MANAGEMENT OF HERBICIDE RESISTANT PALMER AMARANTH (*Amaranthus palmeri*) IN PEANUT

By

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To my wife loving wife, Casey, as well as my parents Mike and Mitchell whose love and support has never ended

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TABLE OF CONTENTS

LIST OF TABLES

Table page

LIST OF FIGURES

Abstract of Thesis Presented to the Graduate School
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MANAGEMENT OF HERBICIDE RESISTANT PALMER AMARANTH (AMARANTHUS PALMERI) IN PEANUT

By

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Palmer amaranth (PA) (*Amaranthus palmeri*), a C4 summer annual, is a pigweed species native to Mexico and the southwestern United States. This pigweed species can grow up to 2 meters in height and is a prolific seed producer. PA began to increase in scope and severity throughout the peanut producing regions of the southeastern United States during the last 25 years. In addition to PA's competitiveness, this species has developed resistance to four different classes of herbicides throughout the United States. Imazapic, an inhibitor of acetolactate synthase (ALS), is an important herbicide for the control of PA in peanut. However, extensive use in peanut production in the southeast, PA has been selected for ALS-resistance. Peanut growers need management strategies to help control herbicide resistant PA, this research was designed to develop strategies to control PA.

Project I evaluated the effect of three rye cover crop management scenarios that included peanut planting into standing rye cover, rolled cover, or no cover. Within each cover crop scenario several soil active herbicides were applied. Plant counts were taken weekly until a threshold of 1 PA per meter of row was achieved. Premergence (PRE) applied pendimethalin or norflurazon, and the untreated controls reached the

threshold within 9 days of application for all cover crop scenarios. Metolachlor applied PRE delayed time to thresholds by 23 days in year one and ≤ 1 day in year two. Flumioxazin applied PRE and metolachlor applied at-cracking (AC) were the most effective herbicide treatments. Both herbicides delayed PA reaching threshold levels by > 54.62 days in 2008 and > 12.59 days in 2009. Project II evaluated the effects of fomesafen alone, at varied rates, or combined with other herbicides, applied PRE, AC, and postemergence (POST), on peanut injury and PA control over two years. Peanut injury was observed for most treatments but was transient and peanuts fully recovered within 28 days after application. Peanut yield was not reduced significantly for any fomesafen treatment in either year. Control of PA was ≥ 78% when fomesafen alone was applied AC at ≥ 0.42 kg/ha. Combined applications of paraquat + bentazon + 2, 4-DB with fomesafen controlled PA ≥ 85% for all rates used. Project III evaluated the effect of lactofen applied with two spray nozzle types, carrier volumes, and PA height ranges of 5 to 10 cm and 15 to 20 cm. Control of PA, at the shorter heights was not affected by spray nozzle type or carrier volume. However, lactofen applied to taller PA was less effective when applied at 94 L/ha, compared to carrier volumes of 187 and 281 L/ha.

In conclusion, PA control could be achieved with the use of flumioxazin applied PRE and metolachlor applied AC. Cover crop had very little affect on control of PA. The use of fomesafen at ≥ 0.42 kg/ha is needed to control PA effectively when applied alone AC. But, when combined with paraquat + bentazon + 2, 4-DB a higher fomesafen rate is not needed. A carrier volume of ≥ 187 L/ha is needed to control PA at ≥ 15 cm when lactofen is applied. Peanut producers need an application of flumioxazin or fomesafen PRE combined with a POST application of a contact herbicide + metolachlor to control ALS-resistant PA.

CHAPTER 1
THE EFFECT OF COVER CROP AND PREMERGENCE HERBICIDES ON THE CONTROL OF ALS-RESISTANT PALMER AMARANTH IN PEANUT

Introduction

Palmer amaranth (PA) (*Amaranthus palmeri* S. Wats) is a native species of Mexico and the southwestern United States (Steckel 2007). PA is a C4 summer annual (Ehleringer 1983) that is common in the peanut producing regions of the southeastern United States (Gleason and Cronquist 1991; Horak Loughin 2000). It is one of three dioecious *Amaranthus* spp. that has become an important weed in agronomic cropping systems in North America (Steckel 2007). Previous research found that PA produced more leaf area, dry weight, and plant volume as compared to common waterhemp (*Amaranthus rudis* S.), another dioecious *Amaranthus* species (Horak and Loughin 2000). Competitiveness of PA can be attributed to its tremendous seed production, 250,700 to 613,074 seeds per female plant (Sellers et al. 2003; Keely et al. 1987), and aggressive growth habits, reaching heights of 2 meters (Bryson and DeFelice 2009). Due to these attributes, PA is considered a troublesome weed in Florida, Georgia, and South Carolina (Webster 2005).

The competitive growth causes PA to greatly interfere with crop growth and yield potential. In Kansas, PA populations of 0.5 to 8 plants m^{-1} of row reduced corn (*Zea mays* L.) yields 11 to 91% (Massinga et al. 2001; Massinga and Currie 2002). Klingman and Oliver (1994) reported soybean [*Glycine max* (L.) Merr.] yield was reduced 17 to 68% with 0.33 to 10 PA plants per m^{-1} of row, respectively. In Texas, PA populations from 1 to 10 plants per 9.1 m of row decreased cotton (*Gossypium hirsutum* L.) yields from 13 to 54% (Morgan 2001). In addition, Smith et al. (2000) found that PA increased stripper cotton harvest time by 2-to3-fold while Burke et al. (2007) reported that one PA plant per meter of row will reduce peanut yield by 28%.

Imazapic (Cadre) and diclosulam (Strongarm), both acetolactate synthase (ALS)-inhibiting herbicides, were registered in 1996 and 2000, respectively, for use in peanut. ALS-inhibiting herbicides control susceptible plant species by inhibiting the synthesis of branched chain amino acids (Shaner 1991; Saari et al. 1994). These herbicides have been widely adopted in many crops because of their low use rates, favorable toxicity profile, wide crop selection, high efficacy, and cost effectiveness (Saari et al. 1994). ALS-inhibiting herbicides have been used, in all major crops, but, the intensive use of these herbicides has increased the incident of ALS-resistance. Over 103 species have been documented with ALS-resistance, including PA (Heap 2009). PA, when not resistant, can be controlled effectively with imazapic (Grichar 1997; Grichar 2007). PA resistance to ALS-inhibiting herbicides has been confirmed in Arkansas, Florida, Georgia, Kansas, Mississippi, North Carolina, South Carolina and Tennessee (Heap 2009).

The use of cover crops has been incorporated into agronomic cropping systems for many years. A cover crop system commonly consists of planting a winter-hardy crop in the fall, followed by desiccation and crop planting in the late spring (Moore et al. 1994). Residues from cover crops have been found to modify the soil microenvironment by altering the surface structure, intercepting light and precipitation (Liebman and Janke 1990), and affecting the transfer of heat and water between the soil and atmosphere (Facelli and Pickett 1991; Shaw and Rainero 1990; Stoller and Wax 1973). These modifications can help reduce soil erosion and runoff, while improving soil moisture retention, water infiltration, soil tilth, organic carbon and nitrogen (Mallory et al. 1998; Sainju and Singh 1997; Teasdale 1996; Varco et al. 1999; Yenish et al. 1996).

Cover crops have been found to suppress weeds in row crops such as corn (Hoffman et al. 1993; Johnson et al. 1993), soybean (Reddy 2001, Reddy 2003, Liebl et al. 1992) and cotton (Hurst 1992). The patterns of weed emergence can be altered by cover crop residues, because of a moderating microclimate of the weed germination zone (Van Wijk et. al 1959; Willis et al. 1957). Also, residues create a physical barrier that can restrict emergence of certain weeds (Facelli and Pickett 1991). Weed suppression may also occur from allelopathic compounds that release from cover crop residues (Barnes and Putnam 1986; Barnes et al. 1986; Shilling et al. 1986; Shilling et al. 1985). Burgos et al. (1996) reported that the cover crops Italian rygrass (*Lolium perenne* L.), oat (*Avena sativa*), and sorghum-sudangrass controlled PA 59, 32 and 42%, respectively, 9 weeks after crop planting.

Other studies have indicated that additional weed management is needed when cover crops are used (Masiunas et al. 1995; Mohler and Teasdale 1993; Moore et al. 1994; Shilling et al. 1995; Teasedale and Mohler 1993). Premergence (PRE) herbicides are critical for a successful weed management program for ALS-resistant weeds in peanut however, there are a limited number of PRE herbicides registered in peanut. Currently, PRE herbicides registered in peanut that are non ALS-inhibitors include: flumioxazin (PPO-inhibitor), pendimethalin and ethalfluralin (microtubule inhibitors), norflurazon (pigment inhibitor) and metolachlor (long-chain fatty acid inhibitor). These herbicides vary in their effectiveness on PA and a postemergence application of lactofen or acifluorfen is often necessary. However, lactofen and acifluorfen are labeled to control PA up to the 6 leaf stage or 10 cm in height (Anonymous 2007, Anonymous 2006). Considering that PA can grow up to 3.5 cm per day (Garvey 1999), there is very little time between when a preemergence herbicide begins to fail and the postemergence herbicide must be applied. Therefore, it is essential to better understand the relative length of control that each preemergence herbicide provides and how differing cover crop regimes impact the duration of control.

