K (2006) Influence of droplet spectra on the efficiency of contact fungicides and mixtures of contact and systemic fungicides. Plant Prot Sci 42:26-33

Ramsdale BK, Messersmith CG (2001) Drift-reducing nozzle effects on herbicide performance. Weed Technol 15:453-460

Reed J, Smith D (2001) Droplet size and spray volume effects on insecticide deposit and mortality of heliothine (Lepidoptera: Noctuidae) larvae in cotton. J Econ Entomol 94:640-647

Reichard DL (1988) Drop formation and impaction on the plant. Weed Technol 2:82-87

Ridgway R, Tinney J, MacGregor J, Starler N (1978) Pesticide use in agriculture. Environ Health Perspect 27:103-112

Rockwell A, Ayers P (1996) A variable rate, direct nozzle injection field sprayer. Appl Eng Agric 12:531-538

Sapkota M, Virk S, Rains G (2023) Spray deposition and quality assessment at varying ground speeds for an agricultural sprayer with and without a rate controller. AgriEngineering 5:506-519

Sartori S, Domingues E, Kimura J, Garrito S (2002) Automatic control of boom height and positioning on a self propelled sprayer. Pages 421-431 in Proceedings of the World Congress of Computers in Agriculture and Natural Resources. St. Josheph, Michigan: American Society of Agricultural and Biological Engineering

Sharda A, Fulton JP, McDonald TP, Brodbeck CJ (2011) Real-time nozzle flow uniformity when using automatic section control on agricultural sprayers. Comput Electron Agric 79:169-179

Sharda A, Fulton JP, McDonald TP, Zech WC, Darr MJ, Brodbeck CJ (2010) Real-time pressure and flow dynamics due to boom section and individual nozzle control on agricultural sprayers. Trans ASABE 53:1363-1371

Sharda A, Luck JD, Fulton JP, Shearer SA, McDonald TP (2010) Nozzle uniformity for agricultural sprayers operating under field operation when using automatic section technology. In 2010 Pittsburgh, Pennsylvania, June 20-23, 2010 (p. 1). American Society of Agricultural and Biological Engineers.

Sharpe SM, Boyd NS, Dittmar PJ, MacDonald, GE, Darnell RL, Ferrell, JA (2018) Spray penetration into a strawberry canopy as affected by canopy structure, nozzle type, and application volume. Weed Technol 32:80-84.

Smith DH (1980) Management of Peanut Foliar Disease. Plant Dis 64:356-361

Stalker H (1997) Peanut (*Arachis hypogaea* L.). Field crops Research 53:205-217

Sumner PE, Roberts PM, Edwards RP (2007) Comparison of low-drift nozzles for canopy penetration in cotton. In Proceedings of the 2007 ASAE Annual Meeting 2007 (p. 1). St. Joseph, Michigan: American Society of Agricultural and Biological Engineers.

Sharkey SM, Williams BJ, Parker KM (2021) Herbicide drift from genetically engineered herbicide-tolerant crops. Environ Sci Technol 55:15559-15568

Sikkema PH, Brown L, Shropshire C, Spieser H, Soltani N (2008) Flat fan and air induction nozzles affect soybean herbicide efficacy. Weed Biol Manag 8:31-38

Taylor W, Anderson P, Cooper S (1989) The use of air assistance in a field crop sprayer to reduce drift and modify drop trajectories. In Proceeding of the Brighton Crop Protection Conference:

Weeds, Brighton, UK, 20-23 November 1989.

Taylor WA, Womac AR, Miller PC, Taylor BP (2004). An attempt to relate drop size to drift risk. Pages 210-223 in Proceedings of the International Conference on Pesticide Application for Drift Management. Pullman, WA: Washington State University

Teejet (2013) A user's guide to spray nozzles. In T. Technologies (Ed.). http://www.teejet.com/

Teske M, Thistle H (1999) A simulation of release height and wind speed effects for drift minimization. Trans ASABE 42:583-591

Tewolde H, Black M, Fernandez C, Schubert A (2002) Plant growth response of two runner peanut cultivars to reduced seeding rate. Peanut Sci 29:8-12

Tu Y, Lin Z, Zhang J (1986) The effect of leaf shape on the deposition of spray droplets in rice. Crop Prot 5:3-7

