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Palmer Amaranth (*Amaranthus palmeri* S. Wats.) and Pitted Morningglory (*Ipomoea lacunosa* L.) Control in Dicamba Tolerant Soybean (*Glycine max* L.)

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Abstract

Palmer amaranth and pitted morningglory are difficult to manage weeds present in South Carolina soybean production fields. Glyphosate and ALS-resistant Palmer amaranth biotypes have spread rapidly throughout South Carolina making the control of these weeds more difficult. Recently, soybean varieties with tolerance to dicamba have been introduced along with several new ultra-low volatility formulations of dicamba to help with the problem. Field experiments were conducted near Blackville, SC in 2012 and 2013 to evaluate dicamba herbicide programs for broadleaf weed management in dicamba tolerant soybean. At 2 weeks after POST1 (2 WAP1), Palmer amaranth control ranged from 93% to 100% across the PRE followed by POST treatments in 2012 and 2013. By 2 weeks after POST2 (2 WAP2), control was 95% or better. Treatments containing two or three herbicide applications (PRE, POST1 and POST2) offered good to excellent (92% - 100%) pitted morningglory control. No differences in weed control were observed among treatments with 3 application times compared to those applied twice. In general, all treatments with a PRE followed by at least one POST application provided good to excellent control of Palmer amaranth and pitted morningglory. Overall, a PRE (either dicamba or flumioxazin) followed by a dicamba or a non-dicamba containing POST treatment provided good to excellent control of Palmer amaranth and pitted morningglory when applied at the correct growth stage.

Keywords

Weed Resistance, Soybean, Dicamba, Glyphosate, Broadleaf Weeds

1. Introduction

As the world's population increases, there is an increasing pressure upon the farmers to produce enough food and fiber for the world today. In the modern era, farmers have looked to researchers to develop better crop cultivars that are superior to the traditional landrace or heirloom strains that have been cultivated before modern agriculture. These improvements in crop varieties have allowed for an increased level of crop productivity. Among these breeding advances was the development of higher yielding crops which allowed farmers to plant on the same acreage with greater yield [1] [2]. In addition to these breeding advances, researchers were also able to develop herbicides which helped crop yield by eliminating competing weeds. The introduction of herbicides in modern agriculture has been a double-edged sword. The advantage of weed control achieved by the introduction of herbicides eventually led to the selection of herbicide resistant weeds.

Upon its introduction in 1996, Roundup® Ready soybean allowed growers to make a single postemergence application of glyphosate to fields which effectively managed most of the emerged weeds [3]. The extensive use of glyphosate in glyphosate-resistant soybean resulted in extremely high selection pressure, eventually leading to the selection of glyphosate-resistant biotypes [4]. Globally, there are currently 479 unique cases (species × site of action) of herbicide resistant weeds involving 251 species (146 dicots and 105 monocots) [5]. Currently, weeds have evolved resistance to 162 different herbicides and 23 of the 26 known herbicide sites of action. In 1997, Palmer amaranth (*Amaranthus palmeri* S. Wats.) with resistance to acetolactate synthase (ALS) inhibitors was reported in South Carolina [5]. By 2006, glyphosate-resistant Palmer amaranth was reported and in 2010, Palmer amaranth with resistance to glyphosate and ALS-inhibiting herbicides were also reported [6] [7] [8].

Palmer amaranth and pitted morningglory (*Ipomoea lacunosa* L.) are among the most common and troublesome weeds to manage in South Carolina soybean fields [9]. Palmer amaranth biotypes with resistance to glyphosate and ALS-inhibitors have become an economic burden under predominately glyphosate-based postemergence weed management systems in the Southern US. By tank mixing or stacking two or more herbicide modes of action in a single application, growers may limit the development of weeds like these that show resistance to more than one herbicide mode of action.

Monsanto™ has recently commercially released a genetically modified soybean which allows the plant to metabolize dicamba using the bacterially derived gene dicamba monooxygenase (DMO). This enzyme converts the herbicidally active dicamba (3,6-dichloro-2-methoxybenzoic acid) molecule to 3,6-dichlorosalicylic acid (DCSA) which is an inactivated form with minimal plant activity [10] [11]. The Roundup Ready 2 Xtend™ soybean is the first soybean technology with dicamba and glyphosate tolerance.

