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Use of the Premix of Atrazine, Bicyclopyrone, *S*-Metolachlor, and Mesotrione for Weed Control in Corn (Zea mays L.)

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Abstract

Field studies were conducted under conventional tillage from 2014 through the 2018 growing seasons in central, south-central, and the Panhandle regions of Texas to determine corn tolerance and weed efficacy of the four-way premix of atrazine plus bicyclopyrone plus mesotrione plus *S*-metolachlor (hereafter referred to as ABMS). No corn injury was noted at any location with any ABMS dose or application timing. Preemergence (PRE) applications of ABMS at 2.41 kg ha^{-1} controlled Palmer amaranth (*Amaranthus palmeri* S. Wats.) 73 to 100% while smellmelon (*Cucumis melo* L.) control was 100%. Annual sunflower (*Helianthus annuus* L.) control with ABMS at 2.41 kg ha^{-1} was 86% while a split application applied PRE followed by a postemergence (POST) application provided 99% control. Texas millet (*Urochloa texana* Buckl.) control with ABMS applied PRE ranged from 12 to 35% while broadleaf signalgrass (*Brachiaria platyphylla* [Griseb.] Nash) control was 100%. Browntop panicum [*Urochloa fasciculate* (Sw.) R. Webster] control with a PRE application of ABMS at 2.41 kg ai ha^{-1} was $\leq$ 82% while jungle rice [*Echinochloa colona* (L.) Link] control was 98%. Control of a kochia (Kochia *scoparia* L.) with PRE applications of ABMS at 2.41 kg ha^{-1} was 95% while the split rate of 1.2 kg ha^{-1} applied PRE and POST provided 99% control. Corn yields were variable but in most instances all herbicide treatments improved yield over the untreated check. Excellent control of broadleaf weeds was observed with ABMS; however, annual grass control can be variable, especially with large-seeded annual grasses such as Texas millet.

Keywords: *Amaranthus palmeri* S. Wats., *Brachiaria platyphylla* [Griseb] Nash, *Cucumis melo* L., *Echinochloa colona* (L.) Link, *Helianthus annuus* L., *Urochloa fasciculate* (Sw.) R. Webster, *Urochloa texana* Buckl., Annual Grasses, Broadleaf Weeds.

Introduction

Corn (*Zea mays* L.) is the most cultivated crop grown in the US with almost 36 million ha and over 788,000 ha planted in Texas in 2015 (USDA-NASS, 2015). During the past twenty years the use of herbicide-resistant, especially glyphosate tolerant, corn production systems have been adopted and used extensively in corn grown regions of the nation (Wiggins *et al.*, 2015). In 2009, nearly 61 million ha of soybean [*Glycine max* (L.) Merr.], cotton (*Gossypium hirsutum* L) and corn in the US contained a modified 5-enolpyruvylshikimate-3-phosphate synthase (EPSPS) gene that confers resistance to glyphosate (Anonymous, 2009). The development of herbicide-resistant crops allows weed control by nonselective postemergence (POST) herbicides such as glyphosate and glufosinate, widening the array of weed management programs available to producers (Culpepper, 2006; Owen, 2008). Both glyphosate and glufosinate control a wide range of weeds in herbicide-resistant crops (Culpepper and York, 1998) with little, if any, crop injury (Johnson *et al*., 2000; Burke *et al*., 2008). POST applications of glyphosate or glufosinate can provide consistent and greater control of large-seeded broadleaf weed species including velvetleaf (*Abutilon theophrasti* Medik.) and common cocklebur (*Xanthium strumarium* L.) compared with preemergence (PRE) herbicides in addition to broadleaf weeds that emerge in season such as kochia (*Bassia scoparia*) (Burke *et al*., 2008). The wide use of row crops with herbicide resistance, the reduction of traditional herbicide and cultivation practices, and the use of intense management of weeds using glyphosate as the predominant control strategy has caused a shift in weed populations and created a selective advantage for glyphosate-resistant plants (Bradley et al., 2000; Ritter and Menbere, 2001).

