Response of Glyphosate Resistant Palmer Amaranth (*Amaranthus palmeri*) to Protoporphyrinogen Oxidase Inhibiting Herbicides in Tennessee

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DEDICATION

I would like to dedicate my dissertation to my Grandfather, George Dewey Umphres, Jr., who inspired me to achieve greatness in life. To my husband, who stood beside me during the toughest times and supported me when I needed him the most. I also dedicate this to my parents for their unconditional love and support that knows no bounds and for always challenging me through all aspect of life.

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ABSTRACT

In many agronomic cropping systems across the United States, Palmer amaranth (*Amaranthus palmeri*) is the most economic and troublesome weed for producers. The introduction of glyphosate resistant (GR) crops gave producers the benefit of controlling Palmer amaranth as well as other weeds, a broad window of application, and reduced tillage practices. With the confirmation of GR Palmer amaranth, producers implemented protoporphyrinogen oxidase (PPO or Protox)-inhibiting herbicides to control these populations in crops such as soybean [*Glycine max* (L.) Merr.] and cotton [*Gossypium hirsutum* (L.)]. However the continuous use of PPO herbicides has caused a shift in Palmer amaranth populations for PPO resistance. Therefore the scope of this study was to observe fomesafen response to four Palmer amaranth populations, determine the fomesafen resistance level, evaluate the effect of Palmer amaranth size on fomesafen efficacy, determine susceptibility to other foliar-applied herbicides, and evaluate the efficacy of four soil-applied PPO-inhibiting herbicides on PPO-resistant (PPO-R) and PPO-susceptible (PPO-S) Palmer amaranth populations. The PPO-S population was observed with 98% control however, fomesafen efficacy was reduced in SPA, LPA, and WPA populations with 24%, 4%, and 2% control, respectively at 14 days after treatment (DAT). The level of resistance for the PPO-R population SPA was 4-fold relative to the PPO-S population KPA. When determining the height of Palmer amaranth on fomesafen efficacy, control of SPA Sm, Md, and Lg sized plants was 62%, 49%, and 18%, respectively. Atrazine, glufosinate, and mesotrione were observed to have the greatest control (>70%) of the SPA population but resistant to glyphosate and chlorimuron. When subjected to soil-applied PPO herbicides, SPA showed

reduced control with fomesafen and saflufenacil however greater control was observed with flumioxazin and sulfentrazone at 35 DAT.

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INTRODUCTION

Palmer amaranth (*Amaranthus palmeri* S. Watts) also commonly known as carelessweed or palmer pigweed, is an invasive and aggressively competitive summer annual weed in corn (*Zea mays*), soybean (*Glycine max*) and cotton (*Gossypium hirsutum*), and other agronomic cropping systems. Palmer amaranth belongs to the family Amarnathaceae which includes 75 species world-wide (Ward et al., 2013) and is further classified into a distinct subgroup, *Amaranthus*, native specifically to North America (Steckel, 2007). This weed can be identified as being erect, with branched stems, long petioles, and in some cases a white watermark shaped as a V (Bryson and DeFelice 2009).

In many agricultural systems, Palmer amaranth can be difficult to control mainly due to its prolific seed production and rapid growth rate (Steckel 2007) as well as the ability for Palmer amaranth to disperse pollen over great distances (Sosnoskie et al. 2012). One study observed female Palmer amaranth plants that emerged during the months of March to June which produced 200,000 to 600,000 seeds per plant in the absence of competition from other plants (Keeley et al. 1987). Palmer amaranth planted in Missouri during May to early June resulted in the production of 250,000 seeds per plant (Sellers et al. 2003). Several studies have reported rapid growth rate of 0.18 to 21 cm per growing degree day (GDD) had occurred in Palmer amaranth during the early development (Horak and Loughin, 2000; Sellers et al. 2003). In addition, Culpepper et al. (2006) reported a growth rate of 24 to 62% higher in Palmer amaranth compared to other *Amaranthus* species.

Several studies have reported the impact of Palmer amaranth in yield when left un-controlled. In corn, one study observed Palmer amaranth reduced corn yield to 11 and 91% with

plant densities of 0.5 to 8 plants m^{-1}, respectively (Massinga et al. 2001). Another study observed grain yield was reduced by 74% and corn silage yield decreased by 44% (Massinga et al. 2003). Soybean yield was also reduced by 78% (Bensch et al. 2003). Interference of Palmer amaranth in cotton reduced yields up to 59% (Morgan et al. 2001) and at the early stages of cotton development (3 to 9 leaf stages) cotton yield was reduced to 0.9% per plant per m^2 (MacRae et al, 2008). In addition, researchers observed an indirect correlation between lint yield and weed biomass for every kg of dry Palmer amaranth biomass resulted of 5 to 9% yield reduction (Rowland et al. 1999).

The introduction of glyphosate-resistant (GR) crops in the 1990s provided several advantages which include reduced soil erosion, reduced herbicide loss through runoff and a change from conventional to conservative tillage practices (Price et al. 2011). Conservation tillage allowed producers to solely depend on glyphosate herbicides applied as a POST (Price et al. 2011). As a result GR Palmer amaranth evolved due to increased applications at higher glyphosate rates coupled with increase selection pressure (Price et al. 2011; Norsworthy et al. 2008; Culpepper et al. 2006). In 2004, GR Palmer amaranth was first confirmed in Georgia (Culpepper et al. 2006) followed by North Carolina, South Carolina, Virginia, Tennessee, Arkansas, and other states throughout the southeast and mid-west (Heap 2017).

Protoporphyrinogen oxidase (PPO)-inhibiting herbicides have been implemented in many GR soybean systems to manage GR Palmer amaranth. These PPO-inhibiting herbicides (Weed Science Society of America [WSSA] group 14) catalyze the conversion of protoporphyrinogen IX to protoporphyrin IX, which is known as the last step in the biosynthesis of heme and chlorophyll. Inhibition of the PPO enzyme causes formation of free radicals resulting in

degradation of lipids and protein membranes leading to cell death (Duke et al. 1991). Currently, GR Palmer amaranth has evolved resistance to included protoporphyrinogen oxidase (PPO) - inhibiting herbicides in Arkansas (Salas et al. 2016). With these recent reports, control of GR and PPO-R (PPO-resistance) Palmer amaranth has become a greater challenge for producers using GR soybean systems. The objective of this study were to (1) observe fomesafen response to four Palmer amaranth populations, (2) determine the resistance level, (3) evaluate the effect of Palmer amaranth size on control with fomesafen, (4) determine susceptibility to alternate MOA, and (5) evaluate the efficacy of four soil-applied PPO-inhibiting herbicides on PPO-resistant and PPO-susceptible Palmer amaranth populations.

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CHAPTER I

PALMER AMARANTH (AMARANTHUS PALMERI) RESPONSE TO A PROTOPORPHYRINOGEN OXIDASE INHIBITING HERBICIDE

Palmer amaranth (*Amaranthus palmeri*) response to a protoporphyrinogen oxidase inhibiting herbicide

Alinna M. Umphres, Lawrence E. Steckel, Robert C. Scott, James T. Brosnan, G. Neil Rhodes, Jerome Grant, and Thomas C. Mueller

Abstract

Protoporphyrinogen oxidase (PPO or Protox)-inhibiting herbicides are commonly used to control glyphosate resistance (GR) Palmer amaranth in soybeans grown in the United States. Continuous use of PPO herbicides has increased the selection for PPO resistance in Palmer amaranth. The aim of this study was on Palmer amaranth to confirm resistance to fomesafen, determine the resistance factor, evaluate the effect Palmer amaranth size on control with fomesafen, and observe plant response to other foliar-applied herbicides. Several populations showed reduced control at 14 DAT, while susceptible Palmer amaranth control was 98%. A Palmer amaranth population from Shelby County, Tennessee was 4X resistant to fomesafen, also resistant to ALS and glyphosate, but was controlled by atrazine and glufosinate. Palmer amaranth size influenced fomesafen response with less control observed on larger plants.

Introduction

Palmer amaranth (*Amaranthus palmeri* S. Watson) has been the center of attention for many weed scientists as this pernicious weed continues to evolve resistance to multiple modes of actions (MOAs). In a survey conducted by the Weed Science Society of America (WSSA) Palmer amaranth was ranked the most troublesome weed in the United States (Anonymous 2016). There are several attributes of Palmer amaranth that are responsible for its competitive nature. Prolific seed production (Keeley et al. 1987; Sellers et al. 2003), rapid growth rate (Ehleringer 1983; Horak and Loughin 2000; Sellers et al. 2003), wide dispersion of pollen over

great distances (Sosnoskie et al. 2012) and the ability to develop resistance to herbicides (Steckel 2007) are just a few characteristics associated with Palmer amaranth's success as a weed.

The discovery of glyphosate resistant (GR) Palmer amaranth in Georgia during 2004 (Culpepper et al. 2006) has lead producers to shift herbicides in their weed management programs. In GR cropping systems, such as soybean [*Glycine max* (L.) Merr.] and cotton [*Gossypium hirsutum* (L.)], controlling GR Palmer amaranth populations has increased the use of protoporphyrinogen oxidase (PPO or Protox)-inhibiting herbicides (Whitaker et al. 2012). The WSSA has categorized these herbicides into the site of action group 14 (Senseman 2007). The protox enzyme catalyzes the conversion of protoporphyrinogen IX (protogen IX) to protoporphyrin IX (proto IX). This is the last common enzyme in the tetrapyrrole biosynthesis pathway (Dayan et al. 2010). There are two isoforms of the PPO enzyme that are encoded by two different nuclear genes, *PPX1* and *PPX2*. The *PPX1* and *PPX2* isoforms are found in the plastids and the mitochondria, respectively. Herbicides that inhibit this pathway cause an accumulation of Proto IX and when exposed to light, Proto IX molecules interact with oxygen to form a singlet oxygen and oxygen radicals (Dayan and Duke 1997). Consequently, these radicals cause lipid peroxidation resulting in the loss of membrane function and integrity, bleaching of chloroplast pigments, tissue necrosis, reduced plant growth, and ultimately plant death (Duke et al. 1991; Dayan and Duke 2010).

There are several chemical classes that inhibit the PPO enzyme including diphenyl ethers, heterocyclic phenyl ethers, oxadiazoles, phenyl imides, triazolinones and pyrazoles (Senseman 2007; Dayan et al. 2014). Herbicides that inhibit the PPO enzyme are used POST to control many weed species (Anonymous 2017). However, with increased use of PPO herbicides there

has been a shift to PPO resistant weeds. Resistance to PPO-inhibiting herbicides was first documented in waterhemp (*Amaranthus tuberculatus*) in Kansas (Shoup et al. 2003), Illinois (Patzoldt et al. 2005), Missouri, and throughout the Midwest region of the United States (Heap 2017). In 2015, PPO resistance in Palmer amaranth was first suspected in Tennessee (Steckel 2015) followed by Arkansas (Salas et al. 2016) and Illinois (Heap, 2017). Because the *PPX2* gene in Palmer amaranth is identical to waterhemp, Riggins and Tranel (2012) proposed the likely potential for Palmer amaranth to evolve resistance to PPO herbicides. In waterhemp, a codon deletion at the 210th amino acid position in the gene coding for the PPO enzyme (*PPX2*) is the mechanism of resistance (Wuerffel et al. 2015; Dayan et al. 2014). In Arkansas PPO-R Palmer amaranth was found to have the same codon deletion found in PPO-R waterhemp populations (Salas et al. 2016). This recent evidence confirms the theory of Riggins and Tranel (2012) in that PPO resistance could evolve in Palmer amaranth. The objective of this study was to (1) observe fomesafen response to four Palmer amaranth populations, (2) determine the resistance level, (3) evaluate the effect of Palmer amaranth size on control with fomesafen, and (4) determine susceptibility to alternate MOA.

Materials and Methods

Seed material. Palmer amaranth seed was obtained during the fall of 2015 from three counties in Tennessee [Knox (KPA), Shelby (SPA) and Lauderdale (LPA) County], and Woodruff Co., Arkansas (WPA). SPA, LPA, and WPA had survived POST applications of a PPO herbicide (fomesafen). Harvesting of seed was conducted as described by Steckel et al. (2003). Seed heads were hand-harvested from mature female Palmer amaranth plants, allowed to dry for 30 days, and were threshed using an Almaco belt thresher (Almaco, Nevada, Iowa).

Seeds were cleaned by hand sifting through 18 x 16 in mesh screen, cycled through a seed separator (SeedTech Systems, Wilton, California) and cleaned with a gravity table (Agriculex, Guelph, Ontario, Canada). After processing, seed was stored at -20 C until the initiation of experiments.

Planting. Seeds were scarified prior to planting with 70 % sulfuric acid for 30s, rinsed thoroughly with deionized water and allowed to dry for 24 hours. Seeds (~1,000) from each population were planted into individual flats consisting of Pro-Mix BX Mycorrhizae (Premier Brand Inc., New Rochelle, NY) a vermiculite and perlite based potting mixture. After cotyledon emergence, Palmer amaranth seedlings (~ 2.54 cm) were transplanted into 500 mL styrofoam cups (each cup had 4 small drainage holes through the bottom) filled with the peat and vermiculite mixture. Plants were watered daily to maintain soil moisture and a complete fertilizer (15-30-15 MiracleGro, Marysville, OH) was applied 3 times a week.

Confirmation of PPO resistance. The TVA greenhouse (35.949956, -83.942092) conditions involved day/night temperatures of 14 - 22 C at night to 30 - 41 C daytime. Natural light was supplemented with metal halide lamps in a 16 hour interval. A preliminary study was conducted consisting of one greenhouse experiment with three Palmer amaranth populations that had previously shown incomplete control from PPO applications (SPA, LPA, and WPA) and 1 known susceptible (KPA) Palmer amaranth population. This study was conducted as a randomized complete block design with 5 replications. Plants were treated at 9-10 cm in height with fomesafen (Flexstar, Syngenta Crop Protection, LLC, Greensboro, NC) at the recommended labeled rate of 280 g ai ha^{-1}(Anonymous 2017). A pressurized CO_2 backpack sprayer equipped with a single 8002 XR nozzle (TeeJet Technologies, P.O. Box 7900, Wheaton, IL 60187) was

used for treatment application and was calibrated to deliver 190 L ha $^{-1}$ at 210 kPa. At 1, 3, 7, and 14 DAT, control was visually evaluated relative to the non-treated control (UTC) using a scale of 0 to 100, where 0 indicated no injury and 100 no surviving plants were observed. Height was recorded on plants surviving fomesafen treatment at 14 DAT. Data was subjected to analysis of variance using SAS 9.4 (SAS Institute; Cary, NC) using the PROC GLM procedure to test for significant main effects. Means were separated using Fishers protected LSD procedure at the significance level of 0.05. Herbicide treatments and blocks were considered fixed effects while population and block interactions were considered random effects. This study was not replicated due to insufficient seed availability of some populations.

Resistance level of fomesafen. Two greenhouse experiments were conducted using the R-SPA (resistant) and S-KPA (susceptible) Palmer amaranth populations. The R-SPA population was used for all later studies because there was adequate seed available. The design of this experiment was a factorial design with two populations (R and S populations) and eight rates of fomesafen. Herbicide rates consisted of 35, 70, 140, 280, 560, 1120, 2240 g ai ha $^{-1}$ relative to the (1X) labeled rate of 280 g ai ha $^{-1}$. Each run included a total of eight non-treated controls (UTC) plants per run. Treatment application and data collection of plant height and fresh weight biomass were conducted as previously described. Sigma Plot version 12.5 was used to analyze data collected and a simple first-order exponential decay model was used to describe the relationship between Palmer amaranth biomass (normalized to the amount in the UTC) and relative fomesafen rate. The model is represented by the following equation:

Equation 1. $F = a*\exp(-k*x)$

The GR_{50} was then calculated by the relationship of 0.693 divided by k, where k is the first order rate constant.

Effect of Palmer amaranth height. Two greenhouse experiments were conducted using the R (SPA) and S (KPA) Palmer amaranth populations. This study was conducted as a randomized complete block design with 4 replications and 2 runs. Prior to treatment, plants were measured and assigned into three groups based on height. The groups were denoted as small (Sm = 4 cm ± 2.3), medium (Md = 6.9 cm ± 2.1), and large (Lg = 11.7 cm ± 2.2) (Table 2). Plants were treated with fomesafen at the labeled rate of 280 g ai ha^{-1} as previously described. Data collection consisted of visual control ratings (1, 3, 7, and 14 DAT), height, and biomass. Statistical analysis was conducted using the PROC GLIMMIX procedure in SAS in which both greenhouse runs were pooled for analysis. Single degree of freedom contrasts were used to compare the R population to the S population for each plant size at each rating, height, and above ground biomass. Nontransformed means for Palmer amaranth control, height, and above ground biomass are presented since arcsine and square root transformation did not improve the normality of the data. Differences between the R and S population were considered significant when $P \leq 0.10$.

Palmer amaranth response to other MOA. Two greenhouse experiments were conducted to determine susceptibility of R (SPA) and S (KPA) populations to other POST herbicide treatments. The experiment was designed as randomized complete block design with 4 replications and 2 runs. Plants were treated at 7.5 cm in height. Herbicide treatments consisted of atrazine, chlorimuron ethyl, dicamba, fomesafen, glufosinate, glyphosate, mesotrione, and a non-treated control (UTC) (Table 3). Atrazine and mesotrione applications included 1% v/v crop

oil concentrate (COC) and chlorimuron ethyl, dicamba, and fomesafen included 0.25% v/v of a nonionic surfactant (NIS) by volume. Herbicide applications, data collection, and statistical analysis were performed as previously discussed, however contrasts statements compared differences between S and R populations for each herbicide.

Results and Discussion

Palmer amaranth response to fomesafen. At 14 DAT, control remained lower for SPA, LPA, and WPA populations with only providing 24%, 4%, and 2% control, respectively, while control of the KPA population was 98% (Table 1). Plant height data at 14 DAT were consistent with visual evaluations, with KPA treated plants being shorter due to greater control observed with the population. Smaller plants are more easily controlled with PPO herbicides therefore the observed response may have been less if plant size was larger (Anonymous 2017). The data reported in this study confirms PPO resistance of SPA, LPA, and WPA populations. Salas et al. (2016) reported PPO-R Palmer amaranth in Arkansas and that PPO-R populations would be sustained in the soil for the next two years. Therefore management of Palmer amaranth will continue to be a growing concern for producers in Tennessee and Arkansas as Palmer amaranth continues to evolve multiple herbicide resistance.

