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Evaluation of Thiencarbazone-methyl– and Isoxaflutole-Based Herbicide Programs in Corn

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Field studies were conducted in Louisiana and Mississippi in 2009 and 2010 to evaluate PRE herbicide treatments containing isoxaflutole or a prepackaged mixture of thiencarbazone-methyl : isoxaflutole (TCM : isoxaflutole) for weed control in corn. PRE treatments included the premix of TCM : isoxaflutole alone (30 : 80 g ai ha^{-1}) and with atrazine (1,120 g ai ha^{-1}), isoxaflutole alone (90 g ai ha^{-1}) and with atrazine (1,120 g ai ha^{-1}), and the premix of atrazine plus *S*-metolachlor (1,820 plus 1,410 g ai ha^{-1}). POST treatments included glufosinate (450 g ai ha^{-1}) or glyphosate (870 g ae ha^{-1}) applied to 30-cm corn along with a no POST treatment. All PRE treatments controlled barnyardgrass, entireleaf morningglory, rhizomatous johnsongrass, Palmer amaranth, and velvetleaf 87 to 95% 4 wk after planting (WAP) and browntop millet and hophornbeam copperleaf were controlled 86 to 95% 8 WAP. Weed control was improved 8 and 20 WAP when either POST treatment was applied. TCM : isoxaflutole plus atrazine controlled barnyardgrass, entireleaf morningglory, Palmer amaranth, and velvetleaf at least 90% 20 WAP regardless of POST treatment. TCM : isoxaflutole plus atrazine provided greater control of browntop millet (90%) than isoxaflutole alone or with atrazine and atrazine plus *S*-metolachlor where control was 86% 20 WAP. Pooled across POST treatments, all PRE treatments containing isoxaflutole or TCM : isoxaflutole controlled rhizomatous johnsongrass better (74 to 76%) than atrazine plus *S*-metolachlor (67%). Corn yield following herbicide treatments ranged from 9,280 to 11,040 kg ha^{-1} compared with 9,110 kg ha^{-1} for the nontreated. Results indicate that TCM : isoxaflutole or isoxaflutole PRE is an option for use in a corn weed management program and may prolong the use of atrazine where weed resistance may be an issue. Where rhizomatous johnsongrass is a problem, TCM : isoxaflutole or isoxaflutole PRE can provide better control than atrazine plus *S*-metolachlor PRE. Without PRE treatments, glufosinate or glyphosate was needed for season-long weed control.

Nomenclature: Atrazine; glufosinate; glyphosate; isoxaflutole; *S*-metolachlor; thiencarbazone-methyl, methyl 4-[(4,5-dihydro-3-methoxy-4-methyl-5-oxo-1H-1,2,4-triazol-1-yl)carboxamidosulfonyl]-5-methylthiophene-3-carboxylate; barnyardgrass, *Echinochloa crus-galli* (L.) Beauv. ECHCG; browntop millet, *Urochloa ramosa* (L.) Nguyen PANRA; entireleaf morningglory, *Ipomoea hederacea* (L.) Jacq. var. *integriuscula* Gray IPOHG; hophornbeam copperleaf, *Acalypha ostryifolia* Riddell ACCOS; johnsongrass, *Sorghum halepense* (L.) Pers. SORHA; Palmer amaranth, *Amaranthus palmeri* S. Wats. AMAPA; velvetleaf, *Abutilon theophrasti* Medik ABUTH; corn, *Zea mays* L.

Key words: Postemergence, preemergence, weed control.

