Adjuvants to improve pre- and postemergence weed control in soybean

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Herbicides are routinely combined with adjuvants to maximize herbicide performance. However, while the myriad of herbicide amendments made available continuously increases with many of the advertised benefits unsubstantiated. Additionally, cover crops purportedly provide soybean producers with multiple benefits; however, the cover crop residue could hinder soil-applied residual herbicide performance, thus diminishing long-term weed control efficacy. Adjuvants reduce surface tension that may allow soil-applied herbicides to penetrate dense crop residue. This research sought to evaluate the effectiveness of several herbicide-adjuvant combinations for control of *Amaranthus* spp., *Sida spinosa*, and *Echinochloa crus-galli* in soybean, and the effectiveness of two surfactants for improving preemergence herbicide efficacy in a cover crop system. Generally, the herbicide/adjuvant combinations evaluated had no effect on visual weed control. However, weed control differences due to herbicide were observed. Additionally, use of an NIS adjuvant with herbicides evaluated generally improved soil deposition; however, soil deposition of herbicides were not improved by addition of an OS adjuvant. Droplet size and solution deposition at the soil surface were correlated.

DEDICATION

To Taylor, Llewelyn, and Argo, for offering all the love and support I could ever hope for. You are my very best friend and what has kept me going; thank you.

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CHAPTER I

SELECT ADJUVANTS TO IMPROVE POSTEMERGENT HERBICIDE EFFICACY IN THREE WEEDS IN SOYBEAN

Abstract

Herbicides are a vital component of soybean weed management programs. Furthermore, herbicides are routinely combined with adjuvants to maximize herbicide performance. However, while the myriad of herbicide amendments made available continuously increases, many of the advertised benefits remain unsubstantiated. Therefore, this study was conducted to determine the most effective herbicide-adjuvant combinations for control of pigweed, prickly sida, and barnyardgrass in soybean. Studies were conducted near Starkville and Brooksville, MS, using acifluorfen (280 g ai ha^{-1}), fomesafen (421 g ai ha^{-1}), cloransulam-methyl (18 g ai ha^{-1}), clethodim (136 g ai ha^{-1}), quizalofop-P-ethyl (139 g ai ha^{-1}), and fluazifop-P-butyl (421 g ai ha^{-1}). The following adjuvants were used in combination with the herbicides: Agri-Dex® (COC), Penetrator® Plus (COC), Dyne-A-Pak® (NIS), Class Act® NG® (NIS), Induce® (NIS), Liberate® (NIS), StrikeLock® (HSOC), Verifact® (HSOC), MSO® Concentrate with Leci-Tech (MSO), and Zarr™ (MSO). Visual evaluations of weed control were taken at 7, 14, 21, 28, and 35 days after treatment (DAT). No differences in weed control due to the addition of an adjuvant to herbicide programs were observed in either study. However, differences due to herbicide were observed. In 2021, greatest prickly sida control was observed at 7 DAT following application of acifluorfen at 83% control. In both years, greatest pigweed control was achieved following application of acifluorfen or fomesafen at 7 DAT, with control ranging from 69 to 79%. In 2021, all evaluated herbicides provided 78 to 84% barnyardgrass control. However, in 2022, greatest control was observed at 14 DAT with quizalofop and clethodim, resulting in 68 and 66% control, respectively. Overall, weed control ratings were higher in 2021 than in 2022, this is likely due to increased weed pressure because of overseeding in 2022. Growers are encouraged to follow label requirements and utilize the herbicide and adjuvant combination that best fits their weed control objectives and budget.

Introduction

Palmer amaranth (*Amaranthus palmeri* S.Wats.), prickly sida (*Sida spinosa* L.), and barnyardgrass [*Echinochloa crus-galli* (L.) Beauv.] are among the most common and troublesome weeds in Mississippi soybean (*Glycine max* (L.) Merr.) production (Rankins et al. 2005). Research suggests that prickly sida is the second most prevalent broadleaf weed in Mississippi soybean fields (Webster 2013). Studies by Dieleman et al. (1995) and Vail and Oliver (1993) note that barnyardgrass and pigweed can reduce soybean yield by up to 50 and 45%, respectively. In addition, Sellers et al. (2003) observed that redroot pigweed (*Amaranthus retroflexus* L.), smooth pigweed (*Amaranthus hybridus* L.), common waterhemp (*Amaranthus rudis* Sauer), and Palmer amaranth produce over 250,000 seeds per plant. In 2022, Mississippi producers harvested nearly 923,000 hectares of soybean, accounting for 55% of all row-crop production within the state (MDAC 2022). Additionally, the production value of soybean was approximately 1.8 billion dollars, making soybean the second most important commodity in Mississippi (MDAC 2022).

Soybean producers utilize herbicides for weed control (Hartwig 1988). Adjuvants have been used throughout history and are frequently added to herbicides to aid in mixing, application, or overall effectiveness (Pacanoski 2015). For example, in the late 1880's Gillette (1888; 1890) reportedly experimented with soap as a safener by including it in an arsenic solution in an attempt to protect plum (*Prunus domestica* L.), apple (*Malus domestica* Borkh.), and locust tree (*Robinia pseudoacacia* L.) foliage from damage without reducing pesticide efficacy. Additionally, in the 18th and 19th centuries, materials such as resins, molasses, and sugar were used in combination with lime, sulfur, and copper to increase droplet adherence to plants (Green and Beestman 2007). Herbicide labels often require an adjuvant to be used with postemergence applied products or include them in the formulation of herbicides (Jordan et al. 1996; Tu and Randall 2003).

However, selecting an appropriate adjuvant can be difficult due to vague recommendations on herbicide labels, numerous adjuvant classes, and the massive volume of adjuvants available on the market (Curran et al. 1999; Tu and Randall 2003; Zollinger 2000). For example, the 2022 weed control guidelines for Mississippi lists 817 registered adjuvants (MSU Extension 2022). Additionally, the lack of a standard classification method has led adjuvants to be organized by their chemistry, derivation, or intended purpose, resulting in over twenty classes of adjuvants currently available (Hock 2022).

Additives have been used to modify characteristics of herbicide mixtures to improve biological performance (Green and Beestman 2007). Adjuvants can influence the efficacy of herbicides; however, adjuvant effect on herbicide performance depends on many factors such as herbicide rate, adjuvant type, weed species, size and stage of weed at the time of application, and various environmental conditions (Andr et al. 2017; Brathuhn and Petersen 2014; Culpepper et al. 1999; Kapusta et al. 1994; Pacanoski 2015). There are two primary types of chemical additives, activator adjuvants and special-purpose adjuvants. Activator adjuvants are typically used to increase biological efficacy of herbicides, while special-purpose adjuvants modify physical characteristics of solutions (Hazen 2000). Activator adjuvants include surfactants, wetting agents, stickers-spreaders, and penetrants; special purpose adjuvants comprise emulsifiers, dispersants, stabilizing agents, compatibility agents, buffering agents, antifoam agents, and drift control agents (Curran et al. 1999).

In order to be phytotoxic, foliar applied herbicides must be absorbed by plant tissues and arrive at the proper site of action (Sterling 1994). Surfactants facilitate herbicide absorption by modifying plant surfaces and spray formulations, improving contact between foliage and the herbicide solution (Hazen 2000; Tu and Randall 2003). One such modification is a reduction in surface tension that allows spray droplets to spread and evenly coat plant exteriors (Tu and Randall 2003). Furthermore, surfactants promote greater adhesion by aiding in spray droplet traversal of leaf surface structures such as scales and hairs (Hess 1999). Additionally, surfactants help to prolong the drying period of spray droplets and prevent crystallization of active ingredients on plant surfaces (Hess 1999). Surfactants can modify the viscosity and crystalline structure of plant surface waxes, enabling enhanced penetration and absorption of herbicides (Tu and Randall 2003). However, an efficacious surfactant should be chosen based on its affinity for the surface intended to be modified (Hazen 2000).

Herbicide solubility ranges from highly lipophilic (water insoluble) to highly hydrophilic (water soluble), therefore, surfactant solubility also varies greatly (Stock and Briggs 2000). Surfactants are typically given a value ranging from 1 to 20 based on the molecular balance of hydrophilic and lipophilic portions calculated for the compound, known as the hydrophilic-lipophilic balance (HLB) (Hess 1999; Tu and Randall 2003). Generally, a lipophilic surfactant will have an HLB of 8 or less, while intermediate surfactants vary between 9 and 11, and a hydrophilic surfactant will be 12 or greater (Hazen 2000; Hess 1999). Furthermore, many herbicide labels give optimum HLB values to maximize performance, often recommending lower HLB surfactants for water-insoluble herbicides and higher HLB surfactants for water-soluble herbicides (Tu and Randall 2003). However, most surfactant labels do not disclose the product's HLB value or exact composition (Bakke 2021; Stock and Briggs 2000; Tu and Randall 2003). Consequently, data are lacking regarding specific adjuvant selection that improves herbicide efficacy. Therefore, this study was conducted to identify adjuvants that maximize weed control with selected herbicides in soybeans.

Materials and Methods

Field studies were conducted in 2021 and 2022 at the R. R. Foil Plant Science Research Center near Starkville, MS, and the Black Belt Branch Experiment Station near Brooksville, MS, to evaluate herbicide efficacy and weed control response of herbicides with differing adjuvants. Studies at the R. R. Foil Plant Science Research Center focused on broadleaf weed control, whereas studies at the Black Belt Branch Experiment Station focused on barnyardgrass control. They were treated as separate studies due to the different weeds present in the area and different herbicides used.

The experimental design used in both locations was a randomized block design with a factorial arrangement with four replications. Factor A was different in each location. In Brooksville, Factor A included clethodim (Select Max®, Valent U.S.A.); quizalofop-p-ethyl (Assure® II, AMVAC Chemical Corporation); and fluazifop-P-butyl (Fusilade®, Syngenta Crop Protection LLC) for barnyardgrass control and in Starkville, the Factor A included acifluorfen (Ultra Blazer®, UPL NA Inc.); fomesafen (Reflex®, Syngenta Crop Protection LLC); and cloransulam-methyl (FirstRate®, Dow AgroSciences LLC) for broadleaf control. Factor B was the adjuvants, which were used for both experiments (Table 1.1). Adjuvants classified as nonionic surfactants (NIS), crop-oil concentrates (COC), methylated seed oils (MSO), and high-surfactant oil concentrates (HSOC) were assessed in this trial. Due to their potential effect on attributes of herbicide performance, it is crucial to consider the physicochemical properties of adjuvants when determining which to best pair with a particular herbicide (Hazen 2000; Stock and Briggs 2000). NIS are hydrophilic surfactants and do not have an electrical charge; they are commonly implemented to assist with spray droplet retention, spreading, and penetration into plant tissues (Hock 2022; Tu and Randall 2003). Crop-oil concentrate contains 5 to 20% NIS and at least 80% highly refined paraffinic oil and is typically used to aid in spreading, penetration, and enhancing water solubility of lipophilic herbicides (Hazen 2000; Hock 2022). Methylated seed oils are vegetable seed oils that have been chemically esterified to produce methyl esters and are typically blended with 5 to 15% NIS; they function similarly to COC products (Hazen 2000; Hock 2022; Pacanoski 2015). High-surfactant oil concentrates are chemically different from COC or MSO products and contain a minimum of 50% oil and 25-50% surfactant; HSOC was initially created to improve lipophilic herbicide performance without antagonizing hydrophilic herbicides in spray tank mixtures (Wirth and Zollinger 2018; Young et al. 2016).

