Weed Control and Peanut (*Arachis hypogaea* L.) Response to Acetochlor Alone and in Combination with Various Herbicides

Sushila Chaudhari[1], David L. Jordan[1*], Timothy L. Grey[2], Eric P. Prostko[2], and Katherine M. Jennings[3]

ABSTRACT

Acetochlor, a chloroacetamide herbicide, is now registered for preplant (PPI), preemergence (PRE), and postemergence (POST) application in peanut. Field research was conducted during 2011 and 2012 in Georgia and North Carolina to determine peanut response and weed control by acetochlor compared with *S*-metolachlor alone and in programs with other herbicides. In weed-free experiments, peanut tolerance to acetochlor (1.26 and 2.52 kg ai/ha) and *S*-metolachlor (1.42 kg ai/ha) were evaluated when applied PPI, PRE, early postemergence (EPOST), or POST. Peanut tolerance to acetochlor was similar to *S*-metolachlor with no negative impact of either herbicide on peanut yield compared with non-treated peanut in absence of weed interference. When applied PRE, acetochlor controlled Palmer amaranth, pitted morningglory, sicklepod, and Texas millet similarly to *S*-metolachlor while control of broadleaf signalgrass was greater with *S*-metolachlor. Weed control programs containing EPOST and/or POST applications of herbicides following PRE herbicides provided the best overall weed control but did not affect yellow nutsedge control regardless of whether acetochlor or *S*-metolachlor were applied. Herbicide programs including PRE, EPOST, and POST herbicides most often resulted in the greatest yields. There was no difference in peanut yield regardless of the presence of acetochlor or *S*-metolachlor in a comprehensive herbicide program.

Key Words: Crop injury, herbicide mixture, peanut tolerance.

Peanut is a valuable commodity in the United States with approximately 634,800 ha harvested with an estimated value of $1.19 billion (USDA 2016a; USDA 2016b). Weeds compete with peanut for sunlight, moisture, and nutrients throughout the growing season (Wilcut *et al*., 1994), and negatively affect yield, quality, and economic value (Everman *et al*., 2008; Walker *et al*., 1989). Season-long interference from combinations of broadleaf and grass weeds can reduce peanut yield by 60 to 80% and can decrease harvest efficiency in some instances (Everman *et al*., 2008; Wilcut *et al*., 1994). In studies investigating the effect of season-long interference from individual weed species, common ragweed (*Ambrosia artemisiifolia* L.) (Clewis *et al*., 2001) and Palmer amaranth [*Amaranthus palmeri* (S.) Wats] (Burke *et al*., 2007) at a density of 1 plant/m of row, resulted in peanut yield losses of 40 and 28%, respectively. Competition from Texas millet [*Urochloa texana* (Buckl.)] and Florida beggarweed [*Desmodium tortuosum* (Sw.) DC.] can also severely reduce peanut yield (Buchanan et al., 1976; Cardina and Brecke, 1991; Wilcut, *et al*., 1987). The prostrate growth habit of peanut causes peanut to be vulnerable to interference from weeds throughout the season and requires effective season-long management to protect yield and promote efficient digging and vine inversion (Walker *et al*., 1989; Wilcut *et al*., 1994).

S-metolachlor is a chloroacetamide herbicide, labeled for either pre-plant incorporated (PPI), preemergence (PRE), postemergence (POST), or lay-by application in peanut (Anonymous, 2017a). Peanut stunting and delayed emergence with *S*-metolachlor has been noted in previous studies (Cardina and Swann, 1988; Clewis *et al*., 2007; Grichar and Dotray, 2012). Grichar and Dotray (2012) reported peanut stunting from 0 to 15% with *S*-metolachlor alone and in combination with paraquat, and stunting increased as application timing was delayed to 28 d compared to 7 d after peanut cracking. Peanut injury by *S*-metolachlor and the racemic form of metolachlor is dependent on combinations of factors, including herbicide rate, moisture conditions at planting, soil temperature, and rainfall (Cardina and Swann, 1988; Grichar *et al*., 2004). Cardina and Swann (1988) reported that peanut growth suppression was related to higher metolachlor rates followed by irrigation after planting. Although some level of injury was reported in peanut from metolachlor, negative effects were not observed on peanut market grades and yield unless rates higher than those recommended by the manufacturer were

[1]Postdoctoral Research Scholar and Professor, Department of Crop and Soil Sciences, North Carolina State University, Raleigh, NC 27695
[2]Professor and Professor, respectively. Department of Crop and Soil Sciences, The University of Georgia, 2360 Rainwater Drive, Tifton, GA 31793.
[3]Associate Professor, Department of Horticulture Science, North Carolina State University, Raleigh, NC 27695.
*Corresponding author Email: david_jordan@ncsu.edu

applied. *S*-metolachlor provides control of a number of troublesome annual broadleaf weeds and yellow nutsedge when applied alone or in combination with sulfentrazone, diclosulam, or flumioxazin (Clewis *et al.*, 2007; Grichar *et al.*, 2008).

Acetochlor is registered for use in field corn (*Zea mays* L.), cotton (*Gossypium hirsutum* L.), sorghum [*Sorghum bicolor* (L.) Moench.], and soybean [*Glycine max* (L.) Merr.] to control annual grasses and small-seeded broadleaf weeds (Anonymous, 2017b; Cahoon *et al.* 2015; Geier *et al.*, 2009; Steckel *et al.*, 2002). Acetochlor inhibits geranylgeranyl pyrophosphate cyclization enzymes, which are part of the gibberellin biosynthetic pathway and controls weeds by inhibiting growth of seedling shoots (Shaner, 2014). A microencapsulated (ME) formulation of acetochlor recently received registration for PPI, PRE, and POST application in peanut (Anonymous 2017b). In addition to improving crop safety, this formulation of acetochlor extends herbicide persistence in the soil compared with the emulsifiable concentrate formulation (Parker *et al.*, 2005; Scher *et al.*, 1998). Grichar *et al.* (2015) reported no negative effect of acetochlor ME application timing and rate on peanut grade and yield in runner and Spanish market type cultivars. Cahoon *et al.* (2015) documented that acetochlor ME applied PRE caused less than 8% early season injury to cotton and at least 90% control of Palmer amaranth. Early season injury caused by acetochlor was transient and did not negatively impact cotton yield.