Herbicide resistance complicates weed management in corn and many other crops. Glyphosate-resistant weeds, specifically *Amaranthus* species have become an issue across much of the US corn producing areas as well as in Texas (Heap, 2014). Estimates are that more than 1.2 million ha of cropland in the US are now affected by glyphosate-resistant *Amaranthus* species (Stephenson *et al*., 2015). Also, weed resistance to photosystem II (PSII) inhibiting herbicides, including atrazine, has been documented in seven monocot and 17 dicot species across many corn growing areas of the US (Heap, 2014; Stephenson *et al*., 2015). Furthermore, populations of tall waterhemp [*Amaranthus tuberculatus* (Moq.) Sauer] have been identified with resistance to herbicides that inhibit acetolactate synthase (ALS), PSII, protoporphyrinogen oxidase (PPO), 5-enolpyruvylshikimate-3-phosphate-synthase (EPSPS), and 4-hydroxyphenyl-pyruvate-dioxygenase (HPPD) in Illinois and Iowa, and Palmer amaranth populations resistant to ALS, PSII, and HPPD inhibitors have been identified in Kansas (Stephenson *et al*., 2015). The HPPD-inhibiting herbicides have become popular among corn producers because of their broad-spectrum weed control, flexible application timings, tank-mix compatibilities, and crop safety (Bollman et al., 2008; Stephenson and Bond, 2012; Walsh et al., 2012). The added weed resistant issues indicate the continued need for alternative modes of action in corn to reduce the chance of herbicide resistance. Up until now, herbicide active ingredients from a new mode of action have not been commercialized in corn since the 1990s (Duke, 2012) and the use of herbicide premixes, combining existing active ingredients, are an important tool for control of resistant weeds in many corn producing systems (Beckie, 2006; Beckie and Reboud, 2009; Owen, 2016).

Acuron® (Syngenta Crop Protection, LLC; Greensboro, NC 27419) is a new herbicide premix labeled in the US for use as a PRE or POST treatment to control broadleaf and grass weed species in corn used for either grain or corn silage (Anonymous, 2018). It may also be used in sweet corn (*Zea mays* L. var. saccharata) and yellow popcorn (*Zea mays* L. var. everta); however, this premix must be applied PRE or serious crop injury in sweet corn or yellow popcorn may occur (Anonymous, 2018). Acuron is a combination of four herbicide active ingredients from three modes of action: atrazine (PS II), bicyclopyrone (HPPD), mesotrione (HPPD), and S-metolachlor (long-chain fatty acid inhibitor) plus the crop safener benoxacor. It will be referred to as 'ABMS' and is the first bicyclopyrone-containing herbicide available in the marketplace. Previous research with at least two of the three herbicides (atrazine, mesotrione, or *S*-metolachlor) in a premix have been evaluated to determine their weed efficacy in corn (Dobbels and Kapusta, 1993; Ferrell and Witt, 2002; Johnson et al., 2002; Taylor-Lovell and Wax, 2001). However, limited data is available on the efficacy of ABMS on weeds commonly found in the central, south-central, and the Panhandle corn growing regions of Texas. Therefore, the objective of this research was to evaluate the effects of ABMS, either alone or in a system approach, on crop tolerance and weed control efficacy in the corn-producing regions of Texas.

Materials and Methods

Field studies. Studies were conducted during the 2014 through 2018 growing seasons in Burleson County near College Station (central Texas), in 2016 through 2018 in Lavaca County near Yoakum (south-central Texas), and 2015 and 2016 in Potter County near Bushland (Texas Panhandle) to determine weed efficacy and crop tolerance to ABMS applied at various doses and in various combinations. Variables for each test location are given in Table 1 while herbicides premixes used in these studies are presented in Table 2. Results from the Burleson