Resistance level of fomesafen. At 14 DAT, control of the S population was >97 % for dosages of 1/2X, 1X, 2X, 4X, and 8X. R Palmer amaranth control was similar to each other at 2X, 4X, and 8X rates and provided <90% control. However, control of the R population was less complete when applied below the labeled rate of 280 g ai h^{-1}. In addition, above ground biomass was observed to be reduced in both populations at the higher rates of 2X, 4X, and 8X rates (Figure 1). Based on the GR_{50} values generated from the regression equation, the level of

resistance was 4-fold relative to the S population. Similar results were reported in PPO-R populations from Arkansas (Salas et al 2016). These authors reported that fomesafen resistance in three Palmer amaranth populations was 6-, 13-, and 21-fold relative to the sensitive population.

Effect of Palmer amaranth size on fomesafen efficacy. At 14 DAT differences were observed between the R and S population at each size of Palmer amaranth (Table 2). The three sizes of the S population had >95% control. However, control of the R population was lower 62%, 49%, and 18% for the Sm, Md, and Lg plants, respectively. Biomass of the treated Lg R population was observed to be greater than the treated Sm plants, yielding 6x more biomass (Table 2). The size of Palmer amaranth plants used in this experiment were not extremely large, with the largest plants ranging 12 - 14 cm. If larger plants had been examined then it is possible that a more pronounced treatment difference among the three sizes may have been observed. The data presented in this experiment indicates that the optimal window for controlling the R population has been reduced. Therefore in a GR soybean system, controlling PPO-R populations could prove to be more difficult.

Palmer amaranth response to other herbicides. Control of both R and S Palmer amaranth populations resulted in differences among herbicidal response at 14 DAT (Table 3). Both R and S populations did not differ in their susceptibility to atrazine and glufosinate and provided >97% control. Interestingly, control differed between the R and S population for dicamba and mesotrione. Dicamba provided 93% control for the S population however 69% of the R population was controlled. Response from mesotrione was 94% and 71% control for S and R populations, respectively. Efficacy of glyphosate and chlorimurion for both populations was

<9% control. The biomass and height at 14 DAT were consistent with visual evaluation from this study (Table 3). It should be noted that differences from UTC height and biomass across the studies are likely due to varying greenhouse temperatures at the time of each study was conducted. These results confirm that the PPO-R population is resistant to glyphosate, PPO, and ALS herbicides. Similar findings were reported in Arkansas by Salas et al. (2016). These authors reported 100% mortality of PPO-R Palmer amaranth when subjected to treatments of atrazine and glufosinate. The response of dicamba from this study contradict those from Salas et al. (2016). Control with dicamba provided effective (100%) control of the PPO-R populations in Arkansas. However, reduced control with dicamba on PPO-R populations has been reported in other areas of Arkansas (Schwartz-Lazaro et al. 2017). This reduced control observed could be the result of different resistance mechanisms for these Palmer amaranth populations. Glyphosate was included in this study to observe the herbicidal response among both populations. Our results showed glyphosate consistently provided reduced control with 19% and 18% of R and S populations, respectively. In addition the control observed with glyphosate in this study was not the same as reported by Salas et al. (2016) but this may be due to differences in Palmer amaranth populations. Chlorimuron ethyl is an acetolactate synthase (ALS)-inhibitor (Senseman 2007) that only provided 7% and 9% control of the R and S populations, respectively. It is not surprising to observe reduced control of R and S Palmer amaranth populations with an ALS herbicide. This is largely attributed to widespread occurrence of ALS resistance in Palmer amaranth where selection pressure for GR occurred in populations with the ALS resistance trait (Ward et al. 2012; Burgos et al. 2009).

In the past, PPO herbicides have provided control of GR Palmer amaranth in soybean fields. Incorporating these herbicides into weed management programs provided producers with control of broad spectrum of weeds, low use rates, and allowed producers to suppress weeds with ALS and triazine resistance (Taylor-Lovell et al. 2002). However in recent years, reports of PPO-R in Palmer amaranth have been confirmed (Steckel 2015; Salas et al. 2016) and growing suspicions of PPO resistance in other states has increased (Legleiter and Johnson 2016; Geist 2016). The data reported in this study confirms the R population is resistant to glyphosate, ALS, and PPO herbicides in Tennessee. The use of a single POST herbicide has shown to have good weed control, however, over reliance on a single herbicide increases selection pressure for resistance (Somerville et al. 2017). Results from this study indicate effective control of R Palmer amaranth when the MOA was rotated to atrazine or glufosinate. As confirmation of multiple herbicide resistance of Palmer amaranth increases, herbicidal control options become limited. As a result a higher degree of importance will be placed on implementing the best management practices that include rotating MOA and incorporating residual herbicides aimed for the suppression resistant Palmer amaranth populations.

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Appendix I

Table 1. Response from four Palmer amaranth populations treated POST with fomesafen at 280 g ai ha $^{-1}$ 14 days after treatment.

Population [a]	Fomesafen Dose	14 DAT	
		Control	Height
	g ai ha $^{-1}$	%	cm
KPA	280	99	2.0
	0	0	23.6
LPA	280	0.4	23.4
	0	0	26.9
SPA	280	24	16.5
	0	0	22.2
WPA	280	0.8	21.6
	0	0	22.9
LSD		32	3

[a] Abbreviation for Palmer amaranth populations. KPA – Knox Co., TN Palmer amaranth, WPA – Woodruff Co., AR Palmer amaranth, LPA – Lauderdale Co., TN Palmer amaranth, and SPA – Shelby Co., TN Palmer amaranth.

Table 2. The effect of size on resistant and susceptible Palmer amaranth populations for fomesafen efficacy when treated POST at 280 g ai ha $^{-1}$ 14 days after treatment.

Size Class	Control			Height			Biomass		
	Susceptible [a]	Resistant	Pr > F [b]	Susceptible	Resistant	Pr > F	Susceptible	Resistant	Pr > F
	---------- % ----------			---------- cm ----------			---------- g ----------		
Sm	100	62	0.0104	0.0	4.0	0.0631	0.0	2.2	0.2588
Md	99	49	0.0002	0.4	6.5	0.0020	0.0	2.6	0.1457
Lg	95	18	0.0002	7.8	16.7	<.0001	1.5	12.8	<.0001
LSD			27.2			4.0			4.1

[a] Abbreviation for Palmer amaranth populations. Susceptible – Knox Co., TN Palmer amaranth and Resistant – Shelby Co., TN Palmer amaranth.
b Pr >F values are greater than 0.10 then means from the Susceptible and Resistant populations are the same.

Table 3. The response of Palmer amaranth PPO resistant and susceptible populations to other foliar-applied herbicides 14 days after treatment.

Herbicide	Control			Height			Biomass		
	Susceptible [a]	Resistant	Pr > F [b]	Susceptible	Resistant	Pr > F	Susceptible	Resistant	Pr > F
	---------- % ----------			---------- cm ----------			---------- g ----------		
Control	0	0	-	22.2	17.1	-	11.9	11.4	-
Fomesafen + NIS	98	19	<.0001	1.0	11.0	<.0001	0.5	4.4	0.0002
Chlorimuron + NIS	9	7	0.6765	16.5	15.5	0.7526	8.5	8.0	0.9359
Dicamba	94	69	0.0011	1.4	9.4	<.0001	0.2	1.5	0.2602
Glyphosate	1	0	0.9408	20.0	16.7	0.0703	11.6	8.7	0.0847
Mesotrione + COC	94	71	0.0027	1.3	7.6	0.0008	0.9	1.1	0.8558
Atrazine + COC	99	99	1.0000	0.0	0.0	1.0000	0.0	0.0	1.0000
Glufosinate	97	99	0.7893	1.0	0	0.5930	0.3	0.0	0.7584
LSD			14.7			3.5			2.3

[a] Abbreviation for Palmer amaranth populations. Susceptible – Knox Co., TN Palmer amaranth and Resistant – Shelby Co., TN Palmer amaranth.
b Pr >F values are greater than 0.10 then means from the Susceptible and Resistant populations are the same.

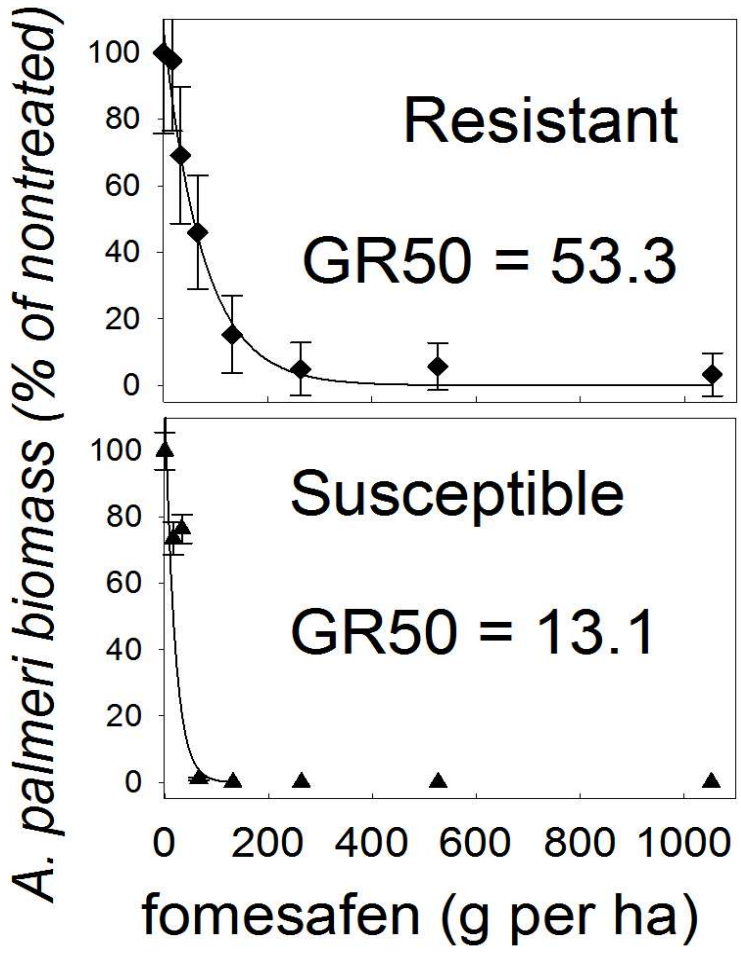


Figure 1. Palmer amaranth biomass on resistant and susceptible populations at 14 days after treatment. Means ± standard error of eight measurements. GR_{50} was calculated based on regression equation stated in text.

Appendix II

Objective 1
Treatments: Flexstar at 1 pt/A and UTC; **Sprayed on Ap. 8, 2016**
Ratings at 1, 3, 7, 14, 21 DAT

KPA- Susceptible Pigweed from Knox Co. TN

SPA - Possible Resistant Pigweed from Shelby Co. TN

LPA - Possible resistant Pigweed from Lauderdale Co. TN
WPA - Possible resistant Pigweed from woodruff Co., AR

Rep	Pop	Trt	Run	Height (in)	Height (cm)	% Injury	% Injury	% Injury	% Injury	Height (in)	Height (cm)
				4/8/2016	4/8/2016	4/9/2016	4/11/2016	4/15/2016	4/22/2016	4/22/2016	4/22/2016
				DAT 0	DAT 0	DAT 1	DAT 3	DAT 7	DAT 14	DAT 14	DAT 14
106	GPW	TRT	A	3.5	8.9	40.0	30	10	2	8.5	21.59
202	GPW	TRT	A	4.0	10.2	20.0	15	5	0	10	25.4
301	GPW	TRT	A	4.0	10.2	20.0	10	5	0	8	20.32
406	GPW	TRT	A	3.8	9.5	50.0	40	10	0	9	22.86
507	GPW	TRT	A	3.5	8.9	30.0	20	10	2	7	17.78
102	KPW	TRT	A	4.5	11.4	60.0	80	99	99	0	0
207	KPW	TRT	A	3.5	8.9	70.0	80	99	99	0	0
303	KPW	TRT	A	4.0	10.2	70.0	90	99	99	0	0
408	KPW	TRT	A	4.3	10.8	60.0	80	99	99	0	0
506	KPW	TRT	A	4.0	10.2	60.0	80	95	50	4	10.16
108	LPW	TRT	A	4.0	10.2	50.0	30	10	0	9	22.86
206	LPW	TRT	A	4.0	10.2	50.0	40	10	0	8.5	21.59
307	LPW	TRT	A	4.3	10.8	50.0	30	15	0	12	30.48
404	LPW	TRT	A	4.0	10.2	40.0	30	15	2	7.5	19.05
508	LPW	TRT	A	4.0	10.2	60.0	50	10	0	9	22.86
104	SPW	TRT	A	3.5	8.9	70.0	80	99	90	0	0

203	SPW	TRT	A	3.5	8.9	70.0	80	50	2	6	15.24
305	SPW	TRT	A	3.5	8.9	50.0	30	10	2	10	25.4
407	SPW	TRT	A	3.8	9.5	40.0	30	10	2	10	25.4
105	GPW	UTC	A	4.5	11.4	0.0	0	0	0	10	25.4
208	GPW	UTC	A	3.8	9.5	0.0	0	0	0	7	17.78
306	GPW	UTC	A	4.5	11.4	0.0	0	0	0	9.5	24.13
401	GPW	UTC	A	4.0	10.2	0.0	0	0	0	10	25.4
505	GPW	UTC	A	4.5	11.4	0.0	0	0	0	8.5	21.59
101	KPW	UTC	A	4.0	10.2	0.0	0	0	0	7	17.78
205	KPW	UTC	A	3.8	9.5	0.0	0	0	0	9	22.86
308	KPW	UTC	A	4.0	10.2	0.0	0	0	0	8	20.32
402	KPW	UTC	A	3.5	8.9	0.0	0	0	0	12	30.48
501	KPW	UTC	A	4.0	10.2	0.0	0	0	0	10.5	26.67
107	LPW	UTC	A	4.5	11.4	0.0	0	0	0	11	27.94
204	LPW	UTC	A	4.5	11.4	0.0	0	0	0	12.5	31.75
302	LPW	UTC	A	3.5	8.9	0.0	0	0	0	10	25.4
403	LPW	UTC	A	3.8	9.5	0.0	0	0	0	10	25.4
502	LPW	UTC	A	3.8	9.5	0.0	0	0	0	9.5	24.13
103	SPW	UTC	A	3.5	8.9	0.0	0	0	0	8	20.32
201	SPW	UTC	A	3.5	8.9	0.0	0	0	0	9	22.86
304	SPW	UTC	A	3.5	8.9	0.0	0	0	0	8	20.32
405	SPW	UTC	A	3.3	8.3	0.0	0	0	0	10	25.4

Objective 2A: Determine the effective palmer size on PPO POST activity at sm, med, and lg
Treatments: Flexstar at 1 pt/A and UTC; **Sprayed on Dec. 3, 2015**
Ratings at 3, 7, 14, 21 DAT

SPW - Susceptible Pigweed from Knox Co.
RPW - Possible Resistant Pigweed Shelby Co.

Rep	Population	Treatment	RUN	Height (in)	Height (cm)	% Injury	% Injury	% Injury	Fresh Wt (g)	Height (cm)
				12/3/2015	12/3/2015	12/6/2015	12/10/2015	12/17/2015	12/17/2015	12/17/2015
				DAT 0	DAT 0	DAT 3	DAT 7	DAT 14	DAT 14	DAT 14
112	RPW-Lg	TRT	A	4.2	10.7	70	80	0	3.72	15
201	RPW-Lg	TRT	A	4.0	10.2	70	50	0	7.98	15
305	RPW-Lg	TRT	A	6.5	16.5	40	30	0	25.47	29
406	RPW-Lg	TRT	A	4.7	11.9	70	40	0	7.2	19
504	RPW-Lg	TRT	A	4.9	12.4	60	40	0	27.36	24
111	RPW-Md	TRT	A	2.1	5.3	80	90	20	0.24	7
202	RPW-Md	TRT	A	2.4	6.1	80	99	99	0.21	6
311	RPW-Md	TRT	A	2.5	6.4	70	95	0	1.06	7
412	RPW-Md	TRT	A	3.0	7.6	70	40	0	10.56	15
503	RPW-Md	TRT	A	2.1	5.3	90	99	99	0	0
608	RPW-Md	TRT	A	2.8	7.1	80	50	0	2.51	12
704	RPW-Md	TRT	A	3.5	8.9	80	99	99	0	3
806	RPW-Md	TRT	A	2.7	6.9	80	99	75	0.43	6
110	RPW-Sm	TRT	A	0.9	2.3	90	99	99	0	0

212	RPW-Sm	TRT	A	1.9	4.8	90	99	99	0	0
304	RPW-Sm	TRT	A	1.6	4.1	90	99	99	0	0
411	RPW-Sm	TRT	A	1.5	3.8	90	99	99	0	0
509	RPW-Sm	TRT	A	1.3	3.3	90	99	99	0	0
607	RPW-Sm	TRT	A	1.9	4.8	90	99	99	0	0
711	RPW-Sm	TRT	A	1.5	3.8	80	80	0	0.43	3
807	RPW-Sm	TRT	A	1.9	4.8	80	99	99	0	2
106	SPW-Lg	TRT	A	4.6	11.7	80	90	90	1.09	8
210	SPW-Lg	TRT	A	4.6	11.7	70	95	99	1.07	9
308	SPW-Lg	TRT	A	4.5	11.4	80	99	99	0.75	8
409	SPW-Lg	TRT	A	7.5	19.1	80	99	0	1.03	12
510	SPW-Lg	TRT	A	6.4	16.3	70	99	95	2.15	14
601	SPW-Lg	TRT	A	5.7	14.5	70	99	70	1.5	12
710	SPW-Lg	TRT	A	4.8	12.2	70	80	0	3.87	12
811	SPW-Lg	TRT	A	5.9	15.0	80	99	99	1.01	7
105	SPW-Md	TRT	A	2.6	6.6	90	99	99	0	0
206	SPW-Md	TRT	A	2.3	5.8	90	99	99	0	0
303	SPW-Md	TRT	A	3.0	7.6	90	99	99	0	0
402	SPW-Md	TRT	A	3.7	9.4	80	99	99	0	3
505	SPW-Md	TRT	A	2.3	5.8	90	99	99	0	0
606	SPW-Md	TRT	A	2.6	6.6	90	99	99	0	0
703	SPW-Md	TRT	A	3.7	9.4	80	99	99	1.08	3
805	SPW-Md	TRT	A	2.9	7.4	90	99	99	0	0
911	SPW-Md	TRT	A	2.4	6.1	90	99	99	0	0
1002	SPW-Md	TRT	A	2.2	5.6	90	99	99	0	0
104	SPW-Sm	TRT	A	1.4	3.6	90	99	99	0	0