En 2009 y 2010 se llevaron a cabo estudios de campo en Louisiana y Mississippi para evaluar tratamientos de herbicidas PRE que contenían isoxaflutole o una mezcla preenvasada de thiencarbazone-methyl:isoxaflutole (TCM:isoxaflutole), para el control de malezas en maíz. Los tratamientos PRE incluyeron la premezcla de TCM:isoxaflutole solo (30:80 g ia ha^{-1}) y con atrazine (1120 g ia ha^{-1}), isoxaflutole solo (90 g ia ha^{-1}) y con atrazine (1120 g ia ha^{-1}), y la premezcla de atrazine más *S*-metolachlor (1820 más 1410 g ia ha^{-1}). Los tratamientos POST incluyeron glufosinate (450 g ia ha^{-1}) o glifosato (870 g ea ha^{-1}) aplicados cuando el maíz tenía 30 cm de altura junto con un testigo sin tratamiento POST. Todos los tratamientos PRE controlaron *Echinochloa crus-galli, Ipomoea hederacea, Sorghum halepense, Amaranthus palmeri* y *Abutilon theophrasti* de 87 a 95% 4 semanas después de la siembra (WAP), y *Urochloa ramosa* y *Acalypha ostryifolia* de 86 a 95% 8 WAP. El control de malezas mejoró a las 8 y 20 WAP cuando se aplicó cualquiera de los dos tratamientos POST. TCM: isoxaflutole más atrazine controló *E.crus-galli, I. hederacea, A. palmeri* y *A. theophrasti* al menos 90% 20 WAP, sin importar el tratamiento POST. TCM:isoxaflutole más atrazine proporcionó mejor control de *U. ramosa* (90%) que isoxaflutole por sí solo o con atrazine y que atrazine más *S*-metolachlor, en cuyo caso el control fue 86% 20 WAP. Promediando los tratamientos POST, todos los tratamientos PRE que contenían isoxaflutole o TCM:isoxaflutole, controlaron *S. halepense* mejor (74 a 76%) que atrazine más *S*-metolachlor (67%). El rendimiento del maíz después de los tratamientos con herbicida varió de 9280 a 11040 kg ha^{-1} en comparación con 9110 kg ha^{-1} para el testigo no tratado. Los resultados indican que la aplicación PRE de TCM:isoxaflutole o isoxaflutole es una opción para usar en un programa de manejo de malezas en maíz y podría prolongar el uso de atrazine donde la resistencia de la maleza puede ser un problema. En situaciones donde *S. halepense* es un problema, TCM:isoxaflutole o isoxaflutole aplicados PRE pueden proporcionar mejor control que atrazine más *S*-metolachlor PRE. Sin tratamientos PRE, se requirió glufosinate o glifosato para el control de malezas a lo largo del ciclo de cultivo.

Corn was planted on more hectares than any other crop in the United States from 2006 to 2010, with an average of 35 million ha planted per year and yield averaging 9.7 Mg ha^{-1} yr^{-1} (Anonymous 2010a). Herbicides were used on 97% of the corn hectares in the United States, with 71% receiving an application of atrazine (Anonymous

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2010b). Weeds resistant to photosystem II (PSII)-inhibiting herbicides, including atrazine, have been documented in many parts of the United States where corn is grown (Heap 2010). Weed biotypes resistant to PSII inhibitors include barnyardgrass, common lambsquarters (*Chenopodium album* L.), common waterhemp (*Amaranthus rudis* Sauer), horseweed [*Conyza canadensis* (L.) Cronq.], jimsonweed (*Datura stramonium* L.), kochia [*Kochia scoparia* (L.) Schrad.], Palmer amaranth, redroot pigweed (*Amaranthus retroflexus* L.), smooth pigweed (*Amaranthus hybridus* L.), and velvetleaf (Heap 2010). In addition, populations of tall waterhemp [*Amaranthus tuberculatus* (Moq.) Sauer] have been identified with resistance to herbicides that inhibit acetolactate synthase (ALS), PSII, protoporphyrinogen oxidase (PPO), and 4-hydroxyphenyl-pyruvate-dioxygenase (4-HPPD) in Illinois and Iowa (Heap 2010), indicating the continued need for alternative modes of action in corn to mitigate herbicide resistance.

From 2006 to 2010, approximately 240,000 ha of corn was planted in Louisiana and Mississippi per year, with yields averaging 8.7 Mg ha^{-1} yr^{-1} (Anonymous 2010a). To date, problematic weeds in Louisiana and Mississippi corn have not developed resistance to herbicides inhibiting PSII, PPO, or 4-HPPD, but there is a need for alternative herbicides to atrazine to mitigate the possible development of herbicide resistance.