Uk S, Courshee RJ (1982) Distribution and likely effectiveness of spray deposits within a cotton canopy from fine ultralow-volume spray applied by aircraft. Pestic Sci 13:529-536

[USDA-NASS] U.S. Department of Agriculture-National Agriculture Statistics Survey (2019) 2018 Agricultural Chemical Use Survey – Peanuts. https://www.nass.usda.gov/Surveys/Guide_to_NASS_ Surveys/Chemical_Use/2018_Peanuts_Soybeans_Corn/ChemUseHighlights_Peanuts_2018.pdf. Accessed: February 12, 2023

[USDA-NASS] U.S. Department of Agriculture-National Agriculture Statistics Survey (2022a) https://quickstats.nass.usda.gov/results /B43A6E86-5ED1-311B-988E-FFC435F2D8A3. Accessed: September 29, 2021

[USDA-NASS] U.S. Department of Agriculture-National Agriculture Statistics Service (2022b) https://www.nass.usda.gov/Statistics_by_Subject/ index.php?sector=CROPS. Accessed: September 29, 2021

[USDA-NASS] U.S. Department of Agriculture-National Agriculture Statistics Service (2021c) Foreign Agriculture Service. https://ipad.fas.usda.gov/cropexplorer/cropview /commodityView.aspx?cropid=2221000. Accessed: September 30, 2021

[USDA-NASS] U.S Department of Agriculture-National Agricultural Statistics Service Survey (2022a). https://www.nass.usda.gov/Surveys/Guide_to_NASS_Surveys/Chemical_Use/. Accessed: September 30, 2022

[USDA-NASS] U.S Department of Agriculture-National Agricultural Statistics Service Survey (2022b) 2021 U.S. Farm Production Expenditures. https://www.nass.usda.gov/Publications/Highlights/2022/2021_FarmExpenditures.pdf. Accessed: September 30, 2022

[USDA-NASS] U.S. Department of Agriculture-National Agriculture Statistics Service (2022) National statistics for peanuts. https://www.nass.usda.gov/Statistics_by_Subject/result.php?39C40847-31E1-311E-BEB3-58E5DD54EC1C&sector=CROPS&group=FIELD%20CROPS&comm=PEANUTS. Accessed: March 02, 2023

van de Zande JC, Huijsmans J, Porskamp H, Michielsen J, Stallinga H, Holterman H, de Jong A (2008) Spray techniques: how to optimise spray deposition and minimize spray drift. Environmentalist 28:9-17

Van de Zande J, Stallinga H, Michielsen J, Van Velde P (2005) Effect of sprayer speed on spray drift. Annual Rev Agric Eng 4:129-142.

Virk S, Prostko E, Kemerait R, Abney M, Rains G, Powell C, Carlson D, Jacobs J, Tyson W (2021) On-farm evaluation of nozzle types for peanut pest management using commercial sprayers. Peanut Sci 48:87-96

Webster TM (2001) Weed survey-southern states: broadleaf crops subsection. In Proc. South. Weed Sci. Soc. 54:244-259

Wilcut, JW, York, AC, Wehtje, GR (1994) The control and interaction of weeds in peanut (*Arachis hypogaea*). Rev Weed Sci 6: 177–205

Wolf RE, Daggupati NP (2009) Nozzle type effect on soybean canopy penetration. Appl Eng Agric 25:23-30

Wolf T (2000) Low-drift nozzle efficacy with respect to herbicide mode of action. Asp Appl Biol 57:29-34.

Wolf TM, Caldwell BC, Mcintyre GI, Hsiao AI (1992) Effect of droplet size and herbicide concentration on absorption and translocation of 14C-2, 4-D in oriental mustard (*Sisymbrium orientate*). Weed Sci 40:568-575

Wolf TM, Grover R, Wallace K, Shewchuk SR, Maybank J (1993) Effect of protective shields on drift and deposition characteristics of field sprayers. Can J Plant Sci 73:1261-1273

Woodward JE (2006) Optimizing efficacy and economic benefits of fungicides for peanut disease control via pre-plant analysis of disease risk and irrigation timing. Ph.D dissertation. Athens, GA: University of Georgia

Woodward JE, Brenneman TB, Kemerait Jr RC. Chemical control of peanut diseases: targeting leaves, stems, roots, and pods with foliar-applied fungicides (2013) Fungicides–showcases of integrated plant disease management from around the world. Rijeck, Crotatia: InTech. 2013 May 15:55-76

Yates WE, Cowden RE, Akesson NB (1985) Drop size spectra from nozzles in high-speed airstreams. Trans ASAE 28:405-0410.