209	SPW-Sm	TRT	A	1.6	4.1	90	99	99	0	0
306	SPW-Sm	TRT	A	1.5	3.8	90	99	99	0	0
410	SPW-Sm	TRT	A	1.8	4.6	90	99	99	0	0
508	SPW-Sm	TRT	A	1.7	4.3	90	99	99	0	0
109	RPW-Lg	UTC	A	4.0	10.2	0	0	0	28.3	34
207	RPW-Lg	UTC	A	5.6	14.2	0	0	0	32.25	25
310	RPW-Lg	UTC	A	5.0	12.7	0	0	0	31.65	25
403	RPW-Lg	UTC	A	4.3	10.9	0	0	0	21.34	25
108	RPW-Md	UTC	A	2.1	5.3	0	0	0	18.3	23
203	RPW-Md	UTC	A	2.5	6.4	0	0	0	22.18	26
307	RPW-Md	UTC	A	3.2	8.1	0	0	0	20.48	19
404	RPW-Md	UTC	A	3.8	9.7	0	0	0	18.06	25
507	RPW-Md	UTC	A	2.3	5.8	0	0	0	28.13	19
604	RPW-Md	UTC	A	2.2	5.6	0	0	0	24.19	19
707	RPW-Md	UTC	A	2.4	6.1	0	0	0	1.04	18
809	RPW-Md	UTC	A	2.1	5.3	0	0	0	12.23	20
901	RPW-Md	UTC	A	2.6	6.6	0	0	0	14.6	28
107	RPW-Sm	UTC	A	1.5	3.8	0	0	0	15.24	18
211	RPW-Sm	UTC	A	1.2	3.0	0	0	0	4.46	10
302	RPW-Sm	UTC	A	1.9	4.8	0	0	0	19.32	23
407	RPW-Sm	UTC	A	1.0	2.5	0	0	0	6.22	12
511	RPW-Sm	UTC	A	1.3	3.3	0	0	0	17.72	17
612	RPW-Sm	UTC	A	1.6	4.1	0	0	0	22.18	28
702	RPW-Sm	UTC	A	1.8	4.6	0	0	0	9	16
103	SPW-Lg	UTC	A	4.0	10.2	0	0	0	30.71	30
204	SPW-Lg	UTC	A	5.3	13.5	0	0	0	35.05	29
312	SPW-Lg	UTC	A	5.7	14.5	0	0	0	29.07	28

405	SPW-Lg	UTC	A	6.0	15.2	0	0	0	25.87	33
501	SPW-Lg	UTC	A	4.8	12.2	0	0	0	27.89	24
605	SPW-Lg	UTC	A	5.1	13.0	0	0	0	32.64	32
708	SPW-Lg	UTC	A	5.3	13.5	0	0	0	35.65	35
810	SPW-Lg	UTC	A	4.2	10.7	0	0	0	35.55	25
102	SPW-Md	UTC	A	2.5	6.4	0	0	0	24.56	21
208	SPW-Md	UTC	A	2.7	6.9	0	0	0	16.68	20
309	SPW-Md	UTC	A	3.4	8.6	0	0	0	25.29	36
401	SPW-Md	UTC	A	3.0	7.6	0	0	0	25.16	29
502	SPW-Md	UTC	A	3.3	8.4	0	0	0	28.97	20
609	SPW-Md	UTC	A	3.0	7.6	0	0	0	24.31	35
701	SPW-Md	UTC	A	2.2	5.6	0	0	0	21.94	23
804	SPW-Md	UTC	A	2.1	5.3	0	0	0	27.27	24
909	SPW-Md	UTC	A	3.0	7.6	0	0	0	24.92	28
101	SPW-Sm	UTC	A	1.8	4.6	0	0	0	15.17	25
205	SPW-Sm	UTC	A	1.5	3.8	0	0	0	17.55	26
301	SPW-Sm	UTC	A	1.9	4.8	0	0	0	16.1	22
408	SPW-Sm	UTC	A	1.0	2.5	0	0	0	23.97	21

Objective 2B: Determine the effective palmer size on PPO POST activity at different heights (sm, med, lg)
Treatments: Flexstar at 1 pt/A and UTC; **Sprayed on April, 14, 2016**

SPW - Susceptible Pigweed from Knox Co.
RPW - Possible Resistant Pigweed from Shelby Co.

Rep	Population	TRT	RUN	Height (in)	Height (cm)	% Injury	% Injury	% Injury	% Injury	Fresh Wt (g)	Height (cm)
				4/14/2016	4/14/2016	4/15/2016	4/17/2016	4/21/2016	4/28/2016	4/28/2016	4/28/2016
				DAT 0	DAT 0	DAT 1	DAT 3	DAT 7	DAT 14	DAT 14	DAT 14
112	RPW-Lg	TRT	B	4.0	10.2	50	80	40	20	12.9	16.51
201	RPW-Lg	TRT	B	4.0	10.2	10	10	10	5	20.84	15.24
305	RPW-Lg	TRT	B	4.0	10.2	60	70	80	40	3.755	7.62
406	RPW-Lg	TRT	B	5.5	14.0	10	30	30	20	19.104	25.4
505	RPW-Lg	TRT	B	4.0	10.2	50	85	99	99	0	0
111	RPW-Md	TRT	B	2.5	6.4	60	90	90	20	0.818	5.08
202	RPW-Md	TRT	B	2.0	5.1	60	85	99	99	0	0
311	RPW-Md	TRT	B	3.5	8.9	60	60	90	40	3.091	5.08
412	RPW-Md	TRT	B	3.0	7.6	60	80	90	85	1.06	5.08
503	RPW-Md	TRT	B	3.0	7.6	50	20	10	5	13.688	12.7
110	RPW-Sm	TRT	B	1.5	3.8	70	95	90	20	1.377	5.08
212	RPW-Sm	TRT	B	1.8	4.4	60	85	95	20	1.337	5.08
304	RPW-Sm	TRT	B	1.5	3.8	0	10	10	5	12.396	15.24
411	RPW-Sm	TRT	B	1.3	3.2	10	10	5	2	10.877	17.78
106	SPW-Lg	TRT	B	6.0	15.2	60	80	95	99	0	0
210	SPW-Lg	TRT	B	6.0	15.2	60	80	99	99	0	0

308	SPW-Lg	TRT	B	6.0	15.2	50	60	90	40	6.109	11.43
409	SPW-Lg	TRT	B	5.5	14.0	70	80	99	99	0	0
105	SPW-Md	TRT	B	2.8	7.0	80	90	99	99	0	0
206	SPW-Md	TRT	B	4.5	11.4	60	90	99	99	0	0
303	SPW-Md	TRT	B	5.0	12.7	70	80	99	99	0	0
402	SPW-Md	TRT	B	3.8	9.5	70	90	99	99	0	0
507	SPW-Md	TRT	B	6.5	16.5	50	80	95	99	0	0
104	SPW-Sm	TRT	B	1.3	3.2	80	99	99	99	0	0
209	SPW-Sm	TRT	B	1.8	4.4	70	90	99	99	0	0
306	SPW-Sm	TRT	B	1.8	4.4	0	90	99	99	0	0
410	SPW-Sm	TRT	B	1.3	3.2	70	95	99	99	0	0
601	SPW-Sm	TRT	B	6.0	15.2	50	80	95	99	0	0
109	RPW-Lg	UTC	B	4.0	10.2	0	0	0	0	25.255	19.05
207	RPW-Lg	UTC	B	4.8	12.1	0	0	0	0	24.052	20.32
310	RPW-Lg	UTC	B	5.0	12.7	0	0	0	0	23.689	24.13
403	RPW-Lg	UTC	B	5.0	12.7	0	0	0	0	29.206	25.4
108	RPW-Md	UTC	B	3.0	7.6	0	0	0	0	24.052	21.59
203	RPW-Md	UTC	B	2.0	5.1	0	0	0	0	23.247	20.32
307	RPW-Md	UTC	B	3.0	7.6	0	0	0	0	19.506	15.24
404	RPW-Md	UTC	B	3.8	9.5	0	0	0	0	20.51	25.4

510	RPW-Md	UTC	B	3.3	8.3	0	0	0	0	19.458	20.32
107	RPW-Sm	UTC	B	2.0	5.1	0	0	0	0	18.35	15.24
211	RPW-Sm	UTC	B	1.5	3.8	0	0	0	0	14.424	15.24
302	RPW-Sm	UTC	B	1.5	3.8	0	0	0	0	18.359	17.78
407	RPW-Sm	UTC	B	1.5	3.8	0	0	0	0	11.392	17.78
605	RPW-Sm	UTC	B	5.0	12.7	0	0	0	0	27.205	22.86
103	SPW-Lg	UTC	B	4.5	11.4	0	0	0	0	32.197	22.86
204	SPW-Lg	UTC	B	5.0	12.7	0	0	0	0	36.842	25.4
312	SPW-Lg	UTC	B	4.5	11.4	0	0	0	0	22.648	21.59
405	SPW-Lg	UTC	B	5.0	12.7	0	0	0	0	32.547	25.4
501	SPW-Lg	UTC	B	6.5	16.5	0	0	0	0	34.169	34.29
102	SPW-Md	UTC	B	3.5	8.9	0	0	0	0	28.117	22.86
208	SPW-Md	UTC	B	3.8	9.5	0	0	0	0	32.09	15.24
309	SPW-Md	UTC	B	4.5	11.4	0	0	0	0	28.263	29.21
401	SPW-Md	UTC	B	4.0	10.2	0	0	0	0	36.099	26.67

502	SPW-Md	UTC	B	3.0	7.6	0	0	0	0	24.778	17.78
101	SPW-Sm	UTC	B	1.0	2.5	0	0	0	0	16.865	20.32
205	SPW-Sm	UTC	B	2.0	5.1	0	0	0	0	18.35	17.78
301	SPW-Sm	UTC	B	1.8	4.4	0	0	0	0	23.648	22.86
408	SPW-Sm	UTC	B	1.5	3.8	0	0	0	0	22.195	22.86

Objective 4B: Evaluate response to other MOAs when sprayed at ~4 inch.

Treatments: **Sprayed on May 6, 2016**

1 UTC
2 Flexstar at 1 pt/A
3 Clarity
4 Classic at 0.008 lb ai/A
5 Roundup PowerMax at 32 fl oz/A
6 Calisto
7 Aatrex
8 Liberty

SPW - Susceptible Pigweed from Knox Co.

RPW - Possible Resistant Pigweed from Shelby Co.

Ratings at 1, 3, 7, 14, 21 DAT

Rep	Pop	Trt.	Run	Height (in)	Height (cm)	% Injury	% Injury	% Injury	% Injury	Height (in)	Height (cm)	Fresh Wt
				5/6/16	5/6/16	5/7/16	5/9/16	5/13/16	5/20/16	5/20/16	5/20/16	10/5/16
				DAT 0	DAT 0	DAT 1	DAT 3	DAT 7	DAT 14	DAT 14	DAT 14	DAT 14
101	KPW	UTC	B	3.50	8.9	0.0	0	0	0	7	17.78	7.24
215	KPW	UTC	B	4.50	11.4	0.0	0	0	0	8.5	21.59	13.2
312	KPW	UTC	B	4.00	10.2	0.0	0	0	0	7	17.78	9.52
403	KPW	UTC	B	3.75	9.5	0	0	0	0	11	27.94	17.08
514	KPW	UTC	B	4	10.2	0	0	0	0	8	20.32	10.03
101	KPW	UTC	C	4.0	10.2	0.0	0	0	0	9	22.86	10.77
215	KPW	UTC	C	5.8	14.6	0.0	0	0	0	9	22.86	11.07
312	KPW	UTC	C	4	10.2	0.0	0	0	0	10	25.4	13.09
403	KPW	UTC	C	5.5	14.0	0	0	0	0	9	22.86	15.33
105	KPW	Roundup	B	3.75	9.5	0.0	0	0	0	7	17.78	7.65
202	KPW	Roundup	B	4.75	12.1	5.0	0	0	0	7	17.78	8.57
307	KPW	Roundup	B	4.00	10.2	0.0	0	0	0	9	22.86	14.5

408	KPW	Roundup	B	4.25	10.8	0	0	0	0	7.5	19.05	11.38
511	KPW	Roundup	B	4.75	12.1	0	0	0	0	8	20.32	9.03
105	KPW	Roundup	C	5.3	13.3	5.0	5	5	0	8	20.32	13.66
202	KPW	Roundup	C	3.8	9.5	5.0	5	5	0	6.5	16.51	11.17
307	KPW	Roundup	C	4.3	10.8	0.0	0	0	5	7	17.78	13.34
408	KPW	Roundup	C	5	12.7	0	0	0	0	11	27.94	14.7
108	KPW	Liberty	B	4.75	12.1	30.0	80	99	90	1.5	3.81	2.38
201	KPW	Liberty	B	4.00	10.2	30.0	80	95	90	2	5.08	0.58
311	KPW	Liberty	B	5.00	12.7	15.0	90	95	99	0	0	0
414	KPW	Liberty	B	4.75	12.1	20	80	95	99	0	0	0
515	KPW	Liberty	B	5	12.7	25	85	95	99	0	0	0
108	KPW	Liberty	C	5.0	12.7	30.0	80	95	99	0	0	0
201	KPW	Liberty	C	3.5	8.9	30.0	90	95	99	0	0	0
311	KPW	Liberty	C	4.25	10.8	20.0	90	95	99	0	0	0
414	KPW	Liberty	C	4	10.2	50	80	95	99	0	0	0
102	KPW	Flexstar	B	4.75	12.1	85.0	90	99	99	0	0	0
203	KPW	Flexstar	B	3.75	9.5	75.0	80	99	99	0	0	0
308	KPW	Flexstar	B	4.00	10.2	80.0	90	99	99	0	0	0
407	KPW	Flexstar	B	4.75	12.1	85	90	99	99	0	0	0
513	KPW	Flexstar	B	4	10.2	85	90	99	99	0	0	0
102	KPW	Flexstar	C	4.0	10.2	80.0	90	99	99	0	0	0
203	KPW	Flexstar	C	4.5	11.4	50.0	80	99	99	0	0	0
308	KPW	Flexstar	C	4.5	11.4	75.0	90	90	90	2	5.08	2.39
407	KPW	Flexstar	C	4.75	12.1	70	90	95	95	1.5	3.81	2.13
104	KPW	Classic	B	3.75	9.5	20.0	10	0	0	8.5	21.59	12.87
210	KPW	Classic	B	4.50	11.4	20.0	10	5	0	9.5	24.13	12.54
314	KPW	Classic	B	3.75	9.5	20.0	10	0	0	5.5	13.97	7.67

416	KPW	Classic	B	3.50	8.9	15	10	5	0	6.5	16.51	11.99
104	KPW	Classic	C	5.0	12.7	20.0	20	40	5	9	22.86	10.05
210	KPW	Classic	C	4.0	10.2	5.0	10	50	20	4	10.16	4.92
314	KPW	Classic	C	3.75	9.5	40.0	40	30	10	4	10.16	3.64
416	KPW	Classic	C	5	12.7	0	10	30	40	5	12.7	4.48
103	KPW	Clarity	B	5.00	12.7	5.0	10	40	99	0	0	0
209	KPW	Clarity	B	4.00	10.2	50.0	50	50	99	0	0	0
302	KPW	Clarity	B	4.00	10.2	30.0	50	99	99	0	0	0
404	KPW	Clarity	B	4.00	10.2	5	20	30	50	5	12.7	2.42
501	KPW	Clarity	B	4	10.2	40	75	95	99	0	0	0
103	KPW	Clarity	C	4.5	11.4	5.0	30	80	99	0	0	0
209	KPW	Clarity	C	4.0	10.2	40.0	50	60	99	0	0	0
302	KPW	Clarity	C	5.0	12.7	30.0	50	90	99	0	0	0
404	KPW	Clarity	C	4	10.2	20	40	60	99	0	0	0
106	KPW	Calisto	B	3.75	9.5	15.0	50	90	95	1.5	3.81	5.28
216	KPW	Calisto	B	5.00	12.7	10.0	60	95	99	0	0	0
304	KPW	Calisto	B	4.25	10.8	20.0	60	95	99	0	0	0
405	KPW	Calisto	B	4.00	10.2	10	60	95	99	0	0	0
502	KPW	Calisto	B	3.75	9.5	10	70	95	99	0	0	0
106	KPW	Calisto	C	4.0	10.2	15.0	50	95	95	0	0	0.8
216	KPW	Calisto	C	4.0	10.2	10.0	60	95	99	0	0	0
304	KPW	Calisto	C	5.0	12.7	20.0	60	90	99	0	0	0
405	KPW	Calisto	C	3.75	9.5	10	70	85	60	3	7.62	2.15
107	KPW	Aatrex	B	4.00	10.2	20.0	75	99	99	0	0	0
206	KPW	Aatrex	B	4.50	11.4	20.0	90	99	99	0	0	0
316	KPW	Aatrex	B	3.75	9.5	20	85	99	99	0	0	0
409	KPW	Aatrex	B	4.75	12.1	25	85	95	99	0	0	0

