Pre-emergence herbicide programs for weed control in soybean (*Glycine max*) and the effect of rainfall amount on herbicide activity

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Preemergence (PRE) herbicides are used to control weeds and reduce pressure on postemergence (POST) herbicides. However, knowledge of length of control each herbicide provides, as well as the amount of activation rainfall required for adequate weed control, is unknown in Mississippi soybean production. Twenty-one PRE applied soybean herbicides were evaluated for their duration of residual control for five weeks over twelve site years on three weed species from 2021-2022. Some differences in control following herbicide application used on certain weed species were observed at different times. However, most PRE herbicides resulted in adequate (≥90%) control of weed species evaluated up to 35 days after emergence. Also, four PRE herbicides were evaluated in the greenhouse to quantify the amount of rainfall needed for activation when applied to three different soil textures. These data suggest that rainfall recommendations vary by herbicide and soil texture, and some herbicides were effective at controlling weed species at low rainfall amounts (<12.7mm).

DEDICATION

I would like to dedicate this research to my wife, my family, and my friends for encouraging me and providing me the support I needed to achieve my goals. I am forever thankful.

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CHAPTER I

DURATION OF CONTROL FOR LABELED PREEMERGENCE HERBICIDES IN SOYBEAN PRODUCTION

1.1 Abstract

Weed control is one of the critical tasks growers face each year. Numerous preemergence (PRE) herbicide options are available in soybean. Utilization of these herbicides can provide weed control benefits and alleviate the pressure on postemergence herbicides for weed control in soybean. However, it has become commonplace for pre-blended herbicides to be used in soybean. Historical data often exist on each component of these premixes; however, data often are lacking with regard to weed control efficacy when more than one product is applied as part of a single formulation. Therefore, this experiment evaluated various preemergence herbicides and their weed control effectiveness. Herbicides evaluated included: acetochlor, cloransulam-methyl, clomazone, dimethenamid-P, flumetsulam, fomesafen, flumioxazin, imazaquin, metribuzin, norflurazon, pendimethalin, pyroxasulfone, *S*-metolachlor, sulfentrazone, sulfentrazone + *S*-metolachlor, *S*-metolachlor + metribuzin, *S*-metolachlor + fomesafen, sulfentrazone + metribuzin, acetochlor + fomesafen, sulfentrazone + flumioxazin, and flumioxazin + pyroxasulfone. Morningglory spp. (*Ipomoea* spp.), prickly sida (*Sida spinosa*), and tall waterhemp (*Amaranthus tuberculatus*) control was evaluated at the R.R. Foil Plant Science Research Center near Mississippi State, MS and the Black Belt Branch Experiment Station near Brooksville, MS in 2021 and 2022. There were differences in control following herbicide application used on certain weed species at different times, but most preemergence herbicides

resulted in adequate (≥90%) control of weed species evaluated. Growers have flexibility to make a PRE herbicide decision based on price, efficacy, and ease of application.

1.2 Introduction

Soybean production in the United States depends upon the use of effective weed control methods, often combining herbicide programs and cultivation (Gebhardt 1981). Weeds reduce the value of soybean by approximately 17% annually in the United States (Wax 1973). Proper weed control is important in maximizing soybean yield (Miller 1974). Hauser et al. (1972), Dowler and Parker (1975), and Johnson (1971) documented the need for a systems approach for weed control in soybean. Reduction in soybean yield due to weed infestation varies from 20-77% depending on soil texture, season, and intensity of weed infestation (Kurchania et al. 2001). Weeds reduce yield by competing with soybeans for light, nutrients, and moisture. They also reduce the quantity and quality of harvested soybean seed by delaying harvest and by decreasing the efficiency of harvesting equipment (McWhorter et al. 1976).

With the commercialization and adoption of glyphosate-resistant (GR) soybean, the use of postemergence (POST)-applied glyphosate for weed control has increased drastically over the last 20 years, especially in the United States (Knezevic et al. 2019; Duke, 2015; Givens et al., 2009; Powles, 2008). Widespread and repeated use of glyphosate has resulted in weed species shifts and the development of glyphosate resistance in 57 weed species worldwide (Striegel et al. 2020; Culpepper, 2006; Johnson et al., 2009; Owen, 2008; Webster and Nichols, 2012). Therefore, a continual need exists to reduce glyphosate dependence in soybean (Norsworthy et al., 2012). An urgent need for diversification of weed control programs with alternative sites of action in soybean is needed to prevent or delay the selection for resistance (Gressel 1991; Knezevic et al. 2019).

Amaranthus species are some of the most troublesome weeds in cropland areas throughout the United States (Holm et al., 1977). Interference from severe infestations of Palmer amaranth (*Amaranthus palmeri*) is known to cause yield loss in a variety of crops (Johnson et al. 1996; Klingaman and Oliver, 1994; Menges, 1988; Monks and Oliver, 1988; Rushing et al. 1985; Shurtleff and Coble 1985; Sweat et al. 1998). The protoporphyrinogen oxidase (PPO) herbicides (herbicide Group 14) have been one of the primary herbicide chemistries for control of Palmer amaranth in Mississippi soybean over the last decade. However, fields in Bolivar, Coahoma, Sunflower, and Tunica counties, or adjacent counties, likely contain Palmer amaranth resistant to PPO herbicides. The presence of PPO-resistant Palmer amaranth complicates herbicide programs in affected areas. Most populations of Palmer amaranth in the Mississippi Delta exhibit multiple resistance to glyphosate and ALS herbicides (herbicide Group 2) (Bond et al. 2016). Therefore, the use of herbicide mixtures containing multiple effective modes of action is critical in areas with PPO-resistant Palmer amaranth (Bond et al. 2016).

The critical period of weed control (CPWC) is a crucial component of integrated weed management and should be used as a guide for herbicide application (Knezevic et al. 2003). The CPWC represents the time interval between two separately measured crop–weed competition components: the critical time for weed removal (CTWR) and the critical weed-free period. During crop emergence, resources present in the environment may be sufficient to support both weed and crop growth. However, with continued competition between weeds and crops, weeds begin to have adverse effects on the crop, marking the beginning of the CPWC, which is also referred to as the CTWR (Knezevic et al. 2019). Understanding how preemergence (PRE) herbicides could influence the CTWR aids in optimizing weed control strategies and allow for the development of better resistance-management strategies (Knezevic et al., 2013).

Preplant or PRE herbicide application and timely POST herbicide treatments as well as cultivation are essential components of a weed control system for soybean production in the Southeastern United States. (Gebhardt 1981). Applying a PRE herbicide may help prevent yield losses from early-season weed competition. Preemergence herbicides often delay weed emergence, affect the competitive ability of the escaped weeds, and decrease the soil weed seed bank (Barnes et al. 2004; Butts et al. 2017; Tursun et al. 2016; Kalpana et al. 2004; Adcock and Banks 1991; Crowley et al. 1979; Holloway and Shaw 1995; Tayor-Lovell et al. 2002). Regardless of the targeted soybean planting date, PRE applications should be made before crop emergence. PRE herbicides control both grass and broadleaf weeds in soybean. However, these herbicides rarely provide season-long weed control (Bond et al. 2016). Preemergence herbicides are also a foundation for resistance management in soybean weed control programs as they provide additional sites of action and alternative options for controlling glyphosate-resistant weeds (Oliveira et al. 2017).

Using a sequential program including a PRE herbicide with soil residual activity can give growers greater flexibility in POST herbicide programs and are an effective alternative to single or sequential POST applications (Palmer et al., 1999; Corrigan and Harvey, 2000; Culpepper et al., 2000; Nolte and Young, 2002; Payne and Oliver, 2000). The use of PRE herbicides in glyphosate-resistant soybean could delay the need for POST application of glyphosate by 14 to 34 days and reduce the need for repeated applications of glyphosate. In addition, the use of PRE herbicides in glyphosate-resistant soybean could provide a window of 28 to 66 days after soybean emergence for POST weed removal, as opposed to 14 to 29 days without PRE herbicide application (Knezevic et al. 2019). These systems have been especially beneficial when initial glyphosate applications were delayed for several weeks, which can lead to reduced soybean yields (Corrigan and Harvey 2000; Dalley et al. 2004; Gonzini et al. 1999; Payne and Oliver 2000). Although using a PRE herbicide may result in an additional application, a PRE herbicide could mitigate possible herbicide antagonism resulting from tank mixtures of POST herbicides (Tayor-Lovell et al. 2002).

Evaluating herbicide products and rates is essential to help develop broad spectrum weed control programs (Kalpana et al. 2004). Data are lacking on length of residual control of PRE herbicides. The purpose of this study was to determine how many days of weed control are gained following soil-applied, PRE herbicide application in soybean production systems in order to fully understand how to incorporate them into season long weed control programs.

1.3 Materials and Methods

Field studies were conducted comparing several common soil-applied herbicides to determine the length of residual weed control when applied to soybean. Studies were repeated three times per year in 2021 and 2022 at two different locations each year: the R.R. Foil Plant Science Research Center near Starkville, MS (Catalpa silty clay loam soil) and the Black Belt Branch Experiment Station near Brooksville, MS (Brooksville silty clay). Herbicide treatments were applied to experimental units arranged in a randomized complete block design with four replications. Asgrow AG47XF0 soybeans were planted on 97-cm row spacings at 333,333 seed ha^{-1}. The first run of soybeans in 2021 in both locations were planted on 21 April, the second on 25 May, and the third on 18 June. The first run of soybeans in 2022 in both locations were planted on 27 April, the second on 19 May, and the third on 14 June. Experiments were conducted using 3-row experimental units and all included a running check. Crop management practices, including fertilization, irrigation, and pest management (other than weed control), were based on local Extension recommendations. Treatments were applied immediately after planting on two rows of each three row plot using a CO_2 pressurized backpack sprayer calibrated to deliver 140 L ha^{-1} at the appropriate rate for specific soil textures. Herbicides and application rates are given in Table 1.1, and their physiochemical characteristics are given in Table 1.2

Percent visual weed control of morningglory spp. (*Ipomoea* spp.), prickly sida (*Sida spinosa*), and tall waterhemp (*Amaranthus tuberculatus*) on a 0-100% scale, with 0% being no control and 100% being perfect control, was evaluated every 7 days after herbicide application (DAT) up to 35 DAT. All data were subjected to ANOVA using PROCMIXED in SAS version 9.4., where year and location were treated as random effects and herbicide treatment and planting date were treated as fixed effects. Means were separated using Tukey's protected HSD at α=0.05.

1.4 Results and Discussion

The analysis of variance showed no effect of year, location, or planting date on morningglory weed control (Table 1.3). Therefore, the data were pooled across location, year, and planting date. Comparing herbicide treatments (Table 1.4), there were no differences in the PRE herbicides evaluated with respect to morningglory control at 7 DAT, with control ranging from 97-99%. At every other evaluation timing, there were differences between PRE herbicides evaluated with respect to morningglory control. At both 14 and 21 DAT, application of flumioxazin + pyroxasulfone resulted in greater control of morningglory (98% and 97%, respectively) than both norflurazon and pyroxasulfone (93% and 90%, respectively). There were no differences between any of the other herbicides with respect to morningglory control at 14 or 21 DAT. At 28 DAT, application of sulfentrazone, sulfentrazone + flumioxazin, and flumioxazin + pyroxasulfone resulted in greater morningglory control (93%, 94%, and 94%, respectively) than that following the application of norflurazon (85%). There were no differences between any of the other herbicides with respect to morningglory control at 28 DAT. At 35 DAT, application of flumioxazin + pyroxasulfone and cloransulam-methyl resulted in greater morningglory control (93% and 92%, respectively) than that following application of norflurazon (82%). Additionally, application of dimethenamid-P resulted in less morningglory control (83%) than flumioxazin + pyroxasulfone, but not different than that following application of cloransulam-methyl or norflurazon. There were no differences between any of the other herbicides with respect to morningglory control 35 DAT. Similarly, Taylor-Lovell et al. (2002) found that PRE-applied flumioxazin controlled ivyleaf morningglory at least 90%. Krausz et al. (1998) found that sulfentrazone applied at 280g ai ha^{-1} resulted in 92-100% control of ivyleaf morningglory 56 days after planting.

Analysis of variance showed no effect of year, location, or planting date on prickly sida control (Table 1.5). Therefore, data were pooled across location, year, and planting date. Comparing herbicide treatments (Table 1.6), there were no differences in prickly sida control following PRE herbicide application at 7 and 14 DAT. Prickly sida control at 7 and 14 DAT ranged from 99-100% across all treatments. At every other time, differences were present in prickly sida control following PRE herbicide application. At 21 DAT, application of sulfentrazone + flumioxazin and flumioxazin + pyroxasulfone resulted in greater prickly sida control (100%) than that observed following application of norflurazon. Prickly sida control from all other herbicides evaluated was similar and averaged from 97-99%. At 28 DAT, the application of flumetsulam, fluioxazin, metribuzin, sulfentrazone + flumioxazin, and flumioxazin + pyroxasulfone resulted in greater prickly sida control (99%) than that following application of acetochlor, clomazone, norflurazon, pyroxasulfone, and acetochlor + fomesafen. There are no significant differences between any of the other herbicides with respect to prickly sida control 28 DAT. At 35 DAT, the application of flumetsulam resulted in greater control of prickly sida

(99%) than that observed following application of acetochlor + fomesafen (93%). There were no differences between any of the other herbicides with respect to prickly sida control 35 DAT. Similarly, Reddy (2000) found that cloransulam at 35g ha^{-1} applied PRE controlled at least 91% of prickly sida at seven weeks after planting. Copes et al. (2021) found that at 35 days after application, prickly sida control from glyphosate + 2,4-D pre-plant with flumioxazin + chlorimuron-ethyl, flumioxazin + pyroxasulfone, flumioxazin + chlorimuron-ethyl + thifensulfuron-methyl, metribuzin + chlorimuron-ethyl or metribuzin + sulfentrazone was 70% to 89% and similar among treatments.

Analysis of variance showed no effect of year, location, or planting date on tall waterhemp weed control (Table 1.7). Therefore, the data were pooled across location, year, and planting date. Comparing herbicide treatments (Table 1.8), there were no differences in the PRE herbicides evaluated with respect to tall waterhemp control 7 DAT. At all other timing evaluations, there were differences in tall waterhemp control due to PRE herbicide application. At 14 DAT, the application of *S*-metolachlor and flumioxazin + pyroxasulfone provided greater tall waterhemp control (99%) than pyroxasulfone (98%). There were no differences between any of the other herbicides with respect to tall waterhemp control 14 DAT. At 21 and 28 DAT, the application of metribuzin and flumioxazin + pyroxasulfone provided greater tall waterhemp control (99%) than pyroxasulfone (97% and 95%, respectively). There were no differences between any of the other herbicides with respect to tall waterhemp control 21 and 28 DAT. 35 DAT, the application of metribuzin and flumioxazin + pyroxasulfone provided greater tall waterhemp control (99%) than pyroxasulfone and norflurazon (94%). There were no differences between any of the other herbicides with respect to tall waterhemp control 35 DAT. Similarly, Meyer et al. (2016) found that isoxaflutole + *S*-metolachlor + metribuzin provided 99% tall waterhemp control three weeks after treatment. They also found that isoxaflutole + *S*-metolachlor + metribuzin, *S*-metolachlor + mesotrione, and flumioxazin + pyroxasulfone resulted in ≥97% control in the same time span.

These data are consistent with previous research, showing the effectiveness and requirement of these PRE herbicides in a soybean crop. Knezevic et al. (2019) found that the critical time for weed control in soybean without PRE herbicides was determined to be around the V1 to V2 (14 to 21 d after emergence [DAE]) growth stage, depending on the location and weed pressure. However, utilization of PRE-applied herbicides delayed the critical time for weed control from about the V4 (28 DAE) stage up to the R5 (66 DAE) stage. Taylor-Lovell et al. (2002) found that sequential applications, including a PRE herbicide, provided up to 25% greater control than POST-only treatments. McWhorter et al. (1976) found that metribuzin applied PRE was more effective in controlling common cocklebur (*Xanthium strumarium*) and increasing soybean yield than a single application of any herbicide applied POST. Ellis and Griffin (2002) reported that when a PRE-applied herbicide was applied, only a single POST glyphosate application was needed to control barnyardgrass (*Echinochloa crus-galli*), ivyleaf morningglory (*Ipomoea hederacea*), prickly sida (*Sida spinosa*), hemp sesbania (*Sesbania herbacea*), and ragweed (*Ambrosia* spp.) in soybean. Franzenburg et al. (1998) demonstrated that improved weed control from the inclusion of a PRE treatment increased soybean yields compared with a single POST application of glyphosate alone. Oliveira et al. (2017) found that PRE herbicides including metolachlor (1.25lb a.i. acre^{-1}), metolachlor + imazethapyr (1.31 lb a.i. acre^{-1}), imazethapyr (0.06 lb a.i. acre^{-1}), fomesafen (0.24 lb a.i. acre^{-1}), fomesafen + imazethapyr (0.31 lb a.i. acre^{-1}), flumioxazin + imazethapyr (0.15 lb a.i. acre^{-1}), flumioxazin (0.06 lb a.i. acre^{-1}), flumioxazin + metribuzin (0.35 lb a.i. acre^{-1}), and metribuzin (0.25 lb a.i. acre^{-1}) provided good

(>90%) broadleaf and grass weed control. Striegal et al. (2020) found that PRE herbicide programs containing sulfentrazone and S-metolachlor + metribuzin (1,960 + 700 g a.i. ha^{-1}), chlorimuron, flumioxazin, and thifensulfuron-methyl (94 g a.i. ha^{-1}), flumioxazin and pyroxasulfone + metribuzin (160 + 210 g a.i. ha^{-1}), chlorimuron, flumioxazin, and metribuzin (374 g a.i. ha^{-1}), and imazethapyr, pyroxasulfone, and saflufenacil (215 g a.i. ha^{-1}) provided 93–99% Palmer amaranth control.

1.5 Conclusion

The purpose of this study was to determine how many days of weed control are gained following soil-applied PRE herbicide application in soybean production systems. Preemergence herbicide efficacy can depend heavily on soil texture, amount and timing of activation rainfall, and weed species. There were some differences in weed control due to herbicide used, but most PRE herbicides resulted in adequate control of the weed species evaluated. Growers have the flexibility to make a PRE herbicide decision based on price, efficacy, and ease of application. Rotating modes of action help the management of herbicide-resistant weeds by reducing the selection pressure that occurs when making multiple applications per year of herbicides with the same mode of action. Considering most soybean PRE herbicides are effective, this allows growers to do so without sacrificing early-season weed control.