Young BG (2006) Changes in herbicide use patterns and production practices resulting from glyphosate-resistant crops. Weed Technol 20:301-307

Zhang J, Weaver SE, Hamill AS (2000) Risks and reliability of using herbicides at below-labeled rates. Weed Technol 14:106-115

Zhu H, Rowland D, Dorner J, Derksen R, Sorensen R (2002) Influence of plant structure, orifice size, and nozzle inclination on spray penetration into peanut canopy. Trans ASABE 45:1295-1301

Zhu H, Dorner J, Rowland D, Derksen R, Ozkan H (2004) Spray penetration into peanut canopies with hydraulic nozzle tips. Biosyst Eng 87:275-283

Zhu H, Zondag R, Derksen R, Reding M, Krause C (2008) Influence of spray volume on spray deposition and coverage within nursery trees. J Environ Hortic 26:51-57

Zhu H, Salyani M, Fox RD (2011) A portable scanning system for evaluation of spray deposit distribution. Comput Electron Agric 76:38-43

APPENDICES

APPENDIX A

SUPLEMENTARY INFORMATION FOR CHAPTER 2

Table A.1 Two-way mixed effects Analysis of variance (ANOVA) for spray coverage, quantity of spray droplets, $D_{0.1}$, $D_{0.5}$ and $D_{0.9}$, where application, treatment (concatenated volume and droplet size), and interaction (Application × Treatment) were considered fixed effects, and replication was a random effect for studies conducted in 2021. An asterisk indicates a significant effect with *P*-values less than 0.05.

Parameters	*P*-values		
	Application effect	Treatment effect	Application × Treatment effect
Spray coverage (%)	0.0002*	0.0004*	0.155
Quantity of spray droplets	0.001*	<0.001*	0.191
$D_{0.1}$	<0.001*	<0.001*	0.118
$D_{0.5}$	<0.001*	<0.001*	0.239
$D_{0.9}$	<0.001*	<0.001*	0.270

Table A.2 Two-way mixed effects Analysis of variance (ANOVA) for spray coverage, quantity of spray droplets, $D_{0.1}$, $D_{0.5}$ and $D_{0.9}$, where application, treatment (concatenated volume and droplet size), and interaction (Application × Treatment) were considered fixed effects, and replication was a random effect for studies conducted in 2022. An asterisk indicates a significant effect with *P*-values less than 0.05.

Parameters	*P*-values		
	Application effect	Treatment effect	Application × Treatment effect
Spray coverage (%)	<0.001*	<0.001*	0.155
Quantity of spray droplets	0.001*	<0.001*	0.191
$D_{0.1}$	<0.001*	<0.001*	0.118
$D_{0.5}$	<0.001*	0.001*	0.239
$D_{0.9}$	<0.001*	<0.001*	0.270

APPENDIX B

SUPLEMENTARY INFORMATION FOR CHAPTER 4

Table B.1 Two-way mixed effects Analysis of variance (ANOVA) for spray deposition and droplet density, where days of fungicide application (DAP), treatment (concatenated volume and droplet size), and interaction (DAP × Treatment) were considered fixed effects, and replication was a random effect for fungicide studies conducted in 2021 and 2022. An asterisk indicates a significant effect with *P*-values less than 0.05.

Effect	Spray deposition	Droplet density
Days of fungicide application (DAP)	<.0001*	<.0001*
Treatment	<.0001*	<.0001*
DAP x Treatment	<.0001*	<.0001*

Table B.2 ANOVA table (P-values) spray deposition and droplet density for carrier volume, droplet size, and their interaction effect at top, middle and bottom position of the peanut canopies during fungicide application at 45 DAP. An asterisk indicates a significant effect with *P*-values less than 0.05.