Table 1. Variables for each location in the corn herbicide study.					
	Burleson County				
Variables	**2014**	**2015**	**2016**	**2017**	**2018**
Coordinates	30.5361° N 96.4292° W	30.5463° N 96.4316° W	30.5078° N 96.4206° W	30.5078° N 96.4206° W	30.5078° N 96.4206° W
Soil series	Weswood silty clay loam	Belk clay	Weswood silty clay loam	Weswood silty clay loam	Weswood silty clay loam
Soil classification	Fine-silty, mixed, superactive, thermic Udifluventic Haplustepts	Fine, mixed, active, thermic Entic Hapluderts	Fine-silty, mixed, superactive, thermic Udifluventic Haplustepts	Fine-silty, mixed, superactive, thermic Udifluventic Haplustepts	Fine-silty, mixed, superactive, thermic Udifluventic Haplustepts
Organic matter (%)	2.19	2.3	2.21	2.21	2.21
Soil pH	8.1	8.2	8.4	8.4	8.4
Corn hybrid	DKC 64-69	DKC 62-08	N97Z-3111	DKC 67-14	NK-78S
Plant date	April 17	March 30	March 8	March 23	March 12
Application					
PRE	April 17	March 30	March 8	March 24	March 13
POST	May 25	April 30	April 25	April 27	May 1
Sprayer type	CO_2 backpack	CO_2 backpack	CO_2 backpack	CO_2 backpack	CO_2 backpack
Spray volume (L ha^{-1})	140	140	140	140	140
Nozzle type (PRE)	Flat fan	Flat fan	Flat fan	Flat fan	Flat fan
Nozzle type (POST)	Flat fan	Flat fan	Drop	Flat fan	Flat fan
Nozzle tips					
PRE	DG 11003	DG 8003	DG 11003	DG 11003	DG 11003
POST	DG 11003	DG 8003	DG 9504E	TTI 110015	DG 11003
Drop nozzles	No	No	Yes	No	No
Weed populations (m^2)/weed size (cm) at POST[a]					
AMAPA	10-12/5-10	10-12/5-10	20-30/2-5	10/3-5	<10/3-8
BRAPP	-	-	-	-	-
CUMME	-	-	-	-	-
ECHCO	-	-	-	10/3-6	-
HELAN	10/5-13	-	-	-	-
IPOHG	-	10-20/30-91	-	-	-
PANFA	10-20/5-10	10/3-4	10-20/3-5	-	10/3-8
UROTE	-	-	-	-	-
Harvest date	Sept 10	Aug 28	Sept 6	Aug 25	Aug 10

[a] Bayer Codes for weeds: AMAPA, *Amaranthus palmeri* S. Wats.; BRAPP, *Brachiaria platyphylla* [Griseb.] Nash; CUMME, *Cucumis melo* L.; ECHCO, *Echinochloa colona* (L.) Link; HELAN, *Helianthus annuus* L.; IPOHG, *Ipomoea hederacea;* PANFA, *Panicum fasciculatum* Sw,; UROTE, *Urochloa texana* Buckl.

County location are separated into three sections since herbicide treatments in 2014 and 2015 varied somewhat while herbicide treatments in 2016 through 2018 were similar.

Studies were arranged in a randomized complete block design with three replicates of treatments. Plot dimensions at the Burleson County locations were four rows spaced 102 cm apart by 9.5 m long while at the

Table 1 (continued).

	Lavaca County			**Potter County**	
Variables	**2016**	**2017**	**2018**	**2015**	**2016**
Coordinates	29.2780° N 97.1257° W	29.2701° N 97.1233° W	29.2746° N 97.1172° W	35°12'37.4"N 102°03'47.7"W	35°12'37.4"N 102°03'44.0"W
Soil series	Tremona loamy fine sand	Tremona loamy fine sand	Straber loamy fine sand	Pantex silty clay loam	Pantex silty clay loam
Soil classification	Clayey, mixed, active, hyperthermic, Aquic Arenic Paleustalfs	Clayey, mixed, active, hyperthermic, Aquic Arenic Paleustalfs	Fine, mixed, active, thermic Aquic Paleustalfs	Fine, mixed, superactive, thermic Torrertic Paleustolls	Fine, mixed, superactive, thermic Torrertic Paleustolls
Organic matter (%)	1.0	1.08	1.0	1.2	1.1
Soil pH	7.3	7.9	7.3	7.7	7.5
Corn hybrid	DK 66-40	BH 8550	BH 8830	P1151AM	DG55VP77
Plant date	March 29	March 28	March 13	June 4	June 16
Application					
PRE	March 30	March 28	March 14	June 6	June 15
POST	April 26	April 14	April 5	June 26	July 22
Sprayer type	CO_2 backpack	CO_2 backpack	CO_2 backpack	CO_2 Tractor Mounted Boom	CO_2 Lee Agra Spider Sprayer
Spray volume (L ha^{-1})	190	190	190	140	140
Nozzle type (PRE)	Flat fan	Flat fan	Flat fan	Flat fan	Flat fan
Nozzle type (POST)	Flat fan	Flat fan	Flat fan	Flat fan	Flat fan
Nozzle tips					
PRE	DG 11002	DG 11002	DG 11002	TP1102	TP1102
POST	DG 11002	DG 11002	DG 11002	TP1102	TP1102
Drop nozzles	No	No	No	No	No
Weed populations (weeds m^{-2})/weed size (cm) at POST					
AMAPA	10-15/15-20	10-20/15-20	-	15-20/5-10	15-20/5-10
BRAPP	-	-	<10/10-15	-	-
CUMME	-	-	10-15/10-30	-	-
ECHCO	-	-	-	-	-
HELAN	-	-	-	-	-
IPOHG	-	-	-	-	-
KCHSS	-		-	5-10/1-2	5-10/1-2
PANFA	-	-	-		-
UROTE	10-20/10-15	10-20/10-15	-	-	-
Harvest date	August 10	August 14	-	-	October 28

