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Final Report

Influence of herbicides and cover crop management on control of ALS-resistant Palmer amaranth

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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 had greater values compared to common waterhemp (Amaranthus rudis S.), another dioecious *Amaranthus* species, for leaf area, dry weight, and plant volume (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 habits of PA increases its ability to 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% from 0.33 to 10 PA plants per m^{-1} of row. 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); furthermore, Smith et al. (2000) found that PA reduced 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 because of their low use rates, low toxicity, wide crop selection, high efficacy, and cost effectiveness (Saari et al. 1994). The ALS-inhibiting herbicides have been used extensively for weed control because they are registered in all major crops. But, the intensive use of these herbicides has increased the incident of ALS-resistance, with PA being only 1 of 103 species documented with ALS-resistance (Heap 2009). PA, when not resistant, can be controlled effectively with imazapic (Grichar 1997; Grichar 1997; Grichar 2007). Resistance to ALS-inhibiting herbicides in PA has been confirmed in Arkansas, Florida, Georgia, Kansas, Mississippi, North Carolina, South Carolina and Tennessee (Heap 2009).

The use of cover crops has long been incorporated into agronomic cropping systems. A cover crop system commonly consists of planting a winter-hardy crop in the fall, desiccating it with an herbicide in the spring and then followed by spring crop planting (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). Burgo 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.

Studies have indicated that additional weed management is needed regardless of cover crop or subsequent crop (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 but, there are limited 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 will be necessary. However, lactofen and acifluorfen are labeled to control PA at 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. This area was then 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 native infestation of ALS-resistant Palmer amaranth (20 to 40 plants per m^{-2}).

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. 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 ai/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) and 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). All experimental treatments were applied with a CO_2-pressurized plot sprayer calibrated to deliver 187 L/ha.

Weed counts were recorded weekly from the middle of each plot in an area measuring 3.0 m by 0.76 m until the threshold was achieved. A threshold of 1 PA per meter of row was calculated from a study conducted by Burke et al. 2007. If the threshold was reached prior to crop canopy closure, the day of the last evaluation was used as the "days to threshold" datum.

The experimental design was a split-plot with cover crop as the whole-plot factor and herbicide as the split. Herbicide treatments were randomized within each whole-plot with four replications. Linear interpolation was used to calculate days to threshold for each treatment. These data were subjected to analysis of variance to test for treatment effects and interactions. Means were separated using Fisher's protected Least Significant Difference (LSD) at $p = 0.05$.

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 herbicide was significant and all data are presented accordingly.

In 2008, dry weight of annual rye cover crop was 2067 kg ha^{-1}. For pendimethalin and norflurazon treatements, PA reached the 1 plant per meter threshold within 3.34

and 8.64 days after application, respectively, compared to the untreated control which reached threshold at 2.20 days (Table 1-1). This lack of control was expected with norflurazon as the label indicates *Amaranthus* spp. will only be suppressed (Anonymous 2009a). But the label of Prowl H_2O, which contains pendimethalin as the active ingredient, indicates that PA will be controlled (Anonymous 2008). Although, Grichar (2008) 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 22.97 days after application while metolachlor + paraquat + 2, 4-DB applied AC reached threshold 54.62 days after application. The application of flumioxazin PRE resulted in 67.75 days, the greatest number of days until threshold was met for all treatments.

In 2009, analysis of the main effects of cover crop found that days to threshold of standing and rolled rye for all herbicide treatments were 10.16 and 7.04, respectively, compared to no cover crop which held PA only 4.26 days(Table 1-2). Annual rye dry biomass was 2436 kg ha^{-1} which was similar to 2008. Control with pendimethalin and norflurazon was comparable to 2008 only delaying PA threshold ≤ 2.87 days after application for all cover crop scenarios (Table1-3). Metolachlor applied PRE in all cover crop scenarios was not as effective as 2008 only delaying threshold by ≤0.58 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. Flumioxazin did not reach threshold for 26.43 days across all cover crop scenarios (Table 1-3). 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 12.19 days compared to the rolled cover crop (Table 1-4).

Days to threshold decreased significantly for all treatments in 2009 compared to 2008. This could have been due to the elevated rainfall received in 2009, during the month, after herbicide application and lack of rainfall in the months that followed, compared to 2008 (table 1-5). 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 26.43 to 67.75 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 regiment at 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	67.75a[3]
pendimethalin	1.07	PRE	3.34d
norflurazon	1.34	PRE	8.64d
metolachlor	1.35	PRE	22.97c
metolachlor +	1.35	AC	54.62b
paraquat +	0.21	AC	
2, 4-DB	0.25	AC	
untreated	-	-	2.20d

[1] Timing of herbicide treatments (trt) are as followed: PRE=preemergence, AC=At-crack. [2] Number of days required to achieve a threshold of 3 Palmer amaranths per measured area. [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 Fischer's Least Significant Difference (LSD) test.

Table 1-2. Influence of cover crop scenarios on Palmer amaranth days to threshold in 2009.

Cover Crop Scenario	Days to Threshold[1]
Standing	10.16a[2]
Rolled	7.04ab
None	4.26b

[1] Number of days required to achieve a threshold of 3 Palmer amaranths per measured area. [2] 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 Fischer's Least Significant Difference (LSD) test.

Table 1-3. Influence of preemergence and post herbicides on Palmer amaranth days to threshold in 2009.

Herbicide Treatment	Rate kg/ha	Timing of trt.[1]	Days to Threshold[2]
flumioxazin	0.10	PRE	26.43a[3]
pendimethalin	1.07	PRE	0.25c
norflurazon	1.34	PRE	2.87c
metolachlor	1.35	PRE	0.58c
metolachlor +	1.35	AC	12.59b
paraquat +	0.21	AC	
2, 4-DB	0.25	AC	
untreated	-	-	0.22c

[1] Timing of herbicide treatments (trt) are as followed: PRE=preemergence, AC=At-crack.
[2] Number of days required to achieve a threshold of 3 Palmer amaranths per measured area. [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 Fischer's Least Significant Difference (LSD) test.

Table 1-4. Influence of cover crop scenarios none, rolled and standing combined with preemergence and post 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	16.68[3]a[4]A[5]	27.33aA	35.26aA
pendimethalin	1.07	PRE	0.30aC	0.21aC	0.25aC
norflurazon	1.34	PRE	2.13aC	4.25aBC	2.23aC
metolachlor	1.35	PRE	0.17aC	0.55aC	1.01aC
metolachlor +	1.35	AC	6.17aB	9.70abB	21.89bB
paraquat +	0.21	AC			
2, 4-DB	0.25	AC			
untreated	-	-	0.13aC	0.18aC	0.33aC

[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 3 Palmer amaranths per measured area. [3] Values reflect the mean of 4 replications. [4]Means within a row followed by different letters are significantly different from each other at the 0.05 level according to Fischer's Least Significant Difference (LSD) test.[5] Means within a column followed by different letters are significantly different from each other at the 0.05 level according to Fischer's Least Significant Difference (LSD) test.

Table 1-5. 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