Dicamba is a widely used herbicide for broadleaf weed control in grass crops, such as corn, grain sorghum, small grains, pasture and rangeland [12]. Dicamba is a growth regulator that mimics the endogenous plant hormone indole-3-acetic acid (IAA) and causes the over-proliferation of plant cells at the meristematic regions, leading to death [13]. Auxin-like growth regulating herbicides, such as dicamba, are susceptible to off-target movement due to volatilization and subsequent vapor drift [14]. Several different salt formulations of dicamba have been developed to minimize the off-target damage to sensitive broadleaf crops due to volatilization and vapor drift [12]. However, the particle drift potential of dicamba depends on the type of nozzle used. To minimize particle drift, proper nozzle selection is critical. Droplets that are finer have a potential to move to unintended areas. However, nozzles that emit coarser droplet sizes minimize the chances of unintended particle drift [15].

Xtendimax™ with VaporGrip® Technology, Engenia, and FeXapan with VaporGrip® Technology are new ultra-low volatility formulations of dicamba herbicide developed by Monsanto™, BASF™, and Dupont™, respectively, that are labeled for dicamba-tolerant soybean [16] [17] [18]. Despite dicamba's widespread use to control broadleaf weeds for the last 45 years, kochia (*Kochia scoparia* L.) has been the only noxious and economically important weed species confirmed resistant to dicamba [5]. By tank mixing additional modes of action with dicamba, growers will be able to effectively manage glyphosate and ALS-resistant Palmer amaranth and other troublesome broadleaf weeds while helping to minimize the selection of dicamba resistant weed biotypes.

The ability to use either dicamba, glyphosate, or a tank-mix of both herbicides before planting or at selected periods during soybean development will allow growers greater flexibility in managing troublesome weeds in their crop management practices [13]. A proactive approach to weed control is critical; this will slow down or prevent the selection of resistant weed biotypes. Therefore, the objective of this research was to evaluate the efficacy of selected dicamba herbicide programs for the control of Palmer amaranth and pitted morningglory in dicamba tolerant soybean.

2. Materials and Methods

Separate field studies were conducted in 2012 and 2013 on a Dothan loamy sand, (fine-loamy, siliceous, thermic Plinthic Paleudult) with a pH of 6 and organic matter of 2.1% at the Clemson University Edisto Research and Education Center (33.36˚N, −81.32˚W) located near Blackville, SC to evaluate dicamba based herbicide programs for weed control in dicamba tolerant soybean. Prior to the initiation of the field studies, soil samples were collected to a depth of 10 cm at each study site and sent for nutritional analysis to the Clemson University Agricultural Service Laboratory (Clemson, SC, USA) and based on those recommendations, phosphorus (0-46-0) and potassium (0-0-60) fertilizer blend was broadcast over the entire study area each year. Soybean variety "GM_A2205" (Monsanto Company 800 N. Lindbergh Blvd. St. Louis, MO, USA) was seeded 2.5 cm deep on 26 June 2012 and soybean variety "GM_A92205" (Monsanto Company 800

N. Lindbergh Blvd. St. Louis, MO) was seeded 2.5 cm deep on 20 June 2013 in a conventionally-tilled seed bed at 20 seeds·m^{-1} using an Almaco cone plot planter (Almaco Company; Nevada, Iowa, USA). Plot dimensions were two rows wide and 9.4 m long. Cotton (*Gossypium hirsutum* L.) was the previous crop grown at each study location.

Study 1 conducted in both 2012 and 2013 and was arranged in a randomized complete block design with 13 treatments and 3 replications, including an untreated check. Herbicide treatments, timing and rates are listed in **Table 1**. Study 2 was conducted only in 2013 and was arranged in a randomized complete block design with 9 treatments and 3 replications, including an untreated check. Herbicide treatments, timing and rates are listed in **Table 2**. Both studies were conducted as two separate field experiments; therefore, there was no attempt to combine any similar treatments across the studies due to the different environments. The dicamba herbicides rates were selected based on the proposed use rates recommended by Monsanto while the remaining treatments were based on the standard Extension Weed Management recommendations for South Carolina [18]. Treatments were applied in water with a CO_2 pressurized back pack sprayer which delivered 140 L·ha^{-1} at 235 kPa via a four nozzle boom fitted with a Turbo Teejet® 11002 Induction Flat Fan spray nozzle (Teejet, Spraying Systems Co., P.O. Box 7900, Wheaton, IL, USA) at a ground speed of 5 km·h^{-1} [19].

Premergence (PRE) treatments were applied shortly after planting, POST1 applications were done when Palmer amaranth and pitted morningglory were 5 to 10 cm in height, and POST2 applications occurred 14 days after the POST1 application. Percent visual control weed ratings were collected using a scale of 0 to 100 percent with 0 indicating no control and 100 indicating complete control. Ratings were collected 3 weeks after the PRE application (3WAP), 2 weeks after POST1 application (2WAP1) and 2 weeks after POST2 application (2WAP2). Weed species density was assessed by randomly tossing a 0.5 m^2 quadrat between the 2 treated rows, then counting and identifying each weed species present in the quadrat. By request of Monsanto, the soybean was crop destructed before entering the R1 reproductive stage to prevent production of viable seed of the regulated soybean variety; therefore, yield data was not collected in either year.