[a] Bayer Codes for weeds: AMAPA, *Amaranthus palmeri* S. Wats.; BRAPP, *Brachiaria platyphylla* [Griseb.] Nash; CUMME, *Cucumis melo* L.; ECHCO, *Echinochloa colona* (L.) Link; HELAN, *Helianthus annuus* L.; IPOHG, *Ipomoea hederacea;* KCHSS, *Kochia scoparia* L.; PANFA, *Panicum fasciculatum* Sw,; UROTE, *Urochloa texana* Buckl.

Table 2. Premixes of herbicide treatments used in this study

Treatment	**Formulation (Kg ai or ae ha^{-1})***	**US trade name**	**Manufacturer**
Atrazine + bicyclopyrone + mesotrione + *S*-metolachlor	1.12 + 0.07 + 0.27 + 2.4	Acuron	Syngenta Crop Protection
Glyphosate + *S*-metolachlor	2.52 + 3.36	Sequence	Syngenta Crop Protection
Glyphosate + *S*-metolachlor + mesotrione	2.52 + 2.52 + 0.23	Halex GT	Syngenta Crop Protection
Saflufenacil + dimethenamid-P	0.64 + 5.6	Verdict	BASF Corporation
Diflufenzopyr + dicamba	0.1 + 0.25	Status	BASF Corporation
Thiencarbazone-methyl + isoxaflutole	0.84 + 2.11	Corvus	Bayer Crop Protection
Atrazine + *S*-metolachlor	3.47 + 2.69	Bicep II Magnum	Syngenta Crop Protection

* Herbicide formulation expressed as active ingredient or acid equivalent as appropriate.

Lavaca County locations, plots were two rows, spaced 97 cm apart by 7.9 m long. All corn hybrids were planted 3.5 cm deep and at the rate of approximately 70,000 seeds ha^{-1}. At the Potter County location, plots were irrigated via furrow irrigation at approximately 50% of the crop water demand. The field was clean tilled and bedded prior to PRE herbicide applications and planting. Plots were 4.5 m (six, 76 cm rows) by 7.6 m in length, but only the 4 middle rows (3.0 m) were sprayed. Corn was planted 3.5 cm deep at a rate of 74,130 seeds ha^{-1}. An untreated check was included at each location for a comparison.

Weed populations.

Weed populations were from naturally occurring populations and were consistent over the years. At the Burleson County locations, *Amaranthus palmeri* (Palmer amaranth), *Echinochloa colona* (jungle rice), *Helianthus annuus* (common sunflower), and *Urochloa fasciculate* (browntop panicum) populations were moderate (10 plants m^{-2}) while *Ipomoea hederacea* (ivyleaf morningglory) populations were high (20 to 30 plants m^{-2}) with the exception of 2014 when a later than normal planting date (April 17) resulted in lower weed numbers. At the Lavaca County location, *A. palmeri, Brachiaria platyphylla* (broadleaf signalgrass) and *Urochloa texana* (Texas millet) populations were moderate (10 to 12 plants m^{-2}) while *Cucumis melo* (smellmelon) populations were high (15 to 20 plants m^{-2}). At the Potter County location, *A. palmeri* populations were high (20 to 30 plants m^{-2}) while *Bassia scoparia* (kochia) and *Amaranthus graecizans* L. (tumble pigweed) were present in 2016 at low (2 to 5 plants m^{-2}) populations.