Asgrow® 47XFO XtendFlex® soybean were planted on 21 April 2021, and 20 May 2022, in 97 cm rows, with a seeding rate of 333,585 seeds ha^{-1}. Additionally, prickly sida and barnyardgrass seeds were broadcast throughout corresponding experimental units to supplement natural populations and ensure adequate weed pressure. Herbicide applications were performed using CO_2 backpack sprayers calibrated to deliver 140 L ha^{-1} (at 276 kPa at a walking speed of 4.8 km h^{-1}) before weeds reached 10 cm in height. The spray boom featured four nozzles, 48-cm spaced, equipped with Teejet AIXR 110015 nozzles (Spraying Systems Co.®, P.O. Box 832

Tifton, GA 31794). An untreated check and herbicide-alone treatment were included in both studies for comparison purposes. An additional check was included in each plot to account for variability in the area (these checks were not used for rating purposes).

Data collection consisted of a visual evaluation of weed control using a scale of 0 (no visible plant injury) – 100 (complete plant death) (Frans and Talbert 1977). Visual weed control ratings were collected from each experimental unit at 7, 14, and 21 DAT for barnyardgrass studies and 7, 14, 21, 28, and 35 DAT for broadleaf studies. Evaluation intervals for barnyardgrass studies were curtailed due to soybean canopy closure.

Data were subjected to an analysis of variance using the Proc GLIMMIX procedure in SAS version 9.4 (Statistical Analysis Systems Institute, Inc., Cary, NC), considering year and rep as random variables. Where significance was observed, means were separated using Fisher's protected least significant difference ($\alpha = 0.05$). Figures and 95% confidence intervals were generated using GraphPad Prism version 9.5.1 (GraphPad by Dotmatics, Boston, MA).

Results and Discussion

For both experiments, analysis of variance (Table 1.2 and 1.3) revealed a significant year effect; thus, years were analyzed separately. In both experiments, there was no effect of adjuvants; thus, only the herbicide effect is shown pooled across adjuvants and replications.

Experiment 1. Broadleaf weed control in Starkville

As previously mentioned, no differences due to adjuvant were observed in prickly sida control studies; however, differences due to herbicide were observed. Prickly sida control data from 2021 are given in Figure 1.1.A, while observations for 2022 are given in Figure 1.1.B. In 2021, application of acifluorfen resulted in greater prickly sida control than fomesafen at 7 DAT;

however, acifluorfen and fomesafen performed similarly in 2022. No differences in prickly sida control were observed at 14 DAT in 2021, although greater control was observed following acifluorfen and fomesafen application in 2022. Additionally, no differences due to herbicide were observed at 14, 21, 28, and 35 DAT in 2021. However, in 2022, at 7 and 14 DAT, cloransulam did not control prickly sida as well as acifluorfen or fomesafen, though the latter herbicides performed similarly. At 21 and 28 DAT in 2022, cloransulam was observed to better control prickly sida than fomesafen, while control with acifluorfen was akin to cloransulam. There were no differences in herbicide observed at 35 DAT with respect to prickly sida control in 2022. In 2021, greatest prickly sida control was observed at 7 DAT following application of acifluorfen, resulting in 83% control. However, in 2022, acifluorfen resulted in the greatest prickly sida control at 14 DAT with only 34% control.

Similar to results observed in prickly sida control studies, no differences due to adjuvant were observed in pigweed (*Amaranthus* spp. L.) control studies. Pigweed control data in 2021 are given in Figure 1.2.A, while observations for 2022 are given in Figure 1.2.B. In 2021, at 7 DAT, application of acifluorfen provided greater pigweed control than cloransulam. Additionally, fomesafen and acifluorfen were observed to better control pigweed than cloransulam at 14 DAT in 2021. Likewise, similar observations were made at 7, 14, and 28 DAT in 2022 with respect to greater pigweed control with fomesafen and acifluorfen than cloransulam. There were no observed differences in herbicidal control of pigweeds at 21, 28, and 35 DAT in 2021. Similarly, no differences in pigweed control were observed at 28 or 35 DAT in 2022. In both years, greatest pigweed control was achieved with application of acifluorfen or fomesafen at 7 DAT, with control ranging from 69 to 79%.

There were no differences in prickly sida control observed between herbicides at 14, 21, 28, and 35 DAT in 2021. Acifluorfen, fomesafen, and cloransulam are known to poorly control prickly sida; therefore, similar performance among the herbicides was not unexpected (MSU Extension 2023). Prickly sida control reached 83% at 7 DAT in 2021, though control was less than 25% in 2022. This variation in control could be attributed to the lack of precipitation the week following treatment application in 2022, as accumulated rainfall (Table 1.4) at 7 DAT in 2021 measured 39mm, while the same interval in 2022 was devoid of moisture. In 2021, acifluorfen, fomesafen, and cloransulam maintained at least 60% control of prickly sida; however, prickly sida control did not exceed 40% in 2022. In order to supplement natural populations, the experimental site was broadcast seeded with prickly sida in 2022. It is plausible that the resulting increase in prickly sida was cause for lower control in 2022. The greatest prickly sida control in 2022 was achieved at 14 DAT following application of acifluorfen, resulting in 34% control. However, when cloransulam was applied, prickly sida control did not surpass 20%. This is consistent with evaluations by Barnes and Oliver (2004), in which POST application of cloransulam at 18 g ai ha^{-1} resulted in less than 50% prickly sida control.

As previously mentioned, in both 2021 and 2022, greatest pigweed control was achieved with application of acifluorfen or fomesafen. This observation was unsurprising, as both herbicides have been found to provide suitable pigweed control (MSU Extension 2023). Greater pigweed control was observed with fomesafen and acifluorfen than cloransulam at 14 DAT in 2021, and at 7, 14, and 28 DAT in 2022. These results are feasible due to recognized inadequacy with respect to pigweed control with cloransulam (Barnes and Oliver 2004; MSU Extension 2023). Additionally, at 14 DAT in 2021 and 2022, application of cloransulam provided 37 to

52% pigweed control. This observation is comparable with previous studies, which note less than 55% Palmer amaranth control with cloransulam (Barnes and Oliver 2004).

In the current study, no differences in pigweed control were observed at 7 DAT in either year when acifluorfen or fomesafen were applied. Likewise, Hager et al. (2003) evaluated herbicide efficacy on common waterhemp and found no difference between the two herbicides at 7 DAT. At 14 and 21 DAT in both evaluation years, application of fomesafen resulted in pigweed control ranging from 48 to 68%. Additionally, Yu-jun et al. (2014) observed 93 to 99% control of redroot pigweed at 14 and 21 DAT with fomesafen applied at 506 g ai ha^{-1} without adjuvant addition. Considering Yu-jun et al. (2014) applied a higher rate of fomesafen in a greenhouse setting, differences in control levels between experiments are likely due to varying experimental conditions.

Experiment 2. Barnyardgrass control in Brooksville

There was no effect of adjuvant on barnyardgrass control. Barnyardgrass control in 2021 is given in Figure 1.3.A, while barnyardgrass control in 2022 is given in Figure 1.3.B. In 2021, no differences in barnyardgrass control were observed among the evaluated herbicides at 7, 14, and 21 DAT. The herbicides used in this study are known to effectively control barnyardgrass; thus, similar control was anticipated (MSU Extension 2023; Vidrine et al. 1995). Additionally, in 2022, at 7, 14, and 21 DAT, quizalofop and clethodim provided better barnyardgrass control than fluazifop. Despite delivering acceptable control, fluazifop typically does not control barnyardgrass as well as quizalofop or clethodim (MSU Extension 2023). However, at 7, 14, and 21 DAT control from quizalofop and clethodim were similar. In 2021, all evaluated herbicides provided 74 to 84% barnyardgrass control. However, in 2022, greatest control was observed at 14 DAT from quizalofop and clethodim, resulting in 68 and 66% control, respectively. Overall, greater barnyardgrass control was achieved in 2021, than in 2022. Similarly to experiment one, barnyardgrass seed was broadcast throughout experimental units to supplement natural populations. Additionally, 62 mm of rainfall (Table 1.5) was accumulated at 7 DAT in 2021, while the same interval lacked precipitation in 2022. Lower weed control in 2022 could likely be attributed to a lack of adequate rainfall and increased barnyardgrass populations. Weather data for experiment two is given in Table 1.5.

In 2021 barnyardgrass control studies, there were no differences in control observed between quizalofop and clethodim applications. These findings are consistent with barnyardgrass experiments by Vidrine et al. (1995), in which no difference in barnyardgrass control was observed between these herbicides. Applications of quizalofop and clethodim resulted in greater barnyardgrass control than fluazifop at 14 DAT in both 2021 and 2022. This observation is consistent with previous barnyardgrass experiments conducted by Eytcheson and Reynolds (2019). Additionally, at 21 DAT, application of clethodim provided an average of 70% barnyardgrass control. This observation is comparable to previous research in alfalfa (*Medicago sativa* L.), in which 70% barnyardgrass control was observed at 19 DAT with clethodim applied at the same rate as the current study (Foy and Witt 1992).

Conclusion

The purpose of this study was to identify adjuvants that maximize weed control with selected herbicides in soybeans. However, no differences due to adjuvant were observed in broadleaf or barnyardgrass control studies. As previously mentioned, interactions between weeds, herbicides, and adjuvants are exceedingly complicated. Numerous publications have demonstrated that the addition of an adjuvant to herbicide applications may not enhance observed weed control (Andr et al. 2017; Harrison et al. 1986; Kapusta et al. 1994; Webber et al.

2018; Willingham and Graham 1988; Wixson and Shaw 1991). In the current study, addition of an adjuvant to acifluorfen did not increase barnyardgrass control. This is consistent with observations by Chen and Penner (1985), in which barnyardgrass control 14 DAT was not influenced by addition of an adjuvant to acifluorfen application in greenhouse studies. Likewise, Hart et al. (1992) did not observe an increase in efficacy at 16 DAT when a combination of primisulfuron and atrazine was applied with an adjuvant. Additionally, experiments by Reddy and Singh (1992) found no differences in control of guineagrass (*Megathyrsus maximus* (Jacq.) B. K. Simon & S. W. L Jacobs), yellow foxtail (*Setaria pumila* (Poir.) Roem. & Schult.), and Sicklepod (*Senna obtusifolia* (L.) H. S. Irwin & Barneby) when glyphosate was applied with or without an adjuvant under dry conditions. Therefore, growers are encouraged to follow label requirements and use the most suitable herbicide and adjuvant combination for their budget and weed control goals.

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Table 1.1 List of adjuvants, rates used, and manufacturer information for studies investigating barnyardgrass and broadleaf weed control programs in soybean at Brooksville and Starkville, MS sites in 2021 and 2022.

Trade Name	Type	Rate	Manufacturer
		(% v/v)	
Agri-Dex®	COC	1	Helena Chemical Company, Collierville, TN
Penetrator® Plus	COC	1	Helena Chemical Company, Collierville, TN
Dyne-A-Pak®	NIS	1	Helena Chemical Company, Collierville, TN
Class Act® NG®	NIS	0.5	Winfield Solutions LLC, St. Paul, MN
Liberate®	NIS	0.5	Loveland Products Inc., Greeley, CO
Induce®	NIS	0.5	Helena Chemical Company, Collierville, TN
StrikeLock®	HSOC	0.5	Winfield Solutions LLC, St. Paul, MN
Verifact®	HSOC	0.5	Innvictis Crop Care LLC, Loveland, CO
MSO® Concentrate with Leci-Tech	MSO	0.5	Loveland Products Inc., Greeley, CO
Zaar™	MSO	0.5	Helena Agri-Enterprises LLC, Collierville, TN

Table 1.2 Analysis of variance table for prickly sida and pigweed control data at Starkville, MS site in 2021 and 2022.