504	KPW	Aatrex	B	4.75	12.1	15	85	99	99	0	0	0
107	KPW	Aatrex	C	4.5	11.4	20.0	75	99	99	0	0	0
206	KPW	Aatrex	C	4.3	10.8	20.0	90	95	99	0	0	0
316	KPW	Aatrex	C	4	10.2	20	85	99	99	0	0	0
409	KPW	Aatrex	C	4	10.2	30	85	95	99	0	0	0
109	SPW	UTC	B	4.75	12.1	0.0	0	0	0	6.5	16.51	4.95
207	SPW	UTC	B	3.25	8.3	0.0	0	0	0	7.5	19.05	15.32
313	SPW	UTC	B	3.50	8.9	0.0	0	0	0	8.5	21.59	15.51
402	SPW	UTC	B	4.50	11.4	0	0	0	0	6.5	16.51	7.9
109	SPW	UTC	C	3.3	8.3	0.0	0	0	0	6	15.24	11.85
207	SPW	UTC	C	4.0	10.2	0.0	0	0	0	6	15.24	8.5
313	SPW	UTC	C	4	10.2	0.0	0	0	0	7	17.78	13.3
402	SPW	UTC	C	4.5	11.4	0	0	0	0	6	15.24	14.23
113	SPW	Roundup	B	4.00	10.2	0.0	0	0	0	6.5	16.51	5.46
211	SPW	Roundup	B	3.50	8.9	0.0	0	0	0	5	12.7	3.51
309	SPW	Roundup	B	3.25	8.3	0.0	0	0	0	4	10.16	7.61
413	SPW	Roundup	B	3.75	9.5	0	0	0	0	6.5	16.51	7.62
113	SPW	Roundup	C	3.5	8.9	0.0	0	0	0	6.5	16.51	18.73
211	SPW	Roundup	C	3.5	8.9	0.0	0	0	0	7.5	19.05	15.77
309	SPW	Roundup	C	4.5	11.4	0.0	0	0	0	8	20.32	7.37
413	SPW	Roundup	C	4	10.2	0	0	0	0	8.5	21.59	3.79
116	SPW	Liberty	B	3.25	8.3	30.0	90	99	99	0	0	0
205	SPW	Liberty	B	4.00	10.2	25.0	85	95	99	0	0	0
310	SPW	Liberty	B	4.50	11.4	15.0	85	95	99	0	0	0
401	SPW	Liberty	B	4.00	10.2	15	80	95	99	0	0	0
116	SPW	Liberty	C	4.3	10.8	30.0	90	95	99	0	0	0
205	SPW	Liberty	C	5.5	14.0	25.0	85	80	99	0	0	0

310	SPW	Liberty	C	5	12.7	20.0	85	95	99	0	0	0
401	SPW	Liberty	C	5	12.7	20	85	95	99	0	0	0
110	SPW	Flexstar	B	4.50	11.4	70.0	50	20	40	4.5	11.43	2.85
213	SPW	Flexstar	B	3.75	9.5	20.0	15	5	20	5	12.7	5.64
303	SPW	Flexstar	B	3.50	8.9	40.0	20	10	10	5	12.7	4.52
406	SPW	Flexstar	B	3.25	8.3	80	90	99	99	0	0	0
505	SPW	Flexstar	B	3.5	8.9	5	0	0	0	4.5	11.43	4.36
110	SPW	Flexstar	C	4.8	12.1	30.0	20	10	0	5	12.7	5.33
213	SPW	Flexstar	C	3.3	8.3	20.0	15	10	0	5	12.7	7.92
303	SPW	Flexstar	C	3.3	8.3	30.0	20	10	0	5	12.7	4.88
406	SPW	Flexstar	C	3.75	9.5	25	15	5	0	5	12.7	4.4
112	SPW	Classic	B	4.25	10.8	0.0	5	10	5	6	15.24	7.58
214	SPW	Classic	B	3.75	9.5	5.0	5	5	0	8	20.32	11.13
315	SPW	Classic	B	4.00	10.2	10.0	5	5	0	7.5	19.05	6.52
410	SPW	Classic	B	3.75	9.5	15	5	0	0	7	17.78	7.57
509	SPW	Classic	B	3.75	9.5	10	5	0	0	8	20.32	7.46
112	SPW	Classic	C	4.3	10.8	0.0	5	10	10	5	12.7	6.06
214	SPW	Classic	C	5.5	14.0	5.0	5	10	10	4	10.16	8.3
315	SPW	Classic	C	4.75	12.1	10.0	10	20	10	6	15.24	12.04
410	SPW	Classic	C	4.5	11.4	5	10	20	30	3.5	8.89	5.1
111	SPW	Clarity	B	3.75	9.5	5.0	30	40	50	6.5	16.51	3.09
208	SPW	Clarity	B	4.50	11.4	40.0	50	99	99	0	0	0
301	SPW	Clarity	B	4.25	10.8	30.0	40	60	99	0	0	0
412	SPW	Clarity	B	4.00	10.2	10	15	20	70	4	10.16	2.75
111	SPW	Clarity	C	4.0	10.2	10.0	15	20	50	5.5	13.97	1.22
208	SPW	Clarity	C	4.3	10.8	30.0	50	20	80	5	12.7	1.28
301	SPW	Clarity	C	3.8	9.5	30.0	40	50	60	4.5	11.43	2.51

412	SPW	Clarity	C	4	10.2	15	15	20	40	4	10.16	0.96
114	SPW	Calisto	B	5.00	12.7	10.0	30	90	90	4.5	11.43	1.17
212	SPW	Calisto	B	4.00	10.2	20.0	50	95	99	0	0	0
306	SPW	Calisto	B	4.50	11.4	10.0	15	20	40	5.5	13.97	1.53
411	SPW	Calisto	B	3.75	9.5	15	10	10	30	6	15.24	1.84
114	SPW	Calisto	C	3.0	7.6	10.0	30	95	99	0	0	0
212	SPW	Calisto	C	3.5	8.9	20.0	50	80	80	4	10.16	2.74
306	SPW	Calisto	C	3.5	8.9	10.0	20	90	99	0	0	0
411	SPW	Calisto	C	3.25	8.3	20	50	70	30	4	10.16	1.59
115	SPW	Aatrex	B	4.50	11.4	20.0	85	99	99	0	0	0
204	SPW	Aatrex	B	4.00	10.2	15.0	80	95	99	0	0	0
305	SPW	Aatrex	B	4.50	11.4	20.0	80	99	99	0	0	0
415	SPW	Aatrex	B	3.75	9.5	20	85	99	99	0	0	0
506	SPW	Aatrex	B	3.75	9.5	20	85	99	99	0	0	0
115	SPW	Aatrex	C	3.5	8.9	20.0	85	95	99	0	0	0
204	SPW	Aatrex	C	4.0	10.2	15.0	80	95	99	0	0	0
305	SPW	Aatrex	C	3.8	9.5	20.0	80	95	99	0	0	0
415	SPW	Aatrex	C	4	10.2	25	85	99	99	0	0	0

Objective 5A: Titration

Treatments: Sprayed on Sept. 13, 2016

1 UTC

5 Flexstar (1/8, 1/4, 1/2, 1, 2, 4, 8)

SPW - Susceptible Pigweed from Knox Co.

RPW - Possible Resistant Pigweed from Shelby Co.

Ratings at 1, 3, 7, 14, 21 DAT

REP	POP	TRT	RUN	HT (in)	HT (cm)	% Injury	% Injury	% Injury	% Injury	HT (in)	HT (cm)	Fresh Wt
				DAT 0	DAT 0	DAT 1	DAT 3	DAT 7	DAT 14	DAT 14	DAT 14	DAT 15
101	KPW	0X	A	4.25	10.80	0.0	0	0	0	10.5	26.67	11.75
102	KPW	1/8X	A	4.75	12.07	50.0	40	20	5	9	22.86	6.22
103	KPW	1/4X	A	4.75	12.07	50.0	40	30	5	10	25.4	15.98
104	KPW	1X	A	4.75	12.07	90.0	95	99	99	0	0	0
105	KPW	1/2X	A	5.25	13.34	90.0	95	99	99	0	0	0
106	KPW	2X	A	4.50	11.43	90.0	95	99	99	0	0	0
107	KPW	4X	A	5.50	13.97	90.0	95	99	99	0	0	0
108	KPW	8X	A	6.00	15.24	90.0	95	99	99	0	0	0
109	SPW	0X	A	5.50	13.97	0.0	0	0	0	11	27.94	14.72
110	SPW	1/8X	A	4.75	12.07	50.0	40	20	10	12	30.48	11.94
111	SPW	1/4X	A	5.00	12.70	50.0	50	75	5	8.5	21.59	6.47
112	SPW	1X	A	4.75	12.07	50.0	50	60	5	6.5	16.51	8.54
113	SPW	1/2X	A	5.50	13.97	50.0	50	50	5	7.5	19.05	11.65
114	SPW	2X	A	5.50	13.97	70.0	80	90	99	0	0	0
115	SPW	4X	A	4.00	10.16	80.0	90	99	99	0	0	0
116	SPW	8X	A	4.50	11.43	80.0	90	99	99	0	0	0
201	KPW	1/4X	A	5.75	14.61	80.0	80	80	30	7	17.78	5.17
202	SPW	1/4X	A	5.50	13.97	10.0	10	15	15	12	30.48	11.62
203	KPW	8X	A	4.25	10.80	90.0	95	99	99	0	0	0
204	KPW	2X	A	4.00	10.16	90.0	95	99	99	0	0	0

205	SPW	4X	A	6.00	15.24	50.0	50	60	20	6.5	16.51	6.98
206	SPW	1X	A	6.00	15.24	70.0	80	90	5	4	10.16	2.27
207	KPW	1/2X	A	4.50	11.43	80.0	95	99	99	0	0	0
208	SPW	0X	A	4.50	11.43	0.0	0	0	0		0	8.8
209	KPW	4X	A	4.00	10.16	80.0	90	99	99	0	0	0
210	KPW	1/8X	A	5.50	13.97	60.0	60	60	5	10.5	26.67	9.53
211	KPW	0X	A	6.00	15.24	0.0	0	0	0	13	33.02	13.81
212	SPW	1/2X	A	4.75	12.07	20.0	15	15	15	8.5	21.59	13.46
213	SPW	2X	A	4.50	11.43	70.0	90	99	99	0	0	0
214	KPW	1X	A	4.50	11.43	80.0	95	99	99	0	0	0
215	SPW	8X	A	5.25	13.34	85.0	95	99	99	0	0	0
216	SPW	1/8X	A	5.00	12.70	10.0	10	10	10	11	27.94	12.85
301	KPW	1X	A	5.00	12.70	80.0	95	99	99	0	0	0
302	KPW	1/2X	A	5.00	12.70	70.0	80	90	90	2.5	6.35	1.63
303	SPW	1/8X	A	5.00	12.70	15.0	15	15	10	9.5	24.13	7.27
304	SPW	2X	A	5.50	13.97	60.0	60	50	20	6.5	16.51	8.22
305	SPW	1/4X	A	4.50	11.43	70	60	50	5	7	17.78	5.8
306	SPW	1/2X	A	5.50	13.97	80	80	90	80	3	7.62	1.5
307	SPW	0X	A	4.00	10.16	0	0	0	0	11.75	29.845	15.1
308	KPW	4X	A	4.50	11.43	90	95	99	99	0	0	0
309	SPW	1X	A	5.50	13.97	80	80	90	80	3	7.62	1.46
310	KPW	8X	A	4.50	11.43	80	95	99	99	0	0	0
311	SPW	4X	A	5.75	14.61	70	80	90	80	5	12.7	2.56
312	KPW	0X	A	5.75	14.61	0	0	0	0	11.5	29.21	13.95
313	KPW	1/4X	A	5.75	14.61	60	80	90	70	5.75	14.605	4.31
314	KPW	2X	A	5.00	12.70	80	95	99	99	0	0	0
315	KPW	1/8X	A	5.50	13.97	20	20	20	15	7.5	19.05	6.99

316	SPW	8X	A	5.75	14.61	90	95	99	99	0	0	0
401	KPW	1/4X	A	5.00	12.70	70	80	85	30	7	17.78	4.26
402	SPW	8X	A	6.00	15.24	70	80	85	30	6.5	16.51	5.46
403	SPW	1/4X	A	5.75	14.61	60	60	70	10	9.5	24.13	7.85
404	SPW	1X	A	5.00	12.70	80	80	90	80	3.25	8.255	1.39
405	SPW	1/2X	A	5.50	13.97	85	90	99	99	0	0	0
406	KPW	0X	A	4.50	11.43	0	0	0	0	11.5	29.21	18.48
407	SPW	2X	A	4.25	10.80	80	90	95	99	0	0	0
408	KPW	2X	A	4.00	10.16	90	90	99	99	0	0	0
409	SPW	0X	A	5.50	13.97	0	0	0	0	12	30.48	16.06
410	KPW	4X	A	4.00	10.16	90	90	99	99	0	0	0
411	KPW	8X	A	5.75	14.61	90	90	99	99	0	0	0
412	KPW	1X	A	5.75	14.61	80	95	99	99	0	0	0
413	KPW	1/8X	A	4.75	12.07	70	80	90	60	8	20.32	6.07
414	SPW	4X	A	4.75	12.07	80	95	99	99	0	0	0
415	SPW	1/8X	A	5.50	13.97	20	15	15	15	9.25	23.495	18.99
416	KPW	1/2X	A	5.75	14.61	80	95	99	99	0	0	0

Objective 5B: Titration
Treatments: **Sprayed on**

1 UTC
5 Flexstar (1/8, 1/4, 1/2, 1, 2, 4, 8)

SPW - Susceptible Pigweed from Knox Co.

Ratings at 1, 3, 7, 14 DAT

REP	POP	TRT	RUN	HT (in)	HT (cm)	% Injury	% Injury	% Injury	% Injury	HT (in)	HT (cm)	Plant Fresh WT
				DAT 0	DAT 1	DAT 1	DAT 3	DAT 7	DAT 14	DAT 14	DAT 14	DAT 14
101	KPW	0X	B	4.50	11.43	0.0	0	0	0	10	25.4	25.7
102	KPW	1/8X	B	5.00	12.70	40.0	30	20	5	11.25	28.575	20.81
103	KPW	1/4X	B	4.75	12.07	50.0	30	25	10	11	27.94	26.61
104	KPW	1X	B	5.00	12.70	90.0	90	95	99	0	0	0
105	KPW	1/2X	B	5.50	13.97	80.0	90	90	99	0	0	0
106	KPW	2X	B	4.00	10.16	90.0	95	99	99	0	0	0
107	KPW	4X	B	5.75	14.61	90.0	95	99	99	0	0	0
108	KPW	8X	B	5.50	13.97	90.0	95	99	99	0	0	0
109	SPW	0X	B	5.00	12.70	2.0	0	0	0	11	27.94	25.41
110	SPW	1/8X	B	5.00	12.70	20.0	20	20	5	12.5	31.75	23.29
111	SPW	1/4X	B	5.00	12.70	60.0	40	20	10	9	22.86	19.05
112	SPW	1X	B	5.00	12.70	80.0	90	99	99	0	0	0
113	SPW	1/2X	B	4.75	12.07	70.0	90	99	99	0	0	0
114	SPW	2X	B	4.00	10.16	80.0	90	99	99	0	0	0
115	SPW	4X	B	4.00	10.16	80.0	95	99	99	0	0	0
116	SPW	8X	B	5.00	12.70	80.0	95	99	99	0	0	0
201	KPW	1/4X	B	4.75	12.07	60.0	70	40	10	12	30.48	23.17

202	SPW	1/4X	B	6.00	15.24	30.0	40	40	5	10	25.4	19.75
203	KPW	8X	B	5.50	13.97	90.0	95	99	99	0	0	0
204	KPW	2X	B	6.00	15.24	80.0	95	99	99	0	0	0
205	SPW	4X	B	4.25	10.80	90.0	95	99	99	0	0	0
206	SPW	1X	B	5.25	13.34	80.0	90	99	99	0	0	0
207	KPW	1/2X	B	5.00	12.70	80.0	80	90	90	0	0	0
208	SPW	0X	B	4.00	10.16	0.0	0	0	0	10.5	26.67	17.31
209	KPW	4X	B	4.25	10.80	90.0	95	99	99	0	0	0
210	KPW	1/8X	B	5.50	13.97	60.0	50	30	10	11.75	29.845	23.13
211	KPW	0X	B	4.50	11.43	0.0	0	0	0	14	35.56	25.12
212	SPW	1/2X	B	5.00	12.70	40.0	30	30	10	11	27.94	22.33
213	SPW	2X	B	5.00	12.70	85.0	95	99	99	0	0	0
214	KPW	1X	B	5.50	13.97	75.0	90	95	99	0	0	0
215	SPW	8X	B	5.00	12.70	80.0	95	99	99	0	0	0
216	SPW	1/8X	B	6.00	15.24	30.0	20	20	10	12	30.48	49.5
301	KPW	1X	B	6.00	15.24	75.0	90	95	99	0	0	0
302	KPW	1/2X	B	5.50	13.97	80.0	90	99	99	0	0	0
303	SPW	1/8X	B	5.25	13.34	15.0	15	10	5	12	30.48	24.97
304	SPW	2X	B	4.00	10.16	80.0	90	99	99	0	0	0
305	SPW	1/4X	B	5.25	13.34	20	20	15	5	15.5	39.37	39.4
306	SPW	1/2X	B	5.00	12.70	70	60	60	20	8.5	21.59	13.01
307	SPW	0X	B	5.75	14.61	0	0	0	0	17	43.18	31
308	KPW	4X	B	5.50	13.97	85	90	95	99	0	0	0
309	SPW	1X	B	5.00	12.70	50	40	40	30	11.5	29.21	12.15
310	KPW	8X	B	4.25	10.80	80	95	99	99	0	0	0
311	SPW	4X	B	4.25	10.80	90	95	99	99	0	0	0
312	KPW	0X	B	5.25	13.34	0	0	0	0	13.5	34.29	23.05

313	KPW	1/4X	B	5.00	12.70	60	40	20	10	10	25.4	19.69
314	KPW	2X	B	5.25	13.34	75	80	95	99	0	0	0
315	KPW	1/8X	B	5.75	14.61	50	50	30	15	10	25.4	19.31
316	SPW	8X	B	4.75	12.07	90	95	99	99	0	0	0
401	KPW	1/4X	B	5.50	13.97	50	30	20	15	10	25.4	19.25
402	SPW	8X	B	4.00	10.16	80	95	99	99	0	0	0
403	SPW	1/4X	B	5.50	13.97	70	80	80	30	7	17.78	6.81
404	SPW	1X	B	6.00	15.24	70	90	95	99	0	0	0
405	SPW	1/2X	B	6.00	15.24	70	60	50	10	10	25.4	15.62
406	KPW	0X	B	5.50	13.97	0	0	0	0	13.75	34.925	23
407	SPW	2X	B	4.00	10.16	80	95	99	99	0	0	0
408	KPW	2X	B	4.50	11.43	80	90	95	99	0	0	0
409	SPW	0X	B	6.00	15.24	0	0	0	0	16.5	41.91	39.34
410	KPW	4X	B	4.50	11.43	70	90	99	99	0	0	0
411	KPW	8X	B	5.50	13.97	85	90	99	99	0	0	0
412	KPW	1X	B	5.00	12.70	80	90	95	99	0	0	0
413	KPW	1/8X	B	6.00	15.24	60	40	20	5	10	25.4	21.83
414	SPW	4X	B	5.75	14.61	90	95	99	99	0	0	0
415	SPW	1/8X	B	5.50	13.97	15	15	15	5	13	33.02	35.88
416	KPW	1/2X	B	5.50	13.97	80	90	95	99	0	0	0

CHAPTER II

SOIL-APPLIED PROTOPORPHYRINOGEN OXIDASE INHIBITING HERBICIDES FOR CONTROL OF PROTOPORPHRINOGEN RESISTANT AND SUSCEPTIBLE PALMER AMARANTH (AMARNATHUS PALMERI)

Soil-applied protoporphyrinogen oxidase inhibiting herbicides for control of protoporphrinogen resistant and susceptible Palmer amaranth (Amaranthus palmeri)

Alinna M. Umphres, Lawrence E. Steckel, and Thomas C. Mueller[1]

Abstract

Palmer amaranth (*Amaranthus palmeri* S. Watson) resistance to protoporphyrinogen oxidase (PPO)-inhibiting herbicides has become an increasing problem to producers throughout the southeast region of the US. Traditionally, these herbicides can be used as foliar-applied and soil-applied in glyphosate resistant (GR) cropping systems to control GR Palmer amaranth. Heavy reliance on PPO herbicides has contributed to the increased selection for PPO-resistant (PPO-R) Palmer amaranth populations. In 2016, two greenhouse studies were conducted to evaluate the efficacy of soil-applied flumioxazin, fomesafen, saflufenacil and sulfentrazone on a known susceptible (S) and resistant (R) Palmer amaranth population. The data from this study suggests complete control (100%) was achieved for the S population at 35 days after treatment (DAT). The R population showed difference among herbicide treatments with flumioxazin and saflufenacil having similar responses in control and fomesafen and sulfentrazone resulting in less control of the R Palmer amaranth populations.