One effective approach to manage weeds with long periods of emergence is to use sequential applications of PRE and POST herbicides. Grichar *et al.* (2008) reported $>$ 80% yellow nutsedge (*Cyperus esculentus* L.) control at five of six locations in peanut with sequential application of diclosulam PRE followed by *S*-metolachlor applied POST. Control of Palmer amaranth, common lambsquarters (*Chenopodium album* L.), and annual morningglory (*Ipomoea* spp.) in peanut was improved when a POST application of imazapic plus 2,4-DB followed PRE *S*-metolachlor alone or in combination with diclosulam, flumioxazin, or sulfentrazone, compared with PRE- or POST-only treatments (Clewis *et al.* 2007). Grichar *et al.* (2015) reported that the addition of pendimethalin and lactofen to acetochlor, flumioxazin, or *S*-metolachlor programs improved weed control in peanut.

Peanut producers typically include PPI, PRE, EPOST, and POST herbicide applications in their weed management programs for effective season-long control of nutsedge, annual grass, and broadleaf weeds. Dinitroaniline herbicides, such as ethalfluralin, pendimethalin, or trifluralin, are applied PPI to control many annual grass and small-seeded broadleaf weeds (Grichar and Dotray, 2012; Wilcut *et al.*, 1994). Diclosulam, *S*-metolachlor, flumioxazin, and sulfentrazone are registered PRE (Clewis *et al.*, 2007; Jordan, 2016). In addition to these herbicides, acifluorfen, bentazon, clethodim, imazapic, imazethapyr, paraquat, sethoxydim, and 2,4-DB are used in peanut for POST weed control (Grey *et al.*, 2003; Wilcut *et al.*, 1994). Herbicide resistance in weeds has increased concerns about proper herbicide stewardship (Wise *et al.*, 2009). The registration of acetochlor will increase herbicide options for weed control in peanut. Considering the need for soil-applied residual herbicides to manage weeds and the limited published information on acetochlor tolerance to peanut, field research was conducted in Georgia and North Carolina to define utility of acetochlor compared with *S*-metolachlor. The specific objectives of this research were: 1) to determine peanut response to the ME formulation of acetochlor with *S*-metolachlor when applied at different rates and timings under weed-free conditions and 2) to compare weed control with the ME formulation of acetochlor to control by *S*-metolachlor alone or in various herbicide programs which includes combinations with acifluorfen, bentazon, flumioxazin, imazapic, lactofen, paraquat, and pendimethalin.

Material and Methods

Field experiments were conducted in Georgia at the Ponder Research Station near Ty Ty, the Attapulgus Research and Education Center near Attapulgus, the Southwest Georgia Research and Education Center near Plains, and in North Carolina at the Peanut Belt Research Station located near Lewiston-Woodville, and the Upper Coastal Plain Research Station near Rocky Mount during 2011 and 2012. Soil was a Tifton loamy sand soil (fine-loamy, kaolinitic, thermic Plinthic Kandiudult) with 1.07 to 1.39% organic matter (OM) and pH 6.0 at Ty Ty, an Orangeburg loamy sand soil (Fine-loamy, kaolinitic, thermic Typic Kandiudult) with 1.07 to 1.19% OM and pH 6.0 at Attapulgus, and a Greenville sandy clay loam soil (Fine, kaolinitic, thermic Rhodic Kandiudult) with 1.0% OM and pH 5.9 to 6.1 at Plains. Soil at Lewiston-Woodville was a Norfolk sandy loam soil (fine-loamy, siliceous, thermic, Aquic Paleudult) with 0.8 to 1.2% OM and pH 5.9. Goldsboro loamy sand soil (fine loamy, mixed, semiactive,

Table 1. Planting and herbicide application dates evaluating peanut tolerance under weed-free conditions in Georgia and North Carolina, 2011-2012[a].

Location	Year	Cultivar	Planting date	Herbicide application date			
				PPI	PRE	EPOST	POST
Plains, GA	2011	GA-06G	19 May	19 May	19 May	1 June	13 June
Ty Ty, GA	2011	GA-06G	9 May	9 May	10 May	27 May	14 June
Plains, GA	2012	GA-06G	1 May	1 May	1 May	16 May	31 May
Ty Ty, GA	2012	GA-06G	26 April	26 April	27 April	9 May	30 May
Rocky Mount, NC	2011	Bailey	10 May	10 May	10 May	31 May	15 June
Lewiston-Woodville, NC	2011	Bailey	2 May	2 May	2 May	26 May	13 June
Rocky Mount, NC	2012	Bailey	23 May	23 May	23 May	9 June	19 June
Lewiston-Woodville, NC	2012	Bailey	21 May	21 May	21 May	11 June	21 June

[a]Abbreviations: PPI, preplant incorporated; PRE, preemergence; EPOST, early postemergence; POST, postemergence.

thermic, Typic Hapludult) with 1.4% organic matter and pH 6.1 was at Rocky Mount. Soils at these locations are representative of the southeastern United States peanut production region. Experiments were classified as specific combinations of year and/or location within each state. Experiments were conducted in conventionally-prepared, raised seedbeds. Plot size was 4 rows spaced 96-cm apart by 9 m in North Carolina and 2 rows spaced 91-cm apart by 7.6 m in Georgia. Peanut was planted at a depth of 4 to 5 cm at all locations at a rate designed to achieve final in-row populations of 4 and 6 plants/m in North Carolina and Georgia, respectively. Production, irrigation, and pest management practices other than specific treatments were standard for peanut production in Georgia and North Carolina to optimize peanut growth and development (Anonymous, 2017c; Jordan *et al*., 2016).