1.6 Tables

Table 1.1 Preemergence herbicide treatments for season-long weed control in soybean

TRT	Herbicide	Trade Name	Group	Site of action[a]	Rate (g ai ha^{-1})
1	UTC				
2	acetochlor	Warrant®	15	VLCFA	1429
3	cloransulam-methyl	First Rate®	2	ALS	44
4	clomazone	Command® 3ME	13	DOXP Synthase	1401
5	dimethenamid-P	Outlook™	15	VLCFA	947
6	flumetsulam	Python®	2	ALS	75
7	fomesafen	Reflex®	14	PPO	350
8	flumioxazin	Panther® SC	14	PPO	105
9	imazaquin	Scepter®	2	ALS	137
10	metribuzin	Dimetric®	5	PSII	702
11	norflurazon	Solicam®	12	PDS	2204
12	pendimethalin	Prowl® H20	3	Microtubule Assembly	1065
13	pyroxasulfone	Zidua® SC	15	VLCFA	183
14	*S*-metolachlor	Dual Magnum®	15	VLCFA	1784
15	sulfentrazone	Shutdown™	14	PPO	368
16	sulfentrazone + *S*-metolachlor	BroadAxe® XC	14 + 15	PPO + VLCFA	1962
17	*S*-metolachlor + metribuzin	Boundary® 6.5EC	15 + 5	VLCFA + PSII	2369
18	*S*-metolachlor + fomesafen	Dual Magnum® + Reflex®	15 + 14	VLCFA + PPO	1825 + 399
19	sulfentrazone + metribuzin	Shutdown™ + Dimetric®	14 + 5	PPO + PSII	227 + 342
20	acetochlor + fomesafen	Warrant® + Reflex®	15 + 14	VLCFA + PPO	1582 + 354
21	sulfentrazone + flumioxazin	Shutdown™ + Panther® SC	14 + 14	PPO + PPO	164 + 164
22	flumioxazin + pyroxasulfone	Panther® SC + Zidua® SC	14 + 15	PPO + VLCFA	88 + 113

Table 1.2 Physiochemical characteristics of active ingredients used in the study.

Herbicide	Koc	Half-Life
acetochlor	165 mL/g	12 days
cloransulam-methyl	54.4-915 mL/g	8-10 days
clomazone	300 mL/g	24 days
dimethenamid-P	55-125 mL/g	20 days
flumetsulam	15 mL/g	Two months
fomesafen	60 mL/g	100 days
flumioxazin	N/A	11.9-17.5 days
imazaquin	20 mL/g	60 days
metribuzin	60 mL/g	30-60 days
norflurazon	700 mL/g	45-180 days
pendimethalin	17,200 mL/g	44 days
pyroxasulfone	117 mL/g	16-26 days
S-metolachlor	200 mL/g	3-5 months
sulfentrazone	43 mL/g	121-302 days

* Source: Herbicide Handbook (Shaner, 2014)

Table 1.3 ANOVA table for morningglory (*Ipomoea* spp.) control rating at the R.R. Foil Plant Science Research Center, Mississippi State, MS, and the Black Belt Branch Research Station in Brooksville, MS, in 2021 and 2022.

Source	**DF**	**P-value 7 DAT**	**P-value 14 DAT**	**P-value 21 DAT**	**P-value 28 DAT**	**P-value 35 DAT**
Replication	3	0.0891	0.0317	0.0023	0.0159	0.0232
Herbicide	20	0.1716	0.0127	0.0075	0.0005	<0.0001
Planting Date	2	0.3226	0.8958	0.8850	0.8120	0.8149
Herbicide*Planting Date	40	0.7696	0.8288	0.5165	0.3847	0.1158
Year	1	0.8980	0.0356	0.1879	0.3495	0.2118
Location	1	0.4945	0.0199	0.1226	0.2766	0.2661
Error	927					

Table 1.4 Morningglory (*Ipomoea* spp.) control following PRE herbicide application in soybean at the R.R. Foil Plant Science Research Center, Mississippi State, MS, and the Black Belt Branch Research Station in Brooksville, MS, in 2021 and 2022.

TRT	Herbicide	7 DAT[a]	14 DAT[a]	21 DAT[a]	28 DAT[a]	35 DAT[a]
2	acetochlor	99	97ab	95ab	92ab	89abc
3	cloransulam-methyl	99	97ab	94ab	92ab	92ab
4	clomazone	98	96ab	94ab	89ab	84abc
5	dimethenamid-P	97	94ab	91ab	86ab	83bc
6	flumetsulam	99	96ab	94ab	90ab	88abc
7	fomesafen	98	95ab	93ab	89ab	88abc
8	flumioxazin	99	96ab	95ab	91ab	89abc
9	imazaquin	98	96ab	94ab	89ab	88abc
10	metribuzin	99	97ab	96ab	92ab	91abc
11	norflurazon	98	93b	90b	85b	82c
12	pendimethalin	98	95ab	93ab	88ab	85abc
13	pyroxasulfone	98	93b	90b	86ab	84abc
14	*S*-metolachlor	99	96ab	94ab	89ab	88abc
15	sulfentrazone	99	97ab	95ab	93a	91abc
16	sulfentrazone + *S*-	99	96ab	93ab	90ab	88abc
17	*S*-metolachlor + metribuzin	99	96ab	94ab	91ab	90abc
18	*S*-metolachlor + fomesafen	99	95ab	93ab	90ab	89abc
19	sulfentrazone + metribuzin	99	96ab	95ab	91ab	90abc
20	acetochlor + fomesafen	98	95ab	93ab	88ab	85abc
21	sulfentrazone + flumioxazin	98	97ab	96ab	94a	91abc
22	flumioxazin + pyroxasulfone	99	98a	97a	94a	93a
	Mean	99	96	94	90	88
	p-values	0.1716	0.0127	0.0075	0.0005	<0.0001

[a] Means within each column with the same letter are not statistically different from each other (α=0.05)

[b]DAT= days after preemergence herbicide treatment

Table 1.5 ANOVA table for prickly sida (*Sida spinosa*) control rating at the R.R. Foil Plant Science Research Center, Mississippi State, MS and the Black Belt Branch Research Station in Brooksville, MS in 2021 and 2022.

Source	**DF**	**P-value 7 DAT**	**P-value 14 DAT**	**P-value 21 DAT**	**P-value 28 DAT**	**P-value 35 DAT**
Replication	3	0.4170	0.7759	0.2186	0.2056	0.4337
Herbicide	20	0.2920	0.0892	<0.0001	0.0020	0.0033
Planting Date	2	0.4421	0.2004	0.5665	0.5878	0.7798
Herbicide*Planting Date	40	0.8540	0.3964	0.2850	0.3953	0.6131
Year	1	0.4772	0.4911	0.7182	0.8839	0.5621
Location	1	0.5000	0.3446	0.4424	0.2789	0.3396
Error	927					

Table 1.6 Prickly sida (*Sida spinosa*) control following PRE herbicide application in soybean at the R.R. Foil Plant Science Research Center, Mississippi State, MS, and the Black Belt Branch Research Station in Brooksville, MS, in 2021 and 2022.

TRT	**Herbicide**	**7**	**14**	**21**	**28**	**35**
2	acetochlor	99	99	98abc	96b	95ab
3	cloransulam-methyl	100	99	99abc	98ab	97ab
4	clomazone	100	99	99abc	96b	94ab
5	dimethenamid-P	100	99	99abc	98ab	97ab
6	flumetsulam	100	99	99ab	99a	99a
7	fomesafen	99	99	98abc	97ab	96ab
8	flumioxazin	99	99	99abc	99a	98ab
9	imazaquin	99	99	99abc	98ab	97ab
10	metribuzin	100	100	99ab	99a	99ab
11	norflurazon	99	99	97bc	96b	96ab
12	pendimethalin	99	99	99abc	98ab	97ab
13	pyroxasulfone	99	99	96c	96b	96ab
14	*S*-metolachlor	99	99	99abc	98ab	96ab
15	sulfentrazone	99	99	98abc	97ab	97ab
16	sulfentrazone + *S*-	99	99	99abc	98ab	98ab
17	*S*-metolachlor + metribuzin	100	99	99ab	98ab	98ab
18	*S*-metolachlor + fomesafen	100	99	99abc	97ab	97ab
19	sulfentrazone + metribuzin	99	99	99abc	98ab	98ab
20	acetochlor + fomesafen	100	99	98abc	96b	93b
21	sulfentrazone + flumioxazin	100	100	100a	99a	99ab
22	flumioxazin +	100	100	100a	99a	99ab
	Mean	99	99	99	98	97
	p-values	0.2920	0.0892	<0.0001	0.0020	0.0033

[a]Means within each column with the same letter are not statistically different from each other (α=0.05).

[b]DAT= days after preemergence herbicide treatment

Table 1.7 ANOVA table for tall waterhemp (*Amaranthus tuberculatus*) control rating at the R.R. Foil Plant Science Research Center, Mississippi State, MS and the Black Belt Branch Research Station in Brooksville, MS in 2021 and 2022.

Source	**DF**	**P-value 7 DAT**	**P-value 14 DAT**	**P-value 21 DAT**	**P-value 28 DAT**	**P-value 35 DAT**
Replication	3	0.2399	0.7935	0.7032	0.4412	0.7884
Herbicide	20	0.8759	0.0186	0.0090	0.0393	0.0459
Planting Date	2	0.4064	0.2904	0.4351	0.3922	0.3955
Herbicide*Planting Date	40	0.9249	0.5312	0.5616	0.1659	0.1266
Year	1	0.5151	0.5696	0.5749	0.5443	0.5388
Location	1	0.4695	0.1193	0.2981	0.4235	0.3533
Error	844					

Table 1.8 Tall waterhemp (*Amaranthus tuberculatus*) control following PRE herbicide applications in soybean at the R.R. Foil Plant Science Research Center, Mississippi State, MS, and the Black Belt Branch Research Station in Brooksville, MS, in 2021 and 2022.

TRT	Herbicide	7	14	21	28	35
2	acetochlor	99	99ab	98ab	98ab	97ab
3	cloransulam-methyl	99	99ab	99ab	97ab	97ab
4	clomazone	99	99ab	98ab	97ab	96ab
5	dimethenamid-P	99	99ab	99ab	98ab	97ab
6	flumetsulam	99	99ab	99ab	99ab	99ab
7	fomesafen	99	99ab	99ab	99ab	97ab
8	flumioxazin	99	99ab	99ab	99ab	99ab
9	imazaquin	99	99ab	99ab	99ab	98ab
10	metribuzin	99	99ab	99a	99a	99a
11	norflurazon	99	99ab	98ab	96ab	94b
12	pendimethalin	99	99ab	98ab	97ab	95ab
13	pyroxasulfone	99	98b	97b	95b	94b
14	*S*-metolachlor	99	99a	99ab	99ab	99ab
15	sulfentrazone	99	99ab	99ab	98ab	96ab
16	sulfentrazone + *S*-	99	99ab	99ab	99ab	99ab
17	*S*-metolachlor + metribuzin	99	99ab	99ab	98ab	97ab
18	*S*-metolachlor + fomesafen	99	99ab	99ab	99ab	98ab
19	sulfentrazone + metribuzin	99	99ab	99ab	99ab	99ab
20	acetochlor + fomesafen	99	99ab	99ab	99ab	98ab
21	sulfentrazone + flumioxazin	99	99ab	99ab	99ab	98ab
22	flumioxazin + pyroxasulfone	99	99a	99a	99a	99a
	Mean	99	99	99	98	97
	p-values	0.8759	0.0186	0.0090	0.0393	0.0459

[a]Means within each column with the same letter are not statistically different from each other (α=0.05)

[b]DAT= days after preemergence herbicide treatment

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CHAPTER II

RAINFALL ACTIVATION REQUIREMENTS FOR LABELED PREEMERGENCE HERBICIDES IN SOYBEAN PRODUCTION

2.1 Abstract

Preemergence (PRE) herbicides require rainfall to become active in the soil. However, data are lacking in the amount of rainfall/overhead irrigation needed to activate PRE herbicides to maximize efficacy. Greenhouse studies were conducted to assess rainfall activation requirements for soil-applied herbicides in soybean. Soil with differing textures (sandy loam, loam, and clay loam) were collected from various locations in MS. Velvetleaf (*Abutilon theophrasti*) and barnyardgrass (*Echinochloa crus-galli*) control were evaluated following the application of herbicides including metribuzin at 702 g ai ha^{-1}, sulfentrazone at 368 g ai ha^{-1}, pyroxasulfone at 183 g ai ha^{-1}, and *S*-metolachlor at 1784 g ai ha^{-1} with the following rainfall amounts applied immediately after application of all herbicides: 25.4 mm ha^{-1}, 12.7 mm ha^{-1}, 9.5 mm ha^{-1}, 6.4 mm ha^{-1}, 3.2 mm ha^{-1}, and 0 mm ha^{-1} to each soil texture. Rainfall required for maximum efficacy varied by herbicide and soil texture. Some herbicides were effective at controlling weed species at low rainfall amounts (<12.7mm). This should ease growers' concerns of applying a PRE herbicide regardless of rain forecast, which helps introduce more modes of action into a season-long weed control program.

2.2 Introduction

Rainfall or irrigation is critical for preemergence (PRE) herbicide activation. Although rainfall usually has been given major consideration, perhaps soil moisture should be the primary consideration, with rainfall of secondary importance as it affects soil moisture. Three functions of surface-applied moisture with respect to residual herbicides include (a) herbicide movement into the soil and reduction of loss of the herbicide from the soil surface, (b) herbicide movement into the soil for contact with the germinating seeds or emerging weed seedlings, and (c) create sufficient moisture soil conditions for herbicide absorption by weed seedlings (Stickler et al. 1969). Generally, 6.4 mm ha^{-1}, 12.7 mm ha^{-1}, or 25.4 mm ha^{-1} of rainfall is needed to activate a PRE herbicide. However, factors such as soil texture and the amount of moisture already in the soil also are important when designating moisture needs for herbicide activation (Stickler et al. 1969).

The role of PRE herbicides in maintaining the competitive advantage of soybean over weeds during wet weather is readily apparent (Staniforth et al. 1963). Adequate rainfall to dissolve the herbicide into soil water solution so that it can be absorbed by developing weed seedlings within the first 15 days after PRE application is essential for effe ctive weed control (Landau et al., 2021). In situations where a PRE herbicide is very effective, a POST-applied herbicide may not be necessary (Taylor-Lovell et al. 2002).

Preemergence herbicides may provide adequate weed control when wet soil conditions preclude shallow cultivation. The general failure of PRE herbicides to control weeds under dry conditions can reduce effectiveness of a total weed management program (Staniforth et al. 1963). When cultivation is utilized after PRE herbicide application, cultivation timing is critical, and delays due to wet weather may reduce effectiveness. The success of shallow cultivation and PRE herbicide application on weed control depends largely on weather conditions, particularly rainfall, during the two weeks or less following planting. As a rule, 12.7 to 19.1 mm ha^{-1} of rainfall or overhead irrigation during this period is necessary to leach the herbicide into the zone of germinating weed seeds. Excessive rainfall during this period can reduce herbicide effectiveness, delay mechanical cultivation, and prevent effective weed control by cultivation. Many weedy soybean fields result from such delays (Staniforth et al. 1963).

Data are lacking in the amount of rainfall/overhead irrigation needed to activate PRE herbicides with control efficacy. Therefore, the purpose of this study was to determine the amount of activating rainfall needed for PRE herbicides to provide effective weed control. Growers often apply PRE herbicides at planting ahead and hope for adequate rainfall for activation. However, excessive rainfall can result in poor soybean emergence and reduced weed control.

2.3 Materials and Methods

A greenhouse study was conducted to assess rainfall activation requirements for soil-applied herbicides in soybean. The experiment was arranged in a randomized complete block design with four replications in a factorial arrangement of treatments: factor A consisted of three soil textures, and factor B consisted of rainfall amount. A sandy loam soil and a loam soil were collected from the R.R. Foil Plant Science Research Center near Starkville, MS, and a clay loam was collected from the Black Belt Branch Experiment Station near Brooksville, MS. All soil textures were determined by mechanical analysis by Waypoint™ Laboratories in Memphis, TN. The three soils were sieved with a 0.635cm x 0.635cm sieve. The sieved soil from each location was then placed into 2.7x10" containers from Stuewe & Sons, Inc. (Tangent, Oregon) for each soil texture, sub-irrigated to allow soil to moisten, and then allowed to drain and soil to harden.

Eight velvetleaf (*Abutilon theophrasti*) seeds and 0.4 g of barnyardgrass (*Echinochloa crus-galli*) seed were each planted 2.54 cm deep separately into cones of each soil texture. Metribuzin (702 g ai ha^{-1}, Dimetric®), sulfentrazone (368 g ai ha^{-1}, Shutdown™), pryoxasulfone (183 g ai ha^{-1}, Zidua® SC), and *S*-metolachlor (1784 g ai ha^{-1}, Dual Magnum®) were each applied to cones with each weed species and soil texture combination, as well as an untreated check. The physiochemical characteristics of these herbicides are listed in Table 2.1. Herbicide applications were made using a two-nozzle Devries (Gen 3, Devrise Manufacturing Inc., Hollandale, MN) research spray chamber with Teejet® XR 11002 VS nozzles (Teejet® Technologies, Glendale Heights, IL), calibrated to deliver 140 L ha^{-1}. Immediately after application, various rainfall amounts were applied using a rainfall simulator in the same research spray chamber. Rainfall amounts included: 25.4 mm ha^{-1}, 12.7 mm ha^{-1}, 9.5 mm ha^{-1}, 6.4 mm ha^{-1}, 3.2 mm ha^{-1}, and 0 mm ha^{-1} and were applied using with Teejet® XR 11006 VS nozzles (Teejet® Technologies, Glendale Heights, IL). This study was repeated twice.

Visual weed control data were collected every seven days for five weeks after application. Fresh weights of the weeds in each cone were collected 35 days after application. All data were subjected to ANOVA using SAS version 9.4. Data from each experiment timing were analyzed separately due to significant variation between these timings for most evaluation parameters. Means were separated using Tukey's protected HSD at $\alpha = 0.05$.

2.4 Results and Discussion

Barnyardgrass

Differences between experimental run for barnyardgrass control and biomass reduction were observed. Therefore, runs were analyzed and presented separately (Tables 2.2 and 2.3). For experiment one (Figures 2.1 and 2.9), 14 DAT, the application of metribuzin on a clay loam soil followed by 12.7 mm of simulated rainfall resulted in less barnyardgrass control (88%) than that observed following application of 25.4 mm of simulated rainfall (99%). No differences in barnyardgrass control were present between any of the other rainfall amounts following application of metribuzin. At 21 DAT, the application of metribuzin on a clay loam soil followed by 3.2 mm of simulated rainfall resulted in less barnyardgrass control (83%) than that observed following application of 25.4 mm of simulated rainfall (100%). No differences in barnyardgrass control were present between any of the other rainfall amounts following application of metribuzin. At 21 DAT, the application of metribuzin on a sandy loam soil followed by 6.4 mm of simulated rainfall resulted in less barnyardgrass control (73%) than that observed following application of 25.4 mm of simulated rainfall (99%). No differences in barnyardgrass control were present between any of the other rainfall amounts following application of metribuzin. At 28 DAT, the application of metribuzin on a sandy loam soil followed by 6.4 mm of simulated rainfall resulted in less barnyardgrass control (84%) than that observed following application of 25.4 mm and 0 mm of simulated rainfall (99%). No differences in barnyardgrass control were present between any of the other rainfall amounts following application of metribuzin. The application of metribuzin on a clay loam soil followed by 3.2 mm of simulated rainfall resulted in less biomass reduction of barnyardgrass (94%) than that observed following application of 6.4 mm of simulated rainfall (100%). No differences between any of the other rainfall amounts were observed with respect to barnyardgrass biomass reduction following application of metribuzin. The application of metribuzin on a loam soil followed by 12.7 mm of simulated rainfall resulted in less biomass reduction of barnyardgrass (29%) than that observed following application of all other simulated rainfall amounts (83-95%). There were no differences in barnyardgrass control or biomass reduction when metribuzin was applied for any of the other timings, rainfall amounts, or soil textures for experiment one.