Source	Degrees of Freedom	P-value
Herbicide	2	0.0001
Adjuvant	10	0.99
Herbicide*Adjuvant	20	0.33
Year (R)	1	<0.0001

* Year was considered a random variable.

Table 1.3 Analysis of variance table for barnyardgrass control data at Brooksville, MS site in 2021 and 2022.

Source	Degrees of Freedom	P-value
Herbicide	2	0.04
Adjuvant	10	0.55
Herbicide*Adjuvant	20	0.54
Year (R)	1	<0.0001

* Year was considered a random variable.

Table 1.4 Maximum temperature, minimum temperature, and precipitation data[a] throughout weed control evaluation intervals for studies investigating broadleaf weed control programs in soybean at Starkville, MS site in 2021 and 2022.

	Starkville					
	2021			2022		
Date	Max Temp	Min Temp	Precipitation	Max Temp	Min Temp	Precipitation
	°C		mm	°C		mm
14-Jun	33	21	0	34	24	0
15-Jun	33	18	0	36	23	0
16-Jun	31	17	0	34	23	0
17-Jun	32	17	0	36	23	0
18-Jun	33	18	0	34	22	0
19-Jun	24	21	33	32	18	0
20-Jun	33	19	0	35	18	0
21-Jun	31	22	2	36	22	0
22-Jun	27	17	4	37	23	0
23-Jun	32	15	0	37	24	1
24-Jun	34	19	0	36	21	0
25-Jun	31	22	0	37	20	0
26-Jun	32	21	0	36	23	2
27-Jun	33	21	0	31	23	0
28-Jun	33	21	0	33	21	0
29-Jun	32	21	8	34	20	0
30-Jun	33	22	0	32	23	0
1-Jul	32	22	18	33	22	0
2-Jul	31	22	1	34	22	16
3-Jul	29	18	0	30	23	0
4-Jul	31	16	0	32	23	6
5-Jul	33	17	0	36	23	20
6-Jul	29	21	0	35	23	0
7-Jul	27	22	23	34	24	0
8-Jul	32	22	0	36	24	0
9-Jul	33	23	0	37	23	3

Table 1.4 continued

10-Jul	32	22	0	31	22	0
11-Jul	31	23	0	34	22	0
12-Jul	29	22	1	34	22	0
13-Jul	30	22	3	32	23	3
14-Jul	33	21	2	34	23	0
15-Jul	33	21	0	35	22	0
16-Jul	32	21	8	34	23	0
17-Jul	28	22	1	36	22	0
18-Jul	31	22	2	30	23	7
19-Jul	28	22	1	32	21	7
20-Jul	30	23	9	35	26	0
21-Jul	31	22	42	35	22	9
Average	31	20	4	34	22	2
Total			157			69

[a] Data retrieved from the Delta Agricultural Weather Center, deltaweather.extension.msstate.edu

Table 1.5 Maximum temperature, minimum temperature, and precipitation data[a] throughout weed control evaluation intervals for studies investigating barnyardgrass control programs in soybean at Brooksville, MS site in 2021 and 2022.

	Brooksville					
	2021			2022		
Date	Max Temp	Min Temp	Precipitation	Max Temp	Min Temp	Precipitation
	°C		mm	°C		mm
14-Jun	33	21	0	36	24	0
15-Jun	33	21	0	37	24	0
16-Jun	31	18	0	34	23	0
17-Jun	32	18	0	36	24	0
18-Jun	33	18	0	35	23	0
19-Jun	24	21	61	33	19	0
20-Jun	33	21	0	36	18	0
21-Jun	31	22	1	37	23	0
22-Jun	27	17	0	37	23	0
23-Jun	32	17	0	37	24	0
24-Jun	34	21	0	36	22	0
25-Jun	31	23	0	38	21	0
26-Jun	32	21	0	36	23	5
27-Jun	33	22	0	31	23	0
28-Jun	33	22	0	32	21	0
29-Jun	32	21	31	34	21	2
30-Jun	33	22	0	31	22	0
1-Jul	32	22	15	33	22	0
2-Jul	31	23	2	34	22	6
3-Jul	29	19	0	32	22	19
4-Jul	31	17	0	33	23	2
5-Jul	33	18	0	36	23	0
6-Jul	29	22	2	35	23	0
7-Jul	27	22	22	36	24	0
8-Jul	32	22	0	37	25	0
9-Jul	33	22	0	38	22	11

Table 1.5 continued

10-Jul	32	21	15	32	22	0
11-Jul	31	22	0	34	22	0
12-Jul	29	22	0	34	23	0
13-Jul	30	21	3	36	23	0
14-Jul	33	21	0	34	22	0
15-Jul	33	21	0	35	22	0
16-Jul	32	21	13	36	22	0
17-Jul	28	22	0	36	22	0
18-Jul	31	22	28	32	24	0
19-Jul	28	22	9	34	23	3
20-Jul	30	23	0	36	24	0
21-Jul	31	23	4	36	23	7
Average	31	21	5	34	23	2
Total			206			55

[a] Data retrieved from the Delta Agricultural Weather Center, deltaweather.extension.msstate.edu

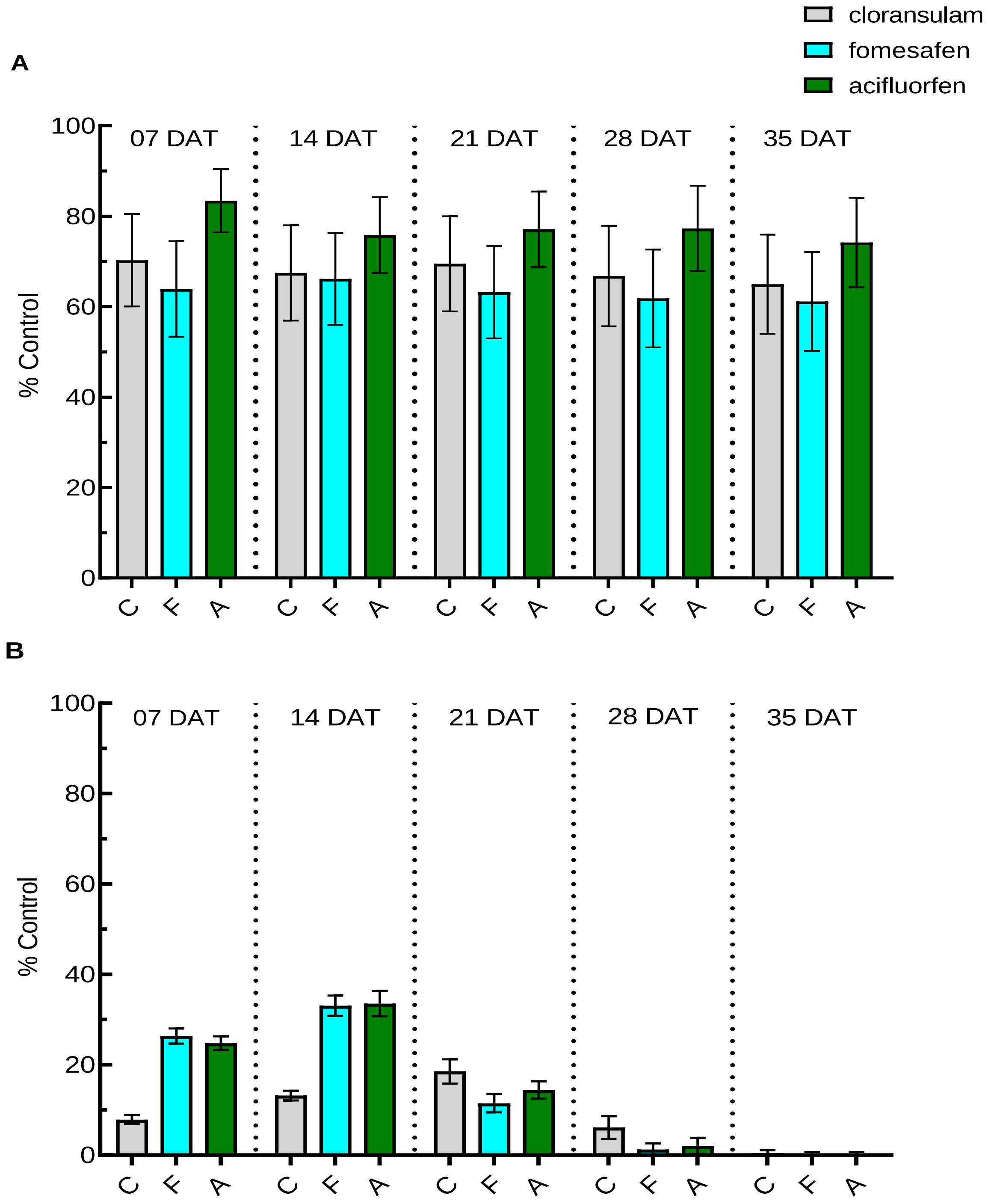

Figure 1.1 Prickly sida control by POST herbicide treatments in soybean evaluated at 7, 14, 21, 28, and 35 days after treatment (DAT), averaged over adjuvant treatment at Starkville, MS site in 2021 (A) and 2022 (B). Error bars correspond to 95% confidence intervals (n = 44).

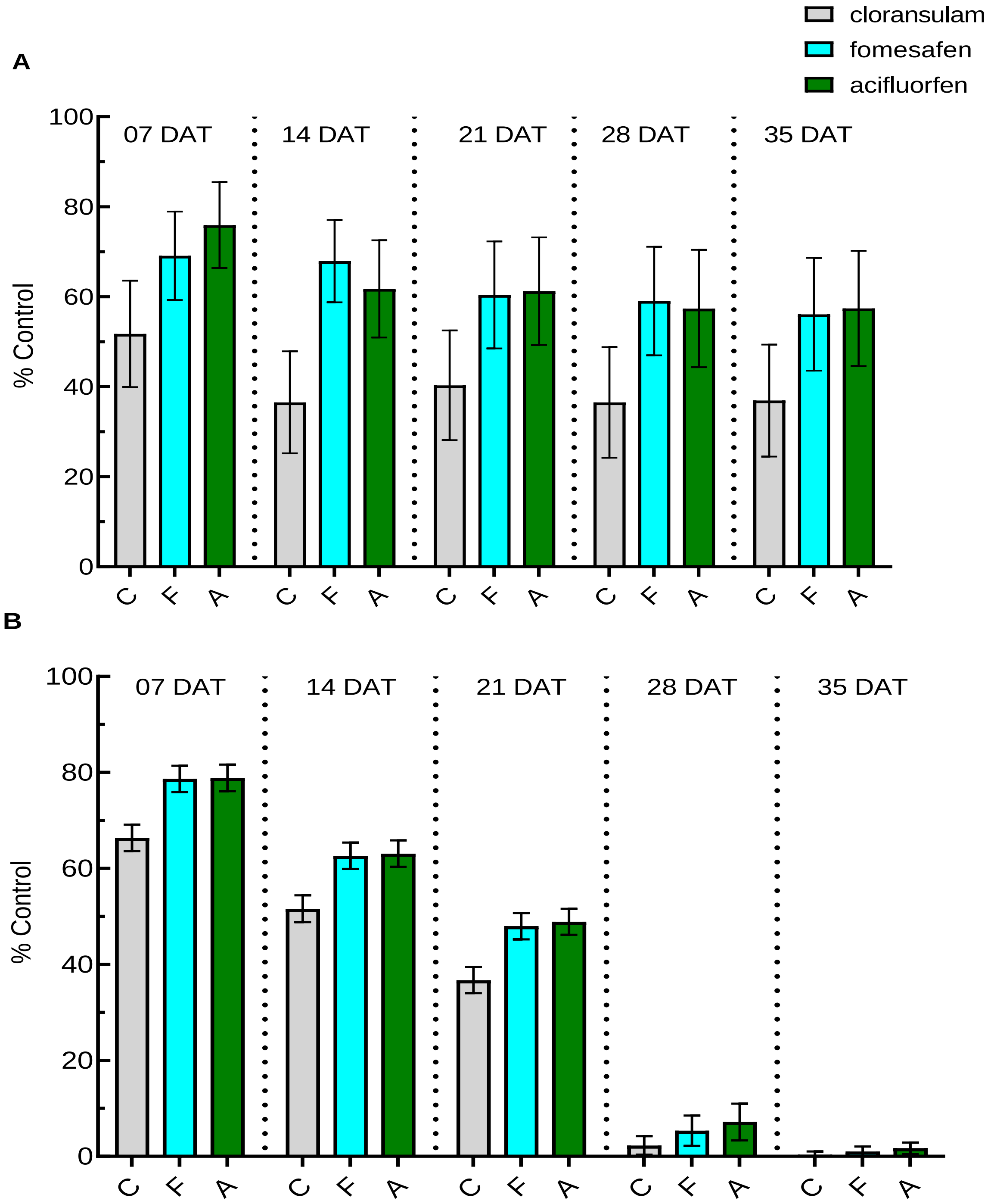

Figure 1.2 Pigweed control by POST herbicide treatments in soybean evaluated at 7, 14, 21, 28, and 35 days after treatment (DAT), averaged over adjuvant treatment at Starkville, MS site in 2021 (A) and 2022 (B). Error bars correspond to 95% confidence intervals (n = 44).