Peanut Tolerance

Peanut cultivars (Branch 2007; Mozingo *et al*. 2006; Isleib *et al*., 2006, 2011), planting dates, and dates of herbicide application are presented in Table 1. Treatments consisted of a factorial arrangement of 3 levels of herbicide and 4 levels of application timings. Herbicide levels included acetochlor (Warrant herbicide, Monsanto Co., St Louis, MO) at 1.26 and 2.52 kg/ha and *S*-metolachlor (Dual Magnum herbicide, Syngenta Crop Protection, Greensboro, NC) at 1.42 kg/ha. These herbicides were applied PPI, PRE, EPOST, or POST. A non-treated control was also included. Herbicides were applied in water using a CO_2-pressurized backpack sprayer calibrated to deliver 140 L/ha using 11002 flat fan (TeeJet Technologies, Wheaton, IL) nozzles at 150 kPa at Plains, 11002DG flat fan nozzles at 260 kPa at Ty Ty, and 8002 flat fan nozzles at 200 kPa at Lewiston-Woodville and Rocky Mount. PPI herbicides were incorporated immediately after application with a power-driven rotary tiller (Plains and Ty Ty) or with 2 passes with a field cultivator in opposite directions at Lewiston-Woodville and Rocky Mount to a depth of approximately 5 cm. Herbicides were applied PRE within 24 h after peanut planting. In Georgia, 3 cm of overhead sprinkler irrigation were applied within 1 wk after application of PRE herbicides. Peanut was not irrigated after planting in North Carolina. EPOST applications were made approximately 14 to 24 d after planting when peanut was approximately at V3 to V4 stage of growth (Boote, 1982) while POST applications were made 25 to 38 d after peanut planting when peanut was at R1 stage of growth (Boote, 1982).

All plots were kept weed-free combining hand removal with herbicides applied PRE and POST. Diclosulam (Strongarm herbicide, Dow AgroSciences, Indianapolis, IN) at 0.026 kg ai/ha, flumioxazin (Valor SX, Valent USA Corp., Walnut Creek, CA) at 0.11 kg ai/ha, or pendimethalin (Prowl H_2O, BASF Corp., Research Triangle Park, NC) at 1.13 kg ai/ha were applied PRE. Clethodim (Select herbicide, Valent USA Corp., Walnut Creek, CA) at 0.13 kg ai/ha or imazapic (Cadre herbicide, BASF Corp., Research Triangle Park, NC) at 0.70 kg ai /ha with crop oil concentrate applied POST to control annual grasses and broadleaf weeds at Plains and Ty Ty. Pendimethalin at 1.1 kg ai/ha was applied PPI and clethodim at 130 g/ha, and 2,4-DB (Butyrac 200, Winfield Solutions, LLC, St. Paul, MN) at 0.28 kg ai/ha were applied POST for weed control at Lewiston-Woodville and Rocky Mount.

Experiments were conducted in a randomized complete block design with four replications. Visual estimates of peanut injury were determined 2-3 and 6-7 weeks after each application timing (WAT) using a scale of 0 to 100 where 0 = no injury and 100 = plant death. Foliar chlorosis, necrosis, leaf defoliation, and plant stunting were considered when making the visible estimates. Peanut pods

Table 2. Planting and herbicide application dates for peanut weed control research in Georgia and North Carolina, 2011-2012.[a]

Location	Year	Cultivar	Planting date	Herbicide application date PRE	EPOST	POST
Plains, GA	2011	GA-06G	19 May	19 May	01 June	13 June
Attapulgus, GA	2011	GA-06G	16 May	18 May	06 June	22 June
Plains, GA	2012	GA-06G	01 May	01 May	16 May	14 June
Attapulgus, GA	2012	GA-06G	10 May	11 May	31 May	18 June
Rocky Mount, NC	2011	CHAMPS	27 May	27 May	15 June	30 June
Lewiston-Woodville, NC	2011	Philips	26 May	26 May	09 June	22 June
Rocky Mount, NC	2012	Bailey	22 May	22 May	09 June	19 June
Lewiston-Woodville, NC	2012	Bailey	22 May	22 May	11 June	21 June

[a]Abbreviations: PRE, preemergence; EPOST, early postemergence; POST, postemergence.

were dug and vines inverted based on pod mesocarp color to obtain optimum yield (Williams and Drexler, 1981). Pod yield was determined 4 to 7 d after digging with final yield adjusted to 8% moisture content.

Weed Control

Field experiments were conducted in Georgia at Plains and Attapulgus and in North Carolina at Lewiston-Woodville and Rocky Mount during 2011 and 2012. Peanut cultivars, planting dates, and herbicide application dates are presented in Table 2. Treatments consisted of a factorial arrangement of two base herbicides (*S*-metolachlor and acetochlor ME) and five herbicide programs with base herbicide applied at different timings (Table 3). A non-treated control was also included. Herbicides were applied using equipment and procedures described in the study evaluating peanut response under weed-free conditions. Preemergence herbicides were applied within 24 h after peanut planting while EPOST and POST herbicides were applied approximately 15 to 22 and 25 to 38 d after peanut was planted, respectively.

Weed control was estimated visually using a scale of 0 (no weed control) to 100 (complete weed control) 14 to 69 d after peanut were planted depending on location. Peanut injury (chlorosis/stunting) was also recorded at 3 to 8 d after POST application at Plains and Lewiston-Woodville both years and Rocky Mount in 2012 while at Attapulgus both years and Rocky Mount 2011 at 8 d after EPOST herbicide application using the scale described previously. Peanut yield was determined as described previously.

Data Analysis

Data for peanut injury were transformed to the arcsine square root before analysis; however, non-transformed means are presented for clarity. Data were subjected to ANOVA using SAS PROC MIXED considering the factorial treatment arrangement (SAS Institute Inc., Cary, NC). Treatment means were separated by Fisher's Protected LSD test at p α 0.05. The non-treated check was not included in the weed control or peanut injury analysis but was included in peanut yield analysis. Peanut population, visible injury, and yield data from both peanut tolerance and weed control

Table 3. Herbicide timing and rate of application in experiments determining weed control with PRE, EPOST, and POST herbicides. [a]

	Herbicide timing	Herbicide rate
Base herbicides		kg/ha
Acetochlor	-	1.26
S-metolachlor	-	1.42
Herbicide programs		
1 base herbicide alone	PRE	1.26 or 1.42
2 base herbicide + flumioxazin	PRE	1.26 or 1.42 + 0.11
3 pendimethalin fb base herbicide + lactofen	PRE fb EPOST	1.12 fb 1.26 or 1.42 + 0.22
4 pendimethalin + flumioxazin fb base herbicide + imazapic	PRE fb POST	1.12 + 0.11 fb 1.26 or 1.42 + 0.07
5 pendimethalin fb base herbicide + acifluorfen + bentazon + paraquat fb base herbicide + imazapic	PRE fb EPOST fb POST	1.12 fb 1.26 or 1.42 + 0.19 + 0.38 + 0.21 fb 1.26 or 1.42 + 0.07

[a]Abbreviations: fb, followed by; PRE, preemergence; EPOST, early postemergence; POST, postemergence.