Thiencarbazone-methyl (TCM) is an ALS-inhibiting herbicide in the sulfonyl-amino-carbonyl-triazolinone chemical class registered for use in corn, wheat (*Triticum aestivum* L.), turf, and ornamentals (Anonymous 2010c). TCM is absorbed through aerial portions of the plants and from the soil and is combined by the manufacturer in various prepackaged mixtures with other complementary herbicides and proprietary crop safeners (Philbrook and Santel 2007).

Isoxaflutole is a soil-applied isoxazole herbicide used for selective broadleaf and grass control in corn and controls susceptible species by inhibiting the 4-HPPD biochemical pathway (Pallett et al. 1998, 2001). Injury to corn has been reported with soil application of isoxaflutole and was most common when isoxaflutole was applied to soils with a pH of 6.2 to 8.1 and organic matter content of 0.8 to 1.9% (Steckel et al. 2003; Wicks et al. 2007). Young et al. (1999) found that isoxaflutole PRE controlled Pennsylvania smartweed (*Polygonum pensylvanicum* L.), smooth pigweed, and velvetleaf at least 88% 60 d after treatment; however, common waterhemp, common ragweed (*Ambrosia artemisiifolia* L.), and common cocklebur (*Xanthium strumarium* L.) were controlled less than 88%. Isoxaflutole PRE controlled triazine-resistant common lambsquarters 98% (Chomas and Kells 2004). Isoxaflutole PRE controlled Palmer amaranth and velvetleaf 23 and 73%, respectively, 88 d after treatment (Robinson and Bean 2010). Stephenson and Scroggs (2009) found that isoxaflutole PRE controlled Palmer amaranth at least 80% at corn harvest. The addition of atrazine to isoxaflutole PRE reduced plant height of common lambsquarters, giant foxtail (*Setaria faberi* Herrm.), and redroot pigweed (Schnitker et al. 2007). To diminish corn injury and maintain levels of weed control observed with isoxaflutole application, a formulation of isoxaflutole that includes the crop safener cyprosulfamide has been developed for use in corn (Philbrook and Santel 2008; Watteyne et al. 2009).

A prepackaged mixture of TCM, isoxaflutole, and the safener cyprosulfamide (TCM : isoxaflutole) has been developed to deliver multiple modes of action for weed management in corn. Santel and Philbrook (2008) and Watteyne et al. (2009) found that TCM : isoxaflutole applied PRE provided good broadleaf and grass weed control and did not injure corn. Robinson and Bean (2010) observed 47% Palmer amaranth and 73% velvetleaf control 88 d after treatment with the prepackaged mixture of TCM : isoxaflutole PRE. Others observed that TCM : isoxaflutole PRE controlled barnyardgrass, entireleaf morningglory, and Palmer amaranth at least 80% at corn harvest (Stephenson and Scroggs 2009).

Little research is available pertaining to the control of problematic weeds in Louisiana and Mississippi corn with isoxaflutole or the prepackaged mixture TCM : isoxaflutole applied PRE. Therefore, the objective of this research was to evaluate the efficacy of isoxaflutole and TCM : isoxaflutole as PRE treatments, applied alone or in combination with atrazine, followed by glufosinate or glyphosate POST.

Materials and Methods

Experiments were conducted in 2009 and 2010 at the Louisiana State University Agricultural Center Dean Lee Research and Extension Center near Alexandria, LA, and the Mississippi State University Delta Research and Extension Center in Stoneville, MS. Soil in Louisiana was a Coushatta silt loam (fine-silty, mixed, superactive, thermic Fluventic Entrudept), with a pH of 8.0 and 1.5% organic matter. Soil in Mississippi was a Dundee very fine sandy loam (fine-silty, mixed, active, thermic Typic Endoaqualf), with a pH of 6.1 and 1.2% organic matter. An augmented factorial arranged in a randomized complete block design was used in all experiments. Factors consisted of five PRE treatments, three POST treatments, and a nontreated. The five PRE treatments included the prepackaged mixture (TCM : isoxaflutole, Corvus, Bayer CropScience, Research Triangle Park, NC) (30 : 80 g ai ha^{-1}), TCM : isoxaflutole plus atrazine (Aatrex, Syngenta Crop Protection, Inc., Greensboro, NC) (30 : 80 plus 1120 g ai ha^{-1}), isoxaflutole (Balance Flexx, Bayer CropScience) (90 g ai ha^{-1}), isoxaflutole plus atrazine (90 plus 1,120 g ai ha^{-1}), and the local standard of the prepackaged mixture of atrazine plus *S*-metolachlor (Bicep II Magnum, Syngenta Crop Protection, Inc.) (1,820 plus 1,410 g ai ha^{-1}). The three POST treatments were no POST herbicide, glufosinate (Ignite, Bayer CropScience) (450 g ai ha^{-1}), and glyphosate (Roundup PowerMax, Monsanto Company, St. Louis, MO) (870 g ae ha^{-1}) applied to 30-cm corn. Plot size was 9 m long with four 0.97-m rows in Louisiana and 9 m long with four 1-m rows in Mississippi. All treatments at both locations were applied with a tractor-mounted, compressed-air sprayer calibrated to deliver 187 L ha^{-1} at 145 kPa using TeeJet 11002 flat-fan nozzles (TeeJet Memphis, Collierville, TN). Dates of planting, emergence, PRE and POST application, and harvest are shown for each location in both years in Table 1.