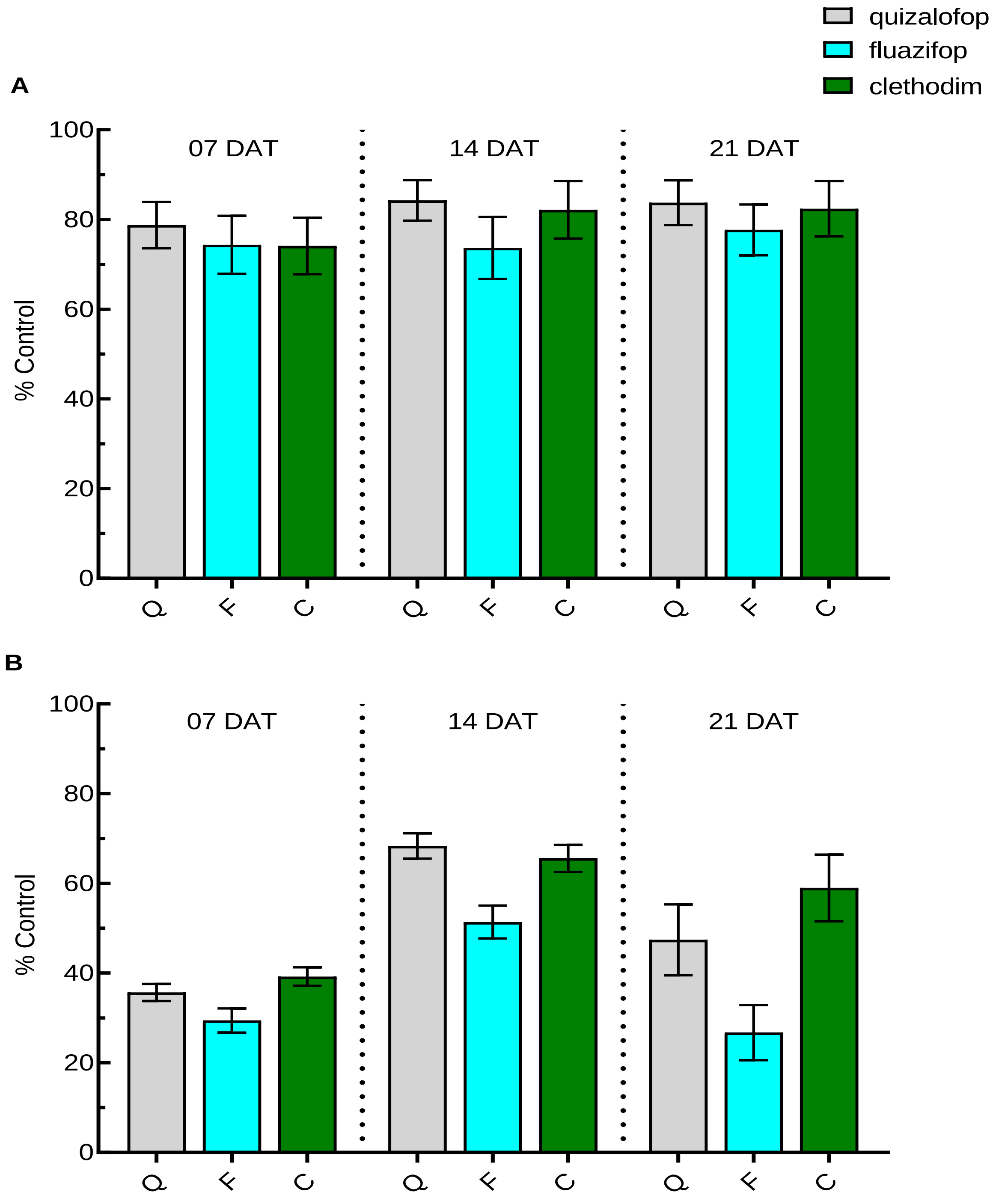

Figure 1.3 Barnyardgrass control by POST herbicide treatments in soybean evaluated at 7, 14, and 21 days after treatment (DAT), averaged over adjuvant treatment at Brooksville, MS site in 2021 (A) and 2022 (B). Error bars correspond to 95% confidence intervals (n = 44).

CHAPTER II

SURFACTANTS TO OPTIMIZE COVER-CROP PENETRATION OF SOYBEAN PREEMERGENCE HERBICIDES

Abstract

Cover crops provide soybean producers with multiple benefits; however, as with any technology, challenges may arise. Cover crop residue could hinder herbicides from reaching the soil, thus diminishing long-term weed control efficacy. We hypothesize that adjuvants reduce the spray solution-surface tension, allowing soil-applied herbicides to penetrate dense crop residue. Therefore, this study was conducted to evaluate the effectiveness of two surfactants on improving spray solution penetration into a cover crop and weed control in soybean. The studies were conducted in three locations in MS (Starkville, Brooksville, and Verona) in 2022. Annual ryegrass cover crops were planted in the fall prior to each crop production. Prior to planting soybean, the cover crop was terminated, and the plants were left standing. Soybean was planted in the standing annual ryegrass residue, followed immediately by herbicide application. *S*-metolachlor (1788 g ai ha^{-1}), flumioxazin (105 g ai ha^{-1}), pyroxasulfone (183 g ai ha^{-1}), and metribuzin (147 g ai ha^{-1}) were applied with either Induce™ (NIS) or Kinetic™ (OS). Rhodamine-B dye (5% v/v) was added to each treatment to quantify deposition using spectrofluorimetry. Generally, herbicide/adjuvant combinations evaluated had no effect on visual barnyardgrass control. *S*-metolachlor applied without addition of an adjuvant resulted in greater soil deposition. Greater metribuzin soil deposition was observed when applied with NIS. Application of flumioxazin with NIS had greater soil deposition. Greater soil deposition of

pyroxasulfone was observed when applied with NIS or without addition of an adjuvant. An observed correlation between droplet size and solution deposition at the soil surface was noted. Growers are encouraged to utilize the herbicide and adjuvant combination that best fits their weed control objectives and budget and follow label requirements.

Introduction

Cover crops provide many benefits, including protecting soil from erosion, soil moisture conservation by limiting evaporation, improved soil tilth, and inhibition of weed emergence (Lins et al. 2007; Locke and Bryson 1997; Reddy 2001; Reddy et al. 1995, 2003). Additionally, cover crops may provide weed control by producing plant residue that creates unfavorable conditions for weed germination and growth (Teasdale 1996). Weed suppression by cover crop residue can be attributed to physical and chemical interference, such as resource competition, shading, and allelopathy (Price et al. 2013; Reddy 2001; Reddy et al. 2003).

Studies by Baraibar et al. (2018) found even the least competitive of evaluated cover crops reduced weed seed production by 50% when compared to the cover crop-free control. Additionally, previous research has reported that herbicide penetration increases as residue ages (Khalil et al. 2018; Locke and Bryson 1997). Furthermore, Reddy (2001) observed annual ryegrass (*Lolium perenne* L. ssp. *multiflorum* (Lam.) Husnot) residue decaying at a slower rate when compared to other evaluated cover crops including oat (*Avena sativa* L.), rye (*Secale cereale* L.), wheat (*Triticum aestivum* L.), hairy vetch (*Vicia villosa* Roth), crimson clover (*Trifolium incarnatum* L.), and subterranean clover (*Trifolium subterraneum* L.). However, annual ryegrass has been found to be an advantageous cover crop in soybean due to its cold hardiness, rapid establishment, disease tolerance, low seed cost, and weed suppression capabilities (Legleiter et al. 2015; Lins et al. 2007). Additionally, previous research observed the lowest total weed dry biomass in annual ryegrass when compared to other evaluated cover crops (Reddy 2001). Cover crops reduce the density of barnyardgrass, a troublesome weed in south-eastern United States row crops known to cause yield loss in soybean (*Glycine max* (L.) Merr.) and other crops (Minton et al. 1989; Reddy et al. 2003; Vidrine et al. 1995).

Although cover crops help suppress weeds, several studies have found that the use of preemergence (PRE) and postemergence (POST) herbicides are still required for optimum season-long weed control in soybean (Nord et al. 2011; Reddy 2001; Reddy et al. 2003; Whalen et al. 2019). Using herbicides in combination with cover crop residues can be especially helpful in controlling problem plants, such as pigweeds, that require light for germination (Teasdale 1996; Teasdale and Mohler 2000). For example, application of metolachlor was observed to reduce smooth pigweed emergence by 16%, while hairy vetch residue reduced smooth pigweed emergence by 13%; however, using a combination of herbicide and residue resulted in 86% reduction (Teasdale et al. 2005). Preemergence herbicides must enter the soil profile to ensure proper contact with germinating seeds; therefore, they require 1.27 to 2.54 cm of natural or simulated rainfall within 10 days of application to be effective (Knake et al. 1967; Price et al. 2013; Riar et al. 2012). However, dense cover crop residue can reduce herbicide efficacy by creating a barrier, thus preventing proper herbicide penetration and deposition in the soil (Gaston et al. 2003; Price et al. 2013; Reddy et al. 1995). Some speculate growers are less likely to utilize PRE herbicides with cover crops in row crop production systems due to concerns about herbicide interception by the cover crops and reduction in soil deposition (Price et al. 2013; Teasdale et al. 2005). Banks and Robinson (1982) observed that a residue density of 9,000 kg ha^{-1} obstructed metribuzin from the soil surface, whereas 25% of applied metribuzin reached the soil when the residue measured 2,250 kg ha^{-1}. Additional research observed weed suppression provided by cover crops might compensate for this reduction in herbicide efficacy (Khalil et al. 2018; Locke and Bryson 1997; Petersen et al. 1988).

Previous studies by Wiggins et al. (2017) observed that POST herbicides did not provide adequate Palmer amaranth control, even when used in combination with a high residue cover crop, thus suggesting the need for integration of PRE herbicides. Additionally, repeated sublethal dosage of herbicides, such as what could occur due to the barrier created by dense cover crop residue, may result in development of herbicide resistance (Tehranchian et al. 2017).