Crop injury, weed control, and harvest.

Crop injury and weed control were visually estimated on a scale of 0 to 100 with 0 indicating no control or injury and 100 indicating complete control or plant death relative to the untreated check (Frans *et al.*, 1986). Weed ratings were taken every two weeks for the first 6 weeks followed by ratings taken monthly thereafter. Corn yield was determined at the Lavaca County location by hand harvesting 3.8 m of each plot, shelling the kernels from the corn ear, and then weighing the kernels. Plots in Burleson County were harvested with a 2-row corn harvester (2 rows by 8.9 m long) in 2014 and 2015. In 2016 through 2018 plots were hand harvested with one row by 4.1 m long harvested in 2016 and 2 rows by 2.1 m long harvested in 2017 and 2018. Crop weights were adjusted to 12% moisture. Grain yield was only acquired from the Potter County location in 2016 using a 2-row combine with a 1.5 m corn header and yields were corrected to a grain moisture of 15%.

Table 3. Weed control and *Zea mays* yield when using the pre-mix of atrazine plus bicyclopyrone plus mesotrione plus *S*-metolachlor (ABMS) alone or in combination with other herbicides in Lavaca County near Yoakum in south-central Texas.

	Rate[d]				2018			
	Kg ai or ae ha^{-1}	Appl timing			BRAPP	CUMME	2016	2017
Treatments[a,b,c]			AMAPA[e,f,g]	UROTE	7 WAP		Yield	
			%				Kg ha^{-1}	
(ABMS)	(2.41)	PRE	100	24	100	100	4644	5554
(ABMS) + A	(1.45) + 0.7	PRE	100	14	100	100	5094	4680
(ABMS) (ABMS) + A	(0.96) (0.96) + 0.7	PRE POST	100	55	100	100	5232	5580
(ABMS) + A (G + S)	(1.45) + 0.7 (0.95 + 1.26)	PRE POST	100	79	-	-	5098	5811
(ABMS) + A	(1.45) + 0.7	POST	100	42	-	-	5062	5759
(S + M + G) + A	(1.05 + 0.1 + 1.02) + 1.12	POST	100	84	-	-	5139	5399
(Sa + D) + D	(0.49) + 0.26	PRE	96	18	75	100	4669	5554
Untreated	-	-	0	0	0	0	4041	4062
LSD			1	23	6	10	597	821

[a] Abbreviations for herbicides: atrazine (A), bicyclopyrone (B), mesotrione (M), *S*-metolachlor (S), dimethenamid (D), glyphosate (G), pyroxasulfone (P), saflufenacil (Sa).

[b] These herbicides sold in the US as premixes: ABMS, Acuron®; S + M + G, Halex GT®; G + S, Sequence®; Sa + D, Verdict. Premixes are noted with parenthesis.

[c] Induce at 0.25% v/v added to all POST treatments.

[d] Herbicide rate expressed as active ingredient or acid equivalent as appropriate.

[e] Data combined over years (2016-2017).

[f] Bayer code for weeds: AMAPA, *Amaranthus palmeri* S. Wats.; UROTE, *Urochloa texana* (Buckl.); BRAPP, *Brachiaria platyphylla* [Griseb] Nash; CUMME, *Cucumis melo* L. var. Dudaim Naud.

[g] Evaluated 13 weeks after planting (WAP) in 2016 and 10 WAP in 2017.

Statistical analysis. Visual estimates of weed control and corn injury were transformed to the arcsine square root prior to analysis of variance, but ratings are expressed in their original form for clarity because the transformation did not alter interpretation. Means were compared with Fisher's Protected LSD test at the 5% probability level (SAS Institute Inc., 2007). The non-treated check was not included in the weed control analysis but was included in corn yield analysis.