For experiment two (Figures 2.2 and 2.10), 14 DAT, the application of metribuzin on a loam soil followed by 0 mm of rainfall resulted in less barnyardgrass control (54%) than that observed following application of 12.7 mm and 25.4 mm of simulated rainfall (81% and 88% respectively). No differences in barnyardgrass control were present between any of the other rainfall amounts following application of metribuzin. Also at 14 DAT, the application of metribuzin on a sandy loam soil followed by 3.2 mm of simulated rainfall resulted in less barnyardgrass control (43%) than that observed following application of 0 mm and 9.5 mm of simulated rainfall (83% and 81%, respectively). No differences in barnyardgrass control were present between any of the other rainfall amounts following application of metribuzin. At 21 DAT, the application of metribuzin on a sandy loam soil followed by 3.2 mm of simulated rainfall resulted in less barnyardgrass control (69%) than that observed following application of 0 mm of simulated rainfall (99%). No differences in barnyardgrass control were present between any of the other rainfall amounts following application of metribuzin. There were no differences in barnyardgrass control or biomass reduction when metribuzin was applied for any of the other timings, rainfall amounts, or soil textures for experiment two.

For both experiments one and two (Figures 2.3, 2.4, 2.9, and 2.10), there were no differences in barnyardgrass control or biomass reduction when pyroxasulfone was applied for any of the timings, rainfall amounts, or soil textures.

For experiment one (Figures 2.5 and 2.9), 21 DAT, the application of sulfentrazone on a loam soil followed by 0 mm of simulated rainfall resulted in less barnyardgrass control (67%) than that observed following application of 25.4 mm of simulated rainfall (98%). No differences in barnyardgrass control were present between any of the other rainfall amounts following application of sulfentrazone. At 21 DAT, the application of sulfentrazone on a sandy loam soil followed by 0 mm and 3.2 mm of simulated rainfall resulted in less barnyardgrass control (78% and 83%) respectively than that observed following application of 12.7 mm and 25.4 mm of simulated rainfall (100%). No differences in barnyardgrass control were present between any of the other rainfall amounts following application of sulfentrazone. At 28 and 35 DAT, the application of sulfentrazone on a sandy loam soil followed by 0 mm and 3.2 mm of simulated rainfall resulted in less barnyardgrass control (78% and 81% respectively) than that observed following application of 25.4 mm of simulated rainfall (100%). No differences in barnyardgrass control were present between any of the other rainfall amounts following application of sulfentrazone. The application of sulfentrazone on a clay loam soil followed by 0 mm and 3.2 mm of simulated rainfall resulted in less biomass reduction of barnyardgrass (56% and 72 % respectively) than that observed following application of all other rainfall amounts (97-100%). The application of sulfentrazone on a loam soil followed by 0 mm and 3.2 mm of simulated rainfall resulted in less biomass reduction of barnyardgrass (69% and 52% respectively) than that observed following application of 25.4 mm of simulated rainfall (95%). No differences between any of the other rainfall amounts were observed with respect to barnyardgrass biomass reduction following application of sulfentrazone. The application of sulfentrazone on a sandy loam soil followed by 0 mm and 3.2 mm of simulated rainfall resulted in less biomass reduction of barnyardgrass (87% and 67% respectively) than that observed following application of 12.7 mm and 25.4 mm of simulated rainfall (99% and 100% respectively), and the application of 3.2 mm of simulated rainfall resulting in less biomass reduction than that observed following application of 9.5 mm of simulated rainfall (96%). No differences between any of the other rainfall amounts were observed with respect to barnyradgrass biomass reduction following application of sulfentrazone. There were no differences in barnyardgrass control or biomass reduction when sulfentrazone was applied for any of the other timings, rainfall amounts, or soil textures for experiment one.

For experiment two (Figures 2.6 and 2.10), 14, 21, 28, and 35 DAT, the application of sulfentrazone on a loam soil followed by 3.2 mm of simulated rainfall resulted in less barnyardgrass control (14 DAT: 85%; 21, 28, and 35 DAT: 69%) than that observed following application of 0 mm, 6.4 mm, 12.7 mm, and 25.4 mm of simulated rainfall (96-100%). No differences in barnyardgrass control were present between any of the other rainfall amounts following application of sulfentrazone. The application of sulfentrazone on a clay loam soil followed by 0 mm and 3.2 mm of simulated rainfall resulted in less biomass reduction of barnyardgrass (76% and 86% respectively) than that observed following application of with 6.4 mm, 12.7 mm, and 25.4 mm of simulated rainfall (100%). No differences between any of the other rainfall amounts were observed with respect to barnyardgrass biomass reduction following application of sulfentrazone. The application of sulfentrazone on a loam soil followed by 3.2 mm of simulated rainfall resulted in less biomass reduction of barnyardgrass (55%) than that observed following application of 0 mm, 6.4 mm, 12.7 mm, and 25.4 mm of simulated rainfall (100%). No differences between any of the other rainfall amounts were observed with respect to barnyardgrass biomass reduction following application of sulfentrazone. There were no differences in barnyardgrass control or biomass reduction when sulfentrazone was applied for any of the other timings, rainfall amounts, or soil textures for experiment two.

For experiment one (Figures 2.7 and 2.9), there were no differences in barnyardgrass control or biomass reduction when *S*-metolachlor was applied for any of the timings, rainfall amounts, or soil textures. For experiment two (Figures 2.8 and 2.10), 28 DAT, the application of *S*-metolachlor on a sandy loam soil followed by 3.2 mm of simulated rainfall resulted in less barnyardgrass control (83%) than that observed following application of 12.7 mm of simulated rainfall (98%). No differences in barnyardgrass control were present between any of the other rainfall amounts following application of *S*-metolachlor. 35 DAT, the application of *S*-metolachlor on a sandy loam soil followed by 3.2 mm of simulated rainfall resulted in less barnyardgrass control (85%) than that observed following application of 12.7 mm and 25.4 mm of simulated rainfall (99%). No differences in barnyardgrasss control were present between any of the other rainfall amounts following application of *S*-metolachlor. There were no differences in barnyardgrass control when *S*-metolachlor was applied for any of the other timings, rainfall amounts, or soil textures for experiment two. There were no differences in barnyardgrass biomass reduction when *S*-metolachlor was applied for any of the timings, rainfall amounts, or soil textures for experiment two.

Velvetleaf

Differences between experimental run for velvetleaf control and biomass reduction, were observed. Therefore, runs were analyzed and presented separately. For experiment one (Figures 2.11 and 2.19), 7 DAT, the application of metribuzin on a clay loam soil followed by 6.4 mm of simulated rainfall resulted in less velvetleaf control (54%) than that observed following application of 0 mm, 12.7 mm, and 25.4 mm of simulated rainfall (100%). No differences in velvetleaf control were present between any of the other rainfall amounts following application of metribuzin. 14 DAT, the application of metribuzin on a clay loam soil followed by 0 mm of simulated rainfall resulted in less velvetleaf control (60%) than that observed following application of 9.5 mm, 12.7 mm, and 25.4 mm of simulated rainfall (97-100%). No differences in velvetleaf control were present between any of the other rainfall amounts following application of metribuzin. There were no differences in velvetleaf control or biomass reduction when metribuzin was applied for any of the other timings, rainfall amounts, or soil textures for experiment one.

For experiment two (Figures 2.12 and 2.20), 7 DAT, the application of metribuzin on a clay loam soil followed by 3.2 mm of simulated rainfall resulted in less velvetleaf control (22%) than that observed following application of 0 mm, 6.4 mm, 9.5 mm, and 25.4 mm of simulated rainfall (100%). No differences in velvetleaf control were present between any of the other rainfall amounts following application of metribuzin. 7 DAT, the application of metribuzin on a loam soil followed by 3.2 mm of simulated rainfall resulted in less velvetleaf control (3%) than that observed following application of 6.4 mm, 9.5 mm, 12.7 mm, and 25.4 mm of simulated rainfall (85-100%). No differences in velvetleaf control were present between any of the other rainfall amounts following application of metribuzin. 7 DAT, the application of metribuzin on a sandy loam soil followed by 3.2 mm of simulated rainfall resulted in less velvetleaf control (10%) than that observed following application of 0 mm, 6.4 mm, 12.7 mm, and 25.4 mm of simulated rainfall (85-100%). No differences in velvetleaf control were present between any of the other rainfall amounts following application of metribuzin. There were no differences in velvetleaf control or biomass reduction when metribuzin was applied for any of the other timings, rainfall amounts, or soil textures for experiment two.

For experiment one (Figures 2.13 and 2.19), 7 DAT, the application of pyroxasulfone on a clay loam soil followed by 6.4 mm of simulated rainfall resulted in less velvetleaf control (63%) than that observed following application of 25.4 mm of simulated rainfall (100%). No differences in velvetleaf control were present between any of the other rainfall amounts following application of pyroxasulfone. 14 DAT, the application of pyroxasulfone on a clay loam soil followed by 3.2 mm of simulated rainfall resulted in less velvetleaf control (25%) than that observed following application of 9.5 mm, 12.7 mm, and 25.4 mm of simulated rainfall (88-100%), and the application of 0 mm, 3.2 mm, and 6.4 mm of simulated rainfall resulting in less velvetleaf control (53%, 25%, and 60% respectively) than that observed following the application of 25.4 mm of simulated rainfall (100%). No differences in velvetleaf control were present between any of the other rainfall amounts following application of pyroxasulfone. 21 DAT, the application of pyroxasulfone on a clay loam soil followed by 3.2 mm of simulated rainfall resulted in less velvetleaf control (41%) than that observed following application of 25.4 mm of simulated rainfall (100%). No differences in velvetleaf control were present between any of the other rainfall amounts following application of pyroxasulfone. 7 DAT, the application of pyroxasulfone on a loam soil followed by 6.4 mm of simulated rainfall resulted in less velvetleaf control (38%) than that observed following application of 25.4 mm of simulated rainfall (97%). No differences in velvetleaf control were present between any of the other rainfall amounts following application of pyroxasulfone. 14 DAT, the application of pyroxasulfone on a loam soil followed by 0 mm, 3.2 mm, and 6.4 mm of simulated rainfall resulted in less velvetleaf control (50%, 63%, and 47% respectively) than that observed following application of with 25.4 mm of simulated rainfall (100%), and the application of 6.4 mm of simulated rainfall resulting in less velvetleaf control than that observed following application of 9.5 mm of simulated rainfall (94%). No differences in velvetleaf control were present between any of the other rainfall amounts following application of pyroxasulfone. 21 DAT, the application of pyroxasulfone on a loam soil followed by 0 mm and 6.4 mm of simulated rainfall resulted in less velvetleaf control (60% and 50% respectively) than that observed following application of 25.4 mm of simulated rainfall (100%), and the application of 6.4 mm of simulated rainfall resulting in less velvetleaf control than that observed following application of 9.5 mm of simulated rainfall (94%). No differences in velvetleaf control were present between any of the other rainfall amounts following application of pyroxasulfone. 28 DAT, the application of pyroxasulfone on a loam soil followed by 0 mm and 6.4 mm of simulated rainfall resulted in less velvetleaf control (66%) than that observed following application of 25.4 mm of simulated rainfall (100%). No differences in velvetleaf control were present between any of the other rainfall amounts following application of pyroxasulfone. 35 DAT, the application of pyroxasulfone on loam soil followed by 0 mm of simulated rainfall resulted in less velvetleaf control (66%) than that observed following application of 25.4 mm of simulated rainfall (100%). No differences in velvetleaf control were present between any of the other rainfall amounts following application of pyroxasulfone. 7 DAT, the application of pyroxasulfone on sandy loam soil followed by 6.4 mm of simulated rainfall resulted in less velvetleaf control (82%) than that observed following application of 0 mm of simulated rainfall (100%). No differences in velvetleaf control were present between any of the other rainfall amounts following application of pyroxasulfone. The application of pyroxasulfone on a clay loam soil followed by 0 mm and 3.2 mm of simulated rainfall resulted in less biomass reduction of velvetleaf (82% and 88% respectively) than that observed following application of 12.7 mm and 25.4 mm of simulated rainfall (100%). No differences between any of the other rainfall amounts were observed with respect to velvetleaf biomass reduction following application of pyroxasulfone. The application of pyroxasulfone on a loam soil followed by 0 mm, 6.4, and 12.7 mm of simulated rainfall resulted in less biomass reduction of velvetleaf (91%, 87%, and 79% respectively) than that observed following application of 25.4 mm of simulated rainfall (100%). No differences between any of the other rainfall amounts were observed with respect to velvetleaf biomass reduction following application of pyroxasulfone. The application of pyroxasulfone on a sandy loam soil followed by 3.2 mm and 6.4 mm of simulated rainfall resulted in less biomass reduction of velvetleaf (87% and 94% respectively) than that observed following application of 12.7 mm of simulated rainfall (100%), and the application of 3.2 mm of simulated rainfall resulting in less velvetleaf control than that observed following application of 9.5 mm of simulated rainfall (99%). No differences between any of the other rainfall amounts were observed with respect to velvetleaf biomass reduction following application of pyroxasulfone. There were no differences in velvetleaf control or biomass reduction when pyroxasulfone was applied for any of the other timings, rainfall amounts, or soil textures for experiment one.

For experiment two (Figures 2.14 and 2.20), 7 DAT, the application of pyroxasulfone on a clay loam soil followed by 6.4 mm of simulated rainfall resulted in less velvetleaf control (22%) than that observed following application of all the other simulated rainfall amounts (100%). 7 DAT, the application of pyroxasulfone on a loam soil followed by 3.2 mm and 6.4 mm of simulated rainfall resulted in less velvetleaf control (35% and 6% respectively) than that observed following application of 25.4 mm of simulated rainfall (100%), and the application of 6.4 mm of simulated rainfall resulting in less velvetleaf control than that observed following application of 0 mm and 9.5 mm of simulated rainfall (69 % and 81% respectively). No differences in velvetleaf control were present between any of the other rainfall amounts following application of pyroxasulfone. 14 DAT, the application of pyroxasulfone on a loam soil followed by 0 mm and 3.2 mm of simulated rainfall resulted in less velvetleaf control (63% and 47% respectively) than that observed following application of 25.4 mm of simulated rainfall (100%), and the application of 3.2 mm of simulated rainfall resulting in less velvetleaf control than that observed following application of 9.5 mm and 12.7 mm of simulated rainfall (91% and 97% respectively). No differences in velvetleaf control were present between any of the other rainfall amounts following application of pyroxasulfone. There were no differences in velvetleaf control when pyroxasulfone was applied for any of the other timings, rainfall amounts, or soil textures for experiment two. There were no differences in velvetleaf biomass reduction when pyroxasulfone was applied for any of the timings, rainfall amounts, or soil textures for experiment two.

For experiment one (Figures 2.15 and 2.19), 7, 14, and 21 DAT, the application of sulfentrazone on a clay loam soil followed by 6.4 mm of simulated rainfall resulted in less velvetleaf control (7 DAT: 54%; 14 and 21 DAT: 60%) than that observed following application of 9.5 mm, 12.7 mm, and 25.4 mm of simulated rainfall (100%). No differences in velvetleaf control were present between any of the other rainfall amounts following application of sulfentrazone. 28 and 35 DAT, the application of sulfentrazone on a clay loam soil followed by 0 mm of simulated rainfall resulted in less velvetleaf control (69%) than that observed following application of 9.5 mm and 25.4 mm of simulated rainfall (100%). No differences in velvetleaf control were present between any of the other rainfall amounts following application of sulfentrazone. 7, 14, and 21 DAT, the application of sulfentrazone on a loam soil followed by 0 mm of simulated rainfall resulted in less velvetleaf control (7 DAT: 72% ; 14 and 21 DAT: 76%) than that observed following application of 9.5 mm, 12.7 mm, and 25.4 mm of simulated rainfall (100%), and the application of 0 mm of simulated rainfall resulting in less velvetleaf control than 6.4 mm of simulated rainfall (100%) 14 DAT. No differences in velvetleaf control were present between any of the other rainfall amounts following application of sulfentrazone. 28 and 35 DAT, the application of sulfentrazone on a loam soil followed by 0 mm of simulated rainfall resulted in less velvetleaf control (79%) than that observed following application of 25.4 mm of simulated rainfall (100%). No differences in velvetleaf control were present between any of the other rainfall amounts following application of sulfentrazone. The application of sulfentrazone on a clay loam soil followed by 0 mm and 6.4 mm of simulated rainfall resulted in less biomass reduction of velvetleaf (65% and 59% respectively) than that observed following application of 9.5 mm, 12.7 mm, and 25.4 mm of simulated rainfall (99-100%). No differences between any of the other rainfall amounts were observed with respect to velvetleaf biomass reduction following application of sulfentrazone. The application of sulfentrazone on a loam soil followed by 0 mm and 3.2 mm of simulated rainfall resulted in less biomass reduction of velvetleaf (46% and 53% respectively) than that observed following application of all other simulated rainfall amounts (96-100%). There were no differences in velvetleaf control or biomass reduction when sulfentrazone was applied for any of the other timings, rainfall amounts, or soil textures for experiment one.

For experiment two (Figures 2.16 and 2.20), 7 DAT, the application of sulfentrazone on a clay loam soil followed by 6.4 mm of simulated rainfall resulted in less velvetleaf control (16%) than all other rainfall amounts (100%). 7 DAT, the application of sulfentrazone on a loam soil followed by 0 mm of simulated rainfall resulted in less velvetleaf control (35%) than that observed following application of 9.5 mm, 12.7 mm, and 25.4 mm of simulated rainfall (100%). No differences in velvetleaf control were present between any of the other rainfall amounts following application of sulfentrazone. There were no differences in velvetleaf control when sulfentrazone was applied for any of the other timings, rainfall amounts, or soil textures for experiment two. There were no significant differences in biomass reduction when sulfentrazone was applied for any of the timings, rainfall amounts, or soil textures for experiment two.