Table 4. Peanut injury from acetochlor and *S*-metolachlor at different application timings under weed-free conditions in North Carolina[a,b].

	Peanut injury 2 WAT			
	Lewiston-Woodville		Rocky Mount	
Main effect	2011	2012	2011	2012
	%			
Herbicide (H)				
acetochlor (1.26 kg/ha)	1 a	1 a	6 a	1 a
acetochlor (2.52 kg/ha)	1 a	1 a	3 ab	3 a
S-metolachlor (1.42 kg/ha)	0 a	2 a	1 b	4 a
H (P value)	0.4235	0.6431	0.0018	0.3450
Application time (AT)				
PPI	1 b	1 a	5 a	4 a
PRE	0 b	1 a	6 a	4 a
EPOST	2 a	2 a	0 b	2 a
POST	0 b	1 a	1 b	3 a
AT (P value)	<0.0001	0.2507	0.0330	0.8019
H × AT (P value)	0.9390	0.8005	0.0540	0.0531

[a]Abbreviations: PPI, preplant incorporated; PRE, preemergence; EPOST, early postemergence; POST, postemergence; WAT, wk after each application timing.

[b]Means within columns for main effects (herbicide or application timing) followed by the same letter are not significantly different according to Fisher's Protected LSD Test at $P \leq 0.05$. The non-treated control was not included in the statistical analysis.

studies were analyzed separately for Georgia and North Carolina because of variation in cultivar selection, and timing for data collection and weed spectrum. However, percent weed control data were analyzed across states and data were combined if the interaction of experiment by base herbicide by herbicide program was not significant.

Results and Discussion

Peanut Tolerance

The interaction of experiment by herbicide treatment by application timing was not significant for peanut population and pod yield in Georgia (P=0.31 and 0.38, respectively) and North Carolina (P=0.76 and 0.23, respectively); therefore, data were combined over experiments for both states. However, this three-way interaction was significant for peanut injury at 2 WAT for Georgia (P = 0.0001) and 2-3 WAT for North Carolina (P = 0.009); therefore, data are presented by experiment. Further analysis indicated that the interaction of herbicide by timing of application was not significant for peanut injury, peanut population, and pod yield. Therefore, data for the main effects of herbicide and timing of application are presented.

Peanut injury 2 WAT during 2011 and 2012 at Lewiston-Woodville and 2012 at Rocky Mount was not affected by herbicide treatment (Table 4). In contrast, at Rocky Mount during 2011, *S*-metolachlor injured peanut less than acetochlor at 1.26 kg/ha. However, similar injury was observed for acetochlor and *S*-metolachlor when acetolchlor was applied at 2.52 kg/ha. Injury did not exceed 6% regardless of herbicide or rate of acetochlor. Significant but minor differences in injury (6% or less) were observed when comparing method and timing of application at these locations (Table 4). Peanut injury in Georgia did not exceed 5% when comparing herbicides pooled over application timing (Table 5). In 1 of 4 experiments injury by *S*-metolachlor exceeded that of the lower rate of acetochlor. A consistent trend was not observed when comparing application timings, although injury was 8% or less. Injury was transient, and by 4 to 5 wk at Lewiston-Woodville and Rocky Mount and 6 to 7 wk after treatments at Ty Ty and Plains, injury was 1% or less (data not shown).

No differences were noted with herbicide treatment or application timing for peanut population or yield in either state or year (Table 6). Visible injury from metolachlor does not always result in lower peanut yield compared with yield of non-treated peanut under weed-free conditions when applied at rates recommended in by the manufacturer (Cardina and Swann, 1988; Clewis *et al.*, 2007; Grichar and Dotray, 2012). In a study similar to the one reported in this article, Grichar *et al.* (2015) observed in Texas that peanut yield and market grade characteristics were not affected by acetochlor rate or application timing (PPI, PRE, EPOST, POST). The indeterminate growth habit of peanut often enables peanut to recover from early season stress including herbicide injury and yield is

Table 5. Peanut injury from acetochlor and *S*-metolachlor at different application timings under weed-free conditions in Georgia (Study 1)[a,b].

	Peanut injury 2-3 WAT			
	Ty Ty		Plains	
Main effect	2011	2012	2011	2012
	%			
Herbicide (H)				
acetochlor (1.26 kg/ha)	4 a	2 b	2 a	2 a
acetochlor (2.52 kg/ha)	3 a	4 ab	4 a	3 a
S-metolachlor (1.42 kg/ha)	3 a	5 a	5 a	3 a
H (P value)	0.3981	0.0420	0.1448	0.1843
Application time (AT)				
PPI	0 c	6 a	1 a	0 b
PRE	1 c	5 a	2 a	0 b
EPOST	8 a	5 a	5 b	5 a
POST	4 b	0 b	6 b	6 a
AT (P value)	<0.0001	0.0002	0.0024	<0.0001
H × AT (P value)	0.9390	0.4349	0.3669	0.0864

[a]Abbreviations: PPI, preplant incorporated; PRE, preemergence; EPOST, early postemergence; POST, postemergence; WAT, wk after each application timing.

[b]Means within columns for main effects (herbicide or application timing) followed by the same letter are not significantly different according to Fisher's Protected LSD Test at $P \leq 0.05$.

often not adversely affected (Carley *et al.*, 2009; Grichar and Dotray, 2012).

Weed Control

The interaction for experiment by base herbicide by herbicide program was significant for Palmer amaranth control (P=0.001); therefore, data are presented by experiment. In contrast, lack of a significant experiment by base herbicide by herbicide program interaction allowed the combining of data over experiments for broadleaf signalgrass [*Urochloa platyphylla* (Nash) R.D. Webster] control (P=0.39), pitted morningglory (*Ipomoea lacunosa* L.) control (P=0.08), sicklepod [*Senna obtusifolia* (L.) H.S. Irwin & Barneby] control (P=0.26), and Texas millet control (P=0.39). The interaction of base herbicide by herbicide program was not significant for control of Palmer amaranth, broadleaf signalgrass, pitted morningglory, and

Table 6. Peanut population and yield response to acetochlor and *S*-metolachlor at different application timings under weed-free conditions in Georgia and North Carolina[a,b].