Adjuvants can increase herbicide dispersion and penetration into plant tissues (Gimenes et al. 2013; Tu and Randall 2003). Adjuvants are ordinarily separated into two primary categories: activator adjuvants and utility adjuvants (Hazen 2000). Activator adjuvants directly enhance the biological activity of herbicides, while utility adjuvants indirectly influence herbicide efficacy by improving the application process (McMullan 2000; Penner 2000). Surfactants (surface active agents) are the most common type of adjuvant and are categorized as activator adjuvants (Hess 1999; Tu and Randall 2003).

Nonionic surfactants (NIS) are hydrophilic, have no electrical charge, and are the most commonly used among adjuvants due to their extensive compatibility with most herbicides (Tu and Randall 2003). Furthermore, they are primarily used to encourage spray droplet retention, spreading, and penetration into plant tissues (Hock 2022; Tu and Randall 2003). Organosilicone-based surfactants (OS) are silicone-based nonionic surfactants known as “superspreaders” because of their ability to greatly lower surface tension (Curran et al. 1999; Stevens 1993; Tu and Randall 2003). Additionally, OS adjuvants have been observed to abbreviate rainfast periods by increasing herbicide absorption into foliage (Bakke 2021).

Previous research indicates OS adjuvants produce a greater reduction in surface tension than conventional adjuvants, such as Agri-Dex® (COC) or Induce® (NIS) (Field and Bishop 1988; Knoche 1994; Singh and Mack 1993). For example, an NIS lowered the surface tension of a spray solution to 34 mN m^{-1}; however, an OS could reduce the surface tension to 22 mN m^{-1} (Penner 2000). Consequently, a drawback sometimes attributed to OS adjuvants is reduced spray retention, as extreme spreading can cause droplets to coalesce and run off plant surfaces (Bakke 2021; Hess 1999). However, reduced spray retention could potentially benefit those aiming to use soil-applied herbicides in a cover crop system (Sperry 2019). Conceivably, spray solution not retained on crop residue would run off onto the soil below, resulting in improved performance with respect to soil-applied herbicides. In general, increased herbicide efficacy could potentially reduce costs by decreasing herbicide rates necessary to obtain proper weed control and elimination of a sprayer pass throughout the growing season (Gimenes et al. 2013; Knoche 1994; Stougaard 1997; Whalen et al. 2019; Zollinger 2000). Moreover, integrating multiple tactics helps to attenuate the evolution of herbicide resistance while conserving the longevity of present and future technologies (Beckie and Harker 2017; Schryver et al. 2017; Wiggins et al. 2017).

Methods to mitigate herbicide interception by cover crop residue are lacking (Price et al. 2013). Therefore, this research aimed to evaluate the effectiveness of non-ionic and silicone-based surfactants for improving deposition and herbicide efficacy using soil-applied herbicides in a cover crop system.

Materials and Methods

Studies were conducted in 2022 at the R. R. Foil Plant Science Research Center near Starkville, MS, the Black Belt Branch Experiment Station near Brooksville, MS, and the North Mississippi Research and Extension Center near Verona, MS.

Before the experiment was installed, annual ryegrass was drill-seeded as a cover crop in mid-October at 101 kg ha^{-1}. Glyphosate, glufosinate, and clethodim were used to terminate the cover crop on 03 May 2022. Biomass samples were collected by cutting annual ryegrass at ground level in two one-half m^2 quadrants for a total of 1 m^2 per plot at each location. Thereafter, samples were weighed, oven-dried at 50°C for five days and weighed again to obtain cover crop dry-weight. After cover crop termination, Asgrow® 47XFO XtendFlex® soybean were planted in four-row experimental units on 18 May 2022, at a seeding rate of 333,585 seeds ha^{-1} and 97 cm row spacing. Details pertaining to the cover crop and soybean are given in Table 2.1.

The experiment utilized a randomized complete block design with four replications in a factorial arrangement of treatments. Factor A included the preemergence herbicides: *S*-metolachlor 1788 g ai ha^{-1} (Dual Magnum®, Syngenta Crop Protection LLC), flumioxazin 105 g ai ha^{-1} (Panther® SC, Nufarm Inc.), pyroxasulfone 183 g ai ha^{-1} (Zidua®, BASF Corporation) and metribuzin 147 g ai ha^{-1} (Glory®, ADAMA). Factor B included the adjuvants Induce™ (NIS) and Kinetic™ (OS) at 0.5 and 0.125 % v/v, respectively. Deposition and weed control were assessed with and without the addition of NIS and OS adjuvants.

Treatments were applied using a CO_2 backpack sprayer calibrated to deliver 140 L ha^{-1} of spray solution (at 276 kPa at a walking speed of 4.8 km h^{-1}) equipped with a four nozzle boom with 48 cm spaced Teejet® AIXR 110015 nozzles (Spraying Systems Co.®). An untreated check and bare ground check were included at each location for comparison purposes. Additionally, Rhodamine-B dye (Red Tracing Dye Liquid, Cole-Parmer®) at a rate of 5% (v/v) was included in each treatment application as a fluorescent tracer dye (Buick et al. 1992; Field and Bishop 1988; Foster et al. 2018).

Spray solution deposition data were estimated using 10 x 10 cm Mylar® cards (Grafix Plastics) twice per plot and Rhodamine-B dye. The cards were placed beneath the crop residue at the soil surface level to estimate the amount of solution deposited on the soil surface. Mylar® card retrieval was carried out immediately after each treatment application, and latex gloves were worn and changed between plots. Following recovery, the Mylar® cards were placed inside prelabeled resealable plastic bags to ensure no cross-contamination occurred. Bagged samples were placed inside a black, lidded storage tub to prevent photodegradation. Mylar® cards were washed in a laboratory by adding 40 mL of deionized water to each bag and agitating the samples. Then, 5 mL of the generated solution was pipetted into cuvettes. Next, the cuvettes were transferred to a Shimadzu RF-6000 spectrofluorometer (Shimadzu Scientific Instruments, Inc., Columbia, MD) to analyze Rhodamine-B dye concentration. Baseline values were created using treatment solution samples (Foster et al. 2018).

Each treatment was analyzed for droplet size to estimate the effect of herbicides and the effect of adjuvants on droplet formation. All treatments were applied in a DeVries Generation III (DeVries Manufacturing Inc., Hollandale, MN) Research Track Sprayer with Teejet® AIXR 110015 nozzles (Spraying Systems Co.®), calibrated to deliver 140 L ha^{-1}, and droplet size was determined using a VisiSize P15 portable particle/droplet imaging system (Oxford Lasers Ltd., Oxfordshire, United Kingdom). Installation, calibration, and operation of the VisiSize P15 system were conducted according to the user manual. These data were used to correlate herbicide deposition on the soil with droplet size.

In field experiments, percent visual weed control was evaluated at 7, 14, 21, 28, and 35 days after treatment (DAT), using a scale of 0 (no visible plant injury) to 100 (complete plant death) (Frans and Talbert 1977). All data were subjected to an analysis of variance using the

Proc GLIMMIX procedure in SAS version 9.4 (Statistical Analysis Systems Institute, Inc., Cary, NC), considering rep as a random variable. Where significance was observed, means were separated using Fisher's protected least significant difference ($\alpha = 0.05$). Figures and 95% confidence intervals were generated using GraphPad Prism version 9.5.1 (GraphPad by Dotmatics, Boston, MA).

Results

The analysis of variance for Rhodamine-B dye deposition demonstrated an effect of location, for this reason, all data were separated by location and re-analyzed (Table 2.2). Differences were observed among herbicides and adjuvants between locations, (Figures 2.1, 2.2, and 2.3, for Brooksville, Starkville, and Verona, respectively). Additionally, the mean dry annual ryegrass residue for Brooksville, Starkville, and Verona sites were 1769, 3561, and 5687 kg ha^{-1}, respectively (Table 2.1).

Following application of *S*-metolachlor, dye deposition at the soil level was greater when the herbicide was applied without an adjuvant than when applied with NIS or OS in Brooksville (Figure 2.1) or Starkville (Figure 2.2). However, soil deposition of *S*-metolachlor + NIS was similar in Starkville to when *S*-metolachlor was applied without an adjuvant. As for metribuzin applications, the addition of NIS resulted in greater soil deposition than metribuzin + OS or metribuzin alone in Brooksville (Figure 2.1) and Starkville (Figure 2.2). Deposition was similar when metribuzin was applied alone or with NIS in Verona (Figure 2.3). For flumioxazin, the addition of NIS to the herbicide application resulted in greater soil deposition than other evaluated flumioxazin treatments, except for in Starkville (Figure 2.2), where no differences between flumioxazin treatments were observed. Furthermore, application of pyroxasulfone with the addition of NIS resulted in greater soil deposition in Starkville (Figure 2.2); however, there were no observed differences between pyroxasulfone treatments in Brooksville (Figure 2.1) and Verona (Figure 2.3).

Regarding droplet size analysis, data were pooled across treatments and replications. Figure 2.4 presents data on the proportion of droplets less than 100 µm for each treatment. Concerning *S*-metolachlor, no differences in the proportion of droplets smaller than 100 µm were observed, regardless of adjuvant addition. However, when metribuzin was combined with an NIS, the proportion of droplets smaller than 100 µm increased compared to its application with an OS adjuvant or without an adjuvant. Flumioxazin, when applied without adding an adjuvant, resulted in a greater percentage of droplets smaller than 100 µm, though the percentage was similar when applied with a NIS. Additionally, pyroxasulfone application without adjuvants resulted in a greater proportion of droplets less than 100 µm, while proportions between adjuvants were similar.

Furthermore, Figure 2.5 provides data concerning the volume median diameter (VMD) for each treatment. In the case of *S*-metolachlor, the VMD was greater when applied without the addition of an adjuvant, although the VMD remained similar when an OS adjuvant was used. Moreover, application of metribuzin with the addition of an OS adjuvant resulted in a greater VMD compared to its application with NIS or without an adjuvant. Similarly, when flumioxazin was applied with an OS Adjuvant, the VMD was greater compared to its use with a NIS or without an adjuvant. Moreover, the VMD of pyroxasulfone was observed to be greater when applied with either adjuvant, while the VMD without adjuvant addition was similar to that of pyroxasulfone with an OS adjuvant.

For barnyardgrass control, there was an effect of location, though it was not influenced by the addition of an adjuvant (Table 2.3). Data is presented by location and averaged across adjuvants (Table 2.4). In Brooksville and Verona, no effect of herbicides was observed at any evaluation interval. Differences due to herbicide were observed only in Starkville at 14 and 21 DAT. At 7 DAT, all evaluated herbicides controlled barnyardgrass 98 to 99% at all locations. In Starkville at 14 DAT, metribuzin or pyroxasulfone produced greater barnyardgrass control than *S*-metolachlor, though flumioxazin performed similarly. Likewise, at 21 DAT in Starkville, applications of metribuzin or pyroxasulfone produced greater barnyardgrass control than applications of *S*-metolachlor or flumioxazin. The addition of an adjuvant to evaluated herbicides did not influence visual barnyardgrass control (Table 2.7). Additionally, a rainfall event resulting in favorable conditions for herbicides to move into soil solution occurred within 5 days of application at Brooksville (Table 2.5), Starkville (Table 2.6), and Verona (Table 2.7) sites (Harre et al. 2021; Hartzler 2023).

Discussion

Soil deposition of herbicides evaluated in the current study were not improved by addition of an OS adjuvant. A potential explanation for poor performance of the OS adjuvant is due to increased herbicide retention on cover crop residues. For example, previous studies by Nelson and Penner (2006) observed increased herbicide retention when flumioxazin was applied with an OS adjuvant. It is conceivable that addition of an OS adjuvant could have caused increased retention of some herbicides on the cover crop residue, resulting in less herbicide reaching the soil and decreased efficacy.