For experiment one (Figures 2.17 and 2.19), 7 DAT, the application of *S*-metolachlor on a clay loam soil followed by 9.5 mm of simulated rainfall resulted in less velvetleaf control (35%) than that observed following applicaion of 0 mm and 12.7 mm of simulated rainfall (94% and 69% respectively), and the application of 3.2 mm of simulated rainfall resulting in less velvetleaf control (47%) than that observed following application of 0 mm of simulated rainfall. No differences in velvetleaf control were present between any of the other rainfall amounts following application of *S*-metolachlor. 14, 28, and 35 DAT, the application of *S*-metolachlor on a clay loam soil followed by 9.5 mm of simulated rainfall resulted in less velvetleaf control (35%) than that observed following application of 12.7 mm of simulated rainfall (14 DAT: 69% ; 28 and 35 DAT: 78%). No differences in velvetleaf control were present between any of the other rainfall amounts following application of *S*-metolachlor. 7 DAT, the application of *S*-metolachlor on a loam soil followed by 9.5 mm and 12.7 mm of simulated rainfall resulted in less velvetleaf control (57% and 63% respectively) than that observed following application of 0 mm of simulated rainfall (94%). No differences in velvetleaf control were present between any of the other rainfall amounts following application of *S*-metolachlor. The application of *S*-metolachlor on a clay loam soil followed by 0 mm, 3.2 mm, and 9.5 mm of simulated rainfall resulted in less biomass reduction of velvetleaf (34%, 23%, and 33% respectively) than that observed following application of 25.4 mm of simulated rainfall (87%), and the application of 3.2 mm of simulated rainfall resulting in less biomass reduction of velvetleaf than that observed following application of 12.7 mm of simulated rainfall (68%). No differences between any of the other rainfall amounts were observed with respect to velvetleaf biomass reduction following application of *S*-metolachlor. The application of *S*-metolachlor on a loam soil followed by 25.4 mm of simulated rainfall resulted in less biomass reduction of velvetleaf (3%) than that observed following application of 0 mm, 3.2 mm, 9.5 mm, and 12.7 mm of simulated rainfall (47%, 58%, 43%, and 41% respectively), and the application of 6.4 mm of simulated rainfall resulting in less biomass reduction of velvetleaf (23%) than that observed following application of 3.2 mm of simulated rainfall. No differences between any of the other rainfall amounts were observed with respect to velvetleaf biomass reduction following application of *S*-metolachlor. The application of *S*-metolachlor on a sandy loam soil followed by 0 mm and 9.5 mm of simulated rainfall resulted in less biomass reduction of velvetleaf (33% and 26%) than that observed following application of 12.7 mm of simulated rainfall (67%). No differences between any of the other rainfall amounts were observed with respect to velvetleaf biomass reduction following application of *S*-metolachlor. There were no differences in velvetleaf control or biomass reduction when *S*-metolachlor was applied for any of the other timings, rainfall amounts, or soil textures for experiment one.

For experiment two (Figures 2.18 and 2.20), 14 DAT, the application of *S*-metolachlor on a clay loam soil followed by 0 mm and 6.4 mm of simulated rainfall resulted in less velvetleaf control (50%) than that observed following application of 9.5 mm, 12.7 mm, and 25.4 mm of simulated rainfall (100%). No differences in velvetleaf control were present between any of the other rainfall amounts following application of *S*-metolachlor. 21 DAT, the application of *S*-metolachlor on a clay loam soil followed by 3.2 mm of simulated rainfall resulted in less velvetleaf control (63%) than that observed following application of 9.5 mm, 12.7 mm, and 25.4 mm of simulated rainfall (97-100%). No differences in velvetleaf control were present between any of the other rainfall amounts following application of *S*-metolachlor. 28 DAT, the application of *S*-metolachlor on a clay loam soil followed by 3.2 mm of simulated rainfall resulted in less velvetleaf control (66%) than that observed following application of 9.5 mm and

25.4 mm of simulated rainfall (100%). No differences in velvetleaf control were present between any of the other rainfall amounts following application of *S*-metolachlor. 35 DAT, the application of *S*-metolachlor on a clay loam soil followed by 3.2 mm and 6.4 mm of simulated rainfall resulted in less velvetleaf control (66% and 85% respectively) than that observed following application of 9.5 mm and 25.4 mm of simulated rainfall (100%). No differences in velvetleaf control were present between any of the other rainfall amounts following application of *S*-metolachlor.

7 DAT, the application of *S*-metolachlor on a loam soil followed by 0 mm, 3.2 mm, and 9.5 mm of simulated rainfall resulted in less velvetleaf control (28%, 54%, and 72% respectively) than that observed following application of 6.4 mm and 12.7 mm of simulated rainfall (100%), and the application of 0 mm of simulated rainfall resulting in less velvetleaf control than that observed following application of 25.4 mm of simulated rainfall (97%). No differences in velvetleaf control were present between any of the other rainfall amounts following application of *S*-metolachlor. 14 and 21 DAT, the application of *S*-metolachlor on a loam soil followed by 0 mm and 9.5 mm of simulated rainfall resulted in less velvetleaf control (14 DAT: 25% and 54% respectively; 21 DAT: 38% and 63% respectively) than that observed following application of 6.4 mm, 12.7 mm, and 25.4 mm of simulated rainfall (100%). No differences in velvetleaf control were present between any of the other rainfall amounts following application of *S*-metolachlor. 28 and 35 DAT, the application of *S*-metolachlor on a loam soil followed by 0 mm and 9.5 mm of simulated rainfall resulted in less velvetleaf control (41% and 72% respectively) than that observed following application of 6.4 mm, 12.7 mm, and 25.4 mm of simulated rainfall (100%), and the application of 0 mm of simulated rainfall resulting in less velvetleaf control than that observed following application of 9.5 mm of

simulated rainfall. No differences in velvetleaf control were present between any of the other rainfall amounts following application of *S*-metolachlor.

14 DAT, the application of *S*-metolachlor on a sandy loam soil followed by 3.2 mm of simulated rainfall resulted in less velvetleaf control (32%) than that observed following application of 9.5 mm, 12.7 mm, and 25.4 mm of simulated rainfall (85%, 94%, and 97% respectively), and the application of 0 mm of simulated rainfall resulting in less velvetleaf control (44%) than that observed following application of 25.4 mm of simulated rainfall. No differences in velvetleaf control were present between any of the other rainfall amounts following application of *S*-metolachlor. 21 DAT, the application of *S*-metolachlor on a sandy loam soil followed by 0 mm, 3.2 mm, and 6.4 mm of simulated rainfall resulted in less velvetleaf control (56%, 44%, and 63% respectively) than that observed following application of 9.5 mm, 12.7 mm, and 25.4 mm of simulated rainfall (100%). No differences in velvetleaf control were present between any of the other rainfall amounts following application of *S*-metolachlor. 28 DAT, the application of *S*-metolachlor on a sandy loam soil followed by 0 mm and 3.2 mm of simulated rainfall resulted in less velvetleaf control (56% and 53% respectively) than that observed following application of 12.7 mm and 25.4 mm of simulated rainfall (100%). No differences in velvetleaf control were present between any of the other rainfall amounts following application of *S*-metolachlor. 35 DAT, the application of *S*-metolachlor on a sandy loam soil followed by 0 mm, 3.2 mm, and 6.4 mm of simulated rainfall resulted in less velvetleaf control (56%, 53%, and 79% respectively) than that observed following application of 12.7 mm and 25.4 mm of simulated rainfall (100%). No differences in velvetleaf control were present between any of the other rainfall amounts following application of *S*-metolachlor.

The application of *S*-metolachlor on a clay loam soil followed by 3.2 mm of simulated rainfall resulted in less biomass reduction of velvetleaf (64%) than that observed following application of 9.5 mm, 12.7 mm, and 25.4 mm of simulated rainfall (100%). No differences between any of the other rainfall amounts were observed with respect to velvetleaf biomass reduction following application of *S*-metolachlor. The application of *S*-metolachlor on a loam soil followed by 0 mm, 3.2 mm, and 9.5 mm of simulated rainfall resulted in less biomass reduction of velvetleaf (25%, 51%, and 41% respectively) than that observed following application of 6.4 mm, 12.7 mm, and 25.4 mm of simulated rainfall (100%). The application of *S*-metolachlor on a sandy loam soil followed by 0 mm, 3.2 mm, and 6.4 mm of simulated rainfall resulted in less biomass reduction of velvetleaf (69%, 30%, and 71% respectively) than that observed following application of 9.5 mm, 12.7 mm, and 25.4 mm of simulated rainfall (100%). There were no differences in velvetleaf control or biomass reduction when *S*-metolachlor was applied for any of the other timings, rainfall amounts, or soil textures for experiment two.

These data are consistent with previous research. Taylor-Lovell et al. (2002) found that large amounts of precipitation (9.4 mm ha^{-1}) received one week after PRE application may enhance performance of PRE herbicides. Burnside and Lipke (1962) found that increasing the rate of amiben lowered the amount of rainfall/ irrigation required for optimum weed control. Mindreboe (1970) found that certain PRE herbicides showed a correlation between days from spraying to first rainfall and % weed control. Landau et.al 2021 found that across three annual weed species, the probability of effective control increased as rainfall increased and was maximized when 10 mm or more of rainfall was received, and herbicide combinations required less rainfall to maximize the probability of effective control. Additionally, had higher odds of successfully controlling weeds were observed when herbicide combinations were utilized compared with the herbicides applied individually. Khalil et al. (2019) found that pyroxasulfone leached very well from cover crop residue up to 14 days after application even at low rainfall amounts (5 mm). Stickler et.al (1969) found that the effectiveness of atrazine increased when soil moisture increased from 25 to 31%, amiben effectiveness increased linearly with increasing moisture, and increasing moisture had little effect on propachlor, highlighting the different moisture requirements for different herbicides. Sebastian et.al (2016) found that *Kochia scoparia* L. can germinate at soil moisture potentials below the moisture required for flumioxazin and indaziflam activation, showing the need for adequate moisture to activate these PRE herbicides.

2.5 Conclusion

The purpose of this study was to determine the amount of activating rainfall needed for PRE herbicides to provide effective weed control. Rainfall recommendations vary by herbicide and soil texture. Most of the herbicides were effective at controlling weed species at low rainfall amounts (<12.7 mm), even down to 0 mm being effective in some cases. This phenomenon may be due to the PRE herbicides being activated with moisture rather than overhead rainfall. This should ease growers' concerns of applying a PRE herbicide regardless of rain forecast, which will introduce more herbicide modes of action into a growing season to help with resistance management.

2.6 Tables and Figures

Table 2.1 Physiochemical characteristics of herbicides used in this study (Herbicide Handbook, Shaner (2014))

Herbicide	**Kd (mL/g)**	**Koc (mL/g)**	**Pka**	**Vapor Pressure**	**Solubility (mg/L)**	**Half Life**
metribuzin	Clay Loam: 0.196 Sandy Loam: 0.0182 Silt Loam: 0.221	Average: 60 Clay Loam: 17 Sandy Loam: 3.14 Silt Loam: 14.5	1.0 (weak base)	1.6×10^{-5} Pa (20° C)	1100 (water 20°C)	30-60 days
pyroxasulfone	1.72	117	none (non-ionizable)	2.4×10^{-6} Pa (25° C)	3.49 (water 20°C)	16-26 days
sulfentrazone	<1	43	6.56	1.07×10^{-7} Pa (25° C)	110 (pH 6) 780 (pH 7)	121-302 days
S-metolachlor	Clay: 1.869 Sandy Loam: 2.157 Loam: 0.773	Average: 200 Clay: 66.7 Sandy Loam: 74.4 Loam: 110.4	none (non-ionizable)	1.73×10^{-3} (20°C) 3.73×10^{-3} Pa (25° C)	488 (water 20°C)	Field Half-life: 3-5 months Bioassay Half-life: 15-50 days

Table 2.2 ANOVA table for barnyardgrass (*Echinochloa crus-galli*) control and biomass reduction for first experiment at the R.R. Foil Plant Science Research Center, Mississippi State, MS in 2022.

Source	**DF**	**P-value 7 DAT**	**P-value 14 DAT**	**P-value 21 DAT**	**P-value 28 DAT**	**P-value 35 DAT**	**P-value Biomass Reduction**
Replication	3	0.1787	0.3934	0.6029	0.6308	0.5228	0.3488
Herbicide	3	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Rainfall Amount	5	0.0012	0.0036	<0.0001	0.0001	0.0001	<0.0001
Herbicide * Rainfall	15	<0.0001	<0.0001	0.0011	0.0003	0.0002	<0.0001
Soil Texture	2	<0.0001	0.0007	<0.0001	<0.0001	<0.0001	<0.0001
Herbicide * Soil	6	<0.0001	0.0051	0.0024	<0.0001	<0.0001	<0.0001
Rain * Soil	10	0.0002	0.1111	0.7977	0.3735	0.5289	0.0008
Herbicide * Rain * Soil	30	<0.0001	0.1321	0.2374	0.5811	0.6320	<0.0001
Error	213						

Table 2.3 ANOVA table for barnyardgrass (*Echinochloa crus-galli*) control and biomass reduction for second experiment at the R.R. Foil Plant Science Research Center, Mississippi State, MS in 2022.

Source	DF	P-value 7 DAT	P-value 14 DAT	P-value 21 DAT	P-value 28 DAT	P-value 35 DAT	P-value Biomass Reduction
Replication	3	0.0639	0.1119	0.1855	0.9197	0.5367	0.6334
Herbicide	3	0.0018	<0.0001	0.0001	<0.0001	0.0001	<0.0001
Rainfall Amount	5	0.0337	0.0557	0.0013	0.0009	<0.0001	0.0013
Herbicide * Rainfall	15	0.0167	0.0015	0.0047	0.0004	0.0029	<0.0001
Soil Texture	2	0.0134	0.0016	0.0011	<0.0001	<0.0001	0.0201
Herbicide * Soil	6	0.0859	<0.0001	0.3496	0.1641	0.0248	0.0202
Rain * Soil	10	0.3264	0.0649	0.0841	0.0417	0.0163	0.2613
Herbicide * Rain * Soil	30	0.4297	0.0001	0.0145	0.0006	<0.0001	0.0006
Error	213						

Table 2.4 ANOVA table for velvetleaf (*Abutilon theophrasti*) control and biomass reduction for first experiment at the R.R. Foil Plant Science Research Center, Mississippi State, MS in 2022.

Source	DF	P-value 7 DAT	P-value 14 DAT	P-value 21 DAT	P-value 28 DAT	P-value 35 DAT	P-value Biomass Reduction
Replication	3	0.3801	0.1381	0.2900	0.3765	0.3478	0.2609
Herbicide	3	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Rainfall Amount	5	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Herbicide * Rainfall	15	<0.0001	<0.0001	<0.0001	0.0408	0.0513	0.0004
Soil Texture	2	0.0031	0.0069	0.0314	0.0022	0.0051	0.0109
Herbicide * Soil	6	0.3836	0.4646	0.5204	0.6322	0.6897	0.2416
Rain * Soil	10	<0.0001	<0.0001	<0.0001	0.0019	0.0021	0.0057
Herbicide * Rain * Soil	30	0.0050	0.0032	0.0021	0.0012	0.0039	<0.0001
Error	213						

Table 2.5 ANOVA table for velvetleaf (*Abutilon theophrasti*) control and biomass reduction for second experiment at the R.R. Foil Plant Science Research Center, Mississippi State, MS in 2022.

Source	**DF**	**P-value 7 DAT**	**P-value 14 DAT**	**P-value 21 DAT**	**P-value 28 DAT**	**P-value 35 DAT**	**P-value Biomass Reduction**
Replication	3	0.7026	0.8066	0.5710	0.1047	0.0900	0.0916
Herbicide	3	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Rainfall Amount	5	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Herbicide * Rainfall	15	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Soil Texture	2	<0.0001	0.1462	0.3005	0.4593	0.0465	0.0059
Herbicide * Soil	6	0.0267	<0.0001	0.1516	0.2363	0.1042	0.0001
Rain * Soil	10	<0.0001	0.0006	<0.0001	0.0071	0.0019	0.0002
Herbicide * Rain * Soil	30	0.2804	<0.0001	<0.0001	0.0438	0.0007	<0.0001
Error	213						

Figure 2.1 Barnyardgrass (*Echinochloa crus-galli*) control at each soil texture and rainfall amount when metribuzin was applied at the R.R. Foil Plant Science Research Center, Mississippi State, MS in 2022 (first experiment).

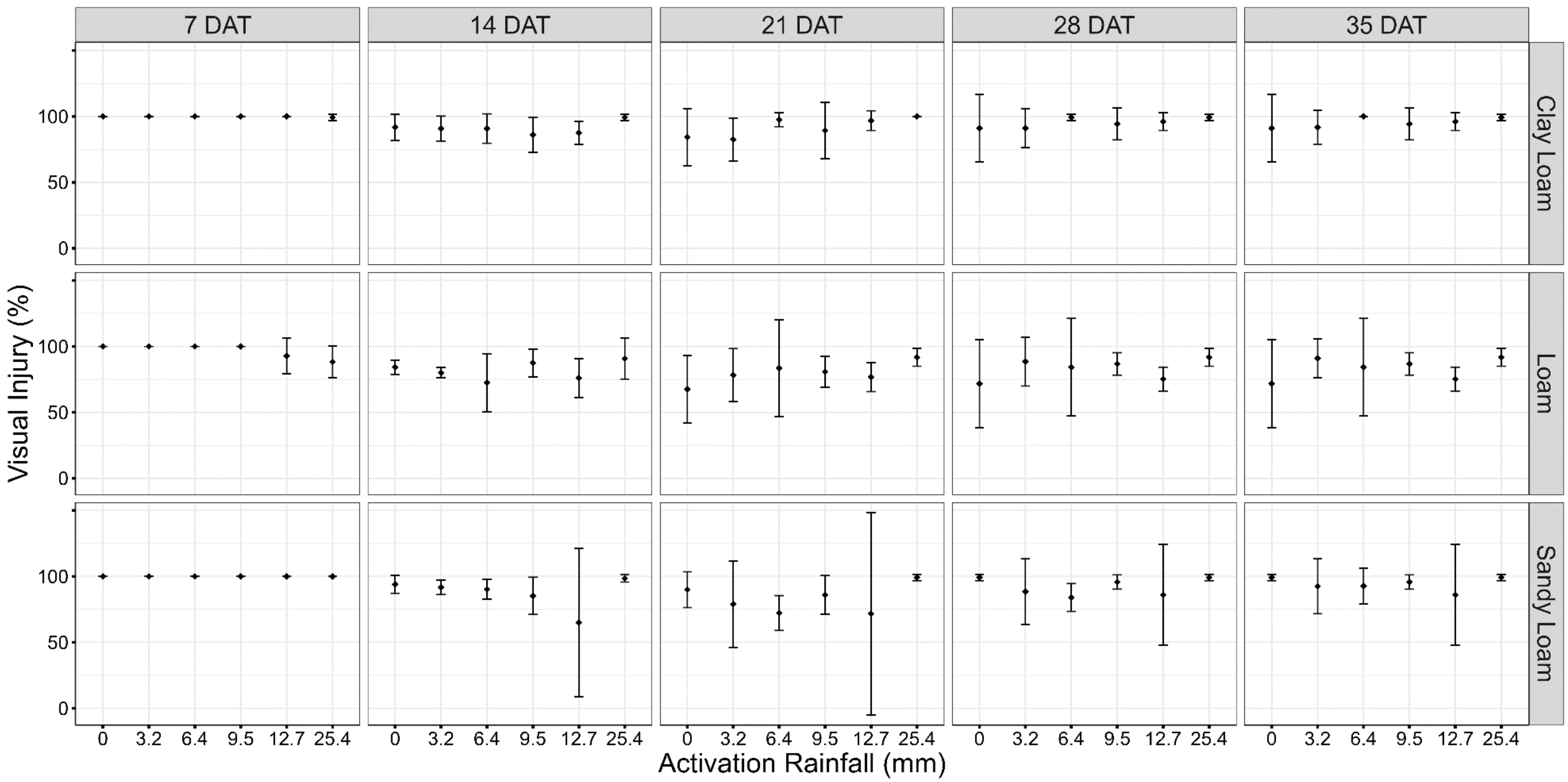


Figure 2.2 Barnyardgrass (*Echinochloa crus-galli*) control at each soil texture and rainfall amount when metribuzin was applied at the R.R. Foil Plant Science Research Center, Mississippi State, MS in 2022 (second experiment).