	Peanut Population		Peanut yield	
Main effect	Georgia	North Carolina	Georgia	North Carolina
	plants row m^{-1}		kg/ha	
Herbicide (H)				
non-treated	11 a	8 a	5870 a	4690 a
acetochlor (1.26)	11 a	8 a	5710 a	4600 a
acetochlor (2.52)	11 a	8 a	5570 a	4580 a
S-metolachlor (1.42)	11 a	8 a	5800 a	4510 a
H (P value)	0.9336	0.9605	0.0803	0.7299
Application time (AT)				
non-treated	11 a	8 a	5870 a	4690 a
PPI	10 a	8 a	5670 a	4680 a
PRE	11 a	8 a	5650 a	4640 a
EPOST	11 a	8 a	5710 a	4410 a
POST	11 a	8 a	5750 a	4520 a
AT (P value)	0.0597	0.3958	0.8100	0.1851
H × AT (P value)	0.6729	0.7431	0.3057	0.6887

[a]Abbreviations: PPI, preplant incorporated; PRE, preemergence; EPOST, early postemergence; POST, postemergence.

[b]Means within columns for main effects (herbicide or application timing) followed by the same letter are not significantly different according to Fisher's Protected LSD Test at $P \leq 0.05$.

Table 7. Palmer amaranth control in peanut with herbicide programs containing acetochlor and *S*-metolachlor.[a]

Main effect		Plains 2011	Plains 2012	Rocky Mount 2011	Rocky Mount 2012
		%			
Base herbicide (BH)					
1	Acetochlor	95 a	92 a	93 a	72 a
2	*S*-metolachlor	86 b	91 a	90 a	76 a
Herbicide program (HP)					
1	Only BH	73 b	68 b	68 b	40 c
2	flumioxazin + BH PRE	90 a	98 a	97 a	76 b
3	pendimethalin PRE fb lactofen + BH EPOST	92 a	94 a	95 a	71 b
4	pendimethalin + flumioxazin PRE fb imazapic + BH POST	99 a	99 a	99 a	88 ab
5	pendimethalin PRE fb paraquat + bentazon + acifluorfen + BH EPOST fb imazapic + BH POST	99 a	97 a	99 a	94 a
BH × HP (P value)		0.0950	0.5150	0.0499	0.0584

[a]Means within columns for main effects (base herbicide or herbicide program) followed by the same letter are not significantly different according to Fisher's Protected LSD Test at P ≤ 0.05.

[b]Palmer amaranth ratings recorded 25 to 47 d after POST application.

sicklepod; therefore, data for the main effects are presented (Tables 7 and 8). In contrast, the interaction of base herbicide by herbicide program was significant for Texas millet control (Table 9).

Palmer amaranth. There was no difference between acetochlor and *S*-metolachlor for Palmer amaranth control except at Plains in 2011, where greater control was obtained from acetochlor compared to *S*-metolachlor (Table 7). At Plains in 2011 and 2012 and Rocky Mount in 2011, herbicide programs containing only base herbicides provided less Palmer amaranth control compared to other herbicide programs. However, at Rocky Mount in 2012, the herbicide program including pendimethalin PRE fb paraquat plus bentazon plus acifluorfen plus acetochlor or *S*-metolachlor EPOST fb imazapic plus acetochlor or *S*-metolachlor POST controlled Palmer amaranth 94%

Table 8. Broadleaf signalgrass, pitted morningglory, and sicklepod control in peanut with herbicide programs containing acetochlor and *S*-metolachlor.[a]

Main effect		Broadleaf signalgrass[b,c]	Pitted morningglory[c]	Sicklepod[c]
		%		
Base herbicide (BH)				
1	Acetochlor	70 b	72 a	49 a
2	*S*-metolachlor	86 a	77 a	54 a
Herbicide program (HP)				
1	Only BH	74 bc	57 c	9 c
2	flumioxazin + BH PRE	86 ab	74 b	41 b
3	pendimethalin PRE fb lactofen + BH EPOST	65 c	81 b	16 c
4	pendimethalin + flumioxazin PRE fb imazapic + BH POST	74 bc	73 b	93 a
5	pendimethalin PRE fb paraquat + bentazon + acifluorfen + BH EPOST fb imazapic + BH POST	91 a	90 a	99 a
BH × HP (P value)		0.1259	0.0999	0.4911

[a]Means within columns for main effects (base herbicide or herbicide program) followed by the same letter are not significantly different according to Fisher's Protected LSD Test at P ≤ 0.05.

[b]Broadleaf signalgrass control recorded 30 d after POST application (DAP) at Attapulgus (2012).

[c]Broadleaf signalgrass control recorded 1 to 3 DAP at Rocky Mount (2011 and 2012); pitted morningglory control recorded 3 to 19 DAP at Lewiston-Woodville and Rocky Mount (2011 and 2012); sicklepod control recorded 25 to 40 DAP at Attapulgus (2011) and Plain (2011 and 2012). Data are pooled over experiments for each species.

Table 9. Texas millet control in peanut with herbicide programs containing acetochlor and *S*-metolachlor.[a]

Base herbicides (BH)	Herbicide program (HP)	Control
		%
Acetochlor	Only BH	53 d
Acetochlor	flumioxazin + BH PRE	39 e
Acetochlor	pendimethalin PRE fb lactofen + BH EPOST	77 bc
Acetochlor	pendimethalin + flumioxazin PRE fb imazapic + BH POST	87 ab
Acetochlor	pendimethalin PRE fb paraquat + bentazon + acifluorfen + BH EPOST fb imazapic + BH POST	94 a
S-metolachlor	Only BH	53 d
S-metolachlor	flumioxazin + BH PRE	64 d
S-metolachlor	pendimethalin PRE fb lactofen + BH EPOST	64 cd
S-metolachlor	pendimethalin + flumioxazin PRE fb imazapic + BH POST	90 a
S-metolachlor	pendimethalin PRE fb paraquat + bentazon + acifluorfen + BH EPOST fb imazapic + BH POST	98 a
BH × HP (P value)		0.0025

[a]Means within columns followed by the same letter are not significantly different according to Fisher's Protected LSD Test at $P \leq 0.05$.