In the current study, cover crop residues were left standing; however, the majority of residue in Verona became horizontal due to lodging. Herbicides are less likely to volatilize under horizontal crop residue because of reduced evaporation and lower soil temperatures (Locke and Bryson 1997). Overall, the level and duration of barnyardgrass control was greater in Verona than in Brooksville or Starkville (Table 2.4). Greater barnyardgrass control in Verona can be attributed to less herbicide binding to clay particles due to the site's soil type. Moreover, greater barnyardgrass control could also be due to lower soil temperature, resulting in decreased herbicide volatility.

Additionally, a correlation was observed between droplet size and solution deposition at the soil surface across all three locations, as illustrated in Figure 2.6. It was consistently observed that treatment solutions that yielded a higher proportion of droplets with diameters smaller than 100 µm exhibited superior deposition at the soil surface.

Overall, barnyardgrass control with flumioxazin and pyroxasulfone was often lower in Brooksville than in Verona (Table 2.4). Typically, the water solubility of a herbicide is inversely correlated to a compound's likelihood to bind to soil particles (Hartzler 2023). Additionally, as herbicide absorption increases, potential weed control is decreased (Glaspie et al. 2021). Absorption of PRE herbicides is more likely to occur in soil with higher organic matter and clay content (Hartzler 2023). Flumioxazin and pyroxasulfone have low water solubility; therefore, it is probable that these herbicides were bound to clay particles present in the soil at Brooksville, resulting in decreased barnyardgrass control (Shaner 2014). Furthermore, plant residues have been observed to absorb herbicides to a greater extent than clay particles (Locke and Bryson 1997; Reddy et al. 1995). Barnyardgrass control in Starkville was consistently lower than in Brooksville (Table 2.4); however, cover crop residue levels were higher in Starkville than in Brooksville (Table 2.6). Consequently, barnyardgrass control differences between these sites could be due to herbicides being more hydrophobically bound to soil organic matter in Starkville than clay particles in Brooksville. Additionally, herbicides intercepted by cover crop residues are susceptible to volatilization, particularly in standing residue compared to horizontal residue (Khalil et al. 2018; Locke and Bryson 1997).

Conclusion

The purpose of this study was to evaluate the effectiveness of non-ionic and silicone-based surfactants for improving deposition and herbicide efficacy using soil-applied herbicides in a cover crop system. The addition of OS adjuvant to herbicide applications did not improve soil deposition in this study. Additionally, the efficacy of barnyardgrass control remained unaffected by the addition of adjuvants to herbicide programs in this study.

An observed correlation between droplet size and solution deposition at the soil surface was noted. This trend suggests a link between droplet size distribution and the effectiveness of solution deposition, highlighting the importance of droplet size management in optimizing soil deposition of preemergence herbicides in a cover crop system. A more efficient method to optimize soil deposition is using nozzle selection for optimal deposition.

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Table 2.1 Soil type, cover crop planting date, cover crop dry weight, cover crop termination date, soybean planting/treatment application date, and date/amount of first rainfall event after treatment application at Brooksville, Starkville, and Verona sites.

		Cover Crop Information			Soybean Information		
						First Rainfall[a]	
Location	Soil Type	Planting Date	Dry Weight kg ha^{-1}	Termination Date	Planting/Application Date	Date	mm
Brooksville	Brooksville silty clay	20-Oct-2021	1769	3-May-2022	19-May-2022	22-May-22	10
Starkville	Catalpa silty clay loam	20-Oct-2021	3561	3-May-2022	18-May-2022	22-May-22	18
Verona	Catalpa silty clay loam	25-Oct-2021	6587	3-May-2022	17-May-2022	22-May-22	19

[a] Weather data retrieved from the Delta Agricultural Weather Center, deltaweather.extension.msstate.edu

Table 2.2 Analysis of variance for Mylar® card data evaluating Rhodamine-B dye concentration in the top of the cover crop canopy and at the soil surface level at Brooksville, Starkville, and Verona sites.

Source	DF	P-value					
		Brooksville		Starkville		Verona	
		RBT	RBB	RBT	RBB	RBT	RBB
Herbicide	3	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Adjuvant	2	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Herbicide*Adjuvant	6	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

DF = Degrees of freedom
RBT = Rhodamine-B dye concentration evaluated in the top of the annual ryegrass cover-crop canopy
RBB = Rhodamine-B dye concentration evaluated at the soil-surface level

Table 2.3 Analysis of variance for barnyardgrass control data at 7, 14, 21, 28, and 35 DAT at Brooksville, Starkville, and Verona sites.

Source	DF	P-value														
		Brooksville					Starkville					Verona				
		07*	14	21	28	35	07	14	21	28	35	07	14	21	28	35
Herbicide	3	0.99	0.74	0.46	0.37	0.08	0.99	<.001	0.001	0.10	0.99	0.99	0.99	0.41	0.61	0.34
Adjuvant	2	0.99	0.80	0.64	0.13	0.38	0.99	0.27	0.16	0.99	0.99	0.99	0.99	0.38	0.30	0.47
Herbicide*Adjuvant	6	0.99	0.30	0.27	0.41	0.25	0.99	0.97	0.50	0.93	0.99	0.99	0.99	0.44	0.55	0.72

*Values in this row represent days after treatment

Table 2.4 Barnyardgrass control by PRE soybean herbicide programs in an annual ryegrass cover crop system 7, 14, 21, 28, and 35 DAT at Brooksville (B), Starkville (S), and Verona (V), MS sites.

Herbicide	Barnyardgrass Control %														
	7 DAT			14 DAT			21 DAT			28 DAT			35 DAT		
	B	S	V	B	S	V	B	S	V	B	S	V	B	S	v
S-metolachlor	99 [ns]	98 [ns]	99 [ns]	98 [ns]	90C[a]	99 [ns]	97 [ns]	65B	95 [ns]	80 [ns]	1 [ns]	86 [ns]	33 [ns]	0 [ns]	73 [ns]
metribuzin	99	98	99	97	96A	99	94	76A	96	76	3	91	38	0	85
Flumioxazin	99	98	99	98	93B	99	96	67B	96	81	0	88	31	0	79
Pyroxasulfone	99	98	99	97	97A	99	96	79A	96	79	7	87	25	0	64
Fisher's LSD	1.9	2.6	3.3	1.0	1.0	3.3	1.3	2.6	0.6	1.9	1.9	3.0	3.3	1.9	8.0

[ns] F-test non-significant ($P<0.05$).

DAT = days after treatment.

[a] Means followed by the same letter are not significantly different according to Fisher's protected LSD ($\alpha = 0.05$).

Table 2.5 Maximum temperature, minimum temperature, and precipitation data[a] throughout weed control evaluation intervals for studies investigating improved deposition and herbicide efficacy in a cover crop system at Brooksville site.

Brooksville			
Date	Max Temp	Min Temp	Precipitation
	°C		mm
17-May	31	16	0
18-May	34	17	0
19-May [b]	34	19	0
20-May	33	22	0
21-May	36	21	0
22-May	33	21	10
23-May	28	21	2
24-May	29	20	14
25-May	27	19	26
26-May	28	19	18
27-May	27	16	0
28-May	27	15	0
29-May	31	15	0
30-May	33	21	0
31-May	33	19	0
1-Jun	33	20	0
2-Jun	31	21	28
3-Jun	28	20	5
4-Jun	29	17	0
5-Jun	31	19	23
6-Jun	31	20	0
7-Jun	33	23	1
8-Jun	33	22	0
9-Jun	29	21	0
10-Jun	28	19	1
11-Jun	31	19	0
12-Jun	34	21	0
13-Jun	36	23	0

Table 2.5 continued

14-Jun	36	24	0
15-Jun	37	24	0
16-Jun	34	23	0
17-Jun	36	24	0
18-Jun	35	23	0
19-Jun	33	19	0
20-Jun	36	18	0
21-Jun	37	23	0
22-Jun	37	23	0
23-Jun	37	24	0
Average	32	20	3
Total			128

[a] Weather data retrieved from the Delta Agricultural Weather Center, deltaweather.extension.msstate.edu

[b] Indicates day of treatment application for location

Table 2.6 Maximum temperature, minimum temperature, and precipitation data[a] throughout weed control evaluation intervals for studies investigating improved deposition and herbicide efficacy in a cover crop system at Starkville site.

Starkville			
Date	Max Temp	Min Temp	Precipitation
	°C		mm
17-May	29	15	0
18-May [b]	33	16	0
19-May	32	19	0
20-May	32	22	0
21-May	34	21	0
22-May	32	21	18
23-May	26	19	0
24-May	28	19	14
25-May	27	19	30
26-May	27	18	15
27-May	26	15	0
28-May	27	14	0
29-May	30	14	0
30-May	32	19	0
31-May	32	19	0
1-Jun	33	21	0
2-Jun	29	21	21
3-Jun	28	18	5
4-Jun	29	17	0
5-Jun	32	18	0
6-Jun	31	20	2
7-Jun	33	24	9
8-Jun	32	22	0
9-Jun	29	21	0
10-Jun	27	18	1
11-Jun	31	19	0
12-Jun	34	21	0
13-Jun	34	24	0

Table 2.6 continued

14-Jun	34	24	0
15-Jun	36	23	0
16-Jun	34	23	0
17-Jun	36	23	0
18-Jun	34	22	0
19-Jun	32	18	0
20-Jun	35	18	0
21-Jun	36	22	0
22-Jun	37	23	0
23-Jun	37	24	1
Average	32	20	3
Total			115

[a] Weather data retrieved from the Delta Agricultural Weather Center, deltaweather.extension.msstate.edu

[b] Indicates day of treatment application for location

Table 2.7 Maximum temperature, minimum temperature, and precipitation data[a] throughout weed control evaluation intervals for studies investigating improved canopy and herbicide efficacy in a cover crop system at Verona site.

Verona			
Date	Max Temp	Min Temp	Precipitation
	°C		mm
17-May[b]	31	13	0
18-May	33	16	0
19-May	32	21	0
20-May	32	22	0
21-May	33	22	0
22-May	31	19	19
23-May	24	17	0
24-May	27	18	17
25-May	26	19	21
26-May	27	17	2
27-May	24	14	0
28-May	27	13	0
29-May	31	14	0
30-May	32	20	0
31-May	33	19	0
1-Jun	34	20	0
2-Jun	28	22	1
3-Jun	30	19	1
4-Jun	31	16	0
5-Jun	32	17	0
6-Jun	31	21	0
7-Jun	33	22	4
8-Jun	32	21	17
9-Jun	30	19	0
10-Jun	26	17	0
11-Jun	32	17	0
12-Jun	34	21	0
13-Jun	36	24	0

Table 2.7 continued

14-Jun	36	23	0
15-Jun	37	24	0
16-Jun	36	24	0
17-Jun	36	22	0
18-Jun	34	22	0
19-Jun	33	18	0
20-Jun	35	16	0
21-Jun	37	21	0
22-Jun	37	22	0
23-Jun	36	23	0
Average	32	19	2
Total			81

[a] Weather data retrieved from the Delta Agricultural Weather Center, deltaweather.extension.msstate.edu