Table 1. Dates of planting, emergence, PRE and POST herbicide applications, and harvest for experiment locations.

State	Year	Planting	Emergence	PRE application	POST application	Harvest
Louisiana	2009	April 8	April 15	April 9	May 6	August 25
	2010	March 30	April 5	April 1	May 3	August 12
Mississippi	2009	April 6	April 15	April 8	May 12	September 22
	2010	April 5	April 14	April 6	May 5	August 24

In Louisiana, 'Pioneer 31P42' and 'Northrup-King N77P-3000GT' were seeded at 74,750 seeds ha^{-1} in 2009 and 2010, respectively. 'Pioneer 31G71' was planted at 76,600 seeds ha^{-1} in both years in Mississippi. Corn was seeded 4 to 5 cm deep at both locations. All studies were conducted using conventional-tillage methods with standard corn production practices.

Control of barnyardgrass, browntop millet, entireleaf morningglory, hophornbeam copperleaf, rhizomatous johnsongrass, Palmer amaranth, and velvetleaf was evaluated. Barnyardgrass, browntop millet, entireleaf morningglory, and Palmer amaranth were present at both locations in 2009 and 2010. Hophornbeam copperleaf and johnsongrass was present only in Louisiana in 2009 and 2010. Velvetleaf was present only in Mississippi in 2009 and 2010. Densities of all weeds ranged from 10 to 20 plants m^{-2} at their respective locations. At the time of POST herbicide application, johnsongrass was 10 to 25 cm tall and all other weeds were 5 to 10 cm tall, regardless of location.

Visual estimates of weed control were recorded 4, 8, and 20 WAP. Weed control and corn injury were visually estimated on a scale of 0 (no injury symptoms) to 100 (complete death of all plants). Yield was determined by harvesting the center two rows of plots using conventional harvesting equipment. Yield was adjusted to 15% moisture before analysis.

All data were subjected to analysis of variance using PROC MIXED in SAS (SAS Institute Inc., Cary, NC) with years, locations, year by location, and replications nested within year by location as random effects (Blouin et al. 2011). PRE and POST herbicide treatments and their interactions were considered fixed effects. Considering year and location an environmental or random effect permits inferences about treatments to be made over a range of environments (Blouin et al. 2011; Carmer et al. 1989). Least square means were calculated and mean separation ($P \leq 0.05$) was produced using PDMIX800 in SAS, which is a macro for converting mean separation output to letter groupings (Saxton 1998).

Table 2. Significance of the main effects of PRE and POST herbicide treatment and interactions among the main effects pooled across environments for the seven weed species evaluated and corn grain yield.[a,b]