[b]Control recorded 20 to 42 DAP at Plains and Lewiston-Woodville (2011 and 2012) and Attapulgus (2011). Percent control combined over experiments.

while all other herbicide programs controlled this weed less than 88% (Table 6). Grichar et al. (2005) reported greater control of Palmer amaranth with POST herbicides following PPI application of *S*-metolachlor was at least 84% compared to only 69% by *S*-metolachlor. Addition of EPOST or POST herbicides with PPI or PRE herbicides often are beneficial in controlling Palmer amaranth that escapes weed control programs early in the year or when this weed emerges later in the season. Clewis *et al*. (2007) reported that a EPOST application of paraquat plus bentazon fb the prepackage mixture of acifluorfen plus bentazon POST plus 2,4-DB or imazapic plus 2,4-DB POST controlled Palmer amaranth 93% and 97%.

Broadleaf signalgrass. *S*-metolachlor controlled 86% broadleaf signalgrass which was greater than control by acetochlor (Table 8). Broadleaf signalgrass can rapidly emerge under warm conditions and throughout the growing season in high numbers (Burke *et al*., 2003). Therefore, multiple herbicide applications are generally needed for season-long control. The herbicide program including pendimethalin PRE fb paraquat plus bentazon plus acifluorfen plus either acetochlor or *S*-metolachlor EPOST fb imazapic plus acetochlor or *S*-metolachlor POST controlled broadleaf signalgrass 91%. Clewis *et al*. (2007) reported that imazapic plus 2,4-DB POST followed by PRE and EPOST herbicide application controlled broadleaf signalgrass at least 96%.

Pitted morningglory. There was no difference between acetochlor and *S*-metolachlor for pitted morningglory control (Table 8). The most effective herbicide program for pitted morningglory was pendimethalin PRE fb paraquat plus bentazon plus acifluorfen plus either acetochlor or *S*-metolachlor EPOST fb imazapic plus either acetochlor or *S*-metolachlor POST which provided 90% control.

Sicklepod. There was no difference between acetochlor and *S*-metolachlor for sicklepod control (Table 8). Herbicide program including pendimethalin plus flumioxazin PRE fb imazapic plus either acetochlor or *S*-metolachlor POST and pendimethalin PRE fb paraquat plus bentazon plus acifluorfen plus either acetochlor or *S*-metolachlor EPOST fb imazapic plus either acetochlor or *S*-metolachlor POST controlled sicklepod at least 93%, while all other herbicide programs provided ≤ 41% control. Previous studies have documented effective control of sicklepod by imazapic POST or flumioxazin PRE followed by paraquat plus bentazon EPOST (Grey and Wehtje, 2005; Webster *et al*., 1997; Wilcut *et al*., 1996).

Texas millet. Acetochlor and *S*-metolachlor alone provided 53% control of Texas millet (Table 9). Previous research (Wilcut *et al*., 1995) indicated that the racemic form of metolachlor provides little or no Texas millet control; however, the dinitroaniline herbicides provide excellent control of annual grasses (Wilcut *et al*., 1994). Imazapic controls Texas millet and broadleaf signalgrass (Grichar *et al*., 2005; Wilcut *et al*., 1995). Herbicide programs including pendimethalin plus flumioxazin PRE fb imazapic plus either acetochlor or *S*-metolachlor POST and pendimethalin PRE fb paraquat plus

Table 10. Peanut injury under weedy conditions as influenced by herbicide programs containing acetochlor and *S*-metolachlor in Georgia, 2011-2012.[a]

Main effect		Attapulgus 2011	Attapulgus 2012	Plains 2011	Plains 2012
		%			
Base herbicide (BH)					
1	Acetochlor	5 a	7 b	6 b	6 a
2	*S*-metolachlor	5 a	10 a	8 a	7 a
Herbicide program (HP)					
1	Only BH	2 b	11 a	0 c	-
2	flumioxazin + bh PRE	8 a	11 a	3 c	4 b
3	pendimethalin PRE fb lactofen + BH EPOST	3 b	9 a	8 b	8 a
4	pendimethalin + flumioxazin PRE fb imazapic + BH POST	9 a	8 ab	8 b	3 b
5	pendimethalin PRE fb paraquat + bentazon + acifluorfen + BH EPOST fb imazapic + BH POST	2 b	4 b	16 a	10 a
BH × HP (P value)		0.8475	0.0761	0.0553	0.6640

[a]Means within columns for main effects (base herbicide or herbicide program) followed by the same letter are not significantly different according to Fisher's Protected LSD Test at P ≤ 0.05.

[b]Peanut injury recorded at 3 to 8 d after POST application at Plains and 8 d after EPOST application at Attapulgus.

bentazon plus acifluorfen plus either acetochlor or *S*-metolachlor EPOST fb imazapic plus acetochlor or *S*-metolachlor POST controlled Texas millet at least 87%, while all other herbicide programs provided ≤ 77% control. Grichar *et al*. (2005) reported that *S*-metolachlor PRE in combination with imazapic POST provided 94% control of Texas millet which was better than S-metolachlor alone.

Peanut injury and yield. The interaction of experiment by base herbicide by herbicide program was not significant for peanut yield for North Carolina (P=0.90); therefore data were combined over experiments. However, this interaction was significant for peanut injury for Georgia (P=0.04) and North Carolina (P=0.03); therefore, data are presented by experiments. Further analysis indicated that the interaction of base herbicide by herbicide program was not significant for peanut injury and yield. Therefore, data for the main effects were combined.

Peanut injury was similar from acetochlor and *S*-metolachlor at all the locations at Georgia and North Carolina except Attapulgus 2012 and Plains 2011, where greater injury was observed with *S*-metolachlor as compared to acetochlor (Tables 10 and 11). Peanut injury with respect to herbicide programs was inconsistent, and maximum injury (21%) was reported from pendimethalin PRE fb paraquat plus bentazon plus acifluorfen plus either acetochlor or *S*-metolachlor EPOST fb imazapic plus either acetochlor or *S*-metolachlor POST at Rocky Mount 2012 (Table 11).