Materials and Methods

Field studies were conducted in 2008 and 2009 at Sandlin Farms near Williston, Florida on a Candler fine sand (hyperthermic, uncoated Typic Quartzipsamments) with less than 1% organic matter. Studies were conducted under no-till methods. Annual rye (*Secale cereale* L.) was planted as a cover crop during mid-December over the entire experimental area. The rye was allowed to grow until treated with glyphosate 5 weeks prior to planting. When desiccation was complete, the cover crop was either left standing, rolled in the direction of future planting with a tractor-powered implement, or roto-tilled to expose bare soil. This location had a severe infestation of ALS-resistant Palmer amaranth (20 to 40 plants per m^{-2}).

The experimental design was a split-plot with cover crop as the main effect and herbicide as the sub-split effect. Herbicide treatments were arranged in a randomized complete block design within each whole-plot with four replications. Plot size was 3.0 m by 7.6 m with 76.2 cm row spacing. All studies received irrigation, fertility, fungicide, and insecticide treatments as recommended by the Florida Cooperative Extension Service. 'Sun Oleic 97R' was planted May 21, 2008 and 'Florida-07' was planted May 15, 2009 in a twin-row configuration. Peanut seeds were planted at a depth of 5 cm with a seeding rate of 17 seeds per meter of row (Wright et al. 2006). Each year aldicarb was applied in furrow at 3.2 kg/ha.

Within each cover crop scenario, preemergence herbicides were applied within 0 to 3 days after planting (DAP). Herbicide treatments consisted of pendimethalin (1.07 kg/ha), metolacholor (1.35 kg/ha), flumioxazin (0.10 kg/ha), norflurazon (1.34 kg/ha). In addition, an at-crack (AC) [7-10 days after emergence (DAE)] application of metolachlor (1.35 kg/ha) + paraquat (0.21 kg/ha) + 2, 4-DB (0.25 kg/ha) was applied. All experimental treatments were applied with a CO_2-pressurized plot sprayer calibrated to deliver 187 L/ha.

Annual rye was harvested in 0.25 m^2 areas randomly throughout the experimental area both years; this data was used to calculate dry biomass kg ha^{-1}. Weed counts were started one week after herbicide application and subsequent counts were recorded weekly. These counts were taken from the middle of each plot in an area measuring 3.0 m by 0.76 m until threshold was achieved. A threshold of 1 PA per meter of row was calculated, based on research of Burke et al. (2007) which showed a yield loss of approximately 30% at this density. If the threshold was not reached prior to crop canopy closure, the day of the last evaluation was used as the "days to threshold" datum.

Linear interpolation was used to calculate days to threshold for each treatment. Data were subjected to analysis of variance using the PROC MIXED procedure of SAS (2008) to test for treatment effects and interactions. Means were separated using Fisher's protected Least Significant Difference (LSD) at $p \leq 0.05$.

Results and Discussion

Statistical analysis detected a significant treatment by year interaction, so data will be presented by year. In 2008, the main effect of cover crop was not significant and herbicide treatment was pooled across cover crop. In 2009, both cover crop and herbicides were significant and all data are presented accordingly.

In 2008, dry weight of annual rye cover crop was 2067 kg ha^{-1} at the time of planting. For pendimethalin and norflurazon treatements, PA reached the 1 plant per meter threshold within 3 and 8 days after application, respectively, compared to the untreated control which reached threshold at 2 days (Table 1-1). This lack of control was expected with norflurazon as the label indicates *Amaranthus* spp. will only be suppressed (Anonymous 2009a). The label for pendimethalin, indicates that PA will be controlled (Anonymous 2008), but, Grichar (2008) also reported that pendimethalin applied PRE in peanut provided less than 42% control of PA approximately 10 weeks after planting. Metolachlor applied PRE suppressed PA for 22 days after application while metolachlor + paraquat + 2, 4-DB applied AC reached threshold 54 days after application. The application of flumioxazin PRE resulted in 67 days to threshold, the greatest number of days until threshold was met for all treatments.

In 2009, there was a significant cover crop by herbicide treatment interaction (Table 1-2). Annual rye dry biomass, at the time of planting, was 2436 kg ha^{-1} which was similar to 2008. Control with pendimethalin and norflurazon was comparable to that observed in 2008 only delaying PA threshold < 3 days after application (Table 1-2). Metolachlor applied PRE was not as effective as 2008 only delaying threshold by ≤ 0.5 days. This was unexpected considering that previous research has shown metolachlor applied PRE in peanut controlled PA 95% and 90% (Grichar 1994; Grichar 2008).

Flumioxazin provided the greatest duration of PA control, nearly 17 days without cover crop and over 34 days when in conjunction with a standing rye cover crop. Flumioxazin applied PRE at 0.10 kg ha^{-1} was found to control PA 85% in peanut 10 weeks after planting (Grichar 2008). Significant differences were found between standing, rolled, and no cover for the metolachlor + paraquat + 2, 4-DB AC treatment. Resulting in a standing cover crop extending days to threshold by 12 days compared to the rolled cover crop (Table 1-2).

Days to threshold decreased for all treatments in 2009 compared to 2008. This could have been due to the increased rainfall received in 2009, during the month after herbicide application and lack of rainfall in the months that followed, compared to 2008 (Table 1-3). In general, an annual rye cover crop, at < 2500 kg ha^{-1} of dry biomass, did not significantly increase the days to threshold for most treatments. But studies that produced cover crop biomass > 7500 kg ha^{-1} reported reduced numbers of weeds compared to no cover treatments (Reddy 2001, Reddy 2003). Pendimethalin and norflurazon are not reliable control options for the high PA populations encountered in this trial. These herbicides could possibly control or suppress PA if populations are low.

These data indicate flumioxazin applied PRE would require a POST application at an average of 16 to 67 days after application. Metolachlor + paraquat + 2, 4-DB applied AC provided an average of 23 days until threshold was achieved. It is unknown why delaying metolachlor application by 7 days (PRE vs AC) so greatly influences PA control. However, similar results have been observed for the control of tropical spiderwort (*Commelina benghalensis*) in peanut (Flanders and Prostko 2003). Regardless of whether metolachlor or flumioxazin is applied, it would be necessary to start a weekly scouting regimen 3 to 4 weeks after application in order to ensure that timely POST applications can be made to control ALS-resistant PA in peanut.

Table 1-1. Influence of preemergence and post herbicides on Palmer amaranth days to threshold in 2008.

Herbicide Treatment	Rate kg/ha	Timing of trt.[1]	Days to Threshold[2]
flumioxazin	0.10	PRE	67a[3]
pendimethalin	1.07	PRE	3d
norflurazon	1.34	PRE	8d
metolachlor	1.35	PRE	22c
metolachlor +	1.35	AC	54b
paraquat +	0.21	AC	
2, 4-DB	0.25	AC	
untreated	-	-	2d

[1] Timing of herbicide treatments (trt) are as followed: PRE=preemergence, AC=At-crack.
[2] Number of days required to achieve a threshold of 1 Palmer amaranth per meter of crop row. [3] Values reflect the mean of 4 replications. Means within a column followed by different letters are significantly different from each other at the 0.05 level according to Fisher's Least Significant Difference (LSD) test.

Table 1-2. Influence of cover crop scenarios none, rolled and standing combined with preemergence and postemergence herbicides on Palmer amaranth days to threshold in 2009.

Herbicide Treatment	Rate kg/ha	Timing of trt.[1]	None[2]	Rolled	Standing
flumioxazin	0.10	PRE	16[3]a[4]A[5]	27aA	35aA
pendimethalin	1.07	PRE	0.3aC	0.2aC	0.2aC
norflurazon	1.34	PRE	2aC	4aBC	2aC
metolachlor	1.35	PRE	0.1aC	0.5aC	1aC
metolachlor +	1.35	AC	6aB	9abB	21bB
paraquat +	0.21	AC			
2, 4-DB	0.25	AC			
untreated	-	-	0.1aC	0.1aC	0.3aC

[1] Timing of herbicide treatments (trt) are as followed: PRE=preemergence, AC=At-crack. [2] Cover crop scenario.[3] Number of days required to achieve a threshold of 1 Palmer amaranth per meter of crop row. [3] Values reflect the mean of 4 replications. [4]Means within a row followed by lower case letters are significantly different from each other at the 0.05 level according to Fisher's Least Significant Difference (LSD) test.[5] Means within a column followed by upper case letters are significantly different from each other at the 0.05 level according to Fisher's Least Significant Difference (LSD) test.

Table 1-3. Monthly average of rainfall (mm) for May through August at Sandlin farm in 2008 and 2009.