Percent visual weed control and weed population densities were analyzed using the PROC GLM procedure in SAS (SAS 9.2, SAS® Institute Inc. Cary, NC, USA). Herbicide treatments and years were considered fixed effects in the model while replicate was considered a random effect. Control and species densities were combined over trial years if no significant treatment by year interaction was observed. Whenever a significant treatment by year interaction occurred the data are presented separately by trial year. Means separations were performed with Fisher's Protected LSD ($P \leq 0.05$).

3. Results and Discussion

The weed control parameters in both studies showed varying levels of significance for treatment and treatment by year across the selected evaluation periods,

Table 1. Herbicide treatments, application timing and rates for dicamba based herbicide weed control program evaluations in study 1.

Treatment[a]	Timing[b]	Rate[c]	Product Name
		kg·ai·ha^{-1} or kg·ae·ha^{-1}	
dic.	PRE	1.12	Clarity
dic.	PRE	1.12	Clarity
gly. + dic.	POST1	1.12 + 0.56	Roundup PowerMAX + Clarity
dic.	PRE	1.12	Clarity
gly. + dic. + aceto.	POST1	1.12 + 0.56 + 1.26	Roundup PowerMAX + Clarity + Warrant
dic.	PRE	1.12	Clarity
gly. + dic. + aceto. + fom.	POST1	1.12 + 0.56 + 1.26 + 0.34	Roundup PowerMAX + Clarity + Warrant+ Reflex
dic.	PRE	1.12	Clarity
gly. + dic.	POST1	1.12 + 0.56	Roundup PowerMAX + Clarity
gly. + dic.	POST2	1.12 + 0.56	Roundup PowerMAX + Clarity
dic.	PRE	1.12	Clarity
gly. + dic. + aceto.	POST1	1.12 + 0.56 + 1.26	Roundup PowerMAX + Clarity +Warrant
gly. + dic.	POST2	1.12 + 0.56	Roundup PowerMAX + Clarity
dic.	PRE	1.12	Clarity
gly. + dic. + aceto. + fom.	POST1	1.12 + 0.56 + 1.26 + 0.34	Roundup PowerMAX + Clarity + Warrant + Reflex
gly. + dic.	POST2	1.12 + 0.56	Roundup PowerMAX + Clarity
flum.	PRE	0.07	Valor SX
flum.	PRE	0.07	Valor SX
gly. + dic.	POST1	1.12 + 0.56	Roundup PowerMAX + Clarity
flum.	PRE	0.07	Valor SX
gly. + dic. + aceto.	POST1	1.12 + 0.56 + 1.26	Roundup PowerMAX + Clarity + Warrant
flum.	PRE	0.07	Valor SX
gly. + dic. + aceto.+ fom.	POST1	1.12 + 0.56 + 1.26 + 0.34	Roundup PowerMAX + Clarity + Warrant + Reflex
flum.	PRE	0.07	Valor SX
gly. + dic.	POST1	1.12 + 0.56	Roundup PowerMAX + Clarity
gly. + dic.	POST2	1.12 + 0.56	Roundup PowerMAX + Clarity
flum.	PRE	0.07	Valor SX
gly. + dic. + aceto.	POST1	1.12 + 0.56 + 1.26	Roundup PowerMAX + Clarity + Warrant
dic.	POST2	0.56	Clarity
flum.	PRE	0.07	Valor SX
gly. + dic. + aceto. + fom.	POST1	1.12 + 0.56 + 1.26 + 0.34	Roundup PowerMAX + Clarity + Warrant +Reflex
gly. + dic.	POST2	1.12 + 0.56	Roundup PowerMAX + Clarity
flum.	PRE	0.07	Valor SX
gly. + *s*-met. + fom.	POST1	1.12 + 1.49 + 0.34	Roundup PowerMAX + Dual Magnum + Reflex

[a]All POST treatments included ammonium sulfate at 2.5 % v/v. [b]Treatment timing: PRE, at planting; POST1, 5 - 10 cm weeds; POST2, 2 weeks after POST1. [c]Active ingredients (ai) rate used for acetochlor (aceto.), fomesafen (fom.), *s*-metolachlor (*s*-met), flumioxazin (flum.). Acid equivalent (ae) rate used for dicamba (dic.) and glyphosate (gly.).

Table 2. Herbicide treatments, application timing and rates for dicamba based herbicide weed control program evaluations in study 2.