Parameter[c,d,e]	Data collection date	PRE	POST	PRE × POST
		P value		
ECHCG	4 WAP	0.6440	0.6477	0.1498
	8 WAP	0.1204	< 0.0001	0.0947
	20 WAP	0.0035	< 0.0001	0.0214
PANRA	4 WAP	—	—	—
	8 WAP	0.2629	< 0.0001	0.0741
	20 WAP	0.0008	0.0011	0.2956
IPOHG	4 WAP	0.3967	0.1134	0.8697
	8 WAP	0.0194	< 0.0001	0.2535
	20 WAP	< 0.0001	< 0.0001	0.0729
ACCOS	4 WAP	—	—	—
	8 WAP	0.1395	< 0.0001	0.3639
	20 WAP	0.4275	< 0.0001	0.9908
SORHA	4 WAP	0.4809	0.7346	0.9387
	8 WAP	0.7805	< 0.0001	0.2577
	20 WAP	0.0214	< 0.0001	0.0873
AMAPA	4 WAP	0.7468	0.6016	0.5909
	8 WAP	0.0017	< 0.0001	0.0246
	20 WAP	0.0006	< 0.0001	0.0082
ABUTH	4 WAP	0.1336	0.3685	0.0971
	8 WAP	0.0307	0.0003	0.6222
	20 WAP	—	—	—
Corn grain yield		—	—	< 0.0001

[a] Abbreviations: ABUTH, velvetleaf; ACCOS, hophornbeam copperleaf; AMAPA, Palmer amaranth; ECHCG, barnyardgrass; IPOHG, entireleaf morningglory; PANRA, browntop millet; SORHA, johnsongrass; WAP, weeks after planting.

[b] Main effects and interaction considered significant for type III error if $P \leq 0.05$.

[c] Barnyardgrass, browntop millet, entireleaf morningglory, and Palmer amaranth present in Louisiana and Mississippi in 2009 and 2010. Hophornbeam copperleaf and johnsongrass present only in Louisiana in 2009 and 2010. Velvetleaf present only in Mississippi in 2009 and 2010.

[d] Browntop millet and hophornbeam copperleaf not present at the 4 WAP evaluation. Velvetleaf not present at the 20 WAP evaluation.

[e] To include the nontreated check, the 15 PRE by POST treatment effects were analyzed for corn grain yield.

Results and Discussion

No herbicide treatment injured corn greater than 3% (data not shown). No main effects or interaction of PRE and POST treatments was detected 4 WAP for any species evaluated (Table 2). An interaction of PRE and POST herbicide treatments was detected for barnyardgrass (20 WAP), Palmer amaranth (8 and 20 WAP), and corn grain yield. The PRE main effect was significant for browntop millet (20 WAP), entireleaf morningglory (8 and 20 WAP), rhizomatous johnsongrass (20 WAP), and velvetleaf (8 WAP). The POST main effect was significant for barnyardgrass (8 WAP), browntop millet (8 and 20 WAP), entireleaf morningglory (8 and 20 WAP), hophornbeam copperleaf (8 and 20 WAP), rhizomatous johnsongrass (8 and 20 WAP), and velvetleaf (8 WAP).

Barnyardgrass. All PRE treatments controlled barnyardgrass 93 to 94% 4 WAP (data not shown). Averaged across PRE treatments, both glufosinate and glyphosate POST increased control of barnyardgrass compared with the no POST treatment, but no differences were observed between glufosinate and glyphosate 8 WAP (Table 3). In the absence of glufosinate or glyphosate POST, TCM : isoxaflutole plus atrazine provided 91% barnyardgrass control 20 WAP, which was greater than all other PRE treatments (Table 4). No

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Table 3. Barnyardgrass, browntop millet, entireleaf morningglory, hophornbeam copperleaf, johnsongrass, and velvetleaf control as influenced by POST herbicide treatment 8 and 20 WAP.[a,b]

	ECHCG	PANRA		IPOHG		ACCOS		SORHA		ABUTH
POST herbicide	8 WAP	8 WAP	20 WAP	8 WAP	20 WAP	8 WAP	20 WAP	8 WAP	20 WAP	8 WAP
	%									
No POST	86 b	84 b	85 b	83 b	84 b	87 b	84 c	61 b	52 b	92 b
Glufosinate	91 a	89 a	88 a	92 a	89 a	95 a	90 b	87 a	82 a	95 a
Glyphosate	92 a	89 a	88 a	92 a	87 a	96 a	94 a	90 a	87 a	95 a

[a] Abbreviations: ABUTH, velvetleaf; ACCOS, hophornbeam copperleaf; ECHCG, barnyardgrass; IPOHG, entireleaf morningglory; PANRA, browntop millet; SORHA, johnsongrass; WAP, weeks after planting.