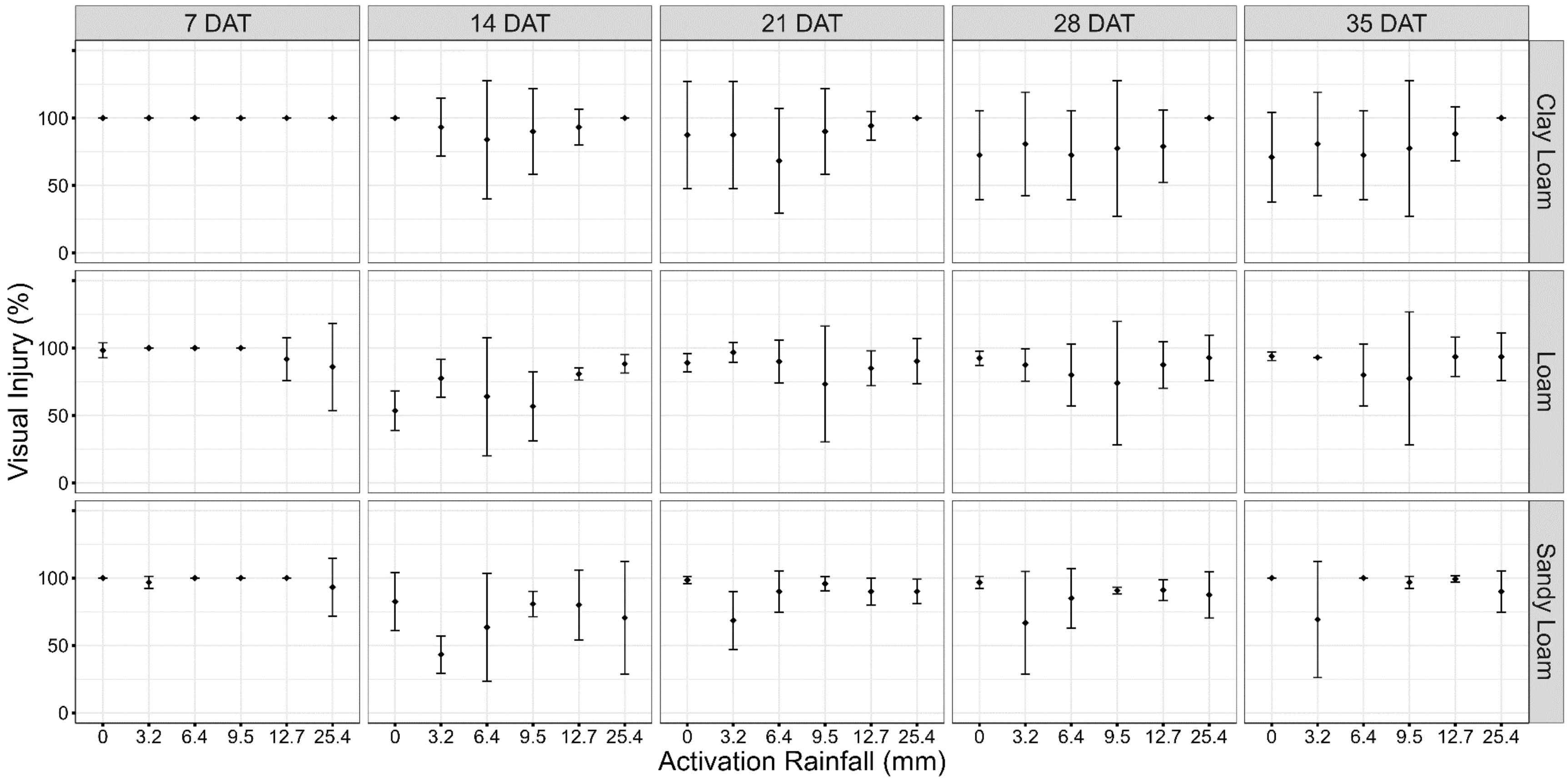


Figure 2.3 Barnyardgrass (*Echinochloa crus-galli*) control at each soil texture and rainfall amount when pyroxasulfone was applied at the R.R. Foil Plant Science Research Center, Mississippi State, MS in 2022 (first experiment).

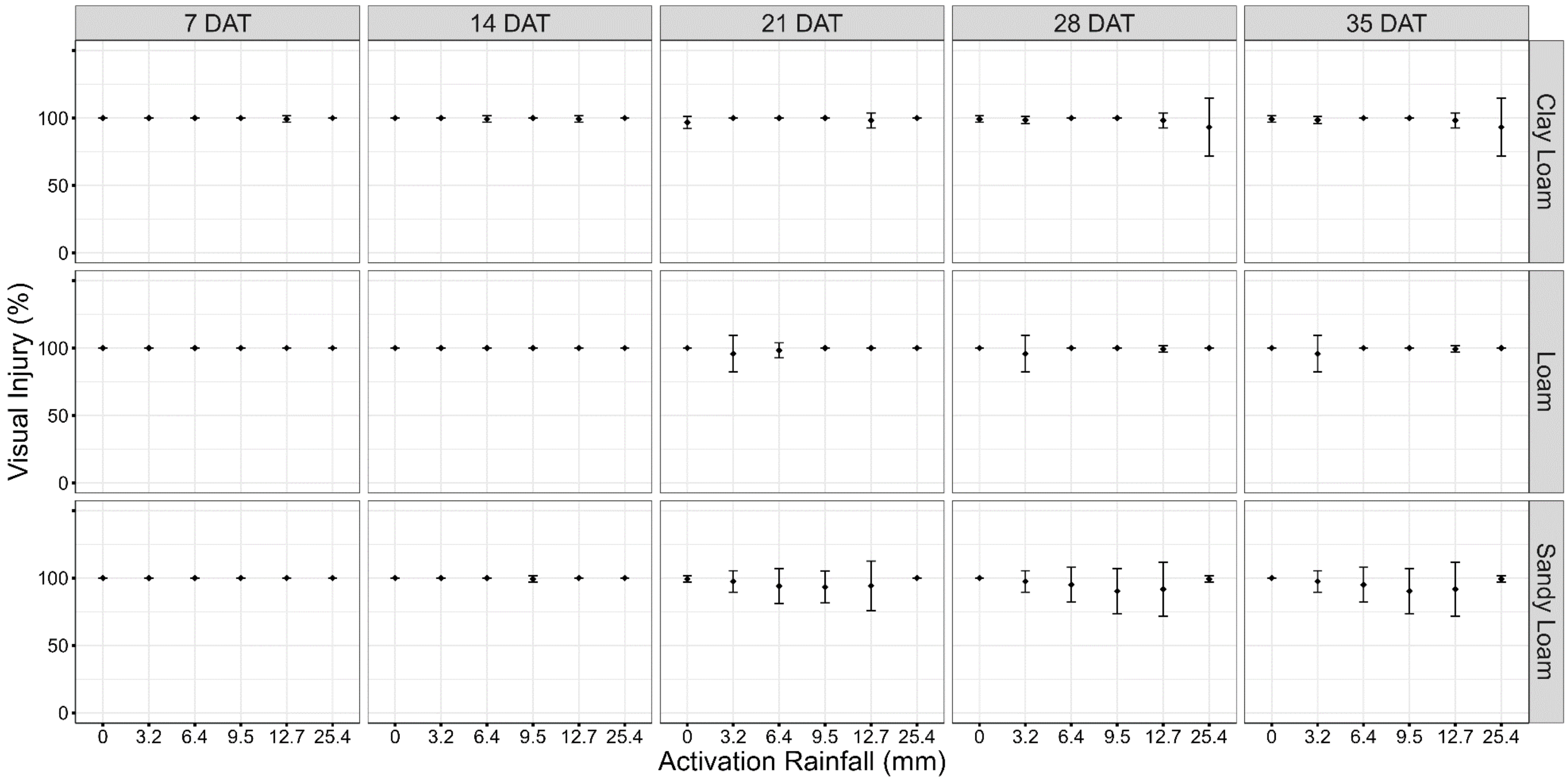


Figure 2.4 Barnyardgrass (*Echinochloa crus-galli*) control at each soil texture and rainfall amount when pyroxasulfone was applied at the R.R. Foil Plant Science Research Center, Mississippi State, MS in 2022 (second experiment).

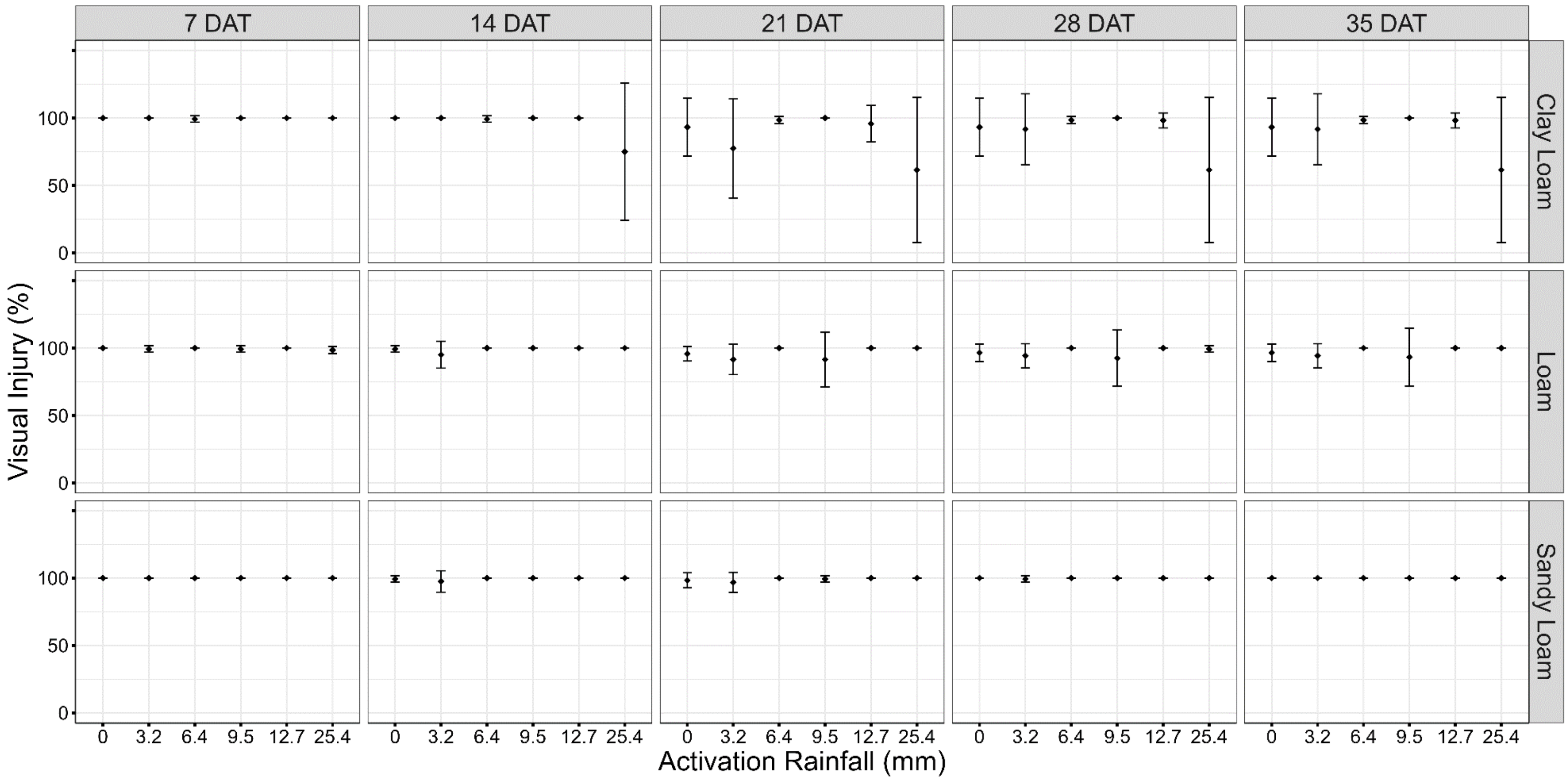


Figure 2.5 Barnyardgrass (*Echinochloa crus-galli*) control at each soil texture and rainfall amount when sulfentrazone was applied at the R.R. Foil Plant Science Research Center, Mississippi State, MS in 2022 (first experiment).

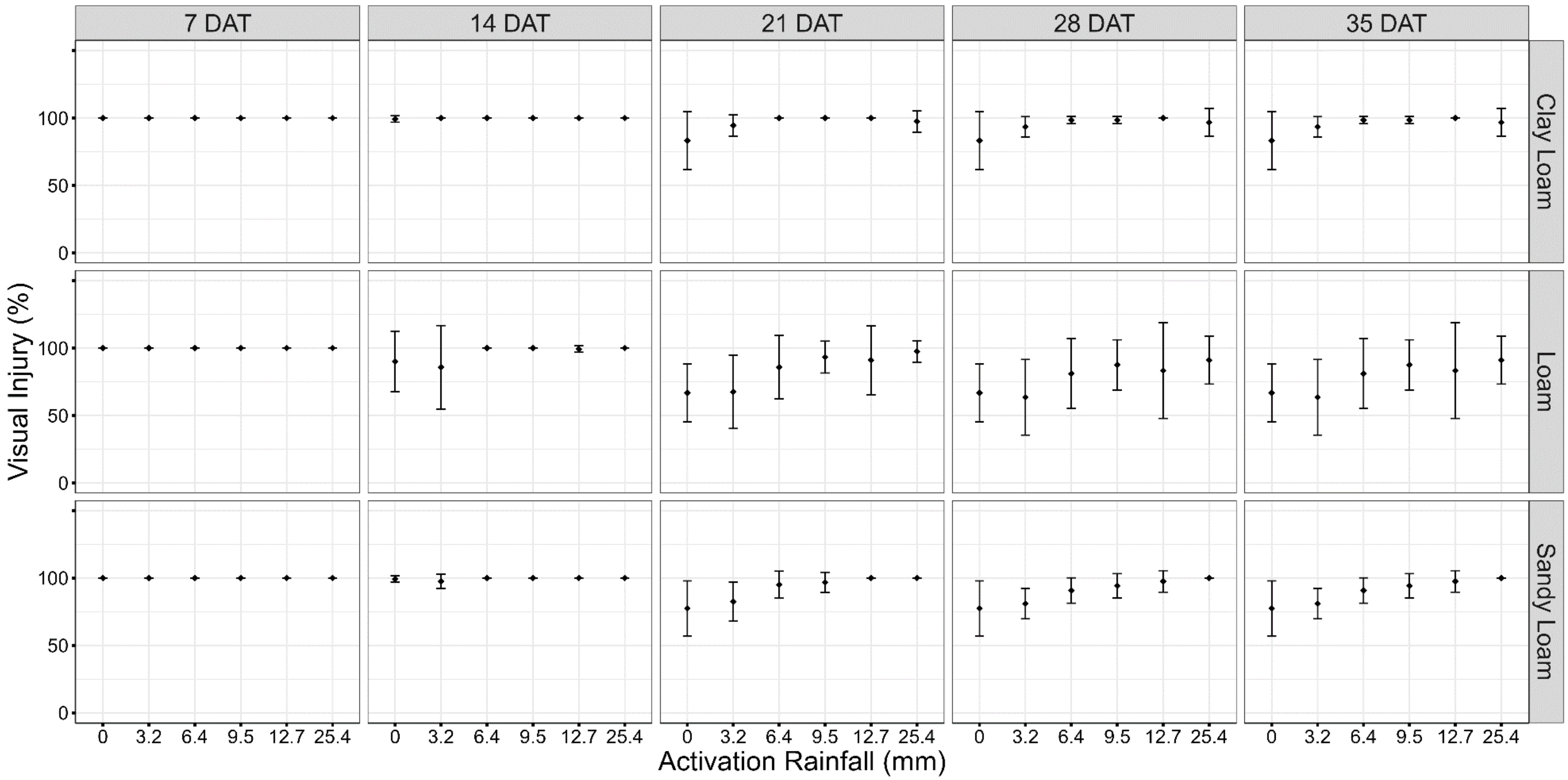


Figure 2.6 Barnyardgrass (*Echinochloa crus-galli*) control at each soil texture and rainfall amount when sulfentrazone was applied at the R.R. Foil Plant Science Research Center, Mississippi State, MS in 2022 (second experiment).

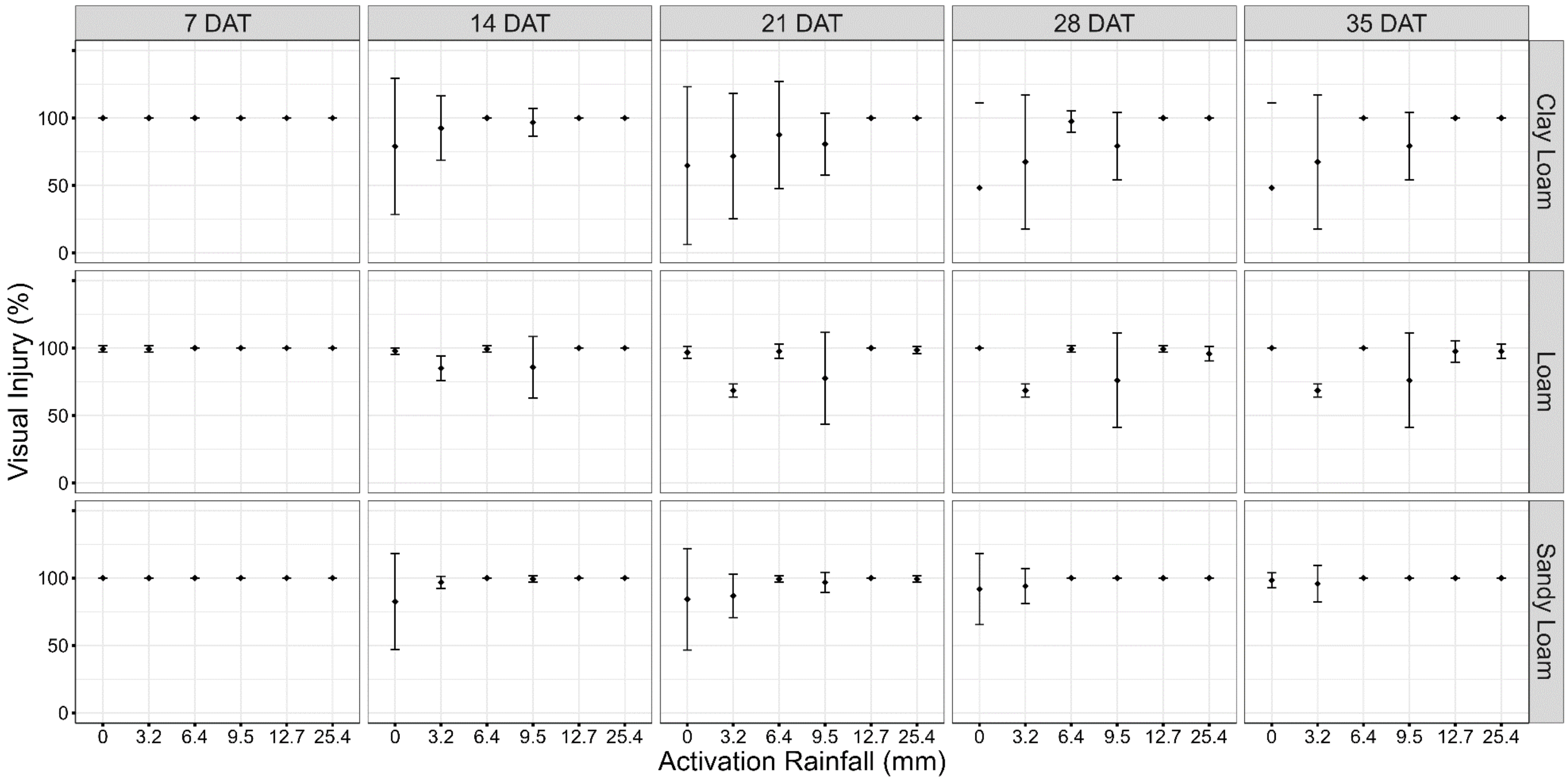


Figure 2.7 Barnyardgrass (*Echinochloa crus-galli*) control at each soil texture and rainfall amount when *S*-metolachlor was applied at the R.R. Foil Plant Science Research Center, Mississippi State, MS in 2022 (first experiment).