There was no difference in peanut yield between acetochlor and *S*-metolachlor and peanut treated with either herbicide yielded more than the non-treated control (Table 11). Herbicide programs including pendimethalin PRE fb lactofen plus either acetochlor or *S*-metolachlor EPOST, pendimethalin plus flumioxazin PRE fb imazapic plus either acetochlor or *S*-metolachlor POST, pendimethalin PRE fb paraquat plus bentazon plus acifluorfen plus either acetochlor or *S*-metolachlor EPOST fb imazapic plus either acetochlor or *S*-metolachlor POST resulted in greater yields as compared to non-treated control. The greater yield from these herbicide programs, which contain EPOST and/or POST treatments, may be attributed to effective weed management throughout the peanut growing season. Increased peanut yield has been reported in other studies by using combinations of PPI, PRE, EPOST, or POST herbicide applications (Clewis *et al*., 2007; Grichar and Dotray, 2012; Jordan *et al*., 2009).

Conclusions

Results from this research demonstrated that acetochlor exhibited similar phytotoxicity to peanut as *S*-metolachlor, a herbicide currently used in peanut production. This herbicide will provide growers with another option in their battle against

Table 11. Peanut injury and yield under weedy conditions as influenced by herbicide programs containing acetochlor and *S*-metolachlor in North Carolina, 2011-2012.[a]

		Injury				
		Lewiston-Woodville		Rocky Mount		
Main effect		2011[b]	2012[b]	2011[c]	2012[b]	Yield
		%				kg/ha
Base herbicide (BH)						
1	non-treated	-	-	-	-	2410 b
2	Acetochlor	4 a	6 a	9 a	10 a	3810 a
3	*S*-metolachlor	3 a	9 a	11 a	8 a	3670 a
Herbicide program (HP)						
1	Only BH	1 b	0 b	0 c	1 b	3040 cd
2	flumioxazin + bh PRE	3 ab	0 b	20 a	3 b	3330 bc
3	pendimethalin PRE fb lactofen + BH EPOST	8 a	19 a	8 bc	8 b	3860 ab
4	pendimethalin + flumioxazin PRE fb imazapic + BH POST	0 b	0 b	8 bc	13 ab	4250 a
5	pendimethalin PRE fb paraquat + bentazon + acifluorfen + BH EPOST fb imazapic + BH POST	6 ab	18 a	14 ab	21 a	4230 a
6	non-treated	-	-	-	-	2410 d
BH × HP (P value)		0.0762	0.2487	0.0413	0.2141	0.8158

[a]Means within columns for main effects (base herbicide or herbicide program) followed by the same letter are not significantly different according to Fisher's Protected LSD Test at $P \leq 0.05$.

[b]Peanut injury ratings taken 3 to 8 d after POST application at Lewiston-Woodville (2011 and 2012) and Rocky Mount (2012).

[c]Peanut injury rating taken 8 d after EPOST or 9 d before POST at Rocky Mount (2011).

hard-to-control weeds. In most instances, acetochlor or *S*-metolachlor are not stand-alone herbicides and should be included in a systems approach for the most effective weed control. The addition of herbicides with multiple sites of action in weed management program not only provided increased control of weeds in peanut but may also provide optimum resistance management (Heap, 2017).

Acknowledgments

Monsanto Co. provided partial funding for this research.

Literature Cited

Anonymous. 2017a. Dual Magnum label SCP 816A-L1W 0715. Greensboro, NC: Syngenta Crop Protection. 50 pages.

Anonymous. 2017b. Warrant herbicide label, preplant, at-planting, preemergence and postemergence applications in peanut. Monsanto Corp., St. Louis, MO. 2 pages.

Anonymous. 2017c. Peanut Update Cooperative Extension Service Series CSS-17-0118. ed. W.S. Monfort Athens, GA: University of Georgia. 56 pages.

Boote, K.J. 1982 Growth Stages of Peanut (*Arachis hypogaea* L.). Peanut Sci. 9:35–40.

Branch, W.D. 2007. Registration of 'Georgia-06G' peanut. J. Plant Reg. 1:120.

Buchanan, G.A., E.W. Hauser, W.J. Ethredge, and S.R. Cecil. 1976. Competition of Florida beggarweed and sicklepod with peanuts II. Effects of cultivation, weeds, and SADH. Weed Sci. 24:29–39.

Burke, I.C., M. Schroeder, W.E. Thomas, and J.W. Wilcut. 2007. Palmer amaranth interference and seed production in peanut. Weed Technol. 21:367–371.

Burke, I.C., W.E. Thomas, J.F. Spears, and J.W. Wilcut. 2003. Influence of environmental factors on broadleaf signalgrass (*Brachiaria platyphylla*) germination. Weed Sci. 51:683–689.

Cahoon, C.W., A.C. York, D.L. Jordan, W.J. Everman, R.W. Seagroves, L.R. Braswell, and K.M. Jennings. 2015. Weed control in cotton by combinations of microencapsulated acetochlor and various residual herbicides applied preemergence. Weed Technol. 29:740–750.

Cardina, J. and B.J. Brecke. 1991. Florida beggarweed (*Desmodium tortuosum*) growth and development in peanuts (*Arachis hypogaea*). Weed Technol. 5:147–153.

Cardina, J. and C.W. Swann. 1988. Metolachlor effects on peanut growth and development. Peanut Sci. 15:57–60.

Carley, D.S., D.L. Jordan, R.L. Brandenburg, and L.C. Dharmasri. 2009. Factors influencing response of Virginia market type peanut (*Arachis hypogaea*) to paraquat under weed-free conditions. Peanut Sci. 36:180–189.

Clewis, S.B., S.D. Askew, and J.W. Wilcut. 2001. Common ragweed interference in peanut. Weed Sci. 49:768–772.

Clewis, S.B., W.J. Everman, D.L. Jordan, and J.W. Wilcut. 2007. Weed management in North Carolina peanuts (*Arachis hypogaea*) with *S*-metolachlor, diclosulam, flumioxazin, and sulfentrazone systems. Weed Technol. 21:629–635.

Everman, W.J., S.B. Clewis, W.E. Thomas, I.C. Burke, and J.W. Wilcut. 2008. Critical period of weed interference in peanut. Weed Technol. 22:63–67.

Geier, P.W., P.W. Stahlman, D.L. Regehr, and B.L. Olson. 2009. Preemergence herbicide efficacy and phytotoxicity in grain sorghum. Weed Technol. 23:197–201

Grey, T.L. and G.R. Wehtje. 2005. Residual herbicide weed control systems in peanut. Weed Technol. 19:560–567.

Grey, T.L., D.C. Bridges, and E.P. Prostko. 2003. Residual weed control with imazapic, diclosulam, and flumioxazin in southeastern peanut (*Arachis hypogaea*). Peanut Sci. 30:22–27.