Treatment[a]	Timing[b]	Rate[c]	Product Name
		kg·ai·ha^{-1} or kg·ae·ha^{-1}	
flum.	PRE	0.07	Valor SX
gly. + dic.	POST1	1.12 + 0.56	Roundup PowerMAX + Clarity
flum.	PRE	0.07	Valor SX
gly. + dic.	POST1	1.12 + 0.56	Roundup PowerMAX + Clarity
gly. + dic.	POST2	1.12 + 0.56	Roundup PowerMAX + Clarity
flum.	PRE	0.07	Valor SX
gly. + dic. + aceto.	POST1	1.12 + 0.56 + 1.27	Roundup PowerMAX + Clarity + Warrant
flum.	PRE	0.07	Valor SX
gly. + dic. + aceto.	POST1	1.12 + 0.56 + 1.27	Roundup PowerMAX + Clarity + Warrant
gly. + dic.	POST2	1.12 + 0.56	Roundup PowerMAX + Clarity
dic. + aceto.	PRE	0.56 + 1.27	Clarity + Warrant
gly. + dic.	POST1	1.12 + 0.56	Roundup PowerMAX + Clarity
aceto. + metrn.	PRE	1.27 + 0.28	Warrant + Metribuzin
gly. + dic.	POST1	1.12 + 0.56	Roundup PowerMAX + Clarity
flum.	PRE	0.07	Valor SX
gly. + fom. + aceto.	POST1	0.84 + 0.42 + 1.27	Roundup PowerMAX + Reflex + Warrant
s-met. + fom.	PRE	1.49	Dual Magnum + Reflex
gly. + lact.	POST1	0.84 + 0.22	Roundup PowerMAX + Cobra

[a] All POST treatments included ammonium sulfate at 2.5 % v/v. [b]Treatment timing: PRE, at planting; POST1, 5 - 10 cm weeds; POST2, 2 weeks after POST1. [c]Active ingredients (ai) rate used for acetochlor (aceto.), fomesafen (fom.), metribuzin (metrn.), s-metolachlor (s-met.), flumioxazin (flum.). Acid equivalent (ae) rate used for dicamba (dic.) and glyphosate (gly.).

which was similar to what was observed by Joseph *et al.* [20] during the same study period. Data were presented separately by year if a significant treatment by year interaction was observed. If no interaction occurred, data was combined across years. The untreated control values for check treatments were not considered in the treatment mean significance. Visual soybean injury was less than 5% for all treatments and studies (data not shown). The total rainfall received at the study sites in 2012 and 2013 was 680 mm and 647 mm, respectively [20]. Similar to studies conducted by Joseph *et al.* [20], rainfall was also lower in June and July of 2012 compared to the same period in 2013 at the study sites.

3.1. Palmer Amaranth Control

In study 1, all PRE treatments effectively controlled Palmer amaranth (>94%) when evaluated at 3 WAP (**Table 3**). Palmer amaranth control in 2013 in the Dicamba PRE only treatment was 60% at 2 WAP2, whereas, it was only 27% in 2012 at the same rating period. Johnson *et al.* [21] also observed that a PRE only application of dicamba provided < 60% control of Palmer amaranth and morningglory *spp.* In contrast, the flumioxazin PRE only treatment provided substantially better Palmer amaranth control (>99%) (**Table 4**). Han *et al.* [22] performed a similar study using flumioxazin as a PRE only application and reported that at a rate of 0.7 kg·ai·ha^{-1} flumioxazin provided approximately 88% *Amaranthus retroflexus* control.

Table 3. Palmer amaranth (AMAPA) percent visual control and plant density in study 1 as affected by herbicide treatments in 2012 & 2013.