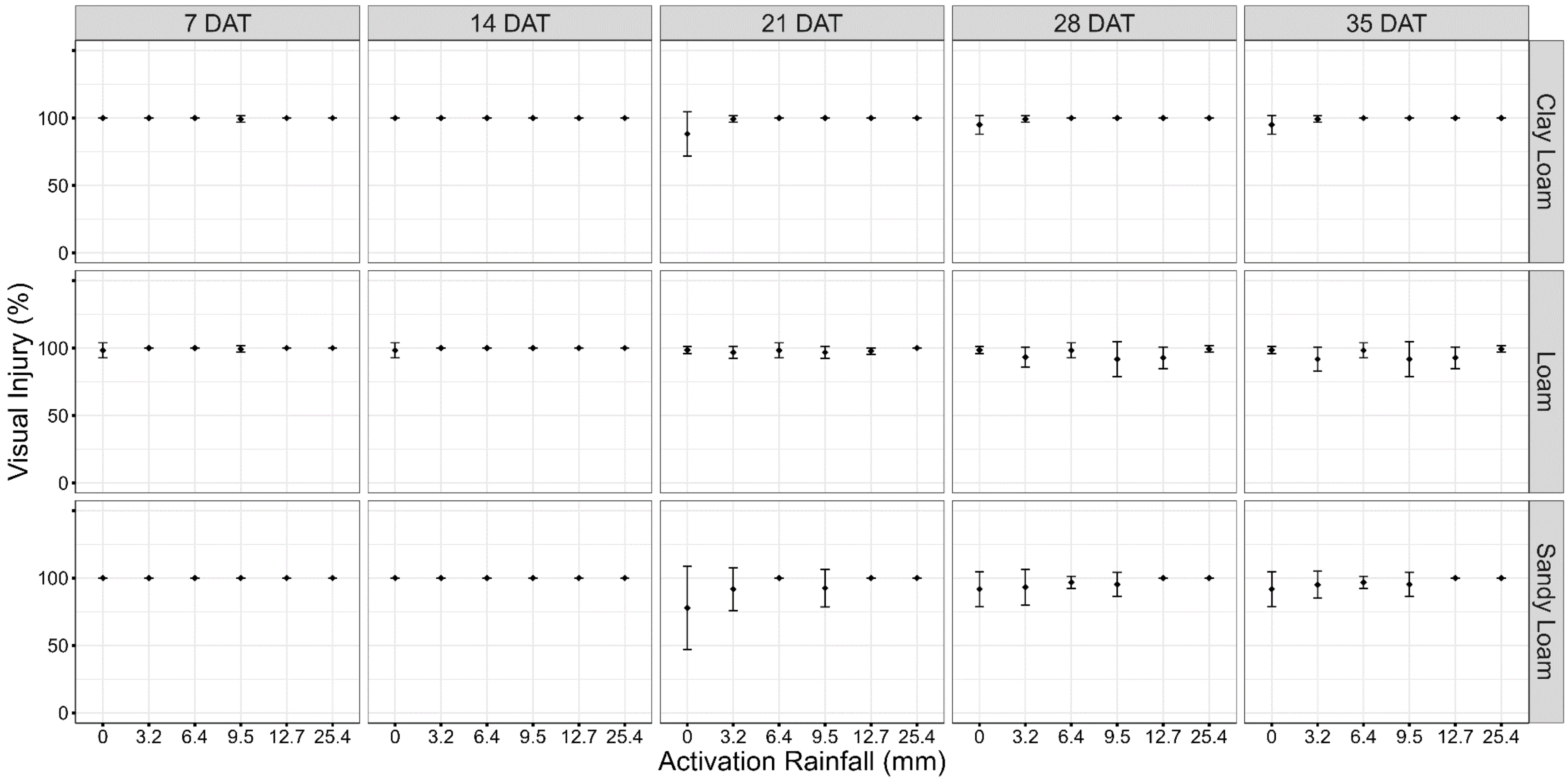


Figure 2.8 Barnyardgrass (*Echinochloa crus-galli*) control at each soil texture and rainfall amount when *S*-metolachlor was applied at the R.R. Foil Plant Science Research Center, Mississippi State, MS in 2022 (second experiment).

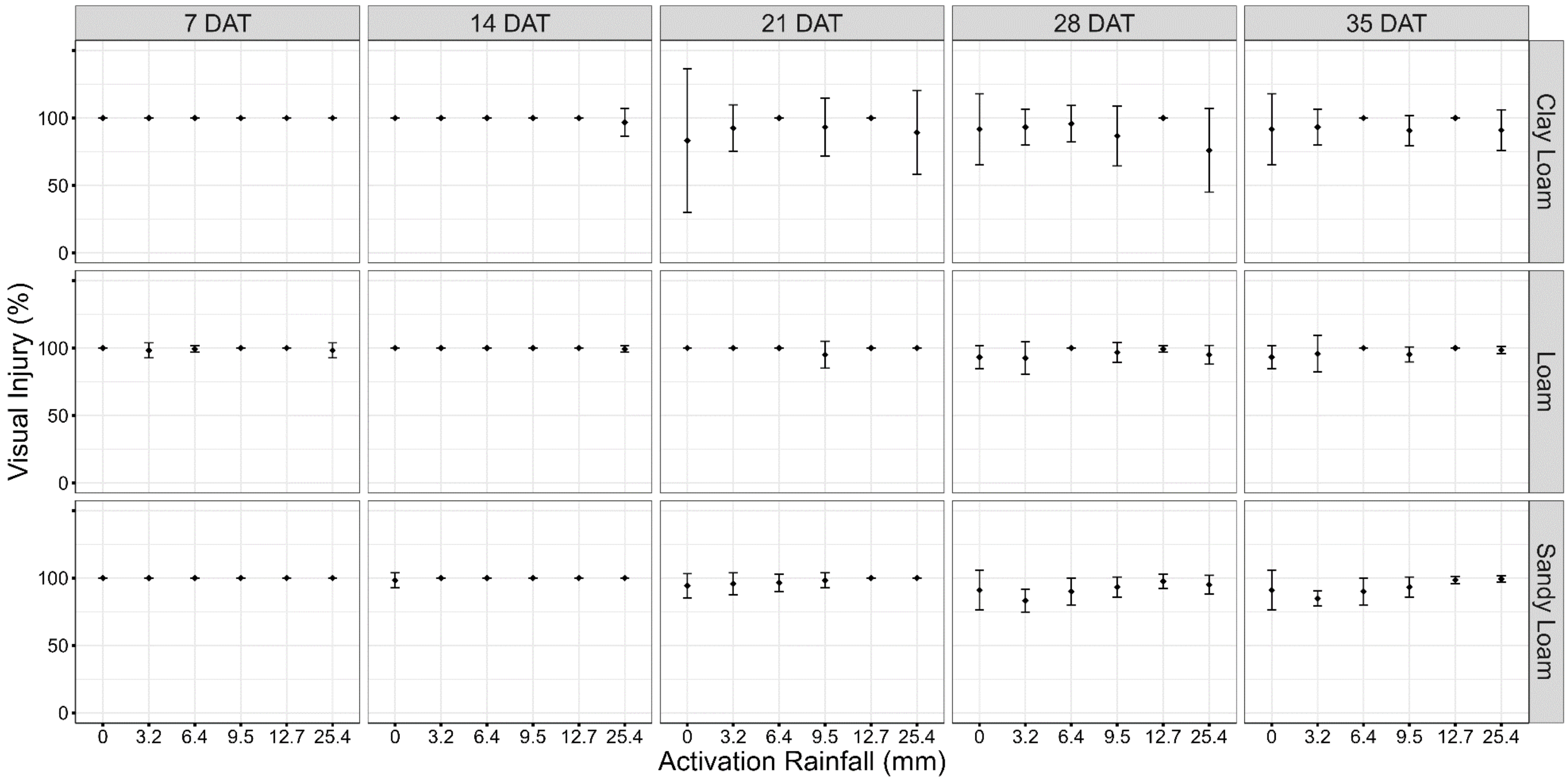


Figure 2.9 Barnyardgrass (*Echinochloa crus-galli*) biomass reduction at each soil texture and rainfall amount for each herbicide at the R.R. Foil Plant Science Research Center, Mississippi State, MS in 2022 (first experiment).

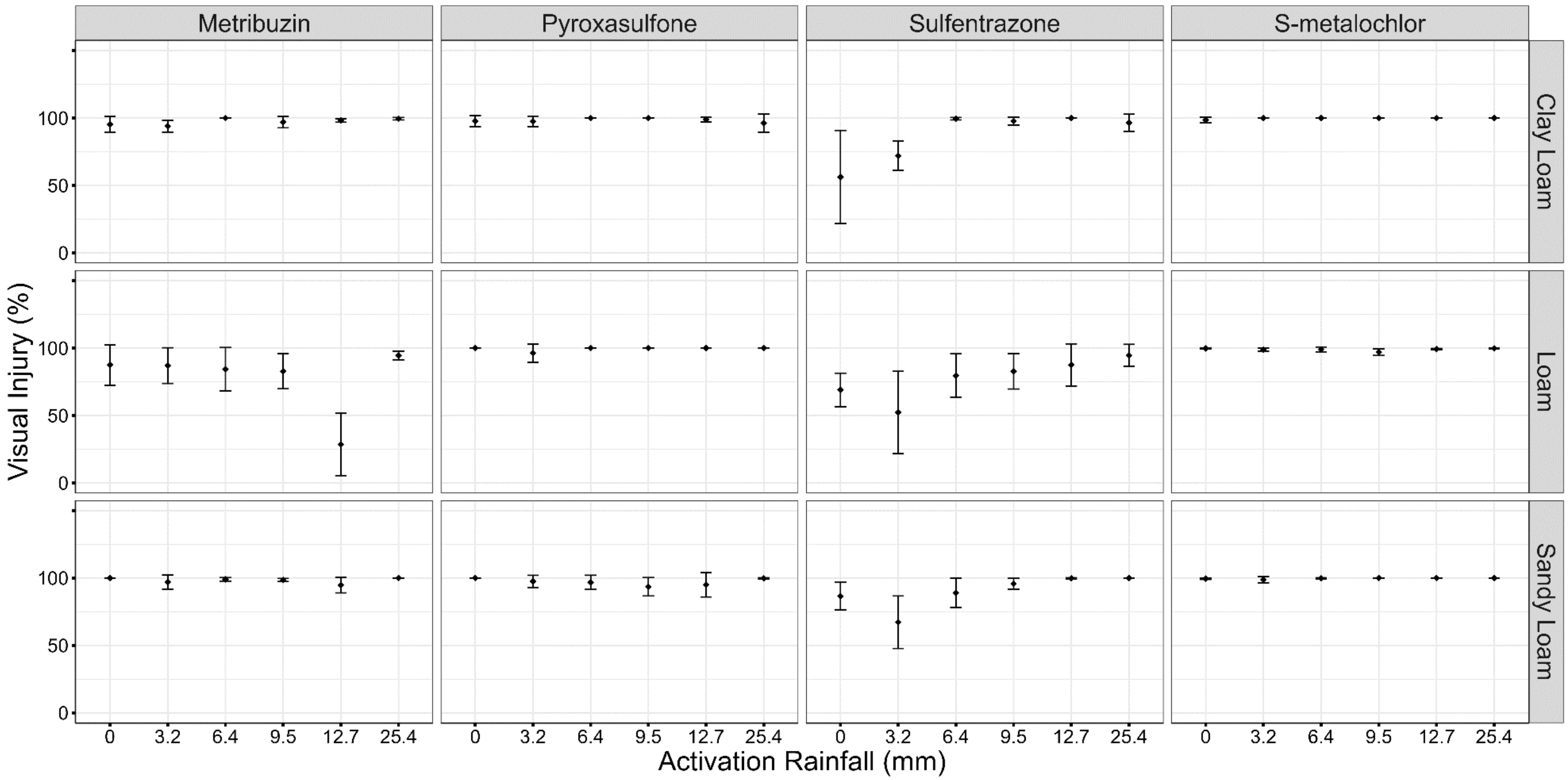


Figure 2.10 Barnyardgrass (*Echinochloa crus-galli*) biomass reduction at each soil texture and rainfall amount for each herbicide at the R.R. Foil Plant Science Research Center, Mississippi State, MS in 2022 (second experiment).

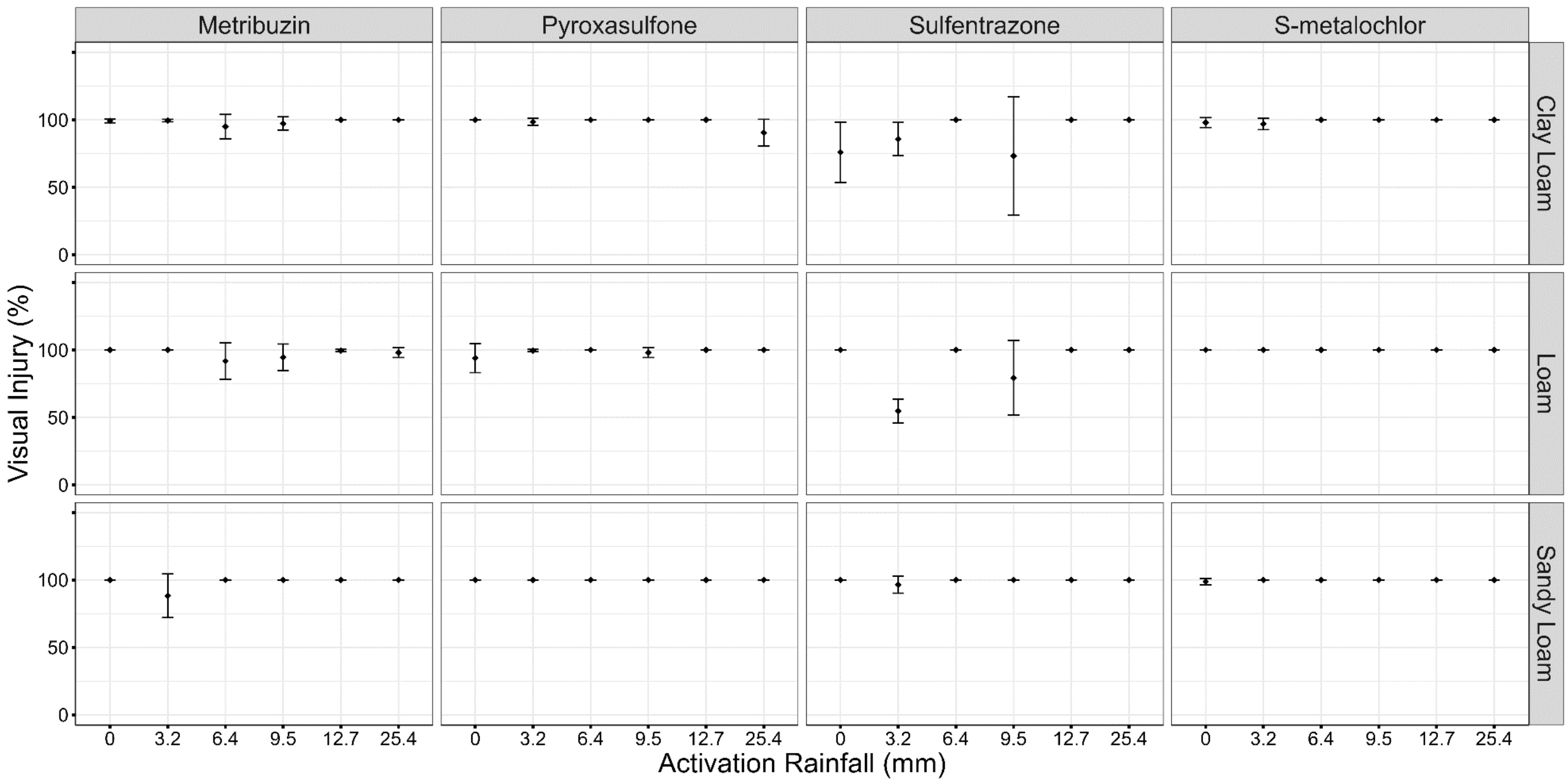


Figure 2.11 Velvetleaf (*Abutilon theophrasti*) control at each soil texture and rainfall amount when metribuzin was applied at the R.R. Foil Plant Science Research Center, Mississippi State, MS in 2022 (first experiment).