Effect	Top		Middle		Bottom	
	Spray deposition	Droplet density	Spray deposition	Droplet density	Spray deposition	Droplet density
Carrier Volume	<.0001*	0.0428*	<.0001*	<.0001*	0.0232*	0.0055*
Droplet size	<.0001*	<.0001*	0.0020*	<.0001*	0.8023	<.0001*
Carrier Volume x Droplet size	0.1713	0.7332	0.1480	0.1853	0.3614	0.6786

Table B.3 ANOVA table (P-values) for spray deposition and droplet density for carrier volume, droplet size, and their interaction effect at top, middle and bottom position of the peanut canopies during fungicide application at 60 DAP. An asterisk indicates a significant effect with *P*-values less than 0.05.

Effect	Top		Middle		Bottom	
	Spray deposition	Droplet density	Spray deposition	Droplet density	Spray deposition	Droplet density
Carrier Volume	<.0001*	0.0003*	0.0004*	<.0001*	0.0277*	0.0084*
Droplet size	<.0001*	<.0001*	0.0004*	<.0001*	0.8343	0.0240*
Carrier Volume x Droplet size	0.1217	0.2530	0.6009	0.1751	0.6513	0.9613

Table B.4 ANOVA table (P-values) for spray deposition and droplet density for carrier volume, droplet size, and their interaction effect at top, middle and bottom position of the peanut canopies during fungicide application at 90 DAP. An asterisk indicates a significant effect with *P*-values less than 0.05.

Effect	Top		Middle		Bottom	
	Spray deposition	Droplet density	Spray deposition	Droplet density	Spray deposition	Droplet density
Carrier Volume	<.0001*	<.0001*	0.0176*	0.0048*	0.2298	0.3301
Droplet size	<.0001*	<.0001*	0.0238*	<.0001*	0.0400*	0.0128*
Carrier Volume x Droplet size	0.2730	0.2799	0.8767	0.2016	0.5580	0.3802

Table B.5 ANOVA table (P-values) for spray deposition and droplet density for carrier volume, droplet size, and their interaction effect at top, middle and bottom position of the peanut canopies during fungicide application at 120 DAP. An asterisk indicates a significant effect with *P*-values less than 0.05.

Effect	Top		Middle		Bottom	
	Spray deposition	Droplet density	Spray deposition	Droplet density	Spray deposition	Droplet density
Carrier Volume	<.0001*	0.0008*	<.0001*	0.0028*	0.0057*	0.0019*
Droplet size	<.0001*	<.0001*	0.0144*	<.0001*	0.5321	<.0001*
Carrier Volume x Droplet size	0.3851	0.1312	0.8177	0.6555	0.1259	0.2804

Table B.6 ANOVA table (P-values) for leaf spot rating at 90 and 120 DAP and southern stem rot at 148 DAP for carrier volume, droplet size, and their interaction effect in the fungicide spray study conducted in 2021. An asterisk indicates a significant effect with *P*-values less than 0.05.

Effect	Leaf spot		Southern stem rot
	90 DAP	120 DAP	148 DAP
Carrier volume	0.4738	0.2342	0.9263
Droplet size	0.8264	0.9908	0.9263
Carrier volume x Droplet Size	0.5252	0.9049	0.4523

Table B.7 ANOVA table (P-values) for leaf spot rating at 97, 120 and 140 DAP and southern stem rotat 147 DAP for carrier volume, droplet size, and their interaction effect in the fungicide spray study conducted in 2022. An asterisk indicates a significant effect with *P*-values less than 0.05.

Effect	Leaf spot			Southern stem rot
	97 DAP	120 DAP	140 DAP	147 DAP
Carrier Volume	0.3088	0.0294*	0.0053*	0.0415*
Droplet Size	0.4084	0.5111	0.0798	0.2421
Carrier Volume x Droplet Size	0.4635	0.1363	0.0243*	0.1267

Table B.8 ANOVA table (P-values) for peanut yield for spray volume, droplet size, and their interaction for spray studies conducted in 2021 and 2022. An asterisk indicates a significant effect with *P*-values less than 0.05.

Effect	Peanut Yield	
	2021	2022
Carrier volume	0.2661	0.1543
Droplet size	0.6682	0.9836
Carrier volume x Droplet size	0.8566	0.1019