Treatment[a]	Timing	Rate[b]	AMAPA control[c]					AMAPA density[c]	
			3 WAP[d]	2 WAP1[d]		2 WAP2[d]		2 WAP2[d]	
		kg·ai·ha^{-1} or kg·ae·ha^{-1}	%					plants·m^{-2}	
				2012	2013	2012	2013	2012	2013
Untreated Check			-	-	-	-	-	22 a	17 c
dic.	PRE	1.12	94 b	58 e	72 d	27 d	60 c	18 bc	19 b
dic. gly. + dic.	PRE POST1	1.12 1.12 + 0.56	99 a	100 a	100 a	100 a	100 a	0 d	0 d
dic. gly. + dic. + aceto.	PRE POST1	1.12 1.12 + 0.56 + 1.26	100 a	100 a	100 a	97b	100 a	0 d	0 d
dic. gly. + dic. + aceto. + fom.	PRE POST1	1.12 1.12 + 0.56 + 1.26 + 0.34	99 a	98 ab	100 a	95 b	100 a	1 d	0 d
dic. gly. + dic. gly. + dic.	PRE POST1 POST2	1.12 1.12 + 0.56 1.12 + 0.56	99 a	100 a	100 a	100 a	100 a	0 d	0 d
dic. gly. + dic. + aceto. gly. + dic.	PRE POST1 POST2	1.12 1.12 + 0.56 + 1.26 1.12 + 0.56	99 a	100 a	100 a	100 a	100 a	0 d	0 d
dic. gly. + dic. + aceto. + fom. gly. + dic.	PRE POST1 POST2	1.12 1.12 + 0.56 + 1.26 + 0.34 1.12 + 0.56	99 a	100 a	100 a	100 a	100 a	0 d	0 d
flum.	PRE	0.07	99 a	100 a	100 a	100 a	100 a	0 d	0 d
flum. gly. + dic.	PRE POST1	0.07 1.12 + 1.12	100 a	100 a	98 ab	100 a	100 a	0 d	0 d
flum. gly. + dic. + aceto.	PRE POST1	0.07 1.12 + 0.56 + 1.26	99 a	100 a	98 ab	100 a	100 a	0 d	0 d
flum. gly. + dic. + aceto. + fom.	PRE POST1	0.07 1.12 + 0.56 + 1.26 + 0.34	99 a	100 a	97 b	100 a	100 a	0 d	0 d
flum. gly. + dic. gly. +dic.	PRE POST1 POST2	0.07 1.12 + 0.56 1.12 + 0.56	99 a	100 a	98 ab	100 a	100 a	0 d	0 d
flum. gly. + dic. + aceto. dic.	PRE POST1 POST2	0.07 1.12 + 0.56 + 1.26 0.56	100 a	100 a	93 c	100 a	100 a	0 d	0 d
flum. gly. + dic. + aceto. + fom. gly. + dic.	PRE POST1 POST2	0.07 1.12 + 0.56 + 1.26 + 0.34 1.12 + 0.56	99 a	100 a	98 ab	100 a	100 a	0 d	0 d
flum. gly. + s-met. + fom.	PRE POST1	0.07 1.12 + 1.49 + 0.34	100 a	100 a	98 ab	100 a	100 a	0 d	0 d

[a]All POST treatments included ammonium sulfate at 2.5% v/v; [b]Active ingredients (ai) rate used for acetochlor (aceto.), fomesafen (fom.), *s*-metolachlor (*s*-met.), flumioxazin (flum.). Acid equivalent (ae) rate used for dicamba (dic.) and glyphosate (gly.); [c]Means within columns with no common letter (s) are significantly different according to Fishers Protected LSD at 5%; [d]Palmer amaranth percent control and population density evaluation periods: 3 weeks after PRE (3 WAP), 2 weeks after POST1 (2 WAP1), 2 weeks after POST2 (2 WAP2).

Table 4. Palmer amaranth (AMAPA) percent visual control and plant density in study 2 as affected by herbicide treatments in 2013.

Treatment[a]	Timing	Rate[b]	AMAPA control[c]			AMAPA density[c]
			3 WAP[d]	2 WAP1[d]	2 WAP2[d]	2 WAP2[d]
		$kg \cdot ai \cdot ha^{-1}$ or $kg \cdot ae \cdot ha^{-1}$	%			$plants \cdot m^{-2}$
Untreated Check			-	-	-	21 a
flum. dic. + gly.	PRE POST1	0.07 1.12 + 0.56	100 a	100 a	100 a	0 b
flum. gly. + dic. gly. + dic.	PRE POST1 POST2	0.07 1.12 + 0.56 1.12 + 0.56	100 a	100 a	100 a	0 b
flum. gly. + dic. + aceto.	PRE POST1	0.07 1.12 + 0.56 + 1.27	98 a	100 a	97 a	1 b
flum. gly. + dic. + aceto. gly. + dic.	PRE POST1 POST2	0.07 1.12 + 0.56 + 1.27 1.12 + 0.56	100 a	100 a	100 a	0 b
dic. + aceto. gly. + dic.	PRE POST1	0.56 + 1.27 1.12 + 0.56	100 a	100 a	98 a	0 b
aceto. + metrn. gly. + dic.	PRE POST1	1.27 + 0.28 1.12 + 0.56	100 a	100 a	97 a	0 b
flum. gly. + fom. + aceto.	PRE POST1	0.07 1.12 + 0.42 + 1.27	100 a	100 a	100 a	0 b
s-met. + fom. gly. + lact.	PRE POST1	1.22 + 0.27 1.12 + 0.22	100 a	100 a	100 a	0 b
s-met. + metrn. gly. + acfln.	PRE POST1	1.55 + 0.37 1.12 + 0.42	100 a	100 a	97 a	0 b
clorm. + flum. + thif. gly. + thif.	PRE POST1	0.03 + 0.08 + 0.008 1.12 + 0.004	100 a	100 a	98 a	0 b