[b] Data pooled over preemergence herbicide treatment. Means followed by the same letter for each parameter and evaluation interval are not significantly different at $P \leq 0.05$.

differences in barnyardgrass control were observed among the other PRE treatments, with control ranging from 84 to 86% 20 WAP (Table 4). Bhowmik et al. (1999) observed 97 to 99% barnyardgrass control with isoxaflutole PRE. Barnyardgrass control 20 WAP was improved when glufosinate or glyphosate were applied POST following TCM : isoxaflutole, isoxaflutole, or isoxaflutole plus atrazine PRE, but not following TCM : isoxaflutole plus atrazine and atrazine plus *S*-metolachlor PRE. Regardless of PRE treatment, no differences were observed between glufosinate and glyphosate for barnyardgrass control 20 WAP (Table 4).

Browntop Millet. All PRE treatments controlled browntop millet 86 to 89% 4 WAP (data not shown). Averaged across PRE treatments, glufosinate and glyphosate POST increased control of browntop millet 3 to 5% 8 and 20 WAP compared with the no POST treatment (Table 3). Averaged across POST treatments, TCM : isoxaflutole plus atrazine provided greater control of browntop millet (90%) 20 WAP than isoxaflutole, isoxaflutole plus atrazine, and atrazine plus *S*-metolachlor (Table 5). However, browntop millet control from TCM : isoxaflutole and isoxaflutole PRE, without the addition of atrazine, was 88 and 86%, respectively, which was similar to the standard PRE of atrazine plus *S*-metolachlor (86%). Stephenson et al. (2004) observed 94% broadleaf signalgrass [*Urochloa platyphylla* (Nash) R.D. Webster] control 6 wk after emergence in corn with atrazine plus *S*-metolachlor PRE.

Entireleaf Morningglory. All PRE treatments controlled entireleaf morningglory at least 92% 4 WAP (data not shown). Stephenson et al. (2004) observed 81% entireleaf morningglory control 6 wk after emergence with atrazine plus *S*-metolachlor. Averaged across PRE treatments, glufosinate and glyphosate POST increased control of entireleaf morningglory 3 to 9% compared with the no POST treatment (Table 3). Averaged across POST treatments, all PRE treatments provided at least 84% entireleaf morningglory control 8 and 20 WAP (Table 5). Entireleaf morningglory control was increased by the addition of atrazine to TCM : isoxaflutole 8 WAP and TCM : isoxaflutole and isoxaflutole PRE 20 WAP compared to TCM : isoxaflutole or isoxaflutole only PRE; however, control with TCM : isoxaflutole and isoxaflutole-containing PRE treatments did not differ from the atrazine plus *S*-metolachlor PRE standard at either rating date.

Hophornbeam Copperleaf. PRE treatments controlled hophornbeam copperleaf 89 to 95% and 88 to 91% at 8 and 20 WAP, respectively, regardless of POST treatment (data not shown). Averaged across PRE treatments, glufosinate and glyphosate controlled hophornbeam copperleaf at least 95% 8 WAP, which was greater than control observed with no POST treatment (Table 3). Glyphosate controlled more hophornbeam copperleaf than glufosinate 20 WAP.

Rhizomatous Johnsongrass. All PRE treatments controlled rhizomatous johnsongrass 87 to 91% and 78 to 82% at 4 and 8 WAP, respectively (data not shown). At 8 and 20 WAP, POST treatment with glufosinate and glyphosate increased rhizomatous johnsongrass control 26 to 35% compared with PRE-only treatments, indicating the need for glufosinate or glyphosate POST application (Table 3). Culpepper et al. (2000) observed 89 and 98% rhizomatous johnsongrass control 8 WAP with glufosinate and glyphosate, respectively. Averaged across POST treatments, PRE treatments containing isoxaflutole or TCM : isoxaflutole controlled rhizomatous johnsongrass 74 to 76%, which was greater than for atrazine

Table 4. Barnyardgrass control as influenced by PRE and POST herbicide treatment 20 wk after planting.[a]

	POST herbicide		
PRE herbicide[b]	No POST	Glufosinate	Glyphosate
	%		
Thiencarbazone-methyl : isoxaflutole	86 def	92 ab	93 a
Thiencarbazone-methyl : isoxaflutole + atrazine	91 abc	91 abc	91 abc
Isoxaflutole	85 ef	90 abc	89 bcd
Isoxaflutole + atrazine	84 f	89 bcd	91 abc
Atrazine + *S*-metolachlor	86 def	88 cde	89 bcd

[a] Means followed by the same letter are not significantly different at $P \leq 0.05$.