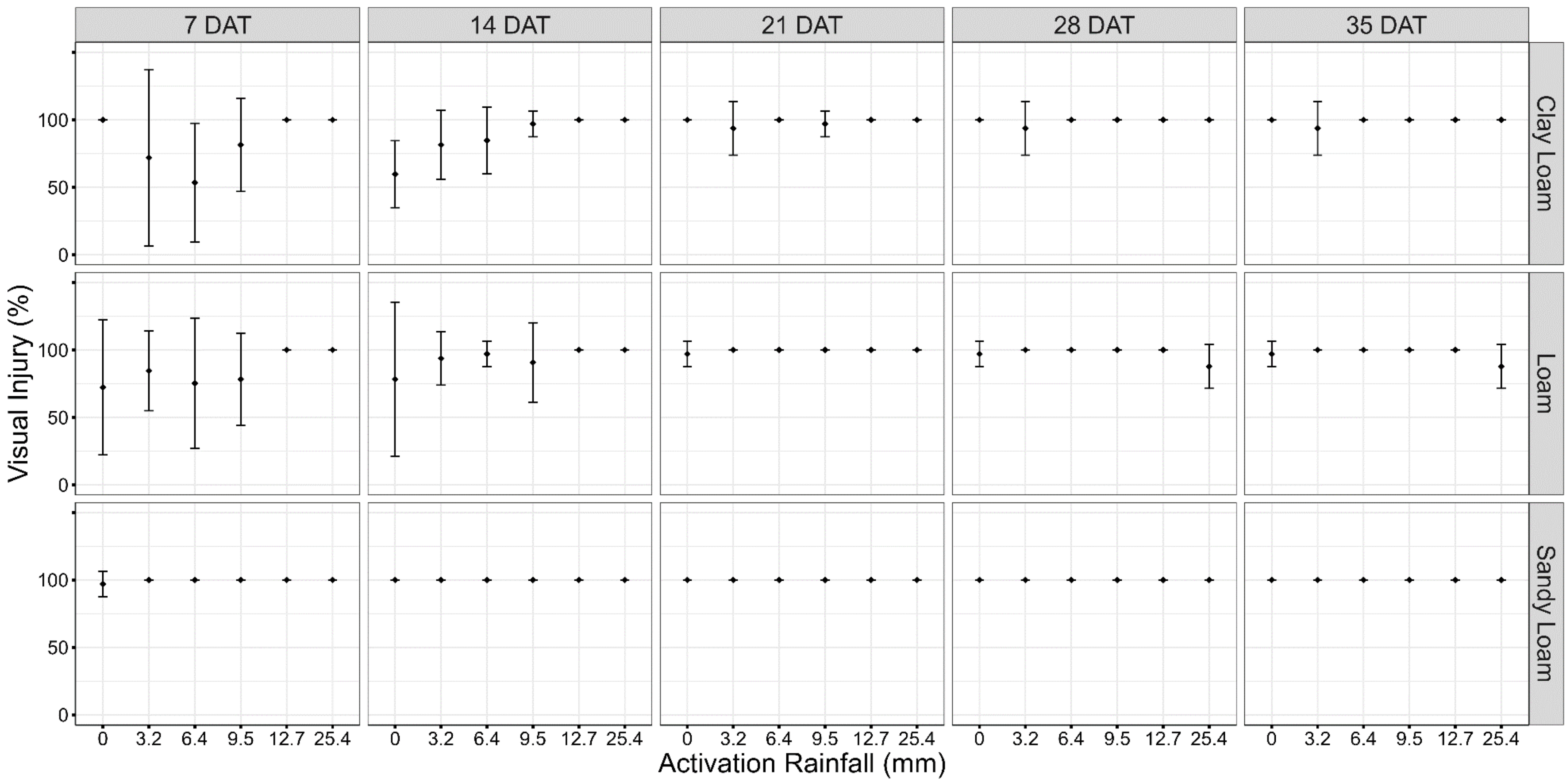


Figure 2.12 Velvetleaf (*Abutilon theophrasti*) control at each soil texture and rainfall amount when metribuzin was applied at the R.R. Foil Plant Science Research Center, Mississippi State, MS in 2022 (second experiment).

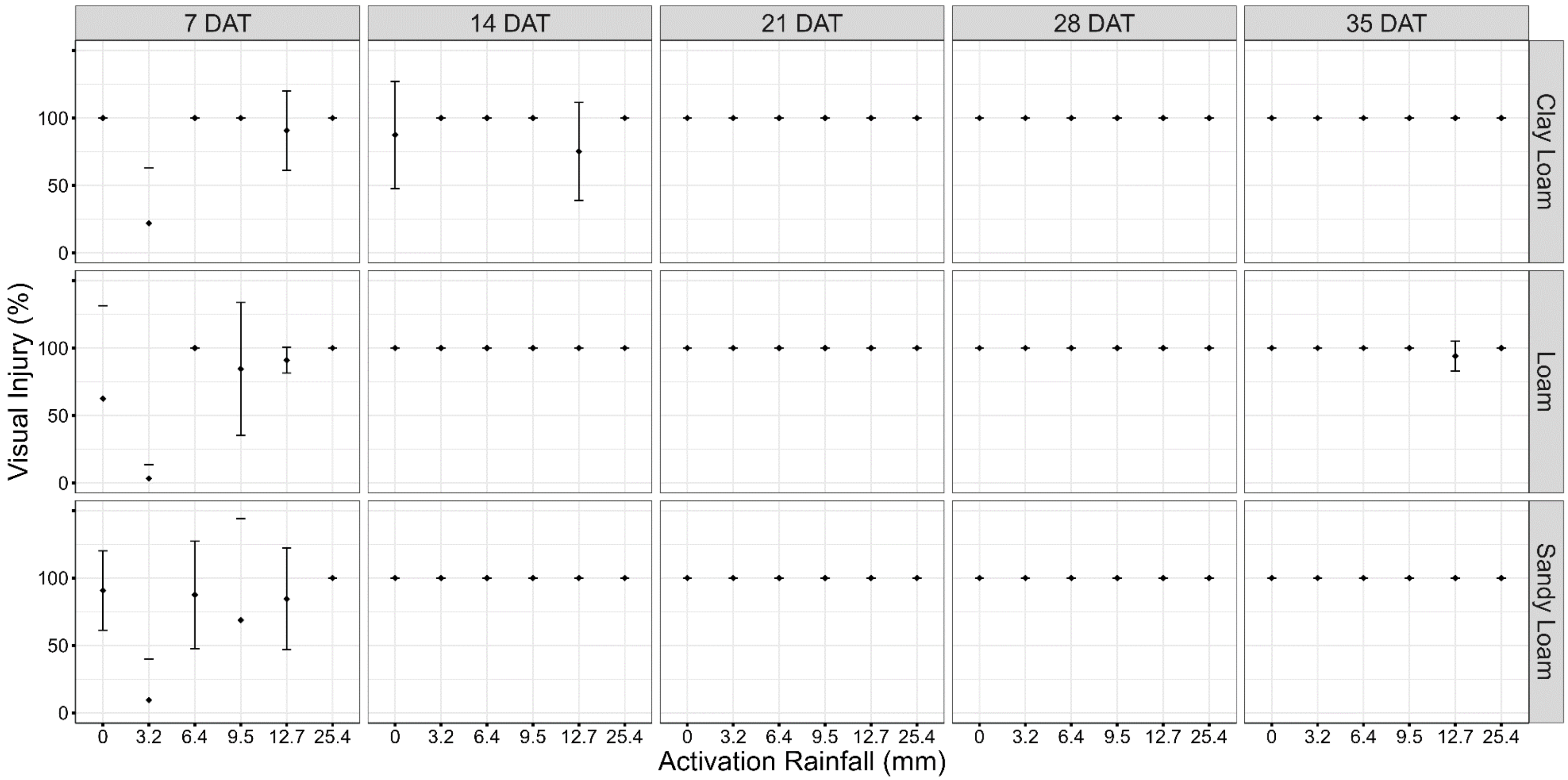


Figure 2.13 Velvetleaf (*Abutilon theophrasti*) control at each soil texture and rainfall amount when pyroxasulfone was applied at the R.R. Foil Plant Science Research Center, Mississippi State, MS in 2022 (first experiment).

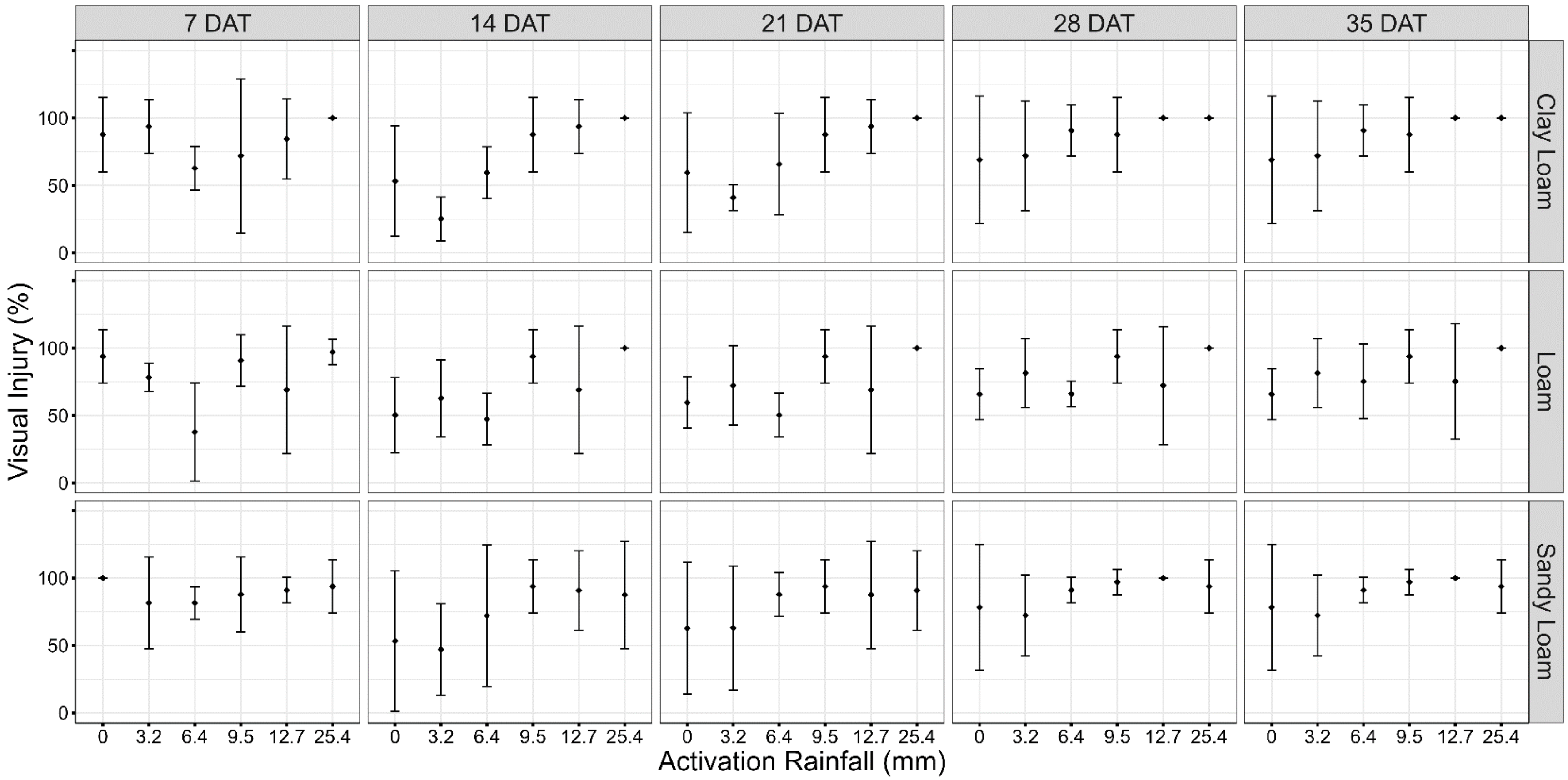


Figure 2.14 Velvetleaf (*Abutilon theophrasti*) control at each soil texture and rainfall amount when pyroxasulfone was applied at the R.R. Foil Plant Science Research Center, Mississippi State, MS in 2022 (second experiment).

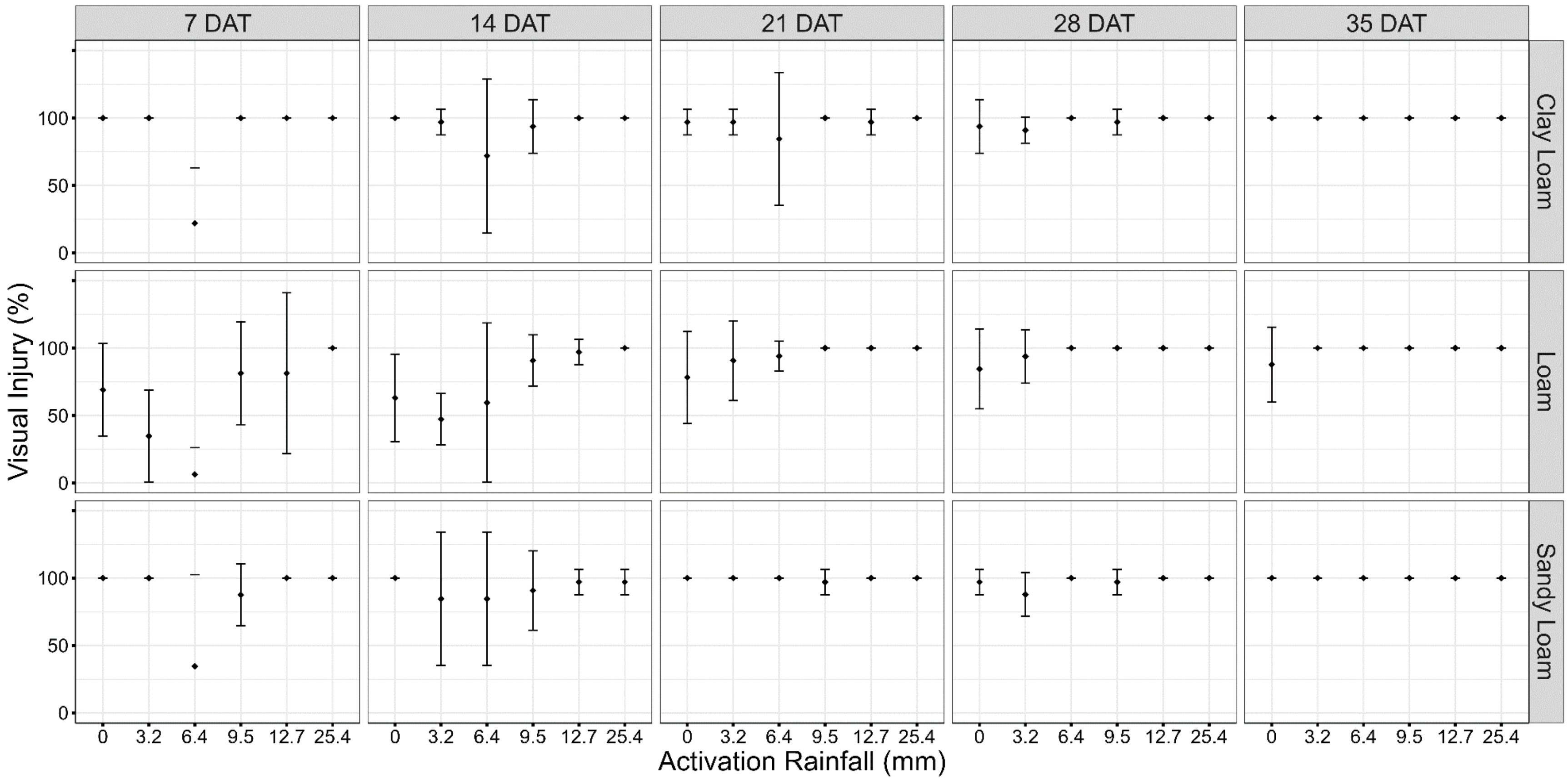


Figure 2.15 Velvetleaf (*Abutilon theophrasti*) control at each soil texture and rainfall amount when sulfentrazone was applied at the R.R. Foil Plant Science Research Center, Mississippi State, MS in 2022 (first experiment).

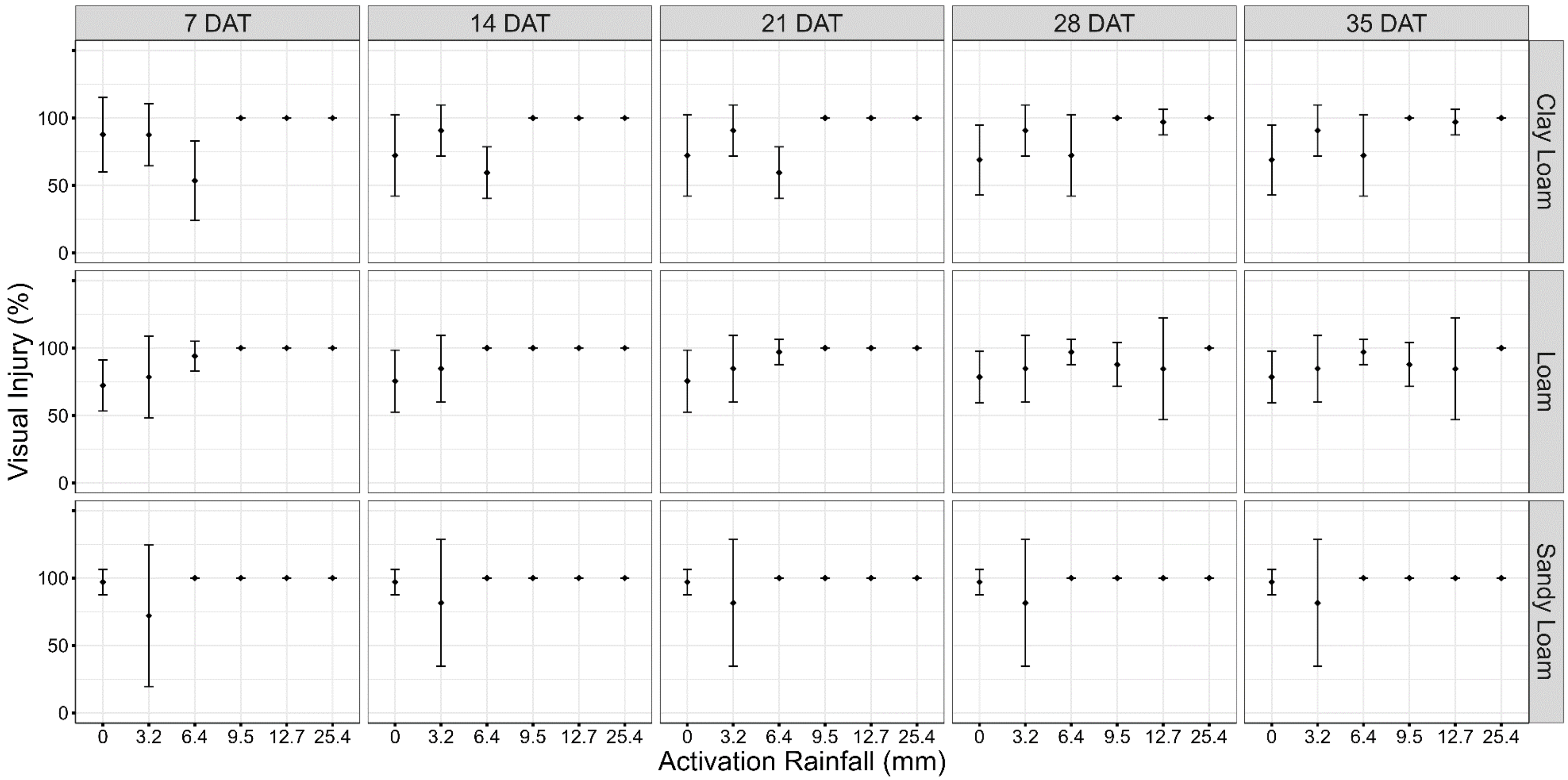


Figure 2.16 Velvetleaf (*Abutilon theophrasti*) control at each soil texture and rainfall amount when sulfentrazone was applied at the R.R. Foil Plant Science Research Center, Mississippi State, MS in 2022 (second experiment).