[b] Indicates day of treatment application for location

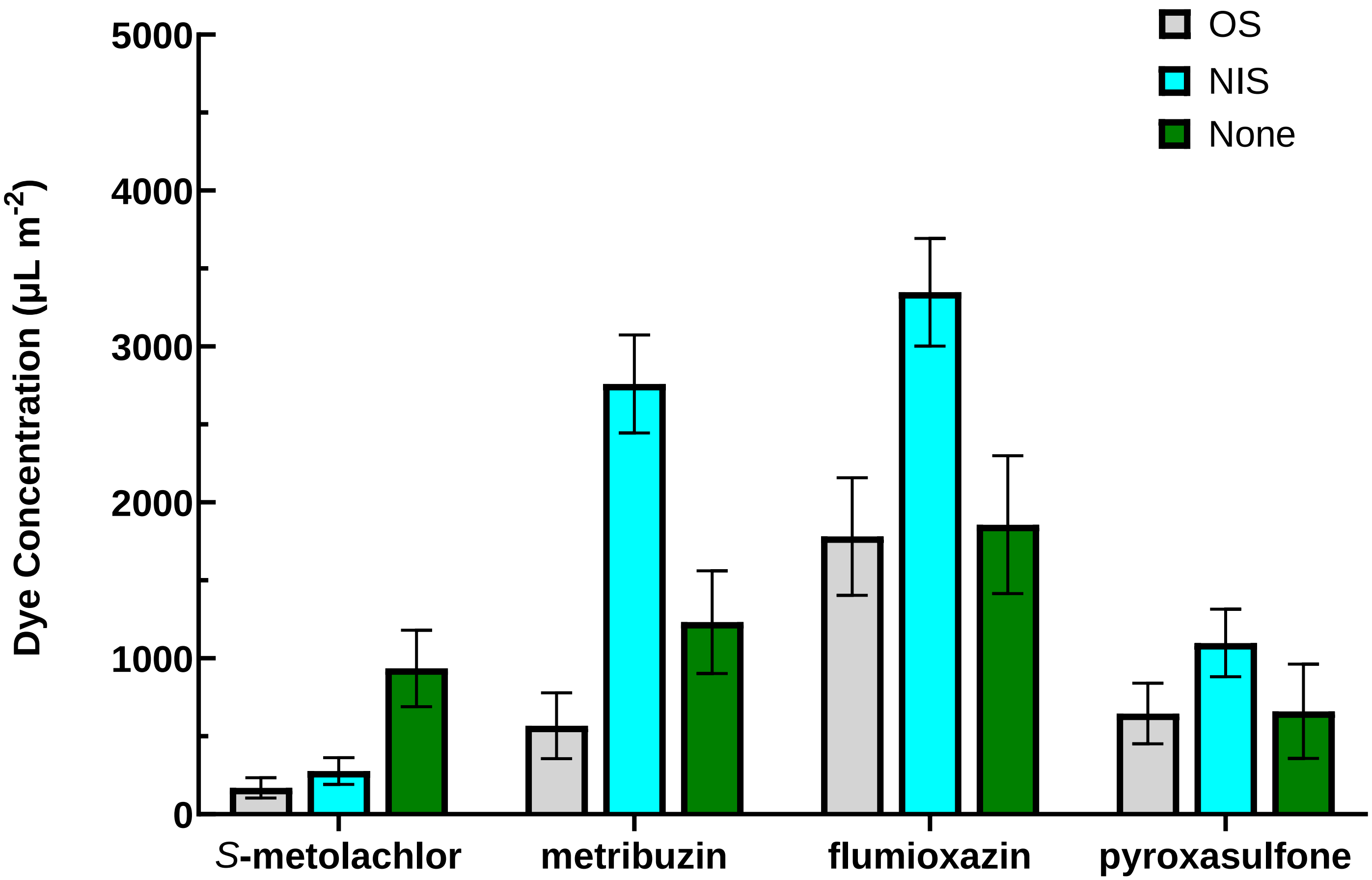

Figure 2.1 Rhodamine-B dye concentration at soil-surface level at Brooksville, MS. Error bars correspond to 95% confidence intervals (n = 32).

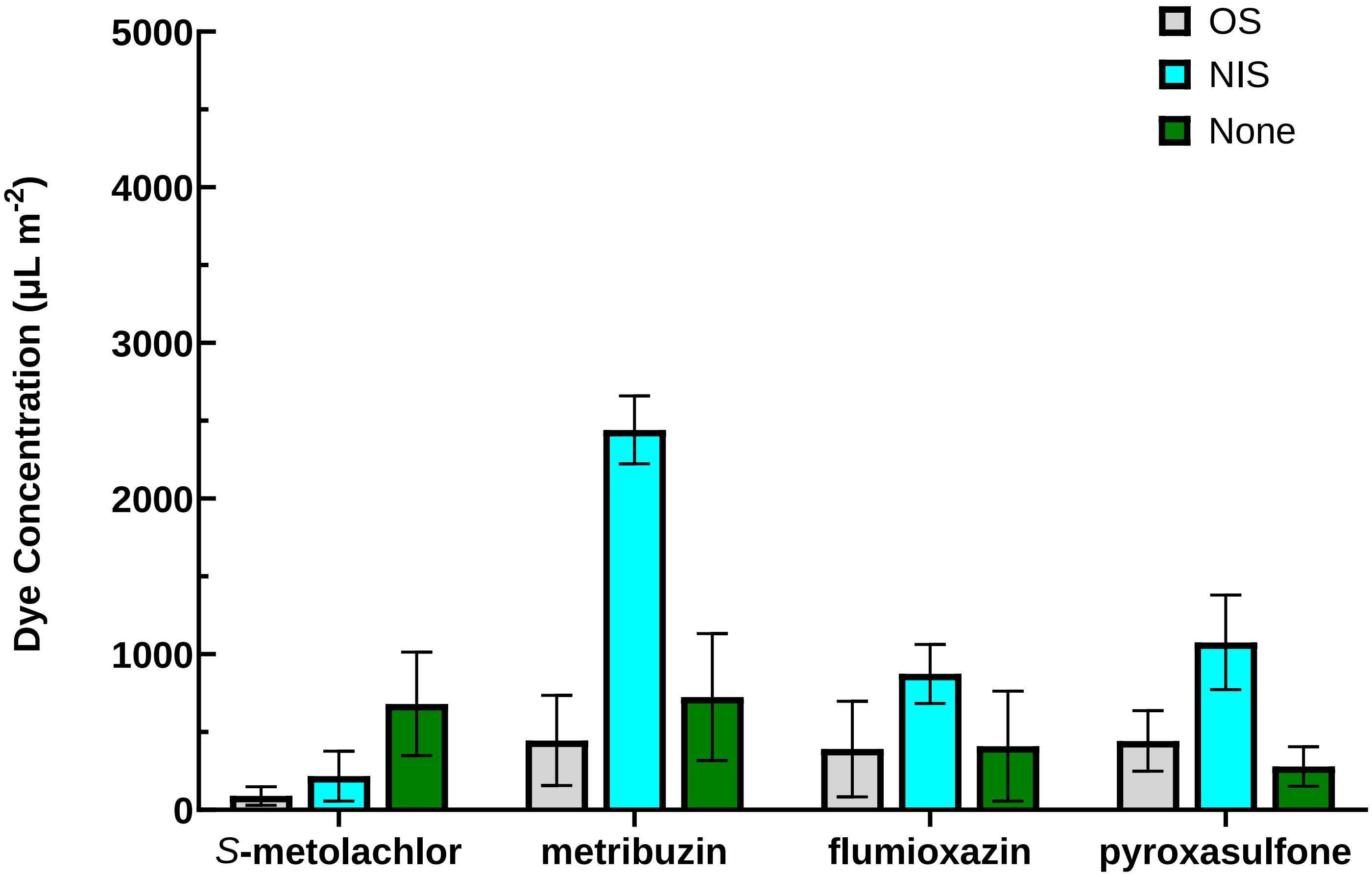

Figure 2.2 Rhodamine-B dye concentration at the soil-surface level at Starkville, MS. Error bars correspond to 95% confidence intervals (n = 32).

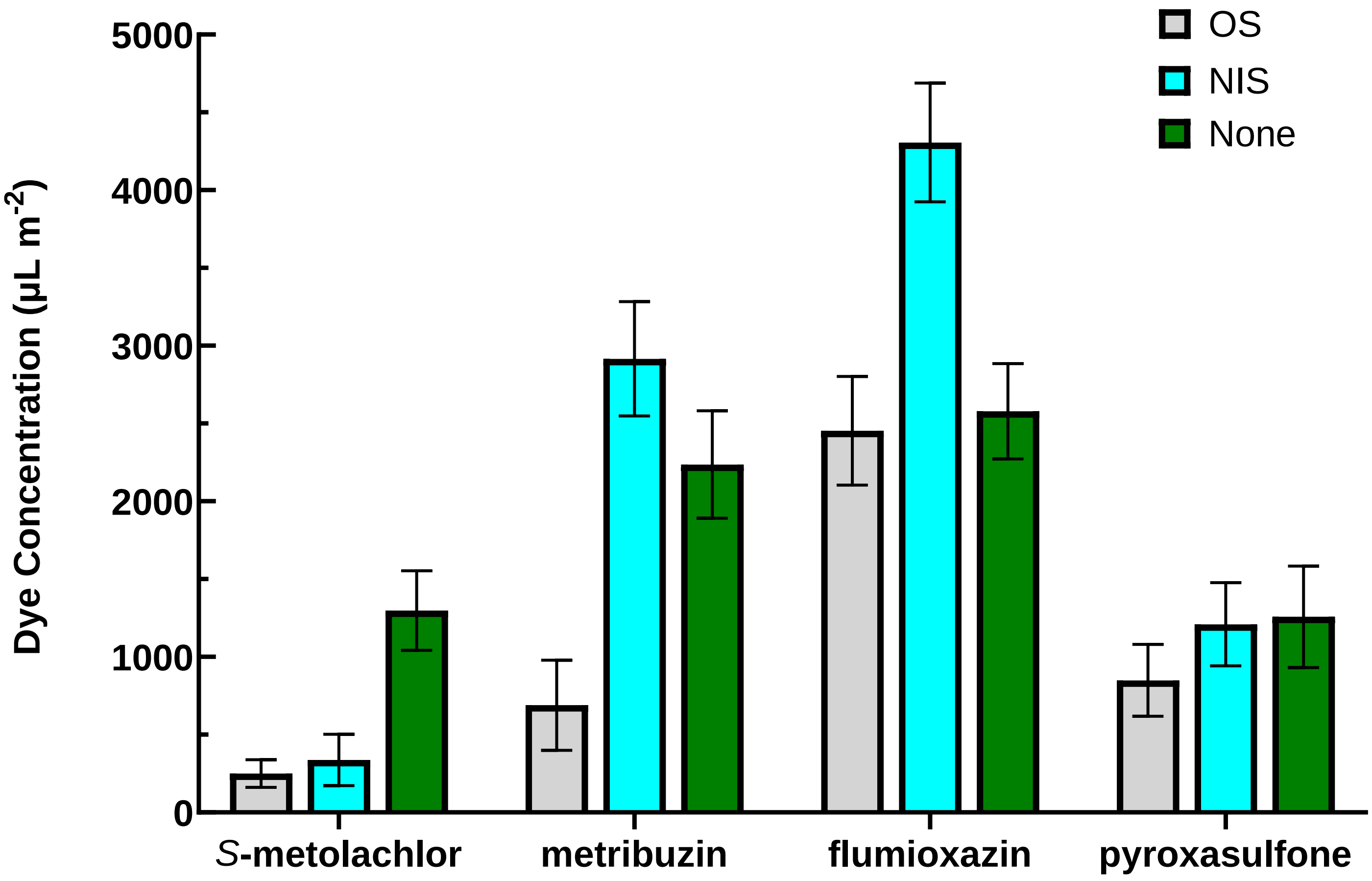

Figure 2.3 Rhodamine-B dye concentration at the soil-surface level at Verona, MS. Error bars correspond to 95% confidence intervals (n = 32).