Nomenclature: flumioxazin, fomesafen, saflufenacil, sulfentrazone,

Key words: Herbicide resistance, PPO Herbicides, Soils

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Introduction

Glyphosate resistant (GR) Palmer amaranth (*Amaranthus palmeri*) is an economically devastating weed for producers throughout the southeastern United States. Palmer amaranth's competitive ability is largely attributed to being prolific seed producers (Keeley et al. 1987), extended emergence throughout the growing season (Jha et al. 2010), shoot heights of 2 m or more (Horak and Loughin 2000), high photosynthetic capacity (Ehleringer 1983), and all the while having the capacity to evolve resistance to multiple herbicides (Heap 2017). Previous studies have observed soybean [Glycine max (L.)] yield reductions as a direct result of Palmer amaranth. Klingeman and Oliver (1994) reported soybean yield loss of 17 to 68% when Palmer amaranth densities were 0.33 to 10 plant m^{-1} of row. In Kansas, Bensch et al. (2003) reported yield losses as high as 78% from a single Palmer amaranth plant per 0.125 m of row. Consequently, these authors also observed Palmer amaranth had accumulated greater plant biomass, increased seed production and had a greater impact on soybean yield when compared to redroot pigweed (*Amaranthus retroflexus*) and common waterhemp (*Amaranthus tuberculatus*). Palmer amaranth resistant to glyphosate has presented a challenge in GR cropping systems. To have successful control producers have implemented the use of soil-residual herbicides in major row crops such as soybean and cotton [*Gossypium hirsutum* (L.)]. The use of protoporphyrinogen oxidase (PPO)-inhibiting herbicides such as flumioxazin, fomesafen, saflufenacil, and sulfentrazone has been implemented in many GR soybean systems. These PPO-inhibiting herbicides (Weed Science Society of America [WSSA] group 14) catalyze the conversion of protoporphyrinogen IX to protoporphyrin IX, which is known as the last step in the biosynthesis of heme and chlorophyll. Inhibition of the PPO enzyme causes formation of

free radicals resulting in degradation of lipids and protein membranes leading to cell death (Duke et al. 1991).

Flumioxazin is one herbicide that has been adopted for use to control GR Palmer amaranth. Flumioxazin is used in many crops including soybean, cotton, corn [Zea mays (L)], peanut [Arachis hypoeaea (L)], and other row crops (Anonymous 2017a, Senseman 2007a). Flumioxazin has a wide window of application that can be used in an early preplant (EPP) burndown program or PRE and can be tank mixed with other PRE herbicides. Flumioxazin controls many broadleaf species including common lambsquarters (*Chenopodium album*), common ragweed (*Ambrosia artemisiifolia*), Palmer amaranth, and various species of morningglory (*Ipomoea* spp.) (Askew et al. 2002; Clewis et al. 2007; Niekamp et al. 1999). In one study authors evaluated the control of GR Palmer amaranth consisting of two standalone herbicides, flumioxazin and fomesafen, and a tank-mix treatment of metribuzin + chlorimuron applied as a PRE (Whitaker et al. 2010). They reported GR Palmer amaranth control with flumioxazin at 94, 84, and 70% control at 0, 30, and 90 DAT, respectively. Other positive attributes to using flumioxazin include a low use rate, flexible crop rotations, and the ability to control weed species with acetolactate synthase (ALS) and triazine resistance (Taylor-Lovell et al. 2002).

Fomesafen is a diphenylether herbicide labeled for use in soybean (Anonymous 2017b, Senseman 2007b). Fomesafen controls various broadleaf weeds such as common cocklebur (*Xanthium strumarium*), common lambsquarters, common ragweed, Palmer amaranth, and other problematic weeds. Nandula et al. (2013) conducted a study that observed alternative soil-applied herbicides to control two GR and one glyphosate-susceptible (GS) Palmer amaranth

populations. These authors concluded that fomesafen along with S-metolachlor and pendimethalin provided 100% control of the Palmer amaranth populations at 4 weeks after treatment (WAT). Previous studies have demonstrated fomesafen control of Palmer amaranth resistant to dinitroaniline and sulfonylurea herbicides when applied as a PRE (Lundsford et al. 1998; Troxler et al. 2002). In addition to controlling Palmer amaranth and other broadleaf weed species, fomesafen can be applied for suppression of yellow nutsedge (*Cyperus esculentus*) and certain grass weeds.

Saflufenacil, belonging to the pyrimidinedione chemical family, is a PPO-inhibiting herbicide labeled for use as a burndown, soil residual control of broadleaf weeds, and as a harvest aid for crop desiccation in major crops (Grossmann et al. 2011). Saflufenacil encompasses both residual and contact activity on susceptible broadleaf weeds including Palmer amaranth and multiple species of morningglory, and various weeds (Anonymous 2017c). One study documented a reduction of Palmer amaranth biomass along with two other *Amaranthus* species ranging from 82 to 98% control when saflufenacil was applied as a PRE at rates of 6 to 30 g ha $^{-1}$, respectively (Geier et al. 2009). Saflufenacil has been adopted by producers primarily because of its low use rates, environmental soundness and for control of weeds resistant to other herbicide modes of action (Soltani et al. 2009).

Sulfentrazone is a member of the phenyl triazolinone herbicide family (Senseman 2007c). One advantage to incorporating sulfentrazone in a weed management program can be attributed to its flexible window of application as a PPI or PRE in soybean (Anonymous d). Sulfentrazone provides residual control of a wide range of weeds. Several studies have observed sulfentrazone PRE control of Palmer amaranth in various cropping systems such as soybean (Sweat et al. 1998)

and sunflower (Reddy et al. 2012). Sulfentrazone can be used as an effective tool for soybean producers for managing GR weeds (Knezevic et al 2009).

In the southeast region of the United States, several authors have reported PPO resistance in Palmer amaranth. Steckel (2015) confirmed PPO resistance in the western region of Tennessee. As of 2016, confirmation of PPO resistance extended to Arkansas (Salas et al. 2016), Indiana (Legleiter and Johnson 2016), and in Missouri (Geist 2016). In these areas, PPO resistance has been confirmed on Palmer amaranth plants surviving the normal labeled dosage rate from POST application, however, limited information is available on the efficacy of soil-residual PPO-inhibiting herbicides. Therefore, the objective of this study was to evaluate the efficacy of four soil-applied PPO-inhibiting herbicides on PPO-resistant and PPO-susceptible Palmer amaranth populations.

Materials and Methods

Two greenhouse experiments were conducted in Knoxville, Tennessee in 2016. The Palmer amaranth seeds used were a known PPO resistant (R) population (data not shown) collected the previous year from a producer's field located in Shelby County, Tennessee and a susceptible (S) population purchased from Azlin Seed Co. in Leland, Mississippi. Both population seeds were subjected to scarification that involved a 70 % sulfuric acid bath for 30s, rinsed thoroughly with deionized water and allowed to dry for 24 h. Styrofoam cups of 500 mL size were used. Each cup had 4 small holes poked in the bottom prior to filling with sifted soil (2 mm screen size) of a silt loam (Sequatchie; 6 pH; 1.9% OM) that had no previous history of herbicide use or Palmer amaranth growth. The day prior to planting, pots were set on to trays filled with water and allowed to sub-irrigate overnight to ensure adequate moisture throughout

the soil profile. The following day pots were removed from trays to drain excess water, then an indention (3cm wide and 3 mm in depth) was made at the soil surface for seeds to be planted in order to reduce seed movement. Seeds of each population were planted into separate pots at a rate of 100 seeds pot $^{-1}$. Each pot only contained one population of seeds. Immediately after planting, pots were sprayed with the use of a one nozzle boom CO_2 backpack sprayer equipped with a 8002 XR nozzle (TeeJet Technologies, P.O. Box 7900, Wheaton, IL 60187) calibrated to deliver 190 L ha $^{-1}$ at 210 kPa.

Herbicide treatments consisted of four different herbicides applied at a rate structure of 26 to 420 g ha $^{-1}$, 35 to 560 g ha $^{-1}$, 6.3 to 100 g ha $^{-1}$, and 26 to 420 g ha $^{-1}$ for flumioxazin (Valor SX, Valent U.S.A. Corporation, Walnut Creek, CA), fomesafen (Flexstar, Syngenta Crop Protection, LLC, Greensboro, NC), saflufenacil (Sharpen, BASF Corporation, Research Triangle Park, NC), and sulfentrazone (Spartan, FMC Corporation, Philadelphia, PA), respectively. Herbicide rates were 1/8X, 1/4X, 1/2X, 1X, and 2X of the normal labeled use rate for flumioxazin (210 g ai ha^{-1}), fomesafen (280 g ai ha^{-1}), saflufenacil (50 g ai ha^{-1}) and sulfentrazone (210 g ai ha^{-1}). To validate herbicide doses, filter paper (10 cm width, 1 mm thickness) was used to capture the sprayed treatments consisting of two duplicates placed between cups prior to treatment. The filter papers were collected after each treatment was applied and placed into individual 250 mL Nalgene bottles then stored in a freezer (-20 C) for later lab analysis (Mueller et al. 2014).

After spraying, cups were arranged in the greenhouse in a randomized complete block design with 4 replications and watered with approximately 0.8 cm to move herbicide into the soil. Pots were watered daily to maintain soil moisture and a complete fertilizer (15-30-15

MiracleGro ®) was applied three times a week. Watering procedures were based on preliminary studies, where too much water leached the herbicide out of the surface zone and too little water did not provide for adequate seed germination (data not shown). Watering activities were carefully monitored and more frequent, light irrigations (~ 2 mm) were used. Visual estimates of Palmer amaranth control where 100% indicated complete control and 0% indicated no control were collected at 3, 7, 14, 21, 28, and 35 days after treatment (DAT). Also at those times number of emerged Palmer amaranth were counted (data not shown). Seedlings with cotyledons fully expanded were considered to be emerged. At 35 DAT, plant height and above ground fresh biomass were collected.

The design of this experiment was a completely crossed three-way factorial with two populations (R and S populations) by four herbicides (flumioxazin, fomesafen, saflufenacil, and sulfentrazone) by five rates with two runs and four replications in each run. Each run included nontreated controls (UTC) with a total of eight UTC cups per run. Data was modeled using Sigma Plot and a rectangular hyperbola model was used to model the relationship between Palmer amaranth control and herbicide rate (Equation 1). In this model a estimates the asymptote or maximum Palmer amaranth control and b is an estimate of the relative rate to achieve 50% of the control. An inverse rectangular hyperbola model was used to model the relationship between Palmer amaranth biomass and relative herbicide rate. In this model a estimates the maximum reduction in Palmer amaranth biomass in relation to the herbicide rate and b estimates the relative herbicide rate to achieve 50% of the biomass reduction (Equation 2). The models are represented by the following equations:

Equation 1. $F = a*x/(b-x)$

Equation 2. F = a*b/(b+x)

Results and Discussion

Herbicide dosage. The herbicide concentrations were normalized to the 1X dosage (Table 4). While some variation was observed, in general the relative dosages were near the targeted concentration. Greater variation at the 200% (2X) dose may be due to concentrations being toward the upper linear range of the LC-MS instrument (Mueller et al. 2014).

Soil-residual control of Palmer amaranth populations. Significant differences were not detected at 3 DAT and is largely attributed to the prolonged emergence of Palmer amaranth (Ward et al. 2012). However at 7 and 14 DAT, significant differences in control were observed between the R and S populations as well as differences we observed in herbicides within treatment rates (data not shown). Data indicated that at the 0.125X and 0.25X rates control of the S population was >98% for flumioxazin, fomesafen and saflufenacil treatments with sulfentrazone providing <93% control at 7 and 14 DAT. Flumioxazin and fomesafen applied at 1X rate controlled 99% of the R population.

At 21 and 28 DAT, control of the S population was greater when compared to the R population (data not shown). Flumioxazin continued to show residual control at >90% and >94% for both R and S populations, respectively, across the five rates. Fomesafen control of the S population was >94%, but control of the R population resulted in <78% control. At 21 and 28 DAT, sulfentrazone provided 86% control of the S population at the 0.125X rate, but control was lower (62%) for the R population.

Differences between the R and S populations continued to be present at 35 DAT (Figures 2, 3). Differences in control of the S population were noted at the 0.125X and 0.25X rates

(Figure 2). At the lowest treatment rate flumioxazin, saflufenacil, and fomesafen controlled the S population at 90%, 89% and 88%, respectively while sulfentrazone provided 84% control of the S population. When the treatment rate increased to 0.25X, flumioxazin and fomesafen were observed to have complete control (100%) of the S population followed by saflufenacil (92%) and sulfentrazone (88%). In general, all herbicides provided effective control of the S population.

The estimates of the regression a parameter showed that all four herbicides provided nearly 100% control at the 1x rate for the S population while only flumioxazin provided 100% control for the R population. The estimate for parameter 'b' showed no differences for the S population while for the R population a higher herbicide rate was needed (saflufenacil 0.016 = flumioxazin 0.019 < fomesafen 0.07 = sulfentrazone 0.087) to achieve 50% control (Table 5). These results were consistent with the published literature on amaranth control by these herbicides (Whitaker et al. 2010; Nandula et al. 2013; Geier et al. 2009; Sweat et al. 1998). In contrast, control of the R population differed at the 0.125X, 0.25X, 0.5X, and 1X rates (Figure 3). At, the 0.125X rate, residual control was in the order of flumioxazin (88%) = saflufenacil (86%) > fomesafen (64%) > sulfentrazone (59%).

Palmer amaranth biomass. Above ground biomass was collected and weighed at 35 DAT for both R and S populations (Figure 4, 5). The UTC R and S populations showed no differences in biomass. Significant differences between populations were detected at 0.125X, 0.25X, and 0.5X herbicide dosages. At the 0.25X dose, flumioxazin (1.6 g) and saflufenacil (3.6 g) resulted in the lowest biomass of R population whereas sulfentrazone (4.8 g) and fomesafen (4.2 g) resulted in greater biomass. As the dosage increased to 0.5X, the R population biomass

was greater in sulfentrazone treatments whereas no differences in biomass were observed for saflufenacil (0.6 g), fomesafen (0.3 g), and flumioxazin (0.08 g). No differences in biomass from any herbicide-treated pots were indicated for the S population. At the 1X rate differences between populations were observed. Sulfentrazone continued to have the greatest biomass for the R populations among the herbicides. Flumioxazin, saflufenacil, and fomesafen biomass was the same. Overall, biomass in the susceptible populations was greatly reduced by all herbicide application (Figure 4).

The estimates in the regression analysis for biomass directly mirrored the control data. The estimate for parameter a or the asymptote showed that the S population biomass was reduced to the same level for all four herbicides (all = 7.25). While the estimate for parameter b showed that the R population needed 25 to 39% higher rate (7.28 compared to 9.71 and 10.71) to achieve the same level of biomass reduction. Moreover the estimate for parameter 'b' showed the order of biomass reduction to be flumioxazin > fomesafen = saflufenacil ≥ sulfentrazone (Table 6).

Flumioxazin was the most effective herbicide to reduce emergence and growth of the R Palmer amaranth population followed by saflufenacil, fomesafen, and then sulfentrazone. Wuerffel et al. (2015) also concluded flumioxazin had greater residual control on PPO-R waterhemp (*Amaranthus tuberculatus),* another problematic weed in soybean systems in the mid-western region of the US. Interestingly, these authors concluded that control with fomesafen and sulfentrazone on PPO-R waterhemp was similar. Although these results differed from those observed in this study, differences in herbicide rates used, and also resistant mechanisms may differ between species. Several authors have concluded that differences in response to PPO

herbicides vary greatly due to chemical families (Patzoldt et al. 2005; Falk et al 2006) and reported the PPO-R waterhemp was more sensitive to flumioxazin. These authors also reported similar findings when sulfentrazone was applied. Although the data in this study did not agree with the authors on the results of sulfentrazone, differential herbicidal response could perhaps be attributed to differences in *Amaranthus* spp.

In this study fomesafen provided complete control (100%) of the S population however, this was not observed for the R population when applied at the label rate. Shoup et al. (2003) concluded that diphenylether herbicides such as fomesafen may have the propensity for reduced response in PPO-R waterhemp. The reasoning these authors provided was that fomesafen is commonly used as a POST for control of waterhemp. In the southeast region of the United States, fomesafen is primarily used in GR soybean systems as a POST to control GR Palmer amaranth. The R population used in this study had four annual applications of POST fomesafen (Flexstar, Prefix) in the last five years (Steckel, personal communication). This further indicates that sensitivity to different PPO herbicide families can occur and from this study, fomesafen and sulfentrazone were observed to have less activity on the R population.