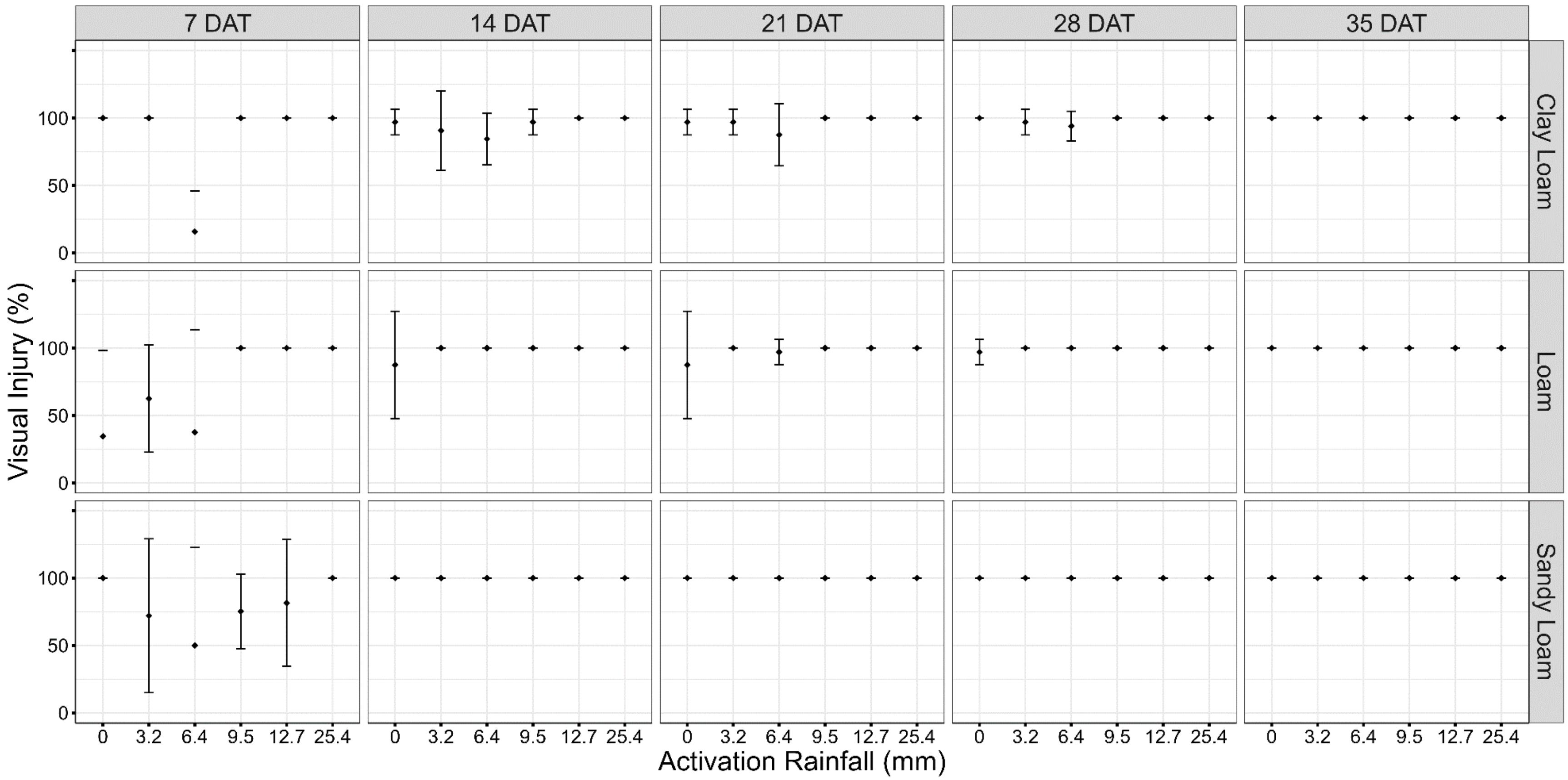


Figure 2.17 Velvetleaf (*Abutilon theophrasti*) control at each soil texture and rainfall amount when *S*-metolachlor was applied at the R.R. Foil Plant Science Research Center, Mississippi State, MS in 2022 (first experiment).

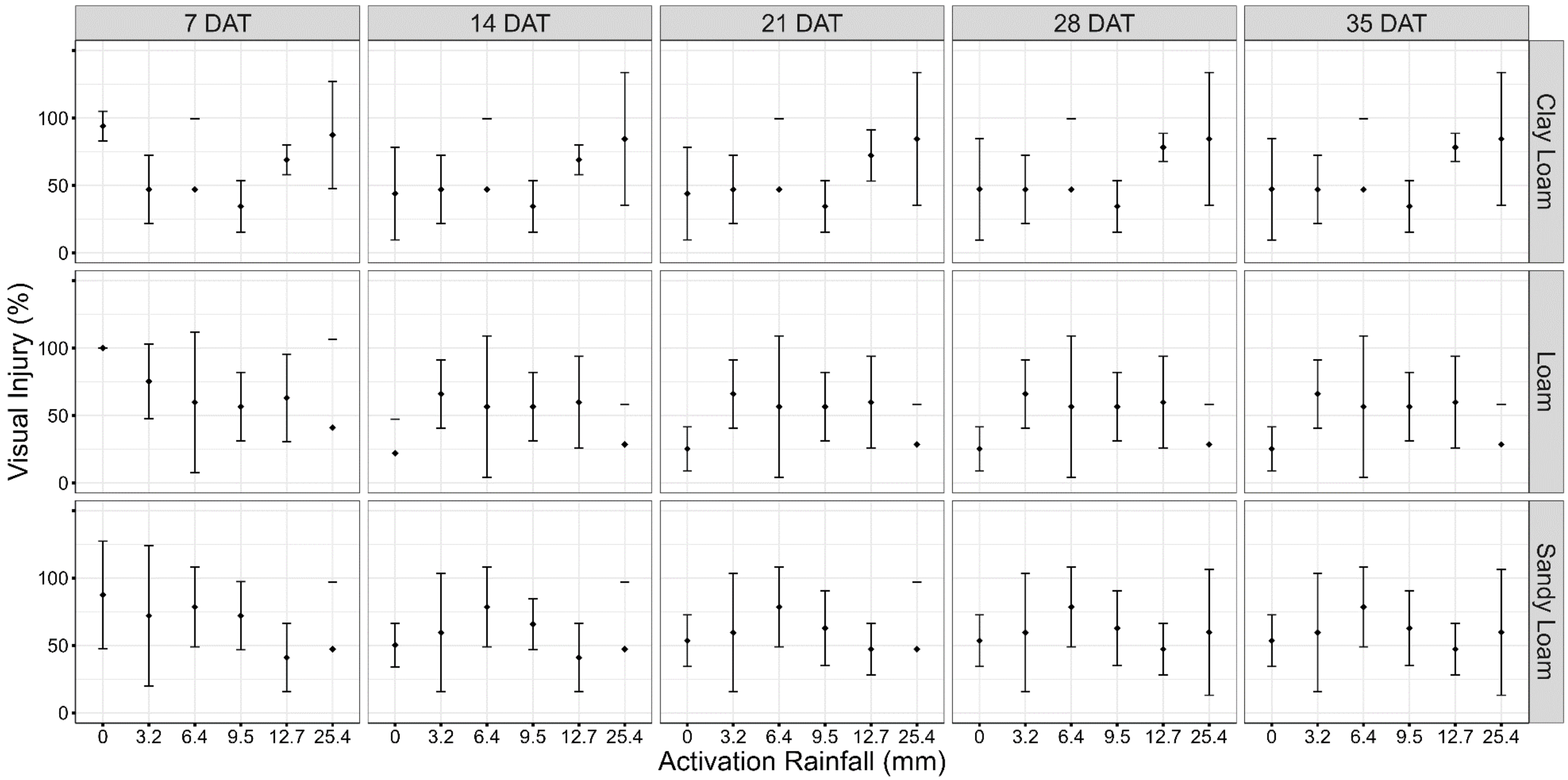


Figure 2.18 Velvetleaf (*Abutilon theophrasti*) control at each soil texture and rainfall amount when *S*-metolachlor was applied at the R.R. Foil Plant Science Research Center, Mississippi State, MS in 2022 (second experiment).

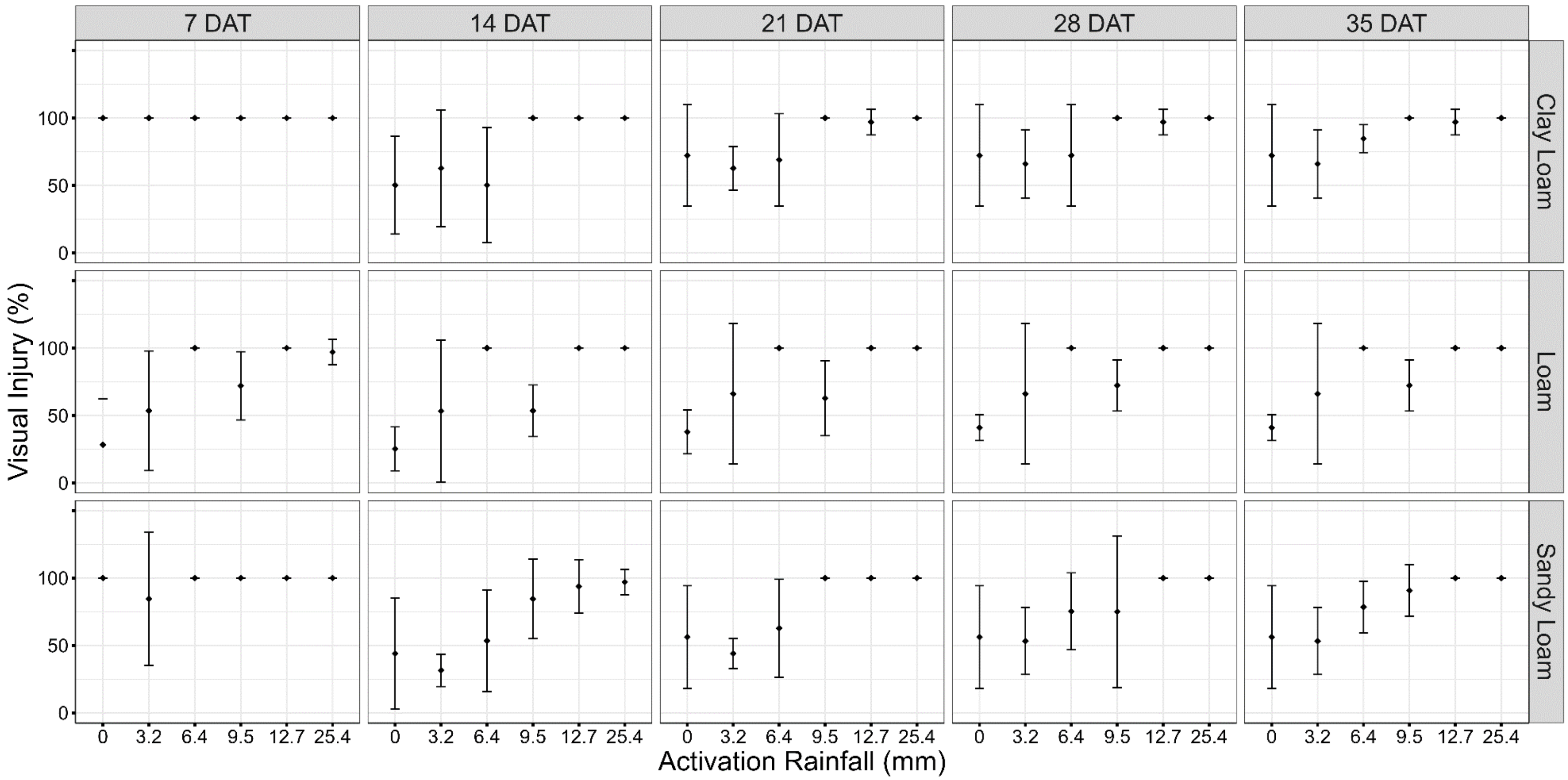


Figure 2.19 Velvetleaf (*Abutilon theophrasti*) biomass reduction at each soil texture and rainfall amount for each herbicide at the R.R. Foil Plant Science Research Center, Mississippi State, MS in 2022 (first experiment).

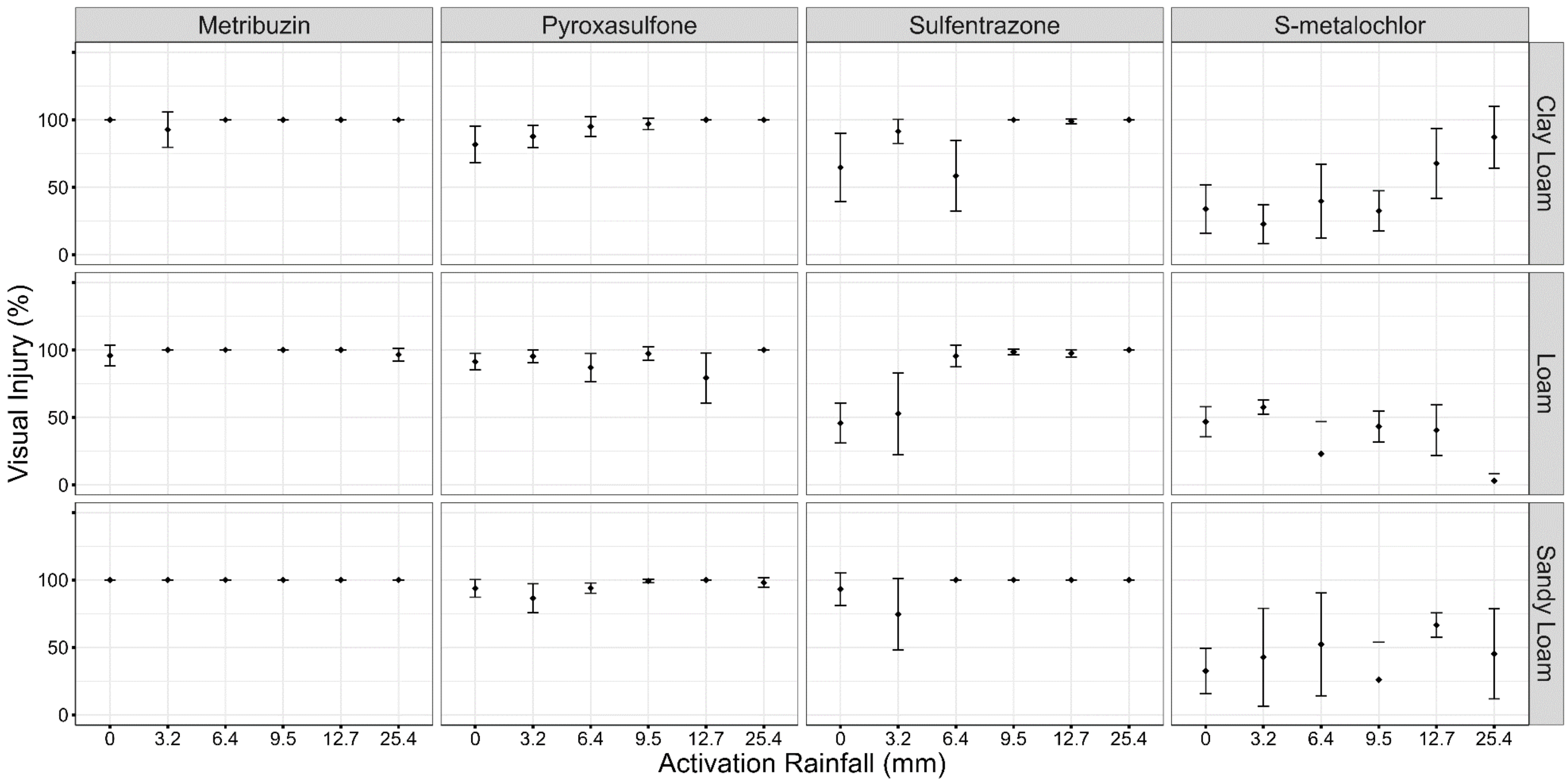
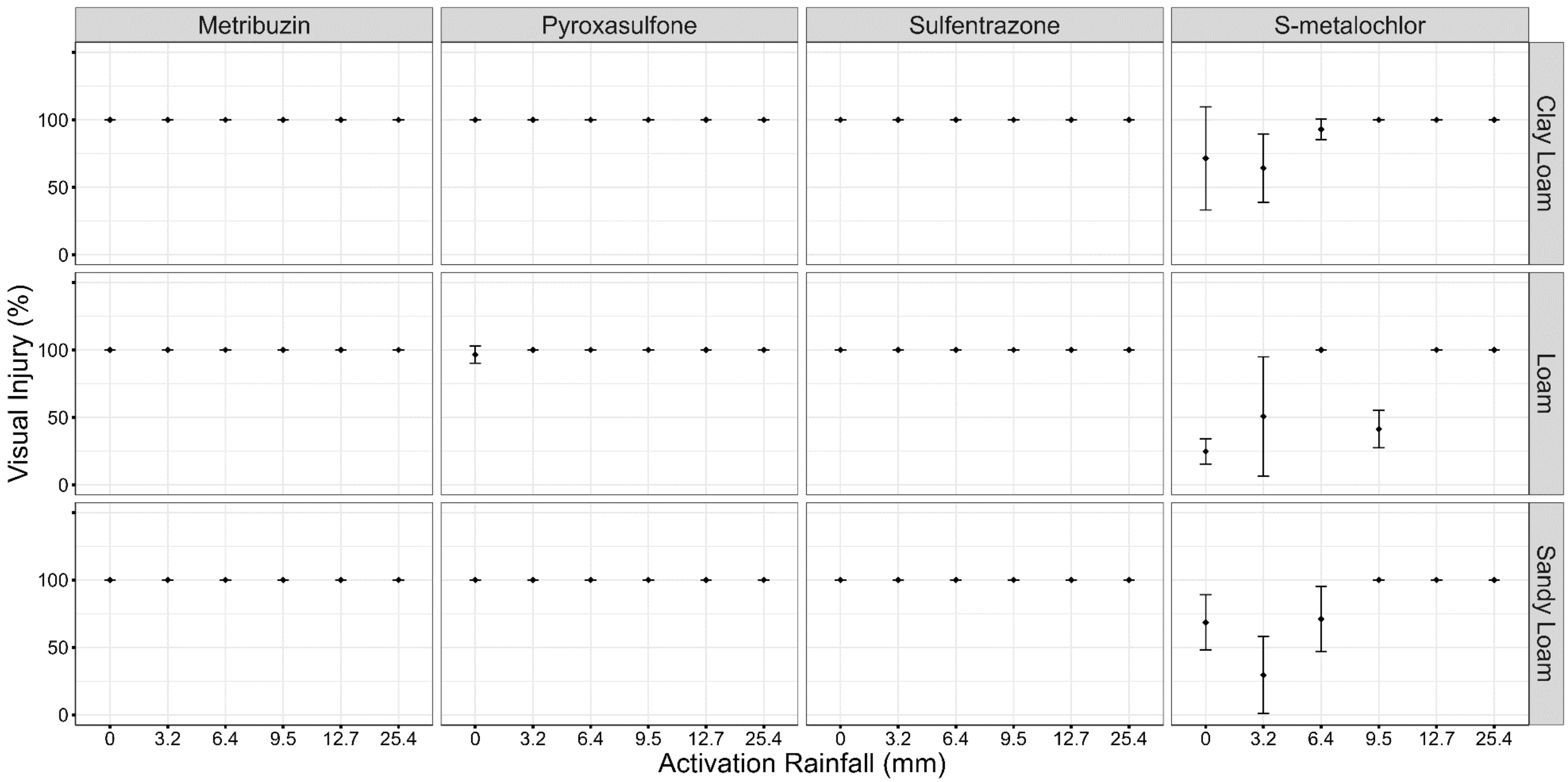


Figure 2.20 Velvetleaf (*Abutilon theophrasti*) biomass reduction at each soil texture and rainfall amount for each herbicide at the R.R. Foil Plant Science Research Center, Mississippi State, MS in 2022 (second experiment).



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