Year	May	June	July	August
	----------------------------rainfall (mm)----------------------------			
2008 (YR1)	4.32	243.59	236.47	300.99
2009 (YR2)	190.50	74.17	143.76	204.47

CHAPTER 2
EVALUATION OF FOMESAFEN HERBICIDE FOR ALS-RESISTANT PALMER AMARANTH CONTROL AND EFFECT ON PEANUT INJURY/YIELD

Introduction

Palmer amaranth (PA) (*Amaranthus palmeri* S. Wats) is a dioecious C4 summer annual that originates from the southwestern United States and Mexico (Ehleringer 1983; Steckel 2007). Currently, in peanut, PA is considered a troublesome weed in Florida, Georgia, and South Carolina (Webster 2005). PA can be difficult to control because of its prolific seed production (Sellers et al. 2003; Keely et al. 1987) and aggressive growth habits (Horak and Loughin 2000).

The growth habits of PA combined with ideal growing conditions increase its ability to compete with most row crops. In corn (*Zea mays* L.), PA populations of 0.5 to 8 plants m^{-1} of row reduced yields 11 to 91%, respectively, (Massinga et al. 2001; Massinga and Currie 2002) and soybean [*Gylcine max* (L.) Merr.] yield was reduced 17 to 68% from 0.33 to 10 PA plants per m^{-1} of row, respectively (Klingman and Oliver 1994). Rowland et al. (1999) reported cotton (*Gossypium hirsutum* L.) lint yield was reduced 92% at PA densities of 8 plants per m^{-1} and Smith et al. (2000) found that PA reduced stripper harvesting time of cotton 2- to 3.5- fold. PA reduced peanut pod weight linearly with each gram increase of one PA per meter of row (Burke et al. 2007). This resulted in a predicted peanut yield loss of 28% for one PA plant per meter of crop row (Burke et al. 2007).

Acetolactate synthase (ALS)-inhibiting herbicides suppress or control susceptible plants by inhibiting acetolactate synthase, an essential enzyme in the biosynthesis of the branched–chain amino acids (Shaner 1991; Saari et al. 1994). Advantages of these herbicides include low use rates, low toxicity, wide crop selection, high efficacy, and cost effectiveness (Saari et al. 1994). In 1996 imazapic was registered for use in peanut. Imazapic effectively controls PA postemergence (POST) (Grichar 1997; Grichar 2007) with little to no visual injury to peanut (Dotray et al 2001; Matocha et. al. 2003). But repeated use of ALS-inhibiting herbicides for weed control in many cropping systems has resulted in the selection of ALS-resistant PA. ALS-resistant PA has been confirmed in Arkansas, Florida, Georgia, Kansas, Mississippi, North Carolina, South Carolina, and Tennessee (Heap 2009).

The use of contact herbicides in peanut was common before the registration of imazapic (G.E. MacDonald – personal communication). Lactofen and aciflurofen , both protoporphyrinogen oxidase (PPO) inhibitors, have been shown to provide > 90% PA control in peanut (Grichar 1997). However, these herbicides have limited soil activity and do not provide residual control of PA. Flumioxazin, also a PPO inhibiting herbicide, has significant soil residual activity which increases duration of weed control. Experiments conducted in Alabama reported that flumioxazon applied in peanut controlled PA > 92% (Grey and Wehtje 2005), but this herbicide can only be applied preemergence (PRE) in peanut (Anonymous 2005). Therefore, lack of rainfall after application can negate the effectiveness of flumioxazin and require the use of other POST herbicides.

Fomesafen, a PPO inhibiting herbicide, is registered for POST use in soybean (Anonymous 2009b) and as a 24c label for early preplant use in cotton (Anonymous 2009c). It has significant soil activity, with an average field half-life of 100 days (Wauchope et al. 1992). Studies have found that fomesafen will effectively control PA, even those resistant to glyphosate and ALS-inhibiting herbicides (Bond et al. 2006;

Norsworthy et al. 2008). PPO-inhibiting herbicides cause phytotoxicity when applied POST on tolerant plants and injury or yield loss is a concern. Previous research has shown that fomesafen injury on soybean (6% to 11%) is consistently less injurious than acifluorfen or lactofen (15% to 32%) (Higgins et al. 1988). Fomesafen is currently not registered in peanut, and little is published concerning its effect on peanut.

PA infestations and the selection of ALS-resistant biotypes have created a serious problem in the southern peanut growing region. PA has the ability to significantly reduce peanut yields; thus incorporation of new herbicides that can be integrated into existing weed management programs is vital to the success and future of peanut production in the southern United States. Therefore, the objectives of our research were as follows: 1) determine whether fomesafen can provide PA control in peanut; 2) determine injury and yield loss to peanut from fomesafen applications; and 3) determine an herbicide management program that includes fomesafen that would best fit into southeastern peanut production systems.

Materials and Methods

Field studies were conducted in 2008 and 2009 at the Plant Science Research and Education Unit (PSREU) in Citra, Florida on a Sparr fine sand (loamy, siliceous, hyperthermic Grossarenic paledult) with ≤ 1% organic matter and at Sandlin farms near Williston, Florida on a Candler fine sand (hyperthermic, uncoated Typic Quartzipsamments) with ≤ 1% organic matter. Studies at the PSREU were conducted under conventional-tillage methods as a weed free experiment and at Sandlin farms under no-till conditions as a weedy experiment. The Sandlin farm location had a severe infestation of ALS-resistant Palmer amaranth (20 to 40 plants per m^{-2}).

Plot size was 3.0 m by 7.6 m on 76.2 cm row spacing. All studies received irrigation, fertility, fungicide and insecticide treatments as recommended by the Florida Cooperative Extension Service. 'Georgia Green' was planted April 23, 2008 and April 22, 2009 at the PSREU in a single-row configuration. 'Sun Oleic 97R' was planted May 21, 2008 and 'Florida-07' was planted May 15, 2009 at the Sandlin farm in a twin-row configuration. Seeds were planted at a depth of 5 cm with a seeding rate of 17 seeds per meter of row (Wright et al. 2006). Each year aldicarb was applied in furrow at 3.2 kg/ha. The experimental area at the PSREU received a preemergence broadcast application of diclosulam (0.42 kg/ha) + pendimethalin (0.92 kg/ha), and a postemergence application of imazapic (0.07 kg/ha). Supplemental hand-weeding was performed as needed to maintain weed-free conditions throughout the growing season at the PSREU. Only herbicide treatments (with no hand weeding) were applied at the Sandlin Farm site in order to document PA control.

Fomesafen Tolerance. Herbicide treatments consisted of fomesafen alone at 0.21, 0.28, 0.42, 0.56 kg/ha applied PRE (0-3 DAP), At-crack (AC) [7-10 days after emergence (DAE)], POST (21-28 DAE), as well as flumioxazin applied PRE at 0.03, 0.07 and 0.14 kg/ha. At the Sandlin Farm site, PA was not present during the PRE application and was approximately 5 cm for the AC application and 15 cm for the POST application.

Fomesafen Management. Herbicide treatments consisted of fomesafen alone at 0.21, 0.28, 0.42, 0.56 kg/ha applied PRE (0-3 DAP), At-crack (AC) [7-10 days after emergence (DAE)], POST (21-28 DAE), as well as flumioxazin applied PRE at 0.07 and 0.14 kg/ha. These treatments were followed by or coupled with a POST application of paraquat (0.21 kg/ha) + bentazon (0.56 kg/ha) + 2, 4-DB (0.25 kg/ha). At the Sandlin Farm site, PA was approximately 5 cm tall for the AC application and 15 cm tall for the POST application.

All experimental treatments were applied with a CO_2-pressurized sprayer calibrated to deliver 187 L/ha. A nonionic surfactant at 0.125% (v/v) was included with all POST and AC treatments.

Visual estimates of peanut injury were recorded 7, 14, 28 DAT and weed control (Sandlin farm) were recorded 14, 28, 56 days after treatment (DAT). Foliar necrosis, chlorosis, and plant stunting were evaluated using a scale of 0 to 100% with 0 = no injury or control and 100 = crop death or complete weed control (Frans et al. 1986). At Citra, days to canopy closure was recorded until soil was not evident between the two center plot rows. The Hull-Scrape method was used with pods from non-treated peanut plots to determine maturity before harvest (Williams and Drexler 1981). The center two rows of each plot were dug by a conventional digger-shaker-inverter and peanuts allowed to field dry approximately 3 days. Peanut was harvested by commercial harvesting equipment and dried to 9% moisture and weighed to determine yield on a kg/ha basis. Yield data was only collected at the Citra location.

The experimental design for all studies was a randomized complete block with four replications. PROC GLM was used to analyze the data for percent PA control, peanut injury, days to canopy closure, and peanut yield (SAS 2008). All data were subjected to analysis of variance (ANOVA) to test treatment effects and interactions. Means were separated using Fisher's Least Significant Difference (LSD) test at $p \leq 0.05$.

Results and Discussion

Fomesafen Alone

ANOVA detected significant differences between herbicide treatment by year and treatment by timing. Therefore, no data were pooled and will be presented by year and treatment by timing. Preemergence (PRE) control data was not collected in 2008 because of application error.