Grichar, W.J., B.A. Besler, R.G. Lemon, and K.D. Brewer. 2005. Weed management and net returns using soil-applied and postemergence herbicide programs in peanut (*Arachis hypogaea* L.) Peanut Sci. 32:25–31.

Grichar, W.J. and P.A. Dotray. 2012. Peanut cultivar response to *S*-metolachlor and paraquat alone and in combination. Peanut Sci. 39:15–21.

Grichar, W.J., B.A. Besler, P.A. Dotray, W.C. Johnson III, and E.P. Prostko. 2004. Interaction of flumioxazin with dimethenamid or metolachlor in peanut (*Arachis hypogaea* L.). Peanut Sci. 31:12–16.

Grichar, W.J., P.A. Dotray, and L.M. Etheredge. 2015. Weed control and peanut (*Arachis hypogaea* L.) cultivar response to encapsulated acetochlor. Peanut Sci. 42:100–108.

Grichar, W.J., P.A. Dotray, and T.A. Baughman. 2008. Yellow nutsedge (*Cyperus esculentus*) control and peanut tolerance to *S*-metolachlor and diclosulam combinations. Weed Technol. 22:442–447.

Heap, I. 2017. The International Survey of Herbicide Resistant Weeds. Online. Internet. March 26, 2017. Available http://www.weedscience.org/summary/MOA.aspx?MOAID=12

Isleib, T.G., S.R. Milla-Lewis, H.E. Pattee, S.C. Copeland, M.C. Zuleta, B.B. Shew, J.E. Hollowell, T.H. Sanders, L.O. Dean, K.W. Hendrix, M. Balota, and J.W. Chapin. 2011. Registration of 'Bailey' peanut. J. Plant Reg. 5:27–39.

Isleib, T.G., P.W. Rice, R.W. Mozingo II, S.C. Copeland, J.B. Graeber, H.E. Pattee, T.H. Sanders, R.W. Mozingo, and D.L. Coker. 2006. Registration of 'Phillips' peanut. Crop Sci. 46: 2308–2309.

Jordan, D.L. 2016. Peanut weed management. Pages 47–80 *in* Jordan, D.L., R.L. Brandenburg, A.B. Brown, S.G. Bullen, G.T. Roberson, and B. Shew (eds.). Peanut Information. North Carolina Cooperative Extension Pub. AG-331. College of Agriculture and Life Sciences, North Carolina State University, Raleigh, NC.

Jordan, D.L., R.L. Brandenburg, A.B. Brown, S.G. Bullen, G.T. Roberson, and B. Shew (eds.). 2016. Peanut Information. North Carolina Cooperative Extension Pub. AG-331. College of Agriculture and Life Sciences, North Carolina State University, Raleigh, NC.

Jordan, D.L., S.H. Lancaster, J.E. Lanier, B.R. Lassiter, and P.D. Johnson. 2009. Weed management in peanut with herbicide combinations containing imazapic and other pesticides. Weed Technol. 23:6–10.

Mozingo, R.W., T.A. Coffelt, P.M. Phipps, and D.L. Coker. 2006. Registration of 'CHAMPS' peanut. Crop Sci. 46:2711–2712.

Parker, D.C., F.W. Simmons, and L.M. Wax. 2005. Fall and early preplant application timing effects on persistence and efficacy of acetamide herbicides. Weed Technol. 19:6–13.

Scher, H.B., M. Rodson, and K. Lee. 1998. Microencapsulation of pesticides by interfacial polymerization utilizing isocyanate of aminoplast chemistry. Pest Manag. Sci. 54:394–400.

Shaner, D.L. 2014. Herbicide Handbook. 10th ed. Lawrence, KS: Weed Science Society of America. Pages 513.

Steckel, L.E., C.L. Sprague, and A.G. Hager. 2002. Common waterhemp (*Amaranthus rudis*) control in corn (*Zea mays*) with single preemergence and sequential applications of residual herbicides. Weed Technol. 16:755–761.

[USDA] U.S. Department of Agriculture. 2016a. Crop values 2015 summary. 12 Sept. 2016. <http://usda.mannlib.cornell.edu/usda/current/CropValuSu/CropValuSu-02-24-2016.pdf>.

[USDA] U.S. Department of Agriculture. 2016b. Crop production 2015 summary. 12 Sept. 2016. <http://www.usda.gov/nass/PUBS/TODAYRPT/cropan16.pdf>.

Walker, R.H., L.W. Wells, and J.A. McGuire. 1989. Bristly starbur (*Acanthospermum hispidium*) interference in peanuts (*Arachis hypogaea*). Weed Sci. 37:196–200.

Webster, T.M., J.W. Wilcut, and H.D. Coble. 1997. Influence of AC 263, 222 rate and application method on weed management in peanut (*Arachis hypogaea*). Weed Technol. 11:520–526.

Wilcut, J.W., A.C. York, and G.R. Wehtje. 1994. The control and interaction of weeds in peanut (*Arachis hypogaea*). Rev. Weed Sci. 6:177–205.

Wilcut, J.W., A.C. York, W.J. Grichar, and G.R. Wehtje. 1995. The biology and management of weeds in peanut (*Arachis hypogaea*). Pages 207–244. In H.E. Pattee and H.T. Stalker (eds.). Advances in Peanut Science. Amer. Peanut Res. Educ. Soc., Stillwater, OK.

Wilcut, J.W., G.R. Wehtje, and R.H. Walker. 1987. Economics of weed control in peanuts (*Arachis hypogaea*) with herbicides and cultivations. Weed Sci. 35:711–715.

Wilcut, J.W., J.S. Richburg III, and G.L. Wiley. 1996. Postemergence AC 263,222 systems for weed control in peanut (*Arachis hypogaea*). Weed Sci. 44:615–621.

Williams, E.J., and J.S. Drexler. 1981. A non-destructive method for determining peanut pod maturity, pericarp, mesocarp, color, morphology, and classification. Peanut Sci. 8:134–141.

Wise, A.M., T.L. Grey, E.P. Prostko, W.K. Vencill, and T.M. Webster. 2009. Establishing the geographic distribution level of acetolactate synthase resistance of Palmer amaranth (*Amaranthus palmeri*) accessions in Georgia. Weed Technol. 23:214–220.