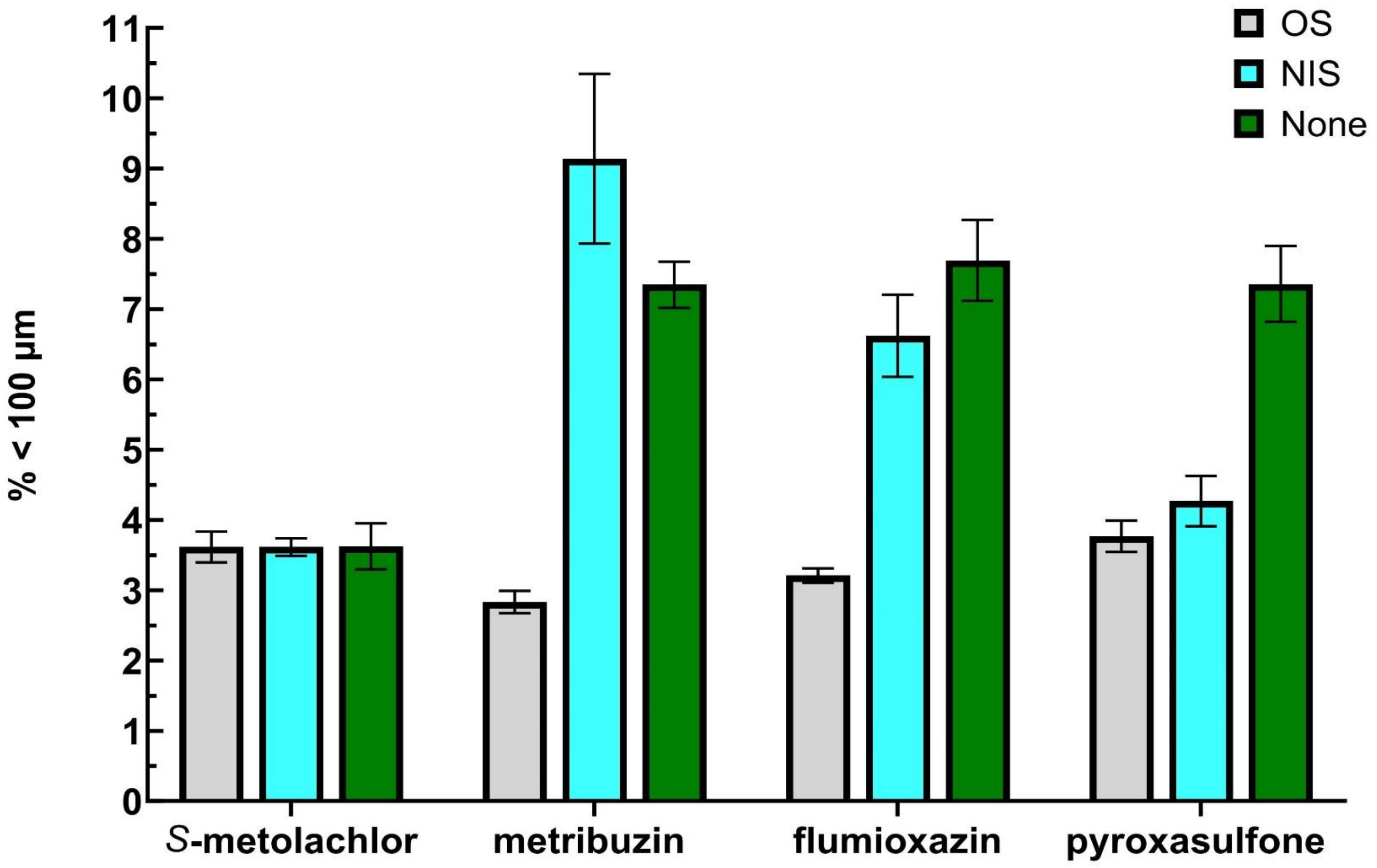

Figure 2.4 Percentage of droplets smaller than 100 µm as affected by the herbicides and adjuvants. Error bars correspond to 95% confidence intervals (n = 32).

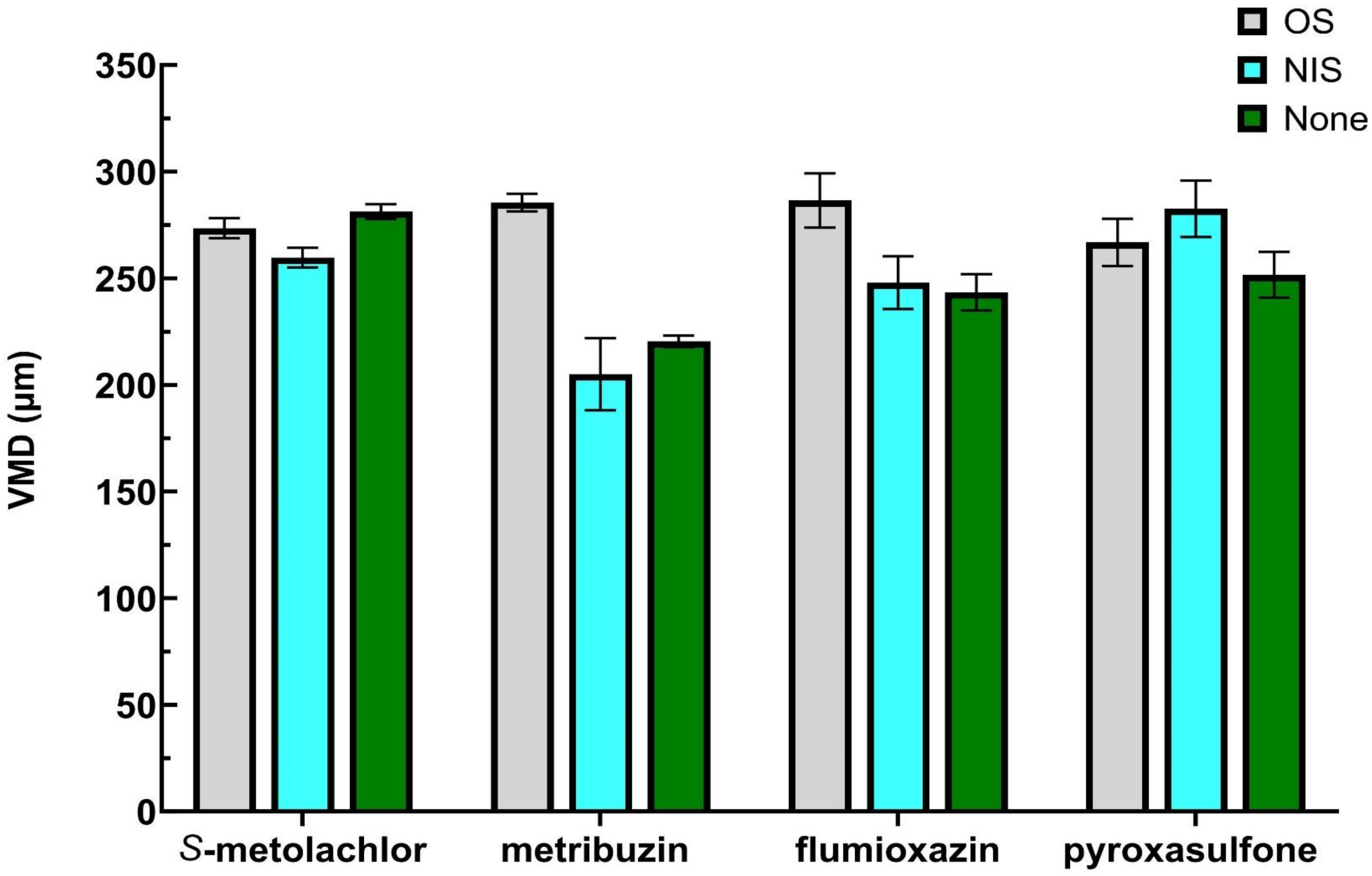

Figure 2.5 Volume median diameter (VMD) of the spray solution as affected by the herbicides and adjuvants. Error bars correspond to 95% confidence intervals (n = 32).

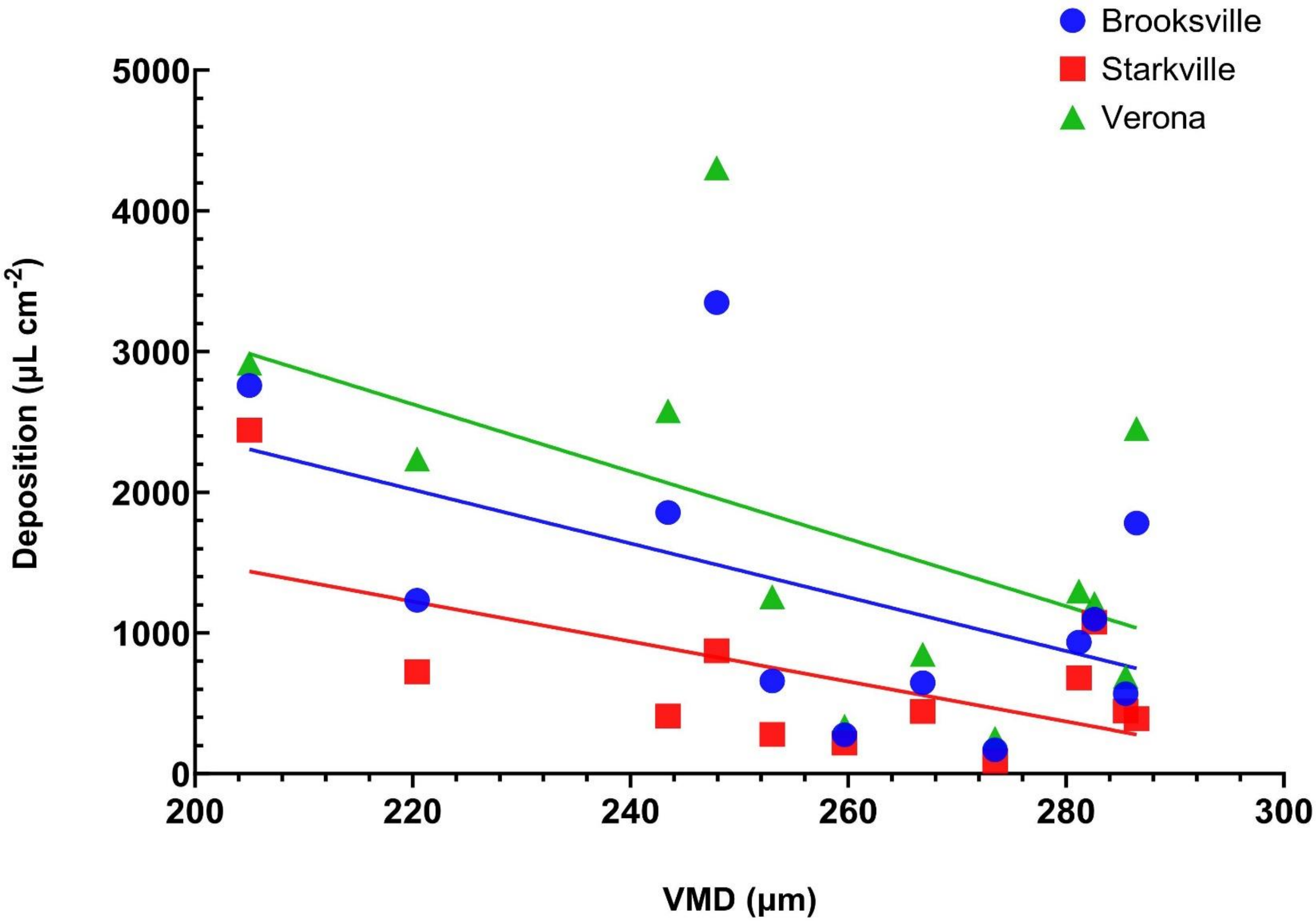

Figure 2.6 Correlation between volume median diameter (VMD) for spray solutions and deposition at the soil surface at Starkville (A), Brooksville (B) and Verona (C), MS.