*Peanut tolerance***.** In 2008, no visual injury was observed for all fomesafen and flumioxazin treatments applied PRE (Table 2-1). At-crack (AC) and postemergence (POST) applications of fomesafen resulted in peanut injury that ranged from 8% to 20% 7 days after treatment (DAT) and 2% to 9% 14 DAT. By 28 DAT, no peanut injury was observed from fomesafen applied AC and POST, regardless of application rate. Canopy closure data was also collected as a measure of peanut vine stunting and recovery. Days to canopy closure was increased, compared to the untreated, for most fomesafen applications. But all peanut canopies closed within 11 days of the untreated control, regardless of fomesafen application timing or rate.

In 2009, visual injury from fomesafen and flumioxazin applied PRE was not observed (Table 2-2). AC applications were similar to that of 2008 with the exception of the lowest rate of fomesafen, 0.21 kg ha^{-1}, which increased from 8% in 2008 to 15% in 2009 7 DAT and 6% to 10% 14 DAT. In 2009, POST applications ranged from 0% to 13% percent peanut injury 7 DAT. No injury was observed at 14 and 28 DAT. Canopy closure was found to be significant for most treatments, but all closed within 8 days of the untreated control. When compared to the untreated control yield was not significantly reduced for any treatment, regardless of visual injury for AC and POST applications.

Fomesafen applied PRE, AC, and POST did not decrease yield significantly, compared to the untreated control either year (Tables 2-1 and 2-2). Grichar (1992), however, stated that fomesafen applied PRE at 0.43 kg ha^{-1} decreased yield by 30%. PRE applications of fomesafen and flumioxazin did not produce any visual injury in either year, however, AC and POST applications of fomesafen caused visual injury that ranged from 0% to 10% 14 DAT. Fomesafen applied POST in soybean at 0.3 and 0.6 kg ha^{-1} resulted in injury that ranged from 2% to 11% (Higgins et al. 1988). Despite visual injury and a delay in canopy closure, AC and POST applications did not reduce yield significantly, compared to the control. Although previous experiments suggests that yield reduction is possible, these data suggest that fomesafen can be applied PRE, AC, or POST without significant risk of peanut yield loss.

*Palmer amaranth control***.** In 2008, fomesafen at all rates applied AC to 2.5 to 5.5 cm tall Palmer amaranth (PA) provided ≥ 93% control 14 DAT, ≥ 86% 28 DAT, and ≥ 84% 56 DAT (Table 2-3). Fomesafen applied POST at rates of 0.21 and 0.28 kg ha^{-1} controlled 15 to 20 cm tall PA, 65% and 50% 14 DAT, 45% and 25% 28 DAT, 13% and 0% 56 DAT. Conversely, fomesafen applied POST at increased rates, 0.42 and 0.56 kg ha^{-1}, controlled PA≥ 89% 14 DAT, ≥ 80% 28 DAT, 69% and 83% 56 DA T. Control of PA was ≥ 84% at all rates of fomesafen applied AC. For POST applications, a rate of 0.56 kg ha^{-1} of fomesafen was necessary to reach > 80% control 56 DAT.

Control of PA decreased over time for all treatments in 2009. PRE applications of fomesafen and flumioxazin resulted in 94% or greater control 14 DAT (Table 2-4). Flumioxazin applied PRE at rates of 0.07 and 0.14 kg ha^{-1} controlled PA≥ 94 % 28 DAT but decreased to 78% and 86% control 56 DAT. Fomesafen applied PRE did not provide > 59% PA control 56 DAT, regardless of application rate. Lower rates of fomesafen at 0.21 and 0.28 kg ha^{-1} applied AC to PA, at 2.5 to 5 cm, provided control of 83% and 86% 14 DAT, respectively. AC fomesafen applications at 0.42 and 0.56 kg ha^{-1} controlled PA 93% and 97% 14 DAT, 77% and 78% 28 DAT, 46% and 53% 56 DAT. By 28 DAT, control with both rates decreased to 55% and 56%. POST applications of fomesafen at 0.21, 0.28, and 0.42 kg ha^{-1} to PA, at 10 to 15cm, provided < 36% PA control 28 DAT. Fomesafen applied POST at 0.56 kg ha^{-1} controlled PA 79% 28 DAT but all rates showed < 11% control 56 DAT.

Fomesafen applied AC at rates of 0.21, 0.28, and 0.42 kg ha^{-1} in 2008 controlled PA 86%, 89%, and 92% 28 DAT but in 2009 control was only 55%, 56%, and 78% 28 DAT. POST applications of fomesafen, excluding 0.56 kg ha^{-1}, resulted in 45%, 25%, and 80% control in 2008 compared with 11%, 25%, and 36% control in 2009, at 28 DAT. In a study conducted by Starke and Oliver (1998) fomesafen at 0.21 and 0.42 kg ha^{-1} controlled PA 32% and 37% 28 DAT. Furthermore, a study conducted in Kansas controlled PA with fomesafen applied at 0.28 kg ha^{-1}, 74% to 76% (Sweat et al. 1998). The inconsistencies in control of PA from different years and studies could be attributed to weather conditions, seed population, and PA size at application. This indicates that fomesafen can be a highly effective herbicide for ALS-resistant PA, but that control failures may occur.

In conclusion, foliar injury of peanut due to AC and POST applications of fomesafen did not negatively affect yield. However, fomesafen applied PRE at all rates, AC at 0.42 and 0.56 kg ha^{-1}, and POST at 0.28, 0.42, and 0.56 kg ha^{-1} were found to reduce yields in Texas (Gilbert et al. 2009). Also, in 2008 higher rates of fomesafen applied AC at Sandlin farm caused significant peanut injury at 42 DAT (Table 2-5). But peanut injury was not detected 28 DAT for any fomesafen treatment in 2009 (data not shown). The reasons for these inconsistencies in peanut injury and yield loss are unknown. The control of PA was ≥ 84% at 56 DAT when fomesafen was applied AC in 2008. However, in year two PA control was ≤ 53% 56 DAT. POST fomesafen applications of 0.56 kg ha^{-1} provided ≥ 79% control of PA both years 28 DAT. Generally, PRE applications of fomesafen at 0.42 and 0.56 controlled PA up to 28 DAT. But PA control for all PRE fomesafen rates at 56 DAT were < 57%. Growers need to be aware that different environmental conditions may cause negative effects from fomesafen applied in peanut based studies conducted by Gilbert et. al (2009).

Fomesafen Management

Statistical analysis detected herbicide treatment by year and treatment by timing interactions for percent control and injury. No such interactions were detected for canopy closure and yield. Therefore, canopy closure and yield data were pooled across years, but PA control and peanut injury data were presented separately by year.

Peanut Tolerance. In 2008, injury from PRE and POST treatments ranged from 21% to 26% 7 DAT (Table 2-6). AC treatments ranged from 38% to 41% injury 7 DAT. Injury declined to a range of 3% to 16% injury for all treatments 14 DAT and no visual injury was observed 28 DAT. In 2009, injury ranged from 26% to 43% for all treatments 7 DAT (Table 2-7). PRE and POST applications resulted in injury at 14 DAT from 8% to 10% while there was no injury observed for AC treatments. Injury was not observed for all treatments 28 DAT, in 2009.

In 2008 and 2009, yield was not significantly reduced compared to the untreated control. Canopy closure was delayed for all treatments but the greatest delay was within 9 days of the untreated control (Table 2-8).

This study found that peanut yield was not significantly reduced after a PRE application of flumioxazin or fomesafen, followed by a POST application, of paraquat. These data agree with research conducted by Grey and Wehtje (2005) and Askew et al. (1999) who found that the use of a PRE herbicide combined with a POST application of a contact herbicide resulted in no significant peanut yield reductions. Other research has shown that paraquat applied POST did not reduce yield when foliar peanut injury occurred (Wehtje et al. 1986; Wilcut et al. 1989). These data, compared to the current experiment, found that foliar injury and canopy closure is not a consistent indicator for peanut yield loss.

Palmer amaranth control. In 2008, control of PA for all treatments ranged from 90% to 100% 28 DAT and 85% to 100% 56 DAT (Table 2-9). In 2009, PA control ranged from 86% to 99% 28 DAT and remained consistent 56 DAT, at a range of 86% to 97% (Table 2-10). Control for both years was good to excellent, with a slight decrease overall in 2009. This could be attributed to differing weather conditions from year to year.

In general, control of PA was increased with the increase of fomesafen rate, although this increase in control was minimal. The control of PA was ≥ 94% when flumioxazin was applied PRE followed by a POST treatment of paraquat + bentazon + 2,4-DB. Similar results were found in Georgia with PA being controlled ≥ 92%, with an application of flumioxazin PRE followed by paraquat + bentazon POST (Grey and

Wehtje 2005). PA was controlled ≥ 85% with all treatments. This suggests that a PRE application of fomeasfen or flumioxazin followed by a POST application will increase control of PA.

Table 2-1. Influence of fomesafen and flumioxazin on % injury, days to row closure, and yield of peanut in 2008 at Citra, FL (weed-free).