Results and Discussion

Broadleaf weed control.

Amaranthus palmeri. *Lavaca County*. Data were combined over years due a lack of treatment by year interaction. All herbicide treatments which included ABMS controlled *Amaranthus palmeri* 100% while the two-way combination of saflufenacil plus dimethenamid and the three-way combination of *S*-metolachlor plus mesotrione plus glyphosate provided 96 and 100% control, respectively (Table 3).

Table 4. Weed control and *Zea mays* yield when using the pre-mix of atrazine plus bicyclopyrone plus mesotrione plus *S*-metolachlor (ABMS) alone or in combination with other herbicides in Burleson County near College Station during the 2014 growing season.

	Rate[e]		AMAPA[f]	HELAN	PANFA	Yield
Treatments[a,b,c]	Kg ai or ae ha^{-1}	Appl	10 WAP[g]			
			%			Kg ha^{-1}
(ABMS)	(2.41)	PRE	100	86	72	11235
(ABMS) + A	(2.41) +1.12	PRE	100	96	71	11424
(ABMS) (Dic + Dif) + G[d]	(2.41) (0.2) + 1.1	PRE POST	100	100	84	11173
(Sa + D)	(0.83)	PRE	100	100	68	10984
(T + I)	(0.13)	POST	99	98	66	8662
(ABMS) + (S + M + G)	(1.2) + (2.17)	PRE POST	100	100	93	8411
(ABMS) (ABMS)	(1.2) (1.2)	PRE POST	100	99	67	9855
(ABMS) (ABMS) + G	(1.2) (1.2) + 0.88	PRE POST	100	100	96	10357
(A + S) (ABMS) + A	(2.0) (2.41) + 0.84	PRE POST	100	100	69	7972
Untreated	-	-	0	0	0	10294
LSD (0.05)	-	-	NS	7	7	2573

[a] Abbreviations for herbicides: atrazine (A), bicyclopyrone (B), dimethenamid (D), dicamba (Dic), Diflufenzopyr (Dif), glyphosate (G), mesotrione (M), isoxaflutole (I), *S*-metolachlor (S), saflufenacil (Sa), thiencarbazone-methy (T).
[b] These herbicides sold in the U S as premixes: A + B + M + S, Acuron®; T + I, Corvus®; A + S, Bicep II Magnum®; S + M + G, Halex GT®; G + S, Sequence®; Sa + D, Verdict. Premixes are noted with parenthesis.
[c] Induce at 0.25% v/v added to all POST treatments.
[d] Ammonium sulfate added at 2.5% v/v.
[e] Herbicide rate expressed as active ingredient or acid equivalent as appropriate.
[f] Bayer code for weeds: AMAPA, *Amaranthus palmeri* S. Watson; HELAN, *Helianthus annuus* L.; IPOHG, *Ipomoea hederacea* var. *integriscula* Grey; PANFA, *Urochloa fasciculate* (Sw.) R. Webster.
[g] WAP, weeks after planting.

Burleson County. Results from 2014 (Table 4) and 2015 (Table 5) were not combined over years because of differences in treatments over the two years. In 2014, all ABMS treatments including ½ X (1.2 kg ha^{-1}) and 1 X rates (2.41 kg ha^{-1}) controlled *A. palmeri* 100% while thiencarbazone-methyl plus isoxaflutole provided 99% control (Table 4). In 2015, all herbicide treatments controlled this weed at least 96% (Table 5). The full rate of ABMS (2.41 kg ai ha^{-1}) provided 100% control while 1/2X rate of ABMS applied PRE followed by a POST application of either the premix of dicamba plus diflufenzopyr and glyphosate, the premix of *S*-metolachlor plus mesotrione plus glyphosate, or ABMS and glyphosate controlled *A. palmeri* at least 98% while the standards of saflufenacil plus dimethenamid and thiencarbazone-methyl plus isoxaflutole controlled *A. palmeri* 96 and 97%, respectively.