Overall, this study further confirms that there is a differential herbicidal response on R and S Palmer amaranth. The herbicide treatments used in this study did not completely eliminate Palmer amaranth biomass in all replications of the R population (Figure 5). Clearly, all the PPO herbicides were still effective, but less on the R vs S population. Riggins and Tranel (2012) stated that Palmer amaranth could evolve resistance to PPO-inhibiting herbicides due to the PPX2 gene in Palmer amaranth which is similar to that in waterhemp and two other *Amaranthus* spp. Therefore the data in this study demonstrates that GR Palmer amaranth in Tennessee has

evolved to include PPO resistance. In previous years, Palmer amaranth control in a GR soybean system relied heavily relied on PPO inhibiting herbicides to control GR Palmer amaranth. The data shown here suggests that changing PPO chemical families can improve Palmer amaranth control issues in PPO-R populations.

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Appendix I

Table 4. Summary of herbicide mean concentrations and standard error at 0 DAT.

	Relative Concentration[a]			
Rate	Flumioxazin	Fomesafen	Saflufenacil	Sulfentrazone
	----------%----------			
12.5	13 ± 4	15.0 ± 4	11 ± 2	19 ± 6
25	28 ± 4	26.0 ± 6	18 ± 3	29 ± 7
50	70 ± 11	55.0 ± 14	48 ± 11	60 ± 11
100	100 ± 0	100.0 ± 0	100 ± 0	100 ± 0
200	155 ± 25	255.0 ± 60	247 ± 54	268 ± 78

[a] Percent mean concentrations were normalized to the 1X labeled dose.

Table 5. Regression parameters (hyperbola, single rectangular, 2 parameter model) for Palmer Amaranth control 35 DAT as affected by PPO herbicides.

Population	Figure	Herbicide	Coefficient a	Std err, a	Coefficient b	Std err, b	r^2
Susceptible	2	fomesafen	102.3	1.9	0.016	0.005	0.78
Susceptible	2	saflufenacil	101.6	1.57	0.019	0.005	0.88
Susceptible	2	flumioxazin	102	1.58	0.013	0.004	0.79
Susceptible	2	sulfentrazone	101.4	1.61	0.029	0.005	0.94
Resistant	3	fomesafen	96.8	2.01	0.07	0.009	0.97
Resistant	3	saflufenacil	96.2	2.64	0.016	0.008	0.61
Resistant	3	flumioxazin	100	1.88	0.019	0.006	0.83
Resistant	3	sulfentrazone	90.4	6.03	0.087	0.031	0.83

Table 6. Regression parameters (hyperbola decay, 2 parameter) for Palmer amaranth biomass 35 DAT as affected by PPO herbicides.

Population	Figure	Herbicide	Coefficient a	Std err, a	Coefficient b	Std err, b	r^2
Susceptible	4	fomesafen	7.28	0.066	0.003	0.001	0.99
Susceptible	4	saflufenacil	7.28	0.062	0.006	0.001	0.99
Susceptible	4	flumioxazin	7.28	0.007	0.0003	0.0001	0.99
Susceptible	4	sulfentrazone	7.28	0.179	0.039	0.004	0.99
Resistant	5	fomesafen	10.28	1.05	0.093	0.031	0.94
Resistant	5	saflufenacil	10.71	1.47	0.14	0.059	0.91
Resistant	5	flumioxazin	10.27	0.354	0.03	0.006	0.99
Resistant	5	sulfentrazone	9.71	1.71	0.156	0.083	0.78

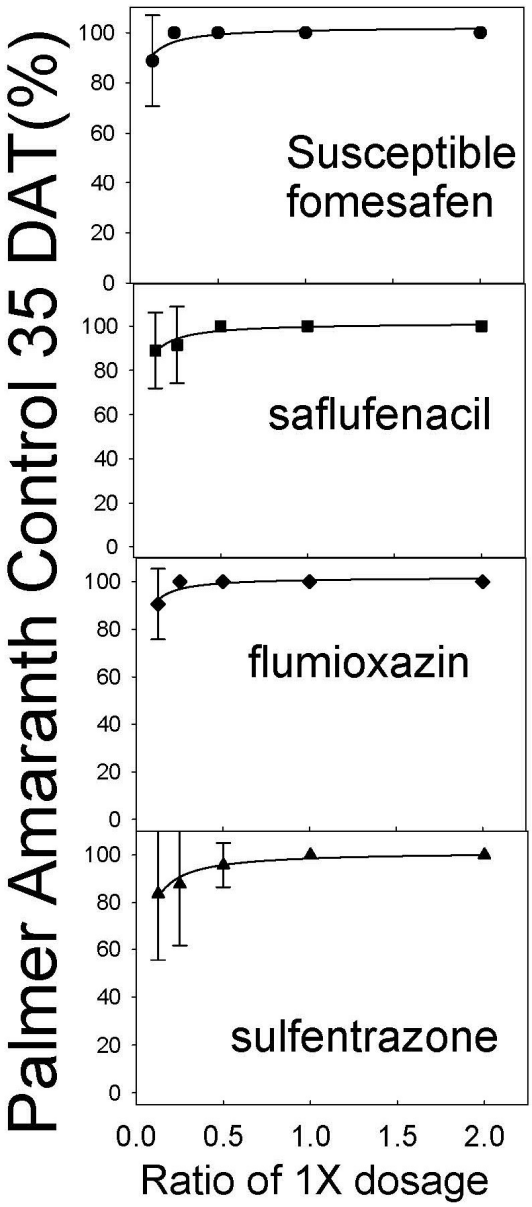


Figure 2. Percent Control of Susceptible Palmer amaranth population at 35 DAT. Data points represent mean + standard error. Solid line is regression curve to equation f = a*x/(b-x).

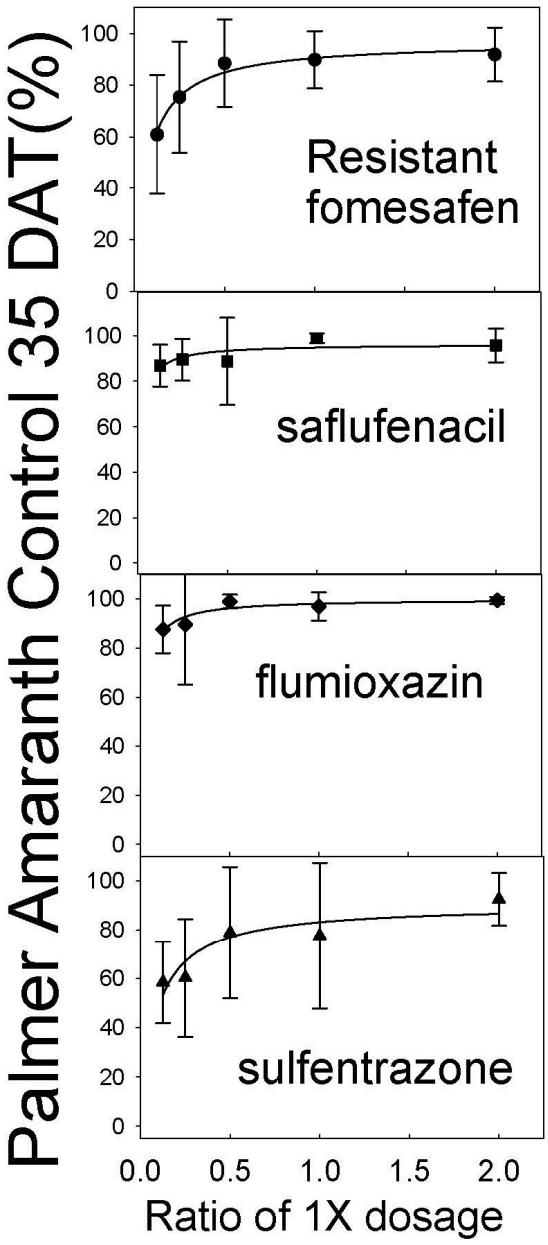


Figure 3. Percent Control of Resistant Palmer amaranth population at 35 DAT. Data points represent mean + standard error. Solid line is regression curve to equation f = a*x/(b-x).

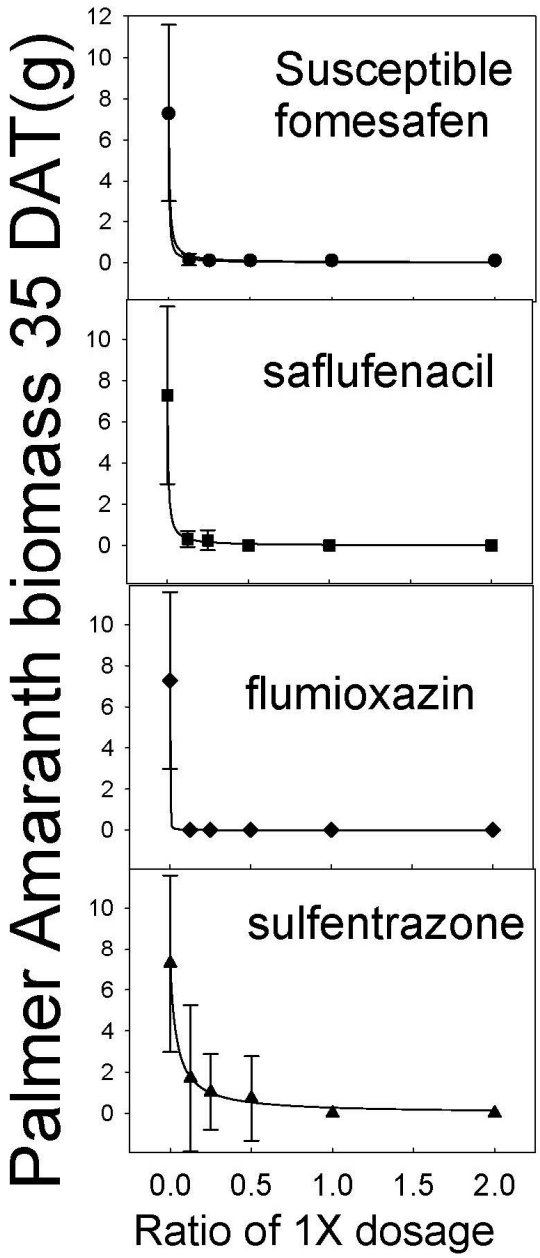


Figure 4. Palmer Amaranth biomass of Susceptible population at 35 DAT. Data points represent mean + standard error. Solid line is regression curve to equation f = (a*b)/(b+x).

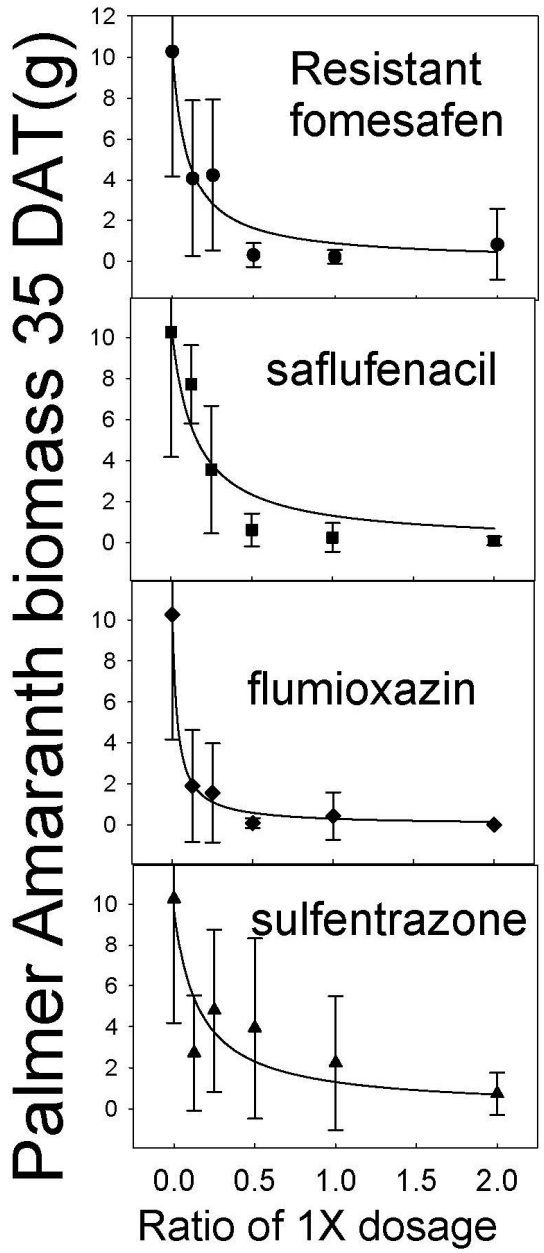


Figure 5. Palmer Amaranth biomass of Resistant population at 35 DAT. Data points represent mean + standard error. Solid line is regression curve to equation f = (a*b)/(b+x).

Appendix II

Objective 3: Soil Residual Response

Treatments: Sprayed on Oct. 20, 2016

1 UTC

2 Valor SX (1/8, 1/4, 1/2, 1, 2)

4 Spartan 4F (1/8, 1/4, 1/2, 1, 2)

5 Flexstar (1/8, 1/4, 1/2, 1, 2)

6 Sharpen (1/8, 1/4, 1/2, 1, 2)

S - Azlin Seed.

R - Shelby Co.

Ratings at 1, 3, 7, 14, 21, 28, 35 DAT

Emergence - numerical count

Control - percent based

RUN	Blk	REP	POP	TRT	Dose	Emergence-DAT						Control-DAT						Ht	WT
						3	7	14	21	28	35	3	7	14	21	28	35	cm	g
1	1	102	R	FLUMI	0.125	0	0	4	4	6	6	100	100	81	81	68	68	9.7	8.2
1	1	102	S	FLUMI	0.125	0	0	0	0	2	2	100	100	100	100	87	87	3.7	0.1
1	1	103	R	FLUMI	0.25	0	0	0	0	0	0	100	100	100	100	100	100	0	0
1	1	103	S	FLUMI	0.25	0	0	0	0	0	0	100	100	100	100	100	100	0	0
1	1	104	R	FLUMI	0.5	0	0	0	0	0	0	100	100	100	100	100	100	0	0
1	1	104	S	FLUMI	0.5	0	0	0	0	0	0	100	100	100	100	100	100	0	0
1	1	105	R	FLUMI	1	0	0	0	0	0	2	100	100	100	100	100	89	1	0.1
1	1	105	S	FLUMI	1	0	0	0	0	0	0	100	100	100	100	100	100	0	0
1	1	106	R	FLUMI	2	0	0	0	0	0	0	100	100	100	100	100	100	0	0
1	1	106	S	FLUMI	2	0	0	0	0	0	0	100	100	100	100	100	100	0	0
1	2	203	R	FLUMI	2	0	0	0	0	0	0	100	100	100	100	100	100	0	0
1	2	203	S	FLUMI	2	0	0	0	0	0	0	100	100	100	100	100	100	0	0
1	2	213	R	FLUMI	0.125	0	0	2	2	2	3	100	100	92	92	92	88	6.1	1.6
1	2	213	S	FLUMI	0.125	0	0	0	0	0	0	100	100	100	100	100	100	0	0
1	2	214	R	FLUMI	0.25	0	2	2	2	2	1	100	87	92	92	92	96	11.4	1.4
1	2	214	S	FLUMI	0.25	0	0	0	0	0	0	100	100	100	100	100	100	0	0

1	2	216	R	FLUMI	0.5	0	1	1	1	1	2	100	93	96	96	96	92	4.4	0.7
1	2	216	S	FLUMI	0.5	0	0	0	0	0	0	100	100	100	100	100	100	0	0
1	2	227	R	FLUMI	1	0	0	0	0	0	0	100	100	100	100	100	100	0	0
1	2	227	S	FLUMI	1	0	0	0	0	0	0	100	100	100	100	100	100	0	0
1	3	304	R	FLUMI	0.5	0	0	0	0	0	0	100	100	100	100	100	100	0	0
1	3	304	S	FLUMI	0.5	0	0	0	0	0	0	100	100	100	100	100	100	0	0
1	3	319	R	FLUMI	2	0	0	0	0	0	1	100	100	100	100	100	96	0.6	0
1	3	319	S	FLUMI	2	0	0	0	0	0	0	100	100	100	100	100	100	0	0
1	3	324	R	FLUMI	0.25	0	0	0	0	0	0	100	100	100	100	100	100	0	0
1	3	324	S	FLUMI	0.25	0	0	0	0	0	0	100	100	100	100	100	100	0	0
1	3	325	R	FLUMI	1	0	0	0	0	0	0	100	100	100	100	100	100	0	0
1	3	325	S	FLUMI	1	0	0	0	0	0	0	100	100	100	100	100	100	0	0
1	3	326	R	FLUMI	0.125	0	0	1	1	1	2	100	100	97	97	96	92	3.8	0.4
1	3	326	S	FLUMI	0.125	0	0	0	0	0	0	100	100	100	100	100	100	0	0
1	4	402	R	FLUMI	1	0	1	1	2	2	2	100	93	95	89	88	86	11.4	3.3
1	4	402	S	FLUMI	1	0	0	0	0	0	0	100	100	100	100	100	100	0	0
1	4	413	R	FLUMI	2	0	0	0	0	0	0	100	100	100	100	100	100	0	0
1	4	413	S	FLUMI	2	0	0	0	0	0	0	100	100	100	100	100	100	0	0
1	4	415	R	FLUMI	0.5	0	0	0	0	0	0	100	100	100	100	100	100	0	0
1	4	415	S	FLUMI	0.5	0	0	0	0	0	0	100	100	100	100	100	100	0	0
1	4	416	R	FLUMI	0.25	0	4	7	9	10	10	100	71	64	53	39	29	8	5.6
1	4	416	S	FLUMI	0.25	0	0	0	0	0	0	100	100	100	100	100	100	0	0
1	4	420	R	FLUMI	0.125	0	1	3	3	3	3	100	93	85	84	82	79	4.7	1.3
1	4	420	S	FLUMI	0.125	0	0	0	0	0	0	100	100	100	100	100	100	0	0
1	1	117	R	FOME	0.125	0	7	14	14	14	13	100	26	33	33	26	30	12.3	7.8
1	1	117	S	FOME	0.125	0	0	0	0	0	0	100	100	100	100	100	100	0	0
1	1	118	R	FOME	0.25	0	0	1	1	2	2	100	100	95	95	89	89	3.8	0.2
1	1	118	S	FOME	0.25	0	0	0	0	0	0	100	100	100	100	100	100	0	0
1	1	119	R	FOME	0.5	0	0	2	3	5	6	100	100	90	86	74	68	5.5	1.6