Herbicide Treatment[3]	Rate kg/ha	Timing of trt.[3]	------------% injury[1]---------- 7 DAT[4]	14 DAT	28 DAT	Days to Closure[2] 76.2 cm rows	Yield % UTC[5]
fomesafen	0.21	PRE	0e[6]	0d	0a	62c-e	109a-c
fomesafen	0.28	PRE	0e	0d	0a	67a-c	100c-f
fomesafen	0.42	PRE	0e	0d	0a	65a-d	111ab
fomesafen	0.56	PRE	0e	0d	0a	69ab	106a-d
flumioxazin	0.03	PRE	0e	0d	0a	67a-c	102a-f
flumioxazin	0.07	PRE	0e	0d	0a	58e	109a-c
flumioxazin	0.14	PRE	0e	0d	0a	64b-e	112a
fomesafen	0.21	AC	8d	2cd	0a	65a-d	104a-e
fomesafen	0.28	AC	15bc	5bc	0a	67a-c	102a-f
fomesafen	0.42	AC	17ab	5bc	0a	71a	101b-f
fomesafen	0.56	AC	20a	7ab	0a	71a	92f
fomesafen	0.21	POST	13c	9a	0a	71a	100c-f
fomesafen	0.28	POST	16a-c	8ab	0a	71a	101b-f
fomesafen	0.42	POST	15bc	9a	0a	71a	98d-f
fomesafen	0.56	POST	18ab	9a	0a	71a	93ef
untreated	-	-	0e	0d	0a	60de	100c-f

[1] Visual assessment of peanut foliar damage and stunting based on the following scale: 0 = no foliar burn or stunting; 100 = complete plant death. [2] Number of days required to achieve complete canopy closure between 76.2 cm wide row spacing. [3] Timing of treatments are as followed: PRE=preemergence, AC=At-crack, POST= postemergence. [4] DAT = days after treatment. [5] Percent of the untreated yield (3056 kg/ha) [6] Values reflect the mean of 4 replications. Means within a column followed by different letters are significantly different from each other at the 0.05 level according to Fisher's Least Significant Difference (LSD) test.*A non-ionic surfactant at 0.125% v/v was used for all AC and POST applications.

Table 2-2. Influence of fomesafen and flumioxazin at varied rates on % injury, days to row closure, and yield of peanut in 2009 at Citra, FL (weed-free).

Herbicide Treatment[3]	Rate kg/ha	Timing of trt.[3]	------------% injury[1]---------- 7 DAT[4]	14 DAT	28 DAT	Days to Closure[2] 76.2 cm rows	Yield % UTC[5]
fomesafen	0.21	PRE	0g[6]	0c	0a	65cd	110a-c
fomesafen	0.28	PRE	0g	0c	0a	67b-c	98b-e
fomesafen	0.42	PRE	0g	0c	0a	64d	90de
fomesafen	0.56	PRE	0g	0c	0a	67b-c	106a-d
flumioxazin	0.03	PRE	0g	0c	0a	64d	109a-c
flumioxazin	0.07	PRE	0g	0c	0a	69a-c	108a-c
flumioxazin	0.14	PRE	0g	0c	0a	66b-c	111ab
fomesafen	0.21	AC	15cd	6b	0a	68a-d	100b-e
fomesafen	0.28	AC	16bc	6b	0a	64d	122a
fomesafen	0.42	AC	19ab	8b	0a	69a-c	105b-c
fomesafen	0.56	AC	20a	10a	0a	69a-c	105b-c
fomesafen	0.21	POST	5f	0c	0a	70ab	109a-c
fomesafen	0.28	POST	10e	0c	0a	72a	114ab
fomesafen	0.42	POST	10e	0c	0a	72a	94c-e
fomesafen	0.56	POST	13de	0c	0a	72a	84e
untreated	-	-	0g	0c	0a	64d	100b-e

[1] Visual assessment of peanut foliar damage and stunting based on the following scale: 0 = no foliar burn or stunting; 100 = complete plant death. [2] Number of days required to achieve complete canopy closure between 76.2 cm wide row spacing. [3] Timing of treatments are as followed: PRE=preemergence, AC=At-crack, POST= postemergence. [4] DAT = days after treatment. [5] Percent of the untreated yield (2402 kg/ha) [6] Values reflect the mean of 4 replications. Means within a column followed by different letters are significantly different from each other at the 0.05 level according to Fisher's Least Significant Difference (LSD) test.*A non-ionic surfactant at 0.125% v/v was used for all AC and POST applications.

Table 2-3. Influence of fomesafen and flumioxazin on % control of Palmer amaranth in 2008 at Williston, FL (weedy).

Herbicide Treatment	Rate kg/ha	Timing of trt.[2]	---% control[1]--- 14 DAT[3]	28 DAT	56 DAT
fomesafen	0.21	AC	96a[4]	86ab	84ab
fomesafen	0.28	AC	93a	89ab	86ab
fomesafen	0.42	AC	98a	92ab	88ab
fomesafen	0.56	AC	99a	98a	96a
fomesafen	0.21	POST	65b	45c	13d
fomesafen	0.28	POST	50c	25d	0e
fomesafen	0.42	POST	89a	80b	69c
fomesafen	0.56	POST	93a	85b	83b
untreated	-	-	0d	0e	0e

[1] Visual assessment of foliar necrosis, chlorosis, and plant stunting were based on the following scale: 0 = no control; 100 = complete weed control. [2] Timing of treatments (trt) are as followed: PRE=preemergence, AC=At-crack, ≈ 5 cm weeds, POST= postemergence, ≈ 15 cm weeds. [3] DAT = days after treatment. [4] Values reflect the mean of 4 replications. Means within a column followed by different letters are significantly different from each other at the 0.05 level according to Fisher's Least Significant Difference (LSD) test.*A non-ionic surfactant at 0.125% v/v was used for all AC and POST applications.

Table 2-4. Influence of fomesafen and flumioxazin on % control of Palmer amaranth in 2009 at Williston, FL (weedy).

Herbicide Treatment	Rate kg/ha	Timing of trt.[2]	14 DAT[3]	% control[1] 28 DAT	56 DAT
fomesafen	0.21	PRE	94ab[4]	79a-c	55cd
fomesafen	0.28	PRE	94ab	69cd	33e-g
fomesafen	0.42	PRE	98ab	81a-c	40c-e
fomesafen	0.56	PRE	99ab	81a-c	59bc
flumioxazin	0.03	PRE	96ab	83a-c	57b-d
flumioxazin	0.07	PRE	100a	94ab	78ab
flumioxazin	0.14	PRE	100a	97a	86a
fomesafen	0.21	AC	86ab	55de	26f-h
fomesafen	0.28	AC	83b	56de	36d-e
fomesafen	0.42	AC	93ab	78a-c	53c-e
fomesafen	0.56	AC	97ab	77bc	46c-f
fomesafen	0.21	POST	13d	11gh	0i
fomesafen	0.28	POST	49c	25fg	6hi
fomesafen	0.42	POST	48c	36ef	11g-i
fomesafen	0.56	POST	88ab	79a-c	11g-i
untreated	-	-	0d	0h	0i

[1] Visual assessment of foliar necrosis, chlorosis, and plant stunting were based on the following scale: 0 = no control; 100 = complete weed control. [2] Timing of treatments (trt) are as followed: PRE=preemergence, AC=At-crack, ≈ 5 cm weeds, POST= postemergence, ≈ 15 cm weeds. [3] DAT = days after treatment. [4] Values reflect the mean of 4 replications. Means within a column followed by different letters are significantly different from each other at the 0.05 level according to Fisher's Least Significant Difference (LSD) test.*A non-ionic surfactant at 0.125% v/v was used for all AC and POST applications.

Table 2-5. Influence of fomesafen on % injury of Palmer amaranth in 2008 at Williston, FL (weedy).

Herbicide Treatment	Rate kg/ha	Timing of trt.[2]	% injury[1] 14 DAT[3]	28 DAT	42 DAT
fomesafen	0.21	AC	9e[4]	2e	0f
fomesafen	0.28	AC	11de	10c-e	6b-d
fomesafen	0.42	AC	16dc	34a	25a
fomesafen	0.56	AC	19c	41a	27a
fomesafen	0.21	POST	12c-e	5de	4cd
fomesafen	0.28	POST	28b	11cd	5b-c
fomesafen	0.42	POST	32ab	17bc	13b
fomesafen	0.56	POST	36a	34b	11bc
untreated	-	-	0f	0f	0f

[1] Visual assessment of peanut foliar damage and stunting based on the following scale: 0 = no foliar burn or stunting; 100 = complete plant death. [2] Timing of treatments are as followed: AC=At-crack, POST= postemergence. [3] DAT = days after treatment. [4] Values reflect the mean of 4 replications. Means within a column followed by different letters are significantly different from each other at the 0.05 level according to Fisher's Least Significant Difference (LSD) test.*A non-ionic surfactant at 0.125% v/v was used for all AC and POST applications.

Table 2-6. Influence of fomesafen and flumioxazin combined with other postemergence herbicides on % injury of peanut in 2008 at Citra, FL (weed-free).