Results from 2016 through 2018 (Table 6) were also not combined over years due to a treatment by year interaction. In 2016, the ½ X rate of ABMS applied PRE followed by a POST application of the three-way combination of *S*-metolachlor plus mesotrione plus glyphosate and atrazine controlled *A. palmeri* 99% and the premix of saflufenacil plus dimethenamid and dimethenamid provided 84% control (Table 6). When ABMS was applied PRE without any application of a POST herbicide control was less than 90%. In 2017, all herbicide treatments controlled *A. palmeri* at least 95% while in 2018 PRE applications of ABMS at the ½ X or full rate followed by POST applications which included atrazine provided at least 98% control (Table 6).

Table 5. Weed control and *Zea mays* yield when using the pre-mix of atrazine plus bicyclopyrone plus mesotrione plus *S*-metolachlor (ABMS) alone or in combination with other herbicides in Burleson County near College Station during the 2015 growing season.

	Rate[e]		**AMAPA[f]**	**IPOHG**	**PANFA**	**Yield**
Treatments[a,b,c]	**Kg ai or ae ha^{-1}**	**Appl**	**12WAP[g]**			
				%		**Kg ha^{-1}**
(ABMS)	(2.41)	PRE	100	65	82	4771
(ABMS) + A	(2.41) +1.12	PRE	100	62	76	4519
(ABMS) (Dic + Dif) + G[d]	(2.41) (0.2) + 1.1	PRE POST	100	67	79	5649
(Sa + D)	(0.83)	PRE	96	62	73	5524
(T + I)	(0.13)	POST	97	67	76	4519
(ABMS) + (S + M + G)	(1.2) + (1.05 + 0.1 + 1.02)	PRE POST	99	71	85	5524
(ABMS) (ABMS)	(1.2) (1.2)	PRE POST	-	-	-	-
(ABMS) (ABMS) + G	(1.2) (1.2) + 0.88	PRE POST	98	69	81	6591
(A + S) (ABMS) + A	(2.0) (2.41) + 0.84	PRE POST	-	-	-	-
Untreated	-	-	0	0	0	1255
LSD (0.05)	-	-	1	6	7	1883

[a] Abbreviations for herbicides: atrazine (A), bicyclopyrone (B), dimethenamid (D), dicamba (Dic), Diflufenzopyr (Dif), glyphosate (G), mesotrione (M), isoxaflutole (I), *S*-metolachlor (S), saflufenacil (Sa), thiencarbazone-methy (T).

[b] These herbicides sold in the U S as premixes: A + B + M + S, Acuron®; T + I, Corvus®; A + S, Bicep II Magnum®; S + M + G, Halex GT®; G + S, Sequence®; Sa + D, Verdict. Premixes are noted with parenthesis.

[c] Induce at 0.25% v/v added to all POST treatments.

[d] Ammonium sulfate added at 2.5% v/v.

[e] Herbicide rate expressed as active ingredient or acid equivalent as appropriate.

[f] Bayer code for weeds: AMAPA, *Amaranthus palmeri* S. Watson; HELAN, *Helianthus annuus*

L.; IPOHG, *Ipomoea hederacea* var. *integriscula* Grey; PANFA, *Urochloa fasciculate* (Sw.) R. Webster.
[g] WAP, weeks after planting.

Atrazine applied PRE has been an effective tool for control of *A. palmeri* in corn. Johnson *et al*., (2012) found that atrazine at 1.68 kg ai ha^{-1} applied PRE controlled *A. palmeri* greater than 98%, 8 weeks after application while Grichar *et al*., (2016) reported that atrazine alone, *S*-metolachlor or dimethenamid plus atrazine, or the three-way combination of *S*-metolachlor plus atrazine plus mesotrione provided 97 to 100% *A. palmeri* control while mesotrione or dimethenamid alone controlled this weed 61% or less. Sarangi and Jhala [29] found that ABMS at 2.89 kg ai ha^{-1} controlled *A. palmeri* 98% 28 days after treatment (DAT) and 94% 42 DAT. Stephenson *et al*., (2015) reported that atrazine alone applied POST provided 96% *A. palmeri* control while thiencarbazone-methyl plus tembotrione or glyphosate alone provided 92% or less control.