[a]All POST treatments included ammonium sulfate at 2.5% v/v; [b]Active ingredients (ai) rate used for flumioxazin (flum.), acetochlor (aceto.), acifluorfen (acfln.), s-metolachlor (s-met.), fomesafen (fom.), metribuzin (metrn.), chlorimuron (clorm.), thifensulfuron-methyl (thif.), lactofen (lact.). Acid equivalent (ae) rate used for dicamba (dic.) and glyphosate (gly.); [c] Means within columns with no common letter (s) are significantly different according to Fishers Protected LSD at 5%; [d]Palmer amaranth percent control and population density evaluation periods: 3 weeks after PRE (3 WAP), 2 weeks after POST1 (2 WAP1), 2 weeks after POST2 (2 WAP2).

At 2 WAP1, Palmer amaranth control ranged from 93% to 100% across the PRE followed by POST treatments in 2012 and 2013. By 2 WAP2, control values were 95% or better. Palmer amaranth control in dicamba PRE followed by glyphosate POST1 and dicamba PRE followed by glyphosate + dicamba + acetochlor + fomesafen POST1 at 2 WAP2 was significantly less than the remaining treatments at 97 and 95%, respectively. In contrast, Palmer amaranth control was excellent (100%) across all treatments in 2013. In 2012, all flumioxazin PRE followed by POST treatments provided excellent Palmer amaranth control (100%) at 2 WAP1. However, flumioxazin PRE followed by glyphosate + dicamba + acetochlor POST1 followed by dicamba POST2 provided significantly less Palmer amaranth control (93%) at 2 WAP1 in 2013. At 2 WAP2 in 2013, Palmer amaranth control was excellent (100%) across all flumioxazin PRE followed by POST treatments. Previous research has shown lower levels of Palmer amaranth control in dicamba POST only treatments which ranged between 59% to 83%, depending on the dicamba rate [23]. Palmer amaranth population densities in the untreated controls were 18 and 19 plants m^{-2} in 2012 and 2013, respectively, at 2 WAP2.

In study 2, all treatments provided 97% or better Palmer amaranth control. In addition, all PRE treatments were highly effective with > 98% control (**Table 4**). There were identical visual percent control ratings in the treatments containing one POST application of dicamba + glyphosate tank mixed vs. two POST applications of the same herbicide. In the Palmer amaranth visual percent control, there were no significant treatment differences observed at 2 WAP2. A final species population density of 21 Palmer amaranth plants·m^{-2} at 2 WAP2 in the untreated control plots confirmed the study area contained significant Palmer amaranth pressure.

3.2. Pitted Morningglory Control

Pitted morningglory control varied significantly within treatments in 2012 and 2013 when evaluated at 2 WAP1 and 2 WAP2 compared to Palmer amaranth in study 1. This led to a treatment by year interaction being observed for 2 WAP1 and 2 WAP2 rating periods. Some experimental or environmental factors could have contributed to the treatment by year interaction observed, mainly the difference in rainfall observed between the two trial years [8].

The treatments containing PRE only applications (dicamba and flumioxazin) performed differently. Unlike in Palmer amaranth, a dicamba PRE only, controlled pitted morningglory better than a flumioxazin PRE only when rated 3 WAP (**Table 5**). In 2012, 2 WAP1, dicamba PRE only provided marginal pitted morningglory control (27%) and in 2013, at the same rating period, control increased to 36%. Pitted morningglory control was 48% 2 WAP2 in 2012 with the flumioxazin PRE only treatment. Niekamp [24] also observed that flumioxazin, while being a good broad spectrum PRE herbicide for broadleaf weed control, provided inconsistent morningglory *spp.* control.

Treatments containing two or three herbicide applications (PRE, POST1 and POST2) offered good to excellent (92% - 100%) pitted morningglory control; however, the PRE followed by POST1 were slightly less effective in 2012 than 2013. In 2013, all dicamba based treatments provided excellent (100%) pitted morningglory control at 2 WAP2. The non-dicamba treatment (flumioxazin PRE followed by glyphosate + S-metolachlor + fomesafen POST1) also showed excellent control (100%). Similarly, previous studies have shown good to excellent morningglory *spp.* control with dicamba POST containing treatments [23] [25].

In study 2, pitted morningglory control varied among treatments, unlike what was observed in Palmer amaranth. Pitted morningglory control ranged from 87% to 97% across all of the PRE treatments at 3 WAP. Dicamba + acetochlor PRE was the least effective treatment at 87% control, whereas, chlorimuron +

Table 5. Pitted morningglory (IPOLA) percent visual control and plant density in study 1 as affected by herbicide treatments in 2012 & 2013.