Herbicide Treatment	Rate kg/ha	Timing of trt.[2]	% injury[1] 7 DAT[3]	14 DAT	28 DAT
fomesafen[4]	0.21	PRE	21b[5]	3fe	0a
fomesafen[4]	0.28	PRE	23b	5d-f	0a
fomesafen[4]	0.42	PRE	22b	8c-e	0a
fomesafen[4]	0.56	PRE	24b	14ab	0a
flumioxazin[4]	0.07	PRE	22b	4d-f	0a
flumioxazin[4]	0.14	PRE	23b	9c-d	0a
fomesafen[6]	0.21	AC	38a	6de	0a
fomesafen[6]	0.28	AC	41a	5d-f	0a
fomesafen[6]	0.42	AC	40a	6de	0a
fomesafen[6]	0.56	AC	40a	8c-e	0a
fomesafen[6]	0.21	POST	22b	11a-c	0a
fomesafen[6]	0.28	POST	25b	16a	0a
fomesafen[6]	0.42	POST	22b	15a	0a
fomesafen[6]	0.56	POST	26b	16a	0a
paraquat +	0.21	POST	25b	7c-e	0a
bentazon +	0.56	POST			
2, 4-DB	0.25	POST			
untreated	-	-	0c	0f	0a

[1] Visual assessment of peanut foliar damage and stunting based on the following scale: 0 = no foliar burn or stunting; 100 = complete plant death. [2] Timing of treatments are as followed: PRE=preemergence, AC=At-crack, POST= postemergence. [3] DAT = days after treatment. [4] Treatment was followed by a POST application of paraquat (0.21 kg/ha) + bentazon (0.56kg/ha) and 2, 4-DB (0.25 kg/ha). [5] Values reflect the mean of 4 replications. Means within a column followed by different letters are significantly different from each other at the 0.05 level according to Fisher's Least Significant Difference (LSD) test. [6] Treatment was combined with paraquat (0.21 kg/ha) + bentazon (0.56kg/ha) and 2, 4-DB (0.25 kg/ha).*A non-ionic surfactant at 0.125% v/v was used for all AC and POST applications.

Table 2-7. Influence of fomesafen and flumioxazin combined with other postemergence herbicides on % injury of peanut in 2009 at Citra, FL (weed-free).

Herbicide Treatment	Rate kg/ha	Timing of trt.[2]	% injury[1] 7 DAT[3]	14 DAT	28 DAT
fomesafen[4]	0.21	PRE	39a-c[5]	8a	0a
fomesafen[4]	0.28	PRE	39a-c	10a	0a
fomesafen[4]	0.42	PRE	38a-c	10a	0a
fomesafen[4]	0.56	PRE	43a	10a	0a
flumioxazin[4]	0.07	PRE	38b-d	10a	0a
flumioxazin[4]	0.14	PRE	36c-e	10a	0a
fomesafen[6]	0.21	AC	26g	0b	0a
fomesafen[6]	0.28	AC	29fg	0b	0a
fomesafen[6]	0.42	AC	34de	0b	0a
fomesafen[6]	0.56	AC	33ef	0b	0a
fomesafen[6]	0.21	POST	39a-c	9a	0a
fomesafen[6]	0.28	POST	40a-c	10a	0a
fomesafen[6]	0.42	POST	41ab	10a	0a
fomesafen[6]	0.56	POST	43a	9a	0a
paraquat +	0.21	POST	38b-d	10a	0a
bentazon +	0.56	POST			
2, 4-DB	0.25	POST			
untreated	-	-	0h	0b	0a

[1] Visual assessment of peanut foliar damage and stunting based on the following scale: 0 = no foliar burn or stunting; 100 = complete plant death. [2] Timing of treatments are as followed: PRE=preemergence, AC=At-crack, POST= postemergence. [3] DAT = days after treatment. [4] Treatment was followed by a POST application of paraquat (0.21 kg/ha) + bentazon (0.56kg/ha) and 2, 4-DB (0.25 kg/ha). [5] Values reflect the mean of 4 replications. Means within a column followed by different letters are significantly different from each other at the 0.05 level according to Fisher's Least Significant Difference (LSD) test. [6] Treatment was combined with paraquat (0.21 kg/ha) + bentazon (0.56kg/ha) and 2, 4-DB (0.25 kg/ha).*A non-ionic surfactant at 0.125% v/v was used for all AC and POST applications.

Table 2-8. Influence of fomesafen and flumioxazin on days to row closure and yield of peanut in 2008 and 2009 at Citra, FL (weed-free).

Herbicide Treatment	Rate kg/ha	Timing of trt.[2]	Days to Closure[1] 76.2 cm rows	Yield % UTC [3]
fomesafen[4]	0.21	PRE	67c-f[5]	104ab
fomesafen[4]	0.28	PRE	68b-f	97ab
fomesafen[4]	0.42	PRE	68b-f	108ab
fomesafen[4]	0.56	PRE	71b	98ab
flumioxazin[4]	0.07	PRE	68b-f	109ab
flumioxazin[4]	0.14	PRE	71b	114a
fomesafen[6]	0.21	AC	67c-f	110a
fomesafen[6]	0.28	AC	66fg	106ab
fomesafen[6]	0.42	AC	67c-f	103ab
fomesafen[6]	0.56	AC	69b-d	104ab
fomesafen[6]	0.21	POST	70bc	107ab
fomesafen[6]	0.28	POST	73a	100ab
fomesafen[6]	0.42	POST	73a	103ab
fomesafen[6]	0.56	POST	73a	94b
paraquat +	0.21	POST	68b-f	105ab
bentazon +	0.56	POST		
2, 4-DB	0.25	POST		
Untreated	-	-	64g	100ab

[1] Number of days required to achieve complete canopy closure between 76.2 cm wide row spacing. [2] Timing of treatments are as followed: PRE=preemergence, AC=At-crack, POST= postemergence. [3] Percent of the untreated yield (Year 1 = 2597 kg/ha, Year 2 = 2800 kg/ha). [4] Treatment was followed by a POST application of paraquat (0.21 kg/ha) + bentazon (0.56kg/ha) and 2, 4-DB (0.25 kg/ha). [5] Values reflect the mean of 4 replications. Means within a column followed by different letters are significantly different from each other at the 0.05 level according to Fisher's Least Significant Difference (LSD) test. [6] Treatment was combined with paraquat (0.21 kg/ha) + bentazon (0.56kg/ha) and 2, 4-DB (0.25 kg/ha).*A non-ionic surfactant at 0.125% v/v was used for all AC and POST applications.

Table 2-9. Influence of fomesafen and flumioxazin combined with other post emergence herbicides on % control of Palmer amaranth in 2008 at Williston, FL (weedy).

Herbicide Treatment	Rate kg/ha	Timing of trt.[2]	% control[1] 14 DAT[3]	28 DAT	56 DAT
fomesafen[4]	0.21	PRE	99ab[5]	98ab	97a-c
fomesafen[4]	0.28	PRE	100a	98ab	97a-c
fomesafen[4]	0.42	PRE	100a	99a	98ab
fomesafen[4]	0.56	PRE	100a	100a	98ab
flumioxazin[4]	0.07	PRE	100a	100a	99ab
flumioxazin[4]	0.14	PRE	100a	98ab	98ab
fomesafen[6]	0.21	AC	95c	90c	85d
fomesafen[6]	0.28	AC	98b	90c	85d
fomesafen[6]	0.42	AC	98b	95b	93c
fomesafen[6]	0.56	AC	99ab	97ab	95bc
fomesafen[6]	0.21	POST	100a	100a	100a
fomesafen[6]	0.28	POST	100a	100a	100a
fomesafen[6]	0.42	POST	100a	100a	100a
fomesafen[6]	0.56	POST	100a	100a	99ab
paraquat +	0.21	POST	100a	100a	98ab
bentazon +	0.56	POST			
2, 4-DB	0.25	POST			
untreated	-	-	0d	0d	0e

[1] Visual assessment of PA control was based on the following scale: 0 = no control; 100 = complete control. [2] Timing of treatments are as followed: PRE=preemergence, AC=At-crack, ≈ 8 cm weeds, POST= postemergence, ≈ 15 cm weeds. [3] DAT = days after treatment. [4] Treatment was followed by a POST application of paraquat (0.21 kg/ha) + bentazon (0.56kg/ha) and 2, 4-DB (0.25 kg/ha). [5] Values reflect the mean of 4 replications. Means within a column followed by different letters are significantly different from each other at the 0.05 level according to Fisher's Least Significant Difference (LSD) test. [6] Treatment was combined with paraquat (0.21 kg/ha) + bentazon (0.56kg/ha) and 2, 4-DB (0.25 kg/ha).*A non-ionic surfactant at 0.125% v/v was used for all AC and POST applications.

Table 2-10. Influence of fomesafen and flumioxazin combined with other post emergence herbicides on % control of Palmer amaranth in 2009 at Williston, FL (weedy).