[b] PRE treatments containing thiencarbazone-methyl or isoxaflutole contain the safener cyprosulfamide.

Table 5. Browntop millet, entireleaf morningglory, johnsongrass, and velvetleaf control as influenced by PRE herbicide treatment 8 and 20 WAP.[a,b]

PRE herbicide[c]	PANRA	IPOHG		SORHA	ABUTH
	20 WAP	8 WAP	20 WAP	20 WAP	8 WAP
	%				
Thiencarbazone-methyl : isoxaflutole	88 ab	87 b	85 bc	77 a	94 ab
Thiencarbazone-methyl : isoxaflutole + atrazine	90 a	92 a	91 ab	76 a	96 a
Isoxaflutole	86 b	87 b	84 c	76 a	94 ab
Isoxaflutole + atrazine	86 b	90 ab	88 ab	74 a	94 ab
Atrazine + *S*-metolachlor	86 b	89 ab	87 bc	67 b	93 b

[a] Abbreviations: ABUTH, velvetleaf; IPOHG, entireleaf morningglory; PANRA, browntop millet; SORHA, johnsongrass; WAP, weeks after planting.

[b] Data pooled over POST herbicide treatment. Means followed by the same letter for each parameter and evaluation interval are not significantly different at P ≤ 0.05.

[c] PRE treatments containing thiencarbazone-methyl or isoxaflutole contain the safener cyprosulfamide.

plus *S*-metolachlor (67%) (Table 5). However, Johnson et al. (2003) found that isoxaflutole plus atrazine did not provide effective control of rhizomatous johnsongrass.

Palmer Amaranth. All PRE treatments controlled Palmer amaranth at least 93% 4 WAP (data not shown). By 8 WAP, PRE-only treatments containing atrazine controlled Palmer amaranth at least 90% (Table 6). TCM : isoxaflutole plus atrazine was the only PRE treatment that controlled Palmer amaranth > 90% 20 WAP when no POST treatment was utilized (Table 6). However, PRE-only treatment TCM : isoxaflutole was no better than atrazine plus *S*-metolachlor as a PRE-only treatment 20 WAP. TCM : isoxaflutole and isoxaflutole PRE, both without atrazine, provided 47 and 23% Palmer amaranth control, respectively, 88 d after treatment (Robinson and Bean 2010). Isoxaflutole plus atrazine and atrazine plus *S*-metolachlor PRE controlled common waterhemp 96% 70 d after emergence (Vyn et al. 2006). POST applications of glufosinate or glyphosate following TCM : isoxaflutole, isoxaflutole, and isoxaflutole plus atrazine increased Palmer amaranth control 6 to 11% 8 and 20 WAP, but POST treatment did not impact Palmer amaranth control for other PRE treatments (Table 6).

Velvetleaf. All PRE treatments controlled velvetleaf at least 94% 4 WAP (data not shown). The addition of glufosinate and glyphosate POST increased control of velvetleaf (Table 3). Averaged across POST treatments, TCM : isoxaflutole plus atrazine controlled velvetleaf 96%, which was greater than atrazine plus *S*-metolachlor PRE (93%) (Table 5). However, all PRE treatments provided greater than 90% control 8 WAP. Schnitker et al. (2007) found that velvetleaf densities were lowest following PRE treatments containing isoxaflutole. Atrazine plus *S*-metolachlor PRE provided 87% control of velvetleaf (Stephenson et al. 2004). Isoxaflutole PRE provided at least 88% control of velvetleaf; however, the addition of atrazine to isoxaflutole increased control to greater than 92% (Young et al. 1999).