Treatment[a]	Timing	Rate[b]	IPOLA control[c]					IPOLA density[c]	
			3 WAP[d]	2 WAP1[d]		2 WAP2[d]		2 WAP2[d]	
		kg·ai·ha^{-1} or kg·ae·ha^{-1}	%					plants·m^{-2}	
				2012	2013	2012	2013	2012	2013
Untreated Control			-	-	-	-	-	22 a	19.7 b
dic.	PRE	1.12	92 b	60 e	75 d	28 d	63 b	20 ab	11 c
dic. gly. + dic.	PRE POST1	1.12 1.12 + 0.56	99 a	100 a	100 a	97 a	100 a	0.7 fg	0 g
dic. gly. + dic. + aceto.	PRE POST1	1.12 1.12 + 0.56 + 1.26	99 a	98 ab	100 a	92 a	100 a	3.3 d	0 g
dic. gly. + dic. + aceto. + fom.	PRE POST1	1.12 1.12 + 0.56 + 1.26 + 0.34	98 a	98 ab	100 a	92 a	100 a	3 de	0 g
dic. gly. + dic. gly. + dic.	PRE POST1 POST2	1.12 1.12 + 1.12 1.12 + 0.56	98 a	98 ab	100 a	92 a	100 a	2.3 def	0 g
dic. gly. + dic. + aceto. gly. + dic.	PRE POST1 POST2	1.12 1.12 + 0.56 + 1.26 1.12 + 0.56	100 a	100 a	100 a	95 a	100 a	1.3 defg	0 g
dic. gly. + dic. + aceto. + fom. gly. + dic.	PRE POST1 POST2	1.12 1.12 + 0.56 + 1.26 + 0.34 1.12 + 0.56	99 a	100 a	100 a	98 a	100 a	0 g	0 g
flum.	PRE	0.07	83 c	77 d	93 abc	48 c	95 a	11.7 c	1 efg
flum. gly. + dic.	PRE POST1	0.07 1.12 + 1.12	100 a	100 a	92 bc	97 a	100 a	0 g	0 g
flum. gly. + dic. + aceto.	PRE POST1	0.07 1.12 + 1.12 + 1.26	99 a	100 a	90 c	100 a	100 a	0 g	0 g
flum. gly. + dic.+ aceto. + fom.	PRE POST1	0.07 1.12 + 1.12 + 1.26 + 0.34	99 a	100 a	88 c	100 a	100 a	0 g	0 g
flum. gly. + dic. gly. + dic.	PRE POST1 POST2	0.07 1.12 + 1.12 1.12 + 0.56	99 a	98 ab	87 c	93.3 a	100 a	1.7 defg	0.3 fg
flum. gly. + dic. + aceto. dic.	PRE POST1 POST2	0.07 1.12 + 1.12 + 1.26 0.56	99 a	100 a	90 c	100 a	100 a	0 g	1 efg
flum. gly. + dic. + aceto. + fom. gly. + dic.	PRE POST1 POST2	0.07 1.12 + 1.12 + 1.26 + 0.34 1.12 + 0.56	100 a	100 a	93 abc	98 a	100 a	0.3 fg	0 g
flum. gly. + *s*-met. + fom.	PRE POST1	0.07 1.12 + 1.49	100 a	100 a	88 c	100 a	100 a	0.3 fg	0 g

[a] All POST treatments included ammonium sulfate at 2.5% v/v; [b] Active ingredients (ai) rate used for acetochlor (aceto.), fomesafen (fom.), *s*-metolachlor (*s*-met.), flumioxazin (flum.). Acid equivalent (ae) rate used for dicamba (dic.) and glyphosate (gly.); [c]Means within columns with no common letter (s) are significantly different according to Fishers Protected LSD at 5%; [d]Pitted morningglory percent control and population density evaluation periods: 3 weeks after PRE (3 WAP), 2 weeks after POST1 (2 WAP1), 2 weeks after POST2 (2 WAP2).

flumioxazin + thifensulfuron was the most effective PRE treatment with 97% pitted morningglory control. At 2 WAP1, pitted morningglory control ranged from 97% to 100% across all treatments. Pitted morningglory control was significantly lower (although still a high level of control at 97%) in the flumioxazin PRE followed by glyphosate + dicamba POST1 followed by glyphosate + dicamba POST2 treatment. At 2 WAP2, very little differences were observed among the treatments (97% - 100% pitted morningglory control) with the exception of chloransulam + flumioxazin + thifensulfuron-methyl PRE followed by glyphosate + thifensulfuron POST1 at 93%. Monks *et al.* [26] observed morningglory *spp.* control ranged from 63% to 82% with thifensulfuron-methyl or acifluorfen applied POST. Similarly, Grichar [27] observed lower pitted morningglory control values for lactofen compared to the s-metolachlor + fomesafen PRE followed by glyphosate + lactofen POST1 treatment (**Table 6**). In general, one POST application provided similar levels of pitted morningglory control as two POST applications. A species density of 24 pitted morningglory plants·m^{-2} at 2 WAP2 illustrated significant weed pressure in the study plots.