Herbicide Treatment	Rate kg/ha	Timing of trt.[2]	% control[1] 14 DAT[3]	28 DAT	56 DAT
fomesafen[4]	0.21	PRE	97bc[5]	91c-f	87b
fomesafen[4]	0.28	PRE	99b	92b-f	90ab
fomesafen[4]	0.42	PRE	97bc	90d-f	87b
fomesafen[4]	0.56	PRE	98a-c	89ef	88ab
flumioxazin[4]	0.07	PRE	99ab	96a-d	94ab
flumioxazin[4]	0.14	PRE	100a	98ab	97a
fomesafen[6]	0.21	AC	100a	97a-c	87b
fomesafen[6]	0.28	AC	100a	97a-c	90ab
fomesafen[6]	0.42	AC	100a	99a	95ab
fomesafen[6]	0.56	AC	100a	97a-c	94ab
fomesafen[6]	0.21	POST	98a-c	93a-e	93ab
fomesafen[6]	0.28	POST	97bc	93a-e	92ab
fomesafen[6]	0.42	POST	98a-c	97a-c	92ab
fomesafen[6]	0.56	POST	99ab	99a	97a
paraquat +	0.21	POST	96c	86f	86b
bentazon +	0.56	POST			
2, 4-DB	0.25	POST			
untreated	-	-	0d	0g	0c

[1] Visual assessment of PA control was based on the following scale: 0 = no control; 100 = complete control. [2] Timing of treatments are as followed: PRE=preemergence, AC=At-crack, ≈ 7 cm weeds, POST= postemergence, ≈ 15 cm weeds. [3] DAT = days after treatment. [4] Treatment was followed by a POST application of paraquat (0.21 kg/ha) + bentazon (0.56kg/ha) and 2, 4-DB (0.25 kg/ha). [5] Values reflect the mean of 4 replications. Means within a column followed by different letters are significantly different from each other at the 0.05 level according to Fisher's Least Significant Difference (LSD) test. [6] Treatment was combined with paraquat (0.21 kg/ha) + bentazon (0.56kg/ha) and 2, 4-DB (0.25 kg/ha).*A non-ionic surfactant at 0.125% v/v was used for all AC and POST applications.

CHAPTER 3
THE INFLUENCE OF CARRIER VOLUME, NOZZLE TYPE, AND PLANT HEIGHT ON CONTROL OF PALMER AMARANTH IN PEANUT

Introduction

In peanut, Palmer amaranth (PA) (*Amaranthus plamer* S. Wats) is considered a troublesome weed in Florida, Georgia, and South Carolina (Webster 2005). PA can also be found throughout the peanut producing areas of the southeastern and southern United States (Gleason and Cronquist 1991; Horak and Loughin 200). PA, a dioecious C4 plant, is a summer annual that is native to the southwestern United States and Mexico (Byrson and DeFelice 2009; Ehleringer 1983; Steckel 2007), where it thrives at higher temperatures. High temperatures are also characteristic of the southern peanut producing region during peanut growth and maturity. The rapid growth and tremendous seed production of PA (Sellers et al. 2003; Keely et al. 1987) combined with growing conditions found in the southeast that make it a competitive weed in peanut.

In 1996 imazapic (Cadre), an acetolactate synthase (ALS)-inhibitor, was registered for use in peanut. Imazapic is systemic within the plant and effectively controls PA when applied postemergence (POST) in peanut (Grichar 1997; Grichar 2007). Repeated use of ALS inhibitors in peanut and other row crops has lead to wide-spread ALS resistance. Currently, ALS resistant PA can be found in Arkansas, Florida, Georgia, Kansas, Mississippi, North Carolina, South Carolina, and Tennessee (Heap 2009).

The prevalence of ALS-resistant PA in peanut has forced producers to reconsider POST contact herbicides, such as diphenlyether herbicides, which were commonly used before the registration of imazapic (G.E. MacDonald – personal communication). But over the past decade spray technology has evolved as well. The high cost of transporting water and the need to cover more hectarage per fill-up has caused many producers to use lower spray volumes (Etheridge 1999). Additionally, sprayers are traveling at faster speed than in the past, resulting in greater drift potential. To counter this, many have switched from the use of standard flat fan (FF) nozzles (such as TeeJet XR) to drift reducing nozzles (like the TeeJet Air Induction). Air induction (AI) nozzles operate by seeding air into the spray stream just prior to the exit orifice (Piggot and Matthews 1999). Etheridge et al. (1999) found that AI nozzles produced larger droplets compared to conventional FF nozzles at a given pressure. Studies have indicated that large droplet producing nozzles are capable of reducing drift > 75% (Miller and Lane 1999; Ellis et al 2002). Although larger droplets reduce drift, spray coverage is also sacrificed. Knoche 1994 considered that smaller droplets from FF nozzles to be more effective than larger droplets when applying POST herbicides at a constant carrier volume.

Recent research found that control of *Abutilon theophrasti* and *Chenopodium album* with fomesafen, a contact herbicide, was improved as carrier volume was increased for both FF and AI nozzles (Sikkema et al. 2008). However, Ramsdale and Messersmith (2001) found that paraquat provided effective grass control regardless of sprayer nozzle type and carrier volume. Studies have shown that nozzle type, water carrier volume, and spray pressure is herbicide- and weed species-specific (Brown et al. 2007; Sikkema et al. 2008). Local peanut producers have reported PA control failures with the application of contact herbicides with AI nozzles. It was assumed that incomplete coverage led to these failures. However, PA size at time of application may also have been a contributing factor.

It is currently unknown how application practices affect PA control with contact herbicides. Since most contact herbicides are of limited effectiveness on PA, it is important to know if altering spray droplet size and carrier volume to improve overall spray coverage will improve the consistency of control. Therefore, a study was conducted to evaluate the efficacy of lactofen, a contact herbicide, on PA at two stages of growth when applied with FF and AI nozzles at three different carrier volumes.

Materials and Methods

Spray Coverage Study

Treatments consisted of XR Teejet (FF) nozzles (Teejet FF nozzle tips; Spraying Systems Company, Wheaton, IL, USA) and AI Teejet nozzles (Teejet AI nozzle tips; Spraying Systems Company, Wheaton, IL, USA) that were calibrated to deliver application volumes of 94, 187, 281 L ha^{-1}. The sprayer was equipped with each series of nozzles and calibrated for each desired carrier volume. Water was sprayed with each nozzle/volume combination over water sensitive cards to generate droplet distribution. Each card was placed parallel to the ground and 50 cm below the spray nozzles. All water sensitive cards were evaluated with a high resolution flat-bed scanner. Percent coverage was calculated by a color identification computer software program, WinCam. Experimental design was a randomized complete block with four replicates. These data were subjected to analysis of variance using PROC GLM to determine treatment effects and interactions (SAS 2008). Means were separated using Fisher's Least Significant Difference (LSD) test at $p \leq 0.05$.

Field Study

Field studies were conducted in 2008 and 2009 at Sandlin Farms near Williston, Florida on a Candler fine sand (hyperthermic, uncoated Typic Quartzipsamments) with less than 1% organic matter. Studies were conducted under no-till methods. This location had a severe infestation of ALS-resistant Palmer amaranth (20 to 40 plants per m^{-2}). Plot size was 3.0 m by 7.6 m on 76.2 cm row spacing. Studies received irrigation, fertility, fungicide and insecticide treatments as recommended by the Florida Cooperative Extension Service. 'Sun Oleic 97R' was planted May 21, 2008 and 'Florida-07' was planted May 15, 2009 in a twin-row configuration. Peanut seeds were planted at a depth of 5 cm with a seeding rate of 17 seeds per meter of row (Wright et al. 2006). Each year aldicarb was applied in furrow at 3.2 kg/ha.

The experiment was a multi-factorial design arranged in a randomized complete block, with nozzle type, carrier volume, and weed size as factors. A series of XR Teejet (FF) nozzles and AI Teejet nozzles were used to obtain the desired application volumes. The timing of herbicide applications were based on PA height ranges of 5 to 10 cm and 15 to 20 cm. Height measurements were recorded randomly in each replication until the desired height range was achieved. Treatments were applied with a CO_2-pressurized sprayer calibrated to deliver 94, 187, or 281 L ha^{-1}. Lactofen was applied at 0.21 kg ha^{-1} + crop oil concentrate 1% (v/v).

Visual estimates of percent PA control were recorded 14, 28, 42 days after treatment (DAT). Foliar necrosis, chlorosis, and plant stunting were evaluated using a scale of 0 to 100% with 0 = no control and 100 = complete weed control (Frans et al. 1986). All data were subjected to an analysis of variance and analyzed using the PROC GLM procedure of SAS (2008) to test treatment effects and interactions. Means were separated using Fisher's Least Significant Difference (LSD) test at $p \leq 0.05$.

Data was not collected in 2009 because of extreme variations in PA emergence and height throughout the experimental area. This was due to abnormally high rainfall in the first four weeks after peanut planting that was followed by 5 weeks of drought.

Results and Discussion

Quantifying Spray Coverage

There were significant interactions between nozzle type and carrier volume which prevented pooling of data. At a carrier volume of 94 L ha^{-1}, 21% coverage was achieved with the use of flat fan (FF) nozzles but coverage was only 11% with air induction (AI) nozzles (Figure 3-1). AI and FF nozzles applied at 187 L ha^{-1} covered an area of 28% and 47%, respectively. Increased carrier volume of 281 L ha^{-1} reached coverage of 55% for AI nozzles and 69% FF for nozzles.