Corn Grain Yield. Corn yield following all herbicide treatments ranged from 9,280 to 11,040 Mg ha^{-1} while the nontreated yielded 9,110 kg ha^{-1} (Table 7). Corn treated with atrazine-containing PRE treatments yielded at least 10,170 kg ha^{-1} (Table 7). Corn treated with TCM : isoxaflutole PRE followed by glyphosate POST yielded 440 kg ha^{-1} more than TCM : isoxaflutole PRE followed by glufosinate POST; however, no differences in corn yield between glufosinate or glyphosate POST were observed for any other PRE treatment. In addition, applying glufosinate or glyphosate POST did not increase corn yield when following TCM : isoxaflutole plus atrazine or atrazine plus *S*-metolachlor PRE.

Without glufosinate or glyphosate POST, TCM : isoxaflutole or isoxaflutole PRE provided similar control of barnyardgrass, browntop millet, entireleaf morningglory, hophornbeam copperleaf, and velvetleaf to the atrazine plus *S*-metolachlor PRE standard. The addition of atrazine to TCM : isoxaflutole PRE provided greater barnyardgrass, browntop millet, and velvetleaf control then atrazine plus *S*-metolachlor PRE. To provide equal Palmer amaranth control to atrazine plus *S*-metolachlor PRE, TCM : isoxaflutole and isoxaflutole required the addition of atrazine. PRE treatments

Table 6. Palmer amaranth control as influenced by PRE and POST herbicide treatment 8 and 20 WAP.[a,b]

PRE herbicide[c]	POST herbicide					
	8 WAP			20 WAP		
	No POST	Glufosinate	Glyphosate	No POST	Glufosinate	Glyphosate
	%					
Thiencarbazone-methyl : isoxaflutole	81 c	92 a	93 a	84 ef	94 a	91 abc
Thiencarbazone-methyl : isoxaflutole + atrazine	91 ab	94 a	95 a	92 ab	92 ab	95 ab
Isoxaflutole	86 bc	95 a	92 a	83 f	91 abc	87 cdef
Isoxaflutole + atrazine	90 ab	93 a	94 a	86 def	90 abcd	92 ab
Atrazine + *S*-metolachlor	92 a	94 a	95 a	88 bcde	89 bcd	91 abc

[a] Abbreviations: WAP, weeks after planting.

[b] Means followed by the same letter at each rating date are not significantly different at P ≤ 0.05.

[c] PRE treatments containing thiencarbazone-methyl or isoxaflutole contain the safener cyprosulfamide.

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Table 7. Corn grain yield as influenced by PRE and POST herbicide treatment.[a,b]

PRE herbicide[c]	POST herbicide		
	No POST	Glufosinate	Glyphosate
	kg ha^{-1}		
Thiencarbazone-methyl : isoxaflutole	9,860 de	10,480 abcd	10,920 ab
Thiencarbazone-methyl : isoxaflutole + atrazine	10,220 cd	10,490 abcd	10,580 abcd
Isoxaflutole	9,280 e	10,710 abc	10,290 bcd
Isoxaflutole + atrazine	10,170 cd	10,590 abcd	11,040 a
Atrazine + *S*-metolachlor	10,430 abcd	10,810 abc	10,510 abcd
Nontreated	9,110 f		

[a] Abbreviations: WAP, weeks after planting.

[b] Means followed by the same letter not significantly different at $P \leq 0.05$.

[c] PRE treatments containing thiencarbazone-methyl or isoxaflutole contain the safener cyprosulfamide.

containing TCM or isoxaflutole PRE provided greater control of rhizomatous johnsongrass as compared to the atrazine plus *S*-metolachlor standard. Applying glufosinate or glyphosate POST increased control of all weeds following PRE treatments without atrazine. Even though resistance to atrazine has not yet been documented in Louisiana or Mississippi, the popularity of atrazine for corn weed control necessitates the evaluation of herbicide options other than atrazine. Our results indicate that TCM : isoxaflutole or isoxaflutole PRE are options for use in a corn weed management program, and their use may reduce the selection pressure on weedy pests by alternating these herbicides with atrazine, thus potentially prolonging the effectiveness of atrazine. When rhizomatous johnsongrass was present, PRE treatments containing TCM : isoxaflutole or isoxaflutole provided better control than the standard PRE of atrazine plus *S*-metolachlor. However, glufosinate or glyphosate was needed to provide season-long control of all weeds tested, regardless of the PRE herbicide utilized.

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