1	1	119	S	FOME	0.5	0	0	0	0	0	0	100	100	100	100	100	100	0	0
1	1	120	R	FOME	1	0	0	2	4	5	6	100	100	90	81	74	68	4.2	0.7
1	1	120	S	FOME	1	0	0	0	0	0	0	100	100	100	100	100	100	0	0
1	1	121	R	FOME	2	0	0	0	1	2	3	100	100	100	95	89	84	4.7	0.6
1	1	121	S	FOME	2	0	0	0	0	0	0	100	100	100	100	100	100	0	0
1	2	204	R	FOME	0.25	0	3	3	3	3	4	100	80	89	89	88	84	8.5	5
1	2	204	S	FOME	0.25	0	0	0	0	0	0	100	100	100	100	100	100	0	0
1	2	206	R	FOME	0.125	0	5	6	7	7	8	100	67	77	74	73	69	9.7	4
1	2	206	S	FOME	0.125	0	0	0	0	0	0	100	100	100	100	100	100	0	0
1	2	210	R	FOME	2	0	1	5	6	6	6	100	93	81	77	76	76	8	5
1	2	210	S	FOME	2	0	0	0	0	0	0	100	100	100	100	100	100	0	0
1	2	220	R	FOME	0.5	0	0	0	0	0	0	100	100	100	100	100	100	0	0
1	2	220	S	FOME	0.5	0	0	0	0	0	0	100	100	100	100	100	100	0	0
1	2	223	R	FOME	1	0	0	0	0	0	0	100	100	100	100	100	100	0	0
1	2	223	S	FOME	1	0	0	0	0	0	0	100	100	100	100	100	100	0	0
1	3	303	R	FOME	0.5	0	1	1	1	0	0	100	95	97	97	100	100	0	0
1	3	303	S	FOME	0.5	0	0	0	0	0	0	100	100	100	100	100	100	0	0
1	3	311	R	FOME	1	0	0	0	0	1	1	100	100	100	100	96	96	3.8	0.1
1	3	311	S	FOME	1	0	0	0	0	0	0	100	100	100	100	100	100	0	0
1	3	313	R	FOME	2	0	0	0	0	0	0	100	100	100	100	100	100	0	0
1	3	313	S	FOME	2	0	0	0	0	0	0	100	100	100	100	100	100	0	0
1	3	320	R	FOME	0.25	0	10	14	13	13	13	100	46	54	55	42	50	8.5	6.9
1	3	320	S	FOME	0.25	0	0	0	0	0	0	100	100	100	100	100	100	0	0
1	3	322	R	FOME	0.125	0	8	15	15	15	15	100	57	51	48	33	42	8	4
1	3	322	S	FOME	0.125	0	0	0	0	1	1	100	100	100	100	83	83	3.8	0.1
1	4	407	R	FOME	2	0	1	5	4	4	3	100	93	74	79	76	79	3.6	0.9
1	4	407	S	FOME	2	0	0	0	0	0	0	100	100	100	100	100	100	0	0
1	4	414	R	FOME	1	0	3	2	2	2	3	100	79	90	89	88	79	3.4	0.8
1	4	414	S	FOME	1	0	0	0	0	0	0	100	100	100	100	100	100	0	0

1	4	419	R	FOME	0.125	0	3	3	4	5	7	100	79	85	79	70	50	3.6	0.4
1	4	419	S	FOME	0.125	0	0	0	0	0	0	100	100	100	100	100	100	0	0
1	4	423	R	FOME	0.5	0	1	4	4	6	6	100	93	79	79	64	57	5.9	0.7
1	4	423	S	FOME	0.5	0	0	0	0	0	0	100	100	100	100	100	100	0	0
1	4	427	R	FOME	0.25	0	6	7	7	9	9	100	57	64	63	45	36	8	3.2
1	4	427	S	FOME	0.25	0	0	0	0	0	0	100	100	100	100	100	100	0	0
1	1	122	R	FOME	0.125	0	0	3	3	3	2	100	100	86	86	84	89	2.5	0.2
1	1	122	S	SAFLU	0.125	0	0	0	2	2	2	100	100	100	87	87	87	7.3	0.9
1	1	123	R	SAFLU	0.25	0	0	0	1	1	1	100	100	100	95	95	95	10.2	0.1
1	1	123	S	SAFLU	0.25	0	0	0	0	0	0	100	100	100	100	100	100	0	0
1	1	124	R	SAFLU	0.5	0	0	1	2	2	2	100	100	95	90	89	89	10.2	2.1
1	1	124	S	SAFLU	0.5	0	0	0	0	0	0	100	100	100	100	100	100	0	0
1	1	125	R	SAFLU	1	0	0	1	1	1	1	100	100	95	95	95	95	16.5	2
1	1	125	S	SAFLU	1	0	0	0	0	0	0	100	100	100	100	100	100	0	0
1	1	126	R	SAFLU	2	0	0	0	0	0	1	100	100	100	100	100	95	0.6	0
1	1	126	S	SAFLU	2	0	0	0	0	0	0	100	100	100	100	100	100	0	0
1	2	217	R	SAFLU	1	0	1	1	1	0	0	100	93	96	96	100	100	0	0
1	2	217	S	SAFLU	1	0	0	0	0	0	0	100	100	100	100	100	100	0	0
1	2	219	R	SAFLU	2	0	0	1	2	2	2	100	100	96	92	92	92	3.5	0.2
1	2	219	S	SAFLU	2	0	0	0	0	0	0	100	100	100	100	100	100	0	0
1	2	221	R	SAFLU	0.5	0	3	3	3	3	3	100	80	89	89	88	88	4.7	0.2
1	2	221	S	SAFLU	0.5	0	0	0	0	0	0	100	100	100	100	100	100	0	0
1	2	224	R	SAFLU	0.25	0	4	7	7	7	7	100	73	74	74	73	73	7.2	2.2
1	2	224	S	SAFLU	0.25	0	0	1	1	1	1	100	100	93	93	92	92	8.9	0.7
1	2	225	R	SAFLU	0.125	0	2	2	4	5	7	100	87	92	85	80	73	6.8	3.9
1	2	225	S	SAFLU	0.125	0	0	0	0	1	1	100	100	100	100	92	92	7.6	0.4
1	3	301	R	SAFLU	0.25	0	1	1	2	2	3	100	95	97	93	91	88	6.1	5
1	3	301	S	SAFLU	0.25	0	0	0	0	0	0	100	100	100	100	100	100	0	0
1	3	302	R	SAFLU	0.5	0	1	1	1	1	1	100	95	97	97	96	96	12.7	1.6

1	3	302	S	SAFLU	0.5	0	0	0	0	0	0	100	100	100	100	100	100	0	0
1	3	305	R	SAFLU	2	0	0	0	0	0	0	100	100	100	100	100	100	0	0
1	3	305	S	SAFLU	2	0	0	0	0	0	0	100	100	100	100	100	100	0	0
1	3	312	R	SAFLU	0.125	1	0	4	4	5	6	100	100	87	86	78	77	8.9	7.5
1	3	312	S	SAFLU	0.125	0	0	0	1	1	1	100	100	100	83	83	83	7.6	0.5
1	3	314	R	SAFLU	1	0	0	0	0	0	1	100	100	100	100	100	96	1.3	0.1
1	3	314	S	SAFLU	1	0	0	0	0	0	0	100	100	100	100	100	100	0	0
1	4	405	R	SAFLU	0.25	0	3	3	3	3	3	100	79	85	84	82	79	10.6	3.7
1	4	405	S	SAFLU	0.25	0	0	1	1	1	1	100	100	90	90	90	90	8.9	1.3
1	4	409	R	SAFLU	1	0	0	0	0	0	0	100	100	100	100	100	100	0	0
1	4	409	S	SAFLU	1	0	0	0	0	0	0	100	100	100	100	100	100	0	0
1	4	418	R	SAFLU	0.5	0	0	5	6	7	8	100	100	74	68	58	43	3	0.4
1	4	418	S	SAFLU	0.5	0	0	0	0	0	0	100	100	100	100	100	100	0	0
1	4	424	R	SAFLU	2	0	4	4	3	3	3	100	71	79	84	82	79	5.9	0.6
1	4	424	S	SAFLU	2	0	0	0	0	0	0	100	100	100	100	100	100	0	0
1	4	425	R	SAFLU	0.125	0	0	0	0	1	1	100	100	100	100	94	93	2.5	0
1	4	425	S	SAFLU	0.125	0	0	0	2	4	5	100	100	100	80	60	50	4.2	0.8
1	1	112	R	SULFEN	0.125	2	4	10	10	8	8	20	58	52	52	58	57	12.5	7
1	1	112	S	SULFEN	0.125	0	5	7	7	8	8	100	41	53	53	48	48	12.3	9.9
1	1	113	R	SULFEN	0.25	0	4	7	8	9	9	100	58	67	62	53	51	9.3	6.6
1	1	113	S	SULFEN	0.25	0	1	1	1	1	1	100	88	93	93	94	94	14	3
1	1	114	R	SULFEN	0.5	0	7	18	18	20	20	100	40	35	30	30	25	9.7	10.9
1	1	114	S	SULFEN	0.5	0	2	2	2	3	4	100	76	87	87	81	74	8.9	5.8
1	1	115	R	SULFEN	1	0	6	17	17	15	14	100	37	19	19	21	24	6.8	3.3
1	1	115	S	SULFEN	1	0	0	0	0	0	0	100	100	100	100	100	100	0	0
1	1	116	R	SULFEN	2	0	2	3	4	5	5	100	79	86	81	74	73	6.6	1.9
1	1	116	S	SULFEN	2	0	0	0	0	0	0	100	100	100	100	100	100	0	0
1	2	202	R	SULFEN	0.125	0	8	10	10	9	9	100	47	62	62	65	65	13.5	11.3
1	2	202	S	SULFEN	0.125	0	0	0	1	1	1	100	100	100	93	92	92	3.2	0.1

1	2	207	R	SULFEN	0.5	0	0	0	1	1	1	100	100	100	96	96	96	2.5	0
1	2	207	S	SULFEN	0.5	0	0	0	1	1	1	100	100	100	93	92	92	2.5	0
1	2	209	R	SULFEN	2	0	0	0	0	0	1	100	100	100	100	100	96	1.9	0
1	2	209	S	SULFEN	2	0	0	0	0	0	0	100	100	100	100	100	100	0	0
1	2	211	R	SULFEN	0.25	0	9	3	8	11	11	100	40	89	70	57	57	12.7	11.9
1	2	211	S	SULFEN	0.25	0	0	0	0	0	0	100	100	100	100	100	100	0	0
1	2	222	R	SULFEN	1	0	3	2	2	2	2	100	80	92	92	92	92	0.6	0.6
1	2	222	S	SULFEN	1	0	0	0	0	0	0	100	100	100	100	100	100	0	0
1	3	310	R	SULFEN	0.5	0	1	4	4	4	4	100	95	87	86	82	85	5.9	3.1
1	3	310	S	SULFEN	0.5	0	0	1	0	0	0	100	100	91	100	100	100	0	0
1	3	315	R	SULFEN	1	0	0	2	2	2	3	100	100	93	93	91	88	4.2	1.2
1	3	315	S	SULFEN	1	0	0	0	0	0	0	100	100	100	100	100	100	0	0
1	3	316	R	SULFEN	0.125	0	8	14	14	15	16	100	57	54	52	33	38	7.8	7.6
1	3	316	S	SULFEN	0.125	0	0	1	0	0	0	100	100	91	100	100	100	0	0
1	3	317	R	SULFEN	2	0	1	2	2	2	2	100	95	93	93	91	92	8.9	1.8
1	3	317	S	SULFEN	2	0	0	0	0	0	0	100	100	100	100	100	100	0	0
1	3	327	R	SULFEN	0.25	0	12	21	21	20	20	100	35	31	28	11	23	6.4	2.9
1	3	327	S	SULFEN	0.25	0	0	0	1	1	1	100	100	100	83	83	83	6.4	0.5
1	4	404	R	SULFEN	0.125	1	6	9	9	9	9	0	57	54	53	45	36	11.9	6.9
1	4	404	S	SULFEN	0.125	0	0	6	6	7	7	100	100	40	40	30	30	6.8	3.7
1	4	410	R	SULFEN	0.25	0	6	7	7	8	9	100	57	64	63	52	36	9.7	5.7
1	4	410	S	SULFEN	0.25	0	5	9	9	9	9	100	40	35	30	30	25	9.3	4.8
1	4	412	R	SULFEN	1	0	7	7	9	9	9	100	50	64	53	45	36	8	3.1
1	4	412	S	SULFEN	1	0	0	0	0	0	0	100	100	100	100	100	100	0	0
1	4	421	R	SULFEN	0.5	0	6	7	7	7	7	100	57	64	63	58	50	7.2	4.2
1	4	421	S	SULFEN	0.5	0	0	0	0	0	0	100	100	100	100	100	100	0	0
1	4	426	R	SULFEN	2	0	1	3	3	3	3	100	93	85	84	82	79	5.7	2.2
1	4	426	S	SULFEN	2	0	0	0	0	0	0	100	100	100	100	100	100	0	0
1	1	101	R	UTC	0	3	9	26	26	24	24	0	0	0	0	0	0	11.6	12.9

1	1	101	S	UTC	0	0	12	15	15	16	16	0	0	0	0	0	0	14	11.4
1	1	127	R	UTC	0	2	10	16	16	14	13	0	0	0	0	0	0	11.9	7.8
1	1	127	S	UTC	0	3	5	15	15	15	15	0	0	0	0	0	0	8	5
1	2	205	R	UTC	0	3	14	23	22	19	16	0	0	0	0	0	0	11.6	14.3
1	2	205	S	UTC	0	3	10	16	16	14	14	0	0	0	0	0	0	12.3	6.8
1	2	212	R	UTC	0	3	16	30	31	32	35	0	0	0	0	0	0	8.9	7.7
1	2	212	S	UTC	0	2	3	12	12	12	12	0	0	0	0	0	0	4.2	1.6
1	3	308	R	UTC	0	0	17	38	36	35	35	0	0	0	0	0	0	9.7	9.7
1	3	308	S	UTC	0	0	2	12	2	2	2	0	0	0	0	0	0	16.5	6.1
1	3	321	R	UTC	0	0	20	23	22	20	17	0	0	0	0	0	0	9.1	7.5
1	3	321	S	UTC	0	0	10	10	10	10	10	0	0	0	0	0	0	11.2	6.9
1	4	401	R	UTC	0	0	16	27	26	22	20	0	0	0	0	0	0	5.9	2.8
1	4	401	S	UTC	0	0	4	13	13	12	12	0	0	0	0	0	0	7.2	4.7
1	4	406	R	UTC	0	0	12	12	12	11	8	0	0	0	0	0	0	6.1	3.3
1	4	406	S	UTC	0	0	5	7	7	8	8	0	0	0	0	0	0	7.6	2.7
2	1	102	R	FLUMI	0.125	0	0	0	0	2	1	100	100	100	100	90	96	2.6	0.3
2	1	102	S	FLUMI	0.125	0	0	0	0	1	2	100	100	100	100	60	60	2.9	0
2	1	103	R	FLUMI	0.25	0	0	0	1	1	1	100	100	100	94	95	96	20.5	5.2
2	1	103	S	FLUMI	0.25	0	0	0	0	0	0	100	100	100	100	100	100	0	0
2	1	104	R	FLUMI	0.5	0	0	0	0	0	0	100	100	100	100	100	100	0	0
2	1	104	S	FLUMI	0.5	0	0	0	0	0	0	100	100	100	100	100	100	0	0
2	1	105	R	FLUMI	1	0	0	0	0	0	0	100	100	100	100	100	100	0	0
2	1	105	S	FLUMI	1	0	0	0	0	0	0	100	100	100	100	100	100	0	0
2	1	106	R	FLUMI	2	0	0	0	0	0	0	100	100	100	100	100	100	0	0
2	1	106	S	FLUMI	2	0	0	0	0	0	0	100	100	100	100	100	100	0	0
2	2	205	R	FLUMI	0.125	0	0	0	2	2	2	100	100	100	82	86	88	3.2	0.2
2	2	205	S	FLUMI	0.125	0	0	0	0	0	0	100	100	100	100	100	100	0	0
2	2	211	R	FLUMI	2	0	0	0	0	0	0	100	100	100	100	100	100	0	0
2	2	211	S	FLUMI	2	0	0	0	0	0	0	100	100	100	100	100	100	0	0

2	2	217	R	FLUMI	0.5	0	0	0	0	0	0	100	100	100	100	100	100	0	0
2	2	217	S	FLUMI	0.5	0	0	0	0	0	0	100	100	100	100	100	100	0	0
2	2	219	R	FLUMI	0.25	0	0	0	0	0	0	100	100	100	100	100	100	0	0
2	2	219	S	FLUMI	0.25	0	0	0	0	0	0	100	100	100	100	100	100	0	0
2	2	225	R	FLUMI	1	0	0	0	0	0	0	100	100	100	100	100	100	0	0
2	2	225	S	FLUMI	1	0	0	0	0	0	0	100	100	100	100	100	100	0	0
2	3	305	R	FLUMI	0.5	0	0	0	0	0	0	100	100	100	100	100	100	0	0
2	3	305	S	FLUMI	0.5	0	0	0	0	0	0	100	100	100	100	100	100	0	0
2	3	310	R	FLUMI	1	0	0	0	0	0	0	100	100	100	100	100	100	0	0
2	3	310	S	FLUMI	1	0	0	0	0	0	0	100	100	100	100	100	100	0	0
2	3	312	R	FLUMI	0.125	0	0	0	0	0	1	100	100	100	100	100	96	12.8	3.1
2	3	312	S	FLUMI	0.125	0	0	0	1	2	1	100	100	100	71	50	78	2.5	0
2	3	317	R	FLUMI	0.25	0	0	0	0	1	1	100	100	100	100	95	96	2.6	0.3
2	3	317	S	FLUMI	0.25	0	0	0	0	0	0	100	100	100	100	100	100	0	0
2	3	324	R	FLUMI	2	0	0	0	0	0	0	100	100	100	100	100	100	0	0
2	3	324	S	FLUMI	2	0	0	0	0	0	0	100	100	100	100	100	100	0	0
2	4	402	R	FLUMI	1	0	0	0	0	0	0	100	100	100	100	100	100	0	0
2	4	402	S	FLUMI	1	0	0	0	0	0	0	100	100	100	100	100	100	0	0
2	4	406	R	FLUMI	0.5	0	0	0	0	0	0	100	100	100	100	100	100	0	0
2	4	406	S	FLUMI	0.5	0	0	0	0	0	0	100	100	100	100	100	100	0	0
2	4	409	R	FLUMI	0.25	0	0	0	0	0	0	100	100	100	100	100	100	0	0
2	4	409	S	FLUMI	0.25	0	0	0	0	0	0	100	100	100	100	100	100	0	0
2	4	422	R	FLUMI	2	0	0	0	0	0	0	100	100	100	100	100	100	0	0
2	4	422	S	FLUMI	2	0	0	0	0	0	0	100	100	100	100	100	100	0	0
2	4	426	R	FLUMI	0.125	0	0	0	1	1	1	100	100	100	93	93	94	3.8	0.1
2	4	426	S	FLUMI	0.125	0	0	0	0	0	0	100	100	100	100	100	100	0	0
2	1	117	R	FOME	0.125	0	0	0	1	1	1	100	100	100	94	95	96	1.3	0
2	1	117	S	FOME	0.125	0	0	0	0	1	1	100	100	100	100	60	50	3.8	0.3
2	1	118	R	FOME	0.25	1	2	3	5	5	5	60	43	60	68	75	78	14.1	11.4