Table 6. Pitted morningglory (IPOLA) percent visual control and plant density in study 2 as affected by herbicide treatments in 2013.

Treatment[a]	Timing	Rate[b]	IPOLA control[c]			IPOLA density[c]
			3 WAP[d]	2 WAP1[d]	2 WAP2[d]	2 WAP2[d]
		kg·ai·ha^{-1} or kg·ae·ha^{-1}		%		plants·m^{-2}
Untreated Check			-	-	-	24 a
flum. gly. + dic.	PRE POST1	0.07 1.12 + 0.56	90 abc	100 a	97 ab	0.1 bc
flum. gly. + dic. gly. + dic.	PRE POST1 POST2	0.07 1.12 + 0.56 1.12 + 0.56	95 ab	97 b	98 a	0 c
flum. gly. + dic. + aceto.	PRE POST1	0.07 1.12 + 0.56 + 1.27	88 bc	100 a	100 a	0 c
flum. gly. + dic. + aceto. gly. + dic.	PRE POST1 POST2	0.07 1.12 + 0.56 + 1.27 1.12 + 0.56	92 abc	100 a	100 a	0 c
dic. + aceto. gly. + dic.	PRE POST1	0.56 + 1.27 1.12 + 0.56	87 c	100 a	97 ab	0 c
aceto. + metrn. gly. + dic.	PRE POST1	1.27 + 0.28 1.12 + 0.56	90 abc	100 a	97 ab	0.2 bc
flum. gly. + fom. + aceto.	PRE POST1	0.07 1.12 + 0.42 + 1.27	95 ab	100 a	100 a	0 c
s-met. + fom. gly. + lact.	PRE POST1	1.22 + 0.27 1.12 + 0.22	92 abc	100 a	98 a	0.2 bc
s-met. + metrn. gly. + acfln.	PRE POST1	1.55 + 0.37 1.12 + 0.42	92 abc	100 a	100 a	0.1 bc
clorm. + flum. + thif. gly. + thif.	PRE POST1	0.03 + 0.08 + 0.008 1.12 + 0.004	97 a	100 a	93 b	0.9 b

[a] All POST treatments included ammonium sulfate at 2.5% v/v; [b] Active ingredients (ai) rate used for flumioxazin (flum.), acetochlor (aceto.), acifluorfen (acfln.), s-metolachlor (s-met.), fomesafen (fom.), metribuzin (metrn.), chlorimuron (clorm.), thifensulfuron-methyl (thif.), lactofen (lact.). Acid equivalent (ae) rate used for dicamba (dic.) and glyphosate (gly.); [c] Means within columns with no common letter (s) are significantly different according to Fishers Protected LSD at 5%; [d]Pitted morningglory percent control and population density evaluation periods: 3 weeks after PRE (3 WAP), 2 weeks after POST1 (2 WAP1, 2 weeks after POST2 (2 WAP2).

4. Summary

These studies demonstrated the effectiveness of different dicamba based herbicide programs on difficult-to-control broadleaf weeds in South Carolina. Dicamba PRE alone was not as effective on broadleaf weed control in soybean compared to flumioxazin PRE only. This can be attributed to the high water solubility of dicamba and its rapid loss in the soil profile, especially in coarse textured soils [28]. Overall, a PRE (either dicamba or flumioxazin) followed by a dicamba + glyphosate POST tank mix provided excellent control of Palmer amaranth and pitted morningglory in these studies.

In the treatments evaluated, those containing 2 applications (PRE followed by POST1) were similar in effectiveness as those containing 3 applications (PRE followed by POST1 and POST2). In terms of cost, fewer herbicide applications are more efficient and will be able to benefit growers who use these programs by reducing overall input costs. Dicamba PRE alone with no additional POST treatments provided the lowest level of weed control in these studies. Non-dicamba containing POST treatments did provide good to excellent control of Palmer amaranth and pitted morningglory. Although the treatments in these research studies showed good to excellent control of broadleaf weeds in diamba tolerant soybean, more research is needed on additional broadleaf weeds across different environments not present in the selected study locations to validate their effectiveness across a larger geographic area.

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Mention of a trade name does not imply endorsement of the product by Clemson University to the exclusion of others that might be available.

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