Potter County. In 2015, the 1 X rate of ABMS applied PRE was compared against the ½ X ABMS rate applied PRE followed by a POST herbicide treatment. The PRE application of ABMS alone at 2.41 kg ha^{-1} provided 73% control; however control was 100% with the split of ABMS at the ½ X dose applied PRE followed by another ½ X rate applied POST (Table 7). Premixes which included either diflufenzopyr plus dicamba and glyphosate or *S*-metolachlor plus mesotrione plus glyphosate and atrazine applied POST following ABMS at 1.2 kg ha^{-1} applied PRE also provided 100% control (Table 7).

Table 6. Weed control and *Zea mays* yield when using the pre-mix of atrazine plus bicyclopyrone plus mesotrione plus *S*-metolachlor alone or in combination with other herbicides in Burleson County near College Station during the 2016 through 2018 growing seasons.

			2016		2017		2018	2016	2017	2018
	Rate[d]		PANFA[e,f]	AMAPA	AMAPA	ECHCO	AMAPA			
Treatments[a,b,c]	Kg ai or ae ha^{-1}	Appl	12 WAP[g]		10 WAP		12 WAP	Yield		
			%					Kg ha^{-1}		
(ABMS)	(2.41)	PRE	70	88	100	98	97	5900	7583	5273
(Sa + D) + D	(0.83) + 0.26	PRE	70	84	95	86	87	6296	8328	4268
(ABMS) + (S + M + G) + A	(1.2) + (2.17) + 0.7	PRE POST	98	99	100	98	98	6703	8600	6635
(ABMS) (ABMS) + A	(1.2) (1.2) + 0.7	PRE POST	96	92	100	100	98	6465	8725	6093
(ABMS) (G + S)	(1.2) (2.21)	PRE POST	95	96	98	100	75	6716	8913	5775
Untreated	-	-	0	0	0	0	0	5022	6591	3515
LSD (0.05)			7	12	NS	13	NS	1354	1632	2197

[a] Abbreviations for herbicides: atrazine (A), bicyclopyrone (B), dimethenamid (D), glyphosate (G), mesotrione (M), *S*-metolachlor (S), saflufenacil (Sa).
[b] These herbicides sold in the US as premixes: A + B + M + S, Acuron®; S + M + G, Halex GT®; G + S, Sequence®; Sa + D, Verdict. Premixes are noted with parenthesis.
[c] Induce at 0.25% v/v added to all POST treatments.
[d] Herbicide rate expressed as active ingredient or acid equivalent as appropriate.
[e] Bayer code for weeds: AMAPA, *Amaranthus palmeri* S. Watson; *rudis* L.; ECHCO, *Echinochloa colona* (L.) Link; PANFA, *Urochloa fasciculate* (Sw.) R. Webster.
[f] PANFA data combined over years (2016, 2018).
[g] WAP, weeks after planting.

Unlike 2015, in 2016, ABMS alone at 2.41 kg ha^{-1} applied PRE provided 93% control. Also, 99% control was achieved with the split rate of ABMS at 1.2 kg ha^{-1} applied PRE followed by ABMS at 1.2 kg ha^{-1} applied POST while ABMS at 1.2 kg ha^{-1} applied PRE followed by a premix of *S*-metolachlor plus mesotrione plus glyphosate and atrazine applied POST provided 90% control (Table 7).

Amaranthus graecizans. *A. graecizans* was present at the Potter County location only in 2016. The full rate of ABMS at 2.41 kg ha^{-1} applied PRE controlled this weed 95% while either the split rate of ABMS at 1.2 kg ha^{-1} applied PRE and POST or the 1/2X rate of ABMS followed by the premix of S-metolachlor plus mesotrione plus glyphosate and atrazine provided 100% control (Table 7).

Cucumis melo. This weed was present at the Lavaca County location in 2018 only. All herbicide treatments including ABMS at various rates and the standard of saflufenacil plus dimethenamid with an additional rate of dimethenamid provided 100% control (Table 3).

In soybean (*Glycine max* L.), Grichar (2007) found that pendimethalin plus *S*-metolachlor applied PRE controlled *C. melo* at least 95% and glyphosate alone applied either early POST or late POST plus mid-POST controlled this weed 100%. Livingston et al., (2004) reported that glyphosate provided excellent *C. melo*

Table 7. Weed control and *Zea