2	1	118	S	FOME	0.25	0	0	0	0	0	0	100	100	100	100	100	100	0	0
2	1	119	R	FOME	0.5	0	0	0	2	2	1	100	100	100	87	90	96	1.3	0
2	1	119	S	FOME	0.5	0	0	0	0	0	0	100	100	100	100	100	100	0	0
2	1	120	R	FOME	1	0	0	0	1	1	2	100	100	100	94	95	91	1.6	0
2	1	120	S	FOME	1	0	0	0	0	0	0	100	100	100	100	100	100	0	0
2	1	121	R	FOME	2	0	0	0	0	0	0	100	100	100	100	100	100	0	0
2	1	121	S	FOME	2	0	0	0	0	0	0	100	100	100	100	100	100	0	0
2	2	201	R	FOME	0.25	0	1	2	2	2	2	100	60	69	82	86	88	14.1	4.2
2	2	201	S	FOME	0.25	0	0	0	0	0	0	100	100	100	100	100	100	0	0
2	2	214	R	FOME	0.125	0	1	3	5	8	9	100	60	54	55	43	47	12.6	5.8
2	2	214	S	FOME	0.125	0	0	0	0	0	0	100	100	100	100	100	100	0	0
2	2	221	R	FOME	1	0	0	0	1	1	1	100	100	100	91	93	94	1.3	0
2	2	221	S	FOME	1	0	0	0	0	0	0	100	100	100	100	100	100	0	0
2	2	223	R	FOME	2	0	0	0	0	0	0	100	100	100	100	100	100	0	0
2	2	223	S	FOME	2	0	0	0	0	0	0	100	100	100	100	100	100	0	0
2	2	226	R	FOME	0.5	0	0	0	0	0	0	100	100	100	100	100	100	0	0
2	2	226	S	FOME	0.5	0	0	0	0	0	0	100	100	100	100	100	100	0	0
2	3	306	R	FOME	0.5	0	0	0	1	1	0	100	100	100	94	95	100	0	0
2	3	306	S	FOME	0.5	0	0	0	0	0	0	100	100	100	100	100	100	0	0
2	3	307	R	FOME	2	0	0	0	0	0	1	100	100	100	100	100	96	0.6	0
2	3	307	S	FOME	2	0	0	0	0	0	0	100	100	100	100	100	100	0	0
2	3	308	R	FOME	0.125	0	2	4	6	9	8	100	33	53	65	54	65	7.7	10.4
2	3	308	S	FOME	0.125	0	0	0	0	1	1	100	100	100	100	75	78	7.6	0.8
2	3	323	R	FOME	0.25	0	0	2	4	5	5	100	100	76	76	74	78	6.8	3
2	3	323	S	FOME	0.25	0	0	0	0	0	0	100	100	100	100	100	100	0	0
2	3	327	R	FOME	1	0	0	0	2	2	2	100	100	100	88	90	91	3.2	0.1
2	3	327	S	FOME	1	0	0	0	0	0	0	100	100	100	100	100	100	0	0
2	4	407	R	FOME	0.25	0	0	0	0	0	0	100	100	100	100	100	100	0	0
2	4	407	S	FOME	0.25	0	0	0	0	0	0	100	100	100	100	100	100	0	0

2	4	408	R	FOME	0.5	0	0	0	2	2	2	100	100	100	86	87	87	2.6	0.1
2	4	408	S	FOME	0.5	0	0	0	0	0	0	100	100	100	100	100	100	0	0
2	4	410	R	FOME	0.125	0	0	0	2	2	2	100	100	100	86	87	87	5.8	1
2	4	410	S	FOME	0.125	0	0	0	0	0	0	100	100	100	100	100	100	0	0
2	4	416	R	FOME	2	0	0	0	0	0	0	100	100	100	100	100	100	0	0
2	4	416	S	FOME	2	0	0	0	0	0	0	100	100	100	100	100	100	0	0
2	4	421	R	FOME	1	0	0	0	0	0	0	100	100	100	100	100	100	0	0
2	4	421	S	FOME	1	0	0	0	0	0	0	100	100	100	100	100	100	0	0
2	1	122	R	SAFLU	0.125	1	1	2	4	5	5	60	71	73	74	75	78	12.8	209.4
2	1	122	S	SAFLU	0.125	0	0	0	0	0	0	100	100	100	100	100	100	0	0
2	1	123	R	SAFLU	0.25	0	0	0	2	2	2	100	100	100	87	90	91	7	2
2	1	123	S	SAFLU	0.25	0	0	0	0	0	1	100	100	100	100	100	50	2.5	0.1
2	1	124	R	SAFLU	0.5	0	0	0	0	0	0	100	100	100	100	100	100	0	0
2	1	124	S	SAFLU	0.5	0	0	0	0	0	0	100	100	100	100	100	100	0	0
2	1	125	R	SAFLU	1	0	0	0	0	0	0	100	100	100	100	100	100	0	0
2	1	125	S	SAFLU	1	0	0	0	0	0	0	100	100	100	100	100	100	0	0
2	1	126	R	SAFLU	2	0	0	0	0	0	0	100	100	100	100	100	100	0	0
2	1	126	S	SAFLU	2	0	0	0	0	0	0	100	100	100	100	100	100	0	0
2	2	203	R	SAFLU	0.5	0	0	0	0	0	0	100	100	100	100	100	100	0	0
2	2	203	S	SAFLU	0.5	0	0	0	0	0	0	100	100	100	100	100	100	0	0
2	2	208	R	SAFLU	2	0	0	0	0	0	0	100	100	100	100	100	100	0	0
2	2	208	S	SAFLU	2	0	0	0	0	0	0	100	100	100	100	100	100	0	0
2	2	212	R	SAFLU	0.125	0	0	0	0	1	1	100	100	100	100	93	94	2.6	0
2	2	212	S	SAFLU	0.125	0	0	0	0	0	0	100	100	100	100	100	100	0	0
2	2	224	R	SAFLU	0.25	0	0	0	0	1	0	100	100	100	100	93	100	0	0
2	2	224	S	SAFLU	0.25	0	0	0	0	0	0	100	100	100	100	100	100	0	0
2	2	227	R	SAFLU	1	0	0	0	0	0	0	100	100	100	100	100	100	0	0
2	2	227	S	SAFLU	1	0	0	0	0	0	0	100	100	100	100	100	100	0	0
2	3	303	R	SAFLU	0.25	0	0	1	1	1	1	100	100	88	94	95	96	17.9	6.9

2	3	303	S	SAFLU	0.25	0	0	0	0	0	0	100	100	100	100	100	100	0	0
2	3	304	R	SAFLU	2	0	0	0	0	0	0	100	100	100	100	100	100	0	0
2	3	304	S	SAFLU	2	0	0	0	0	0	0	100	100	100	100	100	100	0	0
2	3	313	R	SAFLU	0.5	0	0	0	0	0	0	100	100	100	100	100	100	0	0
2	3	313	S	SAFLU	0.5	0	0	0	0	0	0	100	100	100	100	100	100	0	0
2	3	315	R	SAFLU	1	0	0	0	0	0	0	100	100	100	100	100	100	0	0
2	3	315	S	SAFLU	1	0	0	0	0	0	0	100	100	100	100	100	100	0	0
2	3	320	R	SAFLU	0.125	0	0	0	0	0	2	100	100	100	100	100	91	1.3	0
2	3	320	S	SAFLU	0.125	0	0	0	0	0	0	100	100	100	100	100	100	0	0
2	4	401	R	SAFLU	0.5	0	0	0	1	1	1	100	100	100	93	93	94	7.7	0.7
2	4	401	S	SAFLU	0.5	0	0	0	0	0	0	100	100	100	100	100	100	0	0
2	4	404	R	SAFLU	0.125	0	0	0	1	1	1	100	100	100	93	93	94	6.4	0.8
2	4	404	S	SAFLU	0.125	0	0	0	0	0	0	100	100	100	100	100	100	0	0
2	4	411	R	SAFLU	1	0	0	0	0	0	0	100	100	100	100	100	100	0	0
2	4	411	S	SAFLU	1	0	0	0	0	0	0	100	100	100	100	100	100	0	0
2	4	418	R	SAFLU	2	0	0	0	0	0	0	100	100	100	100	100	100	0	0
2	4	418	S	SAFLU	2	0	0	0	0	0	0	100	100	100	100	100	100	0	0
2	4	424	R	SAFLU	0.25	0	1	1	1	1	1	100	71	89	93	93	94	20.5	8.6
2	4	424	S	SAFLU	0.25	0	0	0	0	0	0	100	100	100	100	100	100	0	0
2	1	112	R	SULFEN	0.125	0	1	2	3	0	8	100	71	73	81	100	64	10.2	6.9
2	1	112	S	SULFEN	0.125	0	0	0	0	0	0	100	100	100	100	100	100	0	0
2	1	113	R	SULFEN	0.25	0	2	4	8	8	8	100	43	47	48	60	64	4.9	1.9
2	1	113	S	SULFEN	0.25	0	0	0	0	0	0	100	100	100	100	100	100	0	0
2	1	114	R	SULFEN	0.5	0	0	0	2	2	2	100	100	100	87	90	91	4.5	0.2
2	1	114	S	SULFEN	0.5	0	0	0	0	0	0	100	100	100	100	100	100	0	0
2	1	115	R	SULFEN	1	0	0	0	1	1	1	100	100	100	94	95	96	3.8	0.1
2	1	115	S	SULFEN	1	0	0	0	0	0	0	100	100	100	100	100	100	0	0
2	1	116	R	SULFEN	2	0	0	0	0	0	0	100	100	100	100	100	100	0	0
2	1	116	S	SULFEN	2	0	0	0	0	0	0	100	100	100	100	100	100	0	0

2	2	202	R	SULFEN	0.5	0	0	1	1	2	2	100	100	85	91	86	88	7	2.8
2	2	202	S	SULFEN	0.5	0	0	0	0	0	0	100	100	100	100	100	100	0	0
2	2	206	R	SULFEN	1	0	0	0	0	0	0	100	100	100	100	100	100	0	0
2	2	206	S	SULFEN	1	0	0	0	0	0	0	100	100	100	100	100	100	0	0
2	2	215	R	SULFEN	0.125	0	2	4	8	8	8	100	20	38	27	43	53	13.2	10.8
2	2	215	S	SULFEN	0.125	0	0	0	0	0	0	100	100	100	100	100	100	0	0
2	2	216	R	SULFEN	0.25	0	0	3	5	5	5	100	100	54	55	64	71	6.2	1.5
2	2	216	S	SULFEN	0.25	0	0	0	0	0	0	100	100	100	100	100	100	0	0
2	2	222	R	SULFEN	2	0	0	0	0	0	0	100	100	100	100	100	100	0	0
2	2	222	S	SULFEN	2	0	0	0	0	0	0	100	100	100	100	100	100	0	0
2	3	301	R	SULFEN	0.125	0	2	2	4	5	3	100	33	76	76	74	87	13.7	8.8
2	3	301	S	SULFEN	0.125	0	0	0	0	0	0	100	100	100	100	100	100	0	0
2	3	316	R	SULFEN	0.5	0	1	1	1	2	1	100	67	88	94	90	96	21.8	10.3
2	3	316	S	SULFEN	0.5	0	0	0	0	0	0	100	100	100	100	100	100	0	0
2	3	318	R	SULFEN	2	0	0	0	0	0	0	100	100	100	100	100	100	0	0
2	3	318	S	SULFEN	2	0	0	0	0	0	0	100	100	100	100	100	100	0	0
2	3	322	R	SULFEN	1	0	0	0	0	2	2	100	100	100	100	90	91	1.9	0
2	3	322	S	SULFEN	1	0	0	0	0	0	0	100	100	100	100	100	100	0	0
2	3	325	R	SULFEN	0.25	0	2	2	2	3	3	100	33	76	88	85	87	14.9	7.9
2	3	325	S	SULFEN	0.25	0	0	0	0	0	0	100	100	100	100	100	100	0	0
2	4	403	R	SULFEN	0.5	0	0	0	0	0	0	100	100	100	100	100	100	0	0
2	4	403	S	SULFEN	0.5	0	0	0	0	0	0	100	100	100	100	100	100	0	0
2	4	412	R	SULFEN	0.25	0	0	0	1	1	1	100	100	100	93	93	94	1.3	0
2	4	412	S	SULFEN	0.25	0	0	0	0	0	0	100	100	100	100	100	100	0	0
2	4	413	R	SULFEN	2	0	0	0	0	0	0	100	100	100	100	100	100	0	0
2	4	413	S	SULFEN	2	0	0	0	0	0	0	100	100	100	100	100	100	0	0
2	4	420	R	SULFEN	0.125	0	0	1	2	4	5	100	100	89	86	73	68	5.5	2.3
2	4	420	S	SULFEN	0.125	0	0	0	0	0	0	100	100	100	100	100	100	0	0
2	4	423	R	SULFEN	1	0	1	1	1	1	1	100	71	89	93	93	94	23	9.6

2	4	423	S	SULFEN	1	0	0	0	0	0	0	100	100	100	100	100	100	0	0
2	1	101	R	UTC	0	0	2	5	11	12	13	0	0	0	0	0	0	11.5	5.2
2	1	101	S	UTC	0	0	2	2	2	2	3	0	0	0	0	0	0	2.5	0.1
2	1	127	R	UTC	0	2	5	10	20	28	32	0	0	0	0	0	0	14.1	13.9
2	1	127	S	UTC	0	1	1	3	3	4	3	0	0	0	0	0	0	16.1	13.4
2	2	209	R	UTC	0	0	4	10	14	18	24	0	0	0	0	0	0	10.6	14.3
2	2	209	S	UTC	0	0	2	3	5	5	5	0	0	0	0	0	0	13.3	10.5
2	2	210	R	UTC	0	0	1	3	8	10	10	0	0	0	0	0	0	10.9	8.5
2	2	210	S	UTC	0	0	1	1	1	2	2	0	0	0	0	0	0	12.7	5.2
2	3	314	R	UTC	0	3	6	12	22	37	32	0	0	0	0	0	0	12.8	26.3
2	3	314	S	UTC	0	0	1	1	2	2	3	0	0	0	0	0	0	11.9	9.5
2	3	326	R	UTC	0	0	0	5	12	12	14	0	0	0	0	0	0	9.6	3
2	3	326	S	UTC	0	2	3	4	6	6	6	0	0	0	0	0	0	15.2	13.4
2	4	405	R	UTC	0	2	3	8	14	16	18	0	0	0	0	0	0	15.8	16.6
2	4	405	S	UTC	0	1	1	1	1	1	1	0	0	0	0	0	0	22.9	12.7
2	4	419	R	UTC	0	0	4	10	12	14	13	0	0	0	0	0	0	9.4	10.5
2	4	419	S	UTC	0	0	1	7	8	8	8	0	0	0	0	0	0	11	6.5

CONCLUSION

The use of PPO herbicides in GR cropping systems provided broad-spectrum weed control, low use rates, and are used to control weeds with glyphosate, ALS, and triazines resistance. The data presented in this study confirms resistance to PPO herbicides in the SPA and LPA populations from Tennessee and resistance in WPA populations collected from Arkansas. Management of PPO-R Palmer amaranth populations will continue to be of economic importance for producers throughout the United States. History has shown that the use of a single POST herbicide such as glyphosate can provide adequate weed control, but over reliance can lead to an increased selection pressure to herbicide resistance. Control of the PPO-R population was achieved with atrazine and glufosinate. This data suggests that rotating MOA, incorporating these herbicides into tank mixtures or alternating to a glufosinate resistant cropping system could be useful practices in reducing resistance and the spread of resistant weeds.

Soil-applied herbicides continue to be useful for producers in their weed management programs. These herbicides control the emergence and growth of weeds allowing for reduced competition with crops for resources. The PPO soil-applied herbicides examined in this study resulted in differential herbicidal response of the PPO-R population. The PPO herbicide were shown to be effective however control was observed to be greater in the PPO-S population. Studies have suggested that Palmer amaranth could evolve resistance to PPO-inhibiting herbicides due to similarities of the resistance gene in Palmer amaranth, waterhemp, and two other *Amaranthus* species. Overall, this study clearly demonstrates that GR Palmer amaranth in Tennessee has evolved to include PPO resistance. As confirmation of multiple herbicide resistance of Palmer amaranth increases, herbicidal control options become limited therefore a

higher degree of importance will be placed on implementing the best management practices that include rotating MOA and incorporating residual herbicides aimed for the suppression resistant Palmer amaranth populations.

VITA

Alinna Marie Umphres was born in San Antonio, Texas but raised in Zapata, Texas on a cattle ranch. She graduated from Zapata High School in 2005 and attended Texas A&M University – Kingsville in the Fall of 2005. Alinna received her Bachelors of Science in 2010 in Agribusiness and her Masters of Science in 2013 in Plant and Soil Science. In August of 2014 she began her PhD coursework at the University of Tennessee focusing on Weed Science. She plans to graduate August of 2017 move back home to Bishop, Texas, and being working as an Assistant Professor at Texas A&M University Kingsville in the Fall of 2017.