At 94 and 187 L ha^{-1}, coverage was almost double for the FF verses the AI nozzle. No differences were observed between percent coverage for FF at 187 L ha^{-1} and AI at 281 L ha^{-1}. Though drift potential is greater for FF nozzles, the same spray coverage can be achieved, relative to AI nozzles, while utilizing 1/3 less water.

These data match, in part, with that reported by Ramsdale and Messersmith (2001). At both 94 and 187 L ha^{-1}, spray coverage with FF nozzles is very similar to what is reported here. However, the data reported for AI nozzles, at similar carrier volumes, was near double that reported in this experiment. The reason for these differences is unknown.

Field Study

There were no significant interactions between nozzle type and Palmer amaranth (PA) control. Therefore, nozzle type data were pooled and analyzed for differences among carrier volumes and PA heights.

Lactofen applied 22 days after peanut planting to PA at 5 to 10 cm, resulted in no significant differences between carrier volume and sprayer nozzle type (Table 3-1). Control of PA was consistent and ranged from 99% to 100% for all rating dates. PA control persisted greater than 42 days after application. However, as PA size increased to 15 to 20 cm in height, significant differences were detected between carrier volumes. Lactofen applied at a carrier volume of 94 L ha^{-1}, controlled PA 84% 14 DAT (Table 3-2). This was 7% less control than provided by carrier volumes of 187 and 281 L ha^{-1}. Control continued to decline for the 94 L ha^{-1} application and PA control was 82% and 75% at 28 DAT and 42 DAT, respectively. The higher carrier volumes controlled PA ≥ 88% 28 DAT and 42 DAT.

The use of air induction (AI) and flat fan (FF) nozzles did affect PA control, though percent coverage was different between these nozzles. These data agree with previous research that fomesafen applied with FF and AI nozzles did not affect percent control of *Chenopodium album* (common lambsquarters), *Abutilon theophrasti* (velvetleaf), and *Ambrosia artemisiifolia* (common ragweed) (Sikkema et al. 2008). However, as in this trial, it was observed that increased carrier volume resulted in increased control (Sikkema et al. 2008). Although applications of lactofen were only 5 days apart, percent control of PA was affected by weed height and at time of application. Grichar (2007) has also demonstrated that lactofen can control PA (92%), when treated at the 5 to 10 cm height range. However, control decreased by 48% when the same herbicide was applied to PA at a higher height range of 15 to 20 cm. Also, lactofen was found to decrease percent control of PA with the increase of application time after crop planting (Mayo 1995).

Research is limited on the effects of carrier volume and sprayer nozzle type with respect to individual weed efficacy. The choice of nozzle type has become a critical decision for crop producers. These data indicate that control of PA≤ 10 cm is not affected by nozzle type or carrier volume. However, with lactofen, control was significantly different when PA reached heights of 15 cm or greater. Acceptable control of PA, at 10 to 15 cm, with lactofen was achieved with carrier volumes of 187 and 281 L ha^{-1}. But PA was not sufficiently controlled when applied at a carrier volume of 94 L ha^{-1}. These data suggest that weed size at time of application is most critical toward achieving optimum control. As weeds become larger, an incremental improvement in control can be achieved by increasing carrier volume to 187 L ha^{-1}.

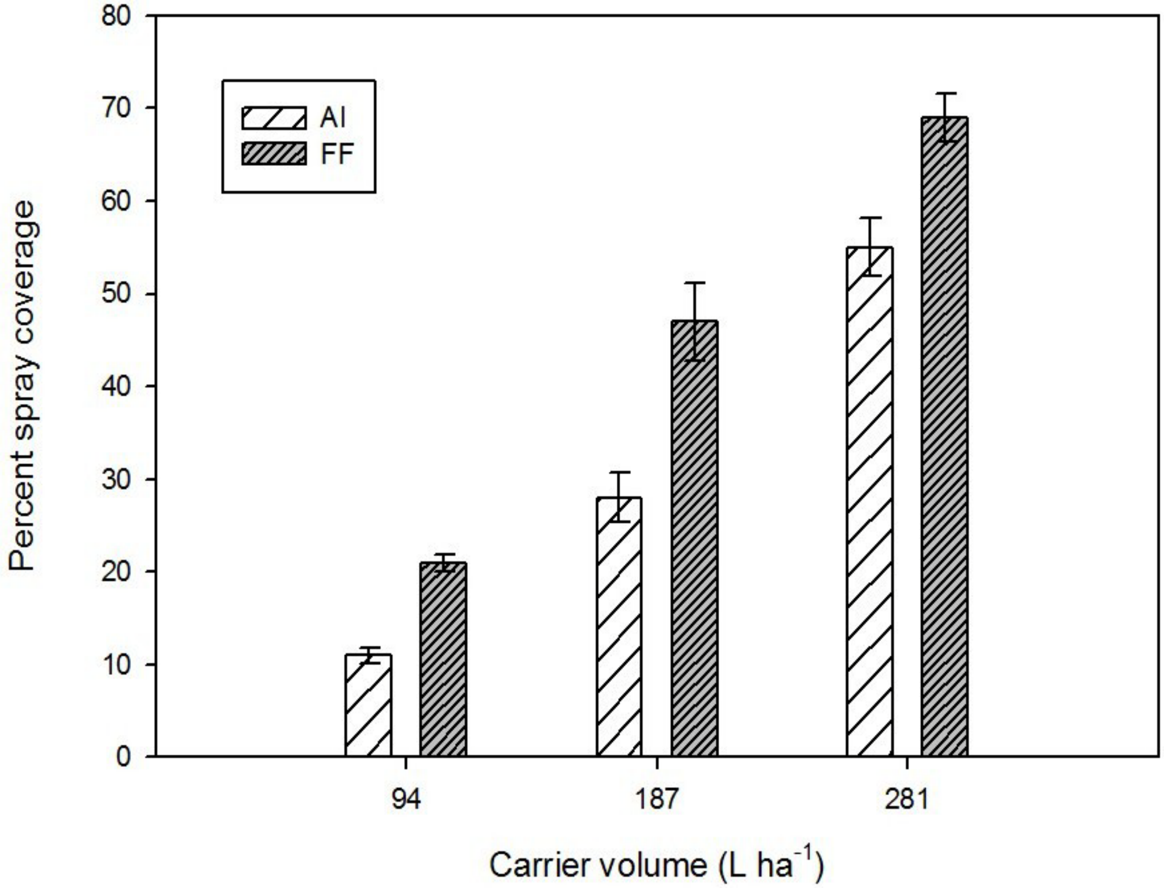

Figure 3-1. Influence of varying carrier volumes and nozzle type on percent spray coverage. Error bars calculated from the mean of 4 replications. AI = air induction nozzle, FF= flat fan nozzle.

Table 3-1. Influence of carrier volume on % control of Palmer amaranth (height range of 5 cm to 10 cm) with the use of lactofen (0.21 kg/ha) + crop oil concentrate 1% (v/v).

Carrier Volume	----------------------% control[1]----------------------		
L/ha	14 DAT[2]	28 DAT	42 DAT
94 L	99a[3]	99a	99a
187 L	100a	99a	99a
281 L	100a	100a	100a

[1] Visual assessment of Palmer amaranth control was based on the following scale: 0 = no control; 100 = complete control. [2] DAT = days after treatment. [3] Values reflect the mean of 4 replications. Means within a column followed by different letters are significantly different from each other at the 0.05 level according to Fisher's Least Significant Difference (LSD) test.

Table 3-2. Influence of carrier volume on % control of Palmer amaranth (height range of 15 cm to 20 cm) with the use of lactofen (0.21 kg/ha) + crop oil concentrate (1% v/v).

Carrier Volume	----------------------% control[1]----------------------		
L/ha	14 DAT[2]	28 DAT	42 DAT
94 L	84b[3]	82b	75b
187 L	91a	89a	88a
281 L	91a	89a	89a

[1] Visual assessment of Palmer amaranth control was based on the following scale: 0 = no control; 100 = complete control. [2] DAT = days after treatment. [3] Values reflect the mean of 4 replications. Means within a column followed by different letters are significantly different from each other at the 0.05 level according to Fisher's Least Significant Difference (LSD) test.

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BIOGRAPHICAL SKETCH

Michael is the son of Mike and Mitchell Dobrow. He was raised in a rural sugarcane and winter vegetable farming community in the glades area of Florida. Michael graduated high school in May 2001 and then attended Abraham Baldwin Agricultural College for two semesters. He transferred to Santa Fe Community College where he graduated with an Associate of Arts degree in May 2005. Michael then attended the University of Florida receiving a Bachelor of Science degree in agronomy in May 2007. As an undergraduate student at the University of Florida, Michael was active in the Agronomy and Soils Club and received the National Student Recognition Award presented by the American Society of Agronomy, Crop Science Society of America and Soil Science Society of America. In the summer of 2007, Michael married the former Miss Casey Reynolds of Ocala, FL.

Michael started in the graduate weed science program at the University of Florida in the Fall of 2007. He started his field research in peanut weed control the summer of 2008. Michael has presented at the Southern Weed Science Society, Florida Weed Science Society, and the Weed Science Society of America meetings. Following completion of his Master of Science degree, he plans to continue, in some facet, his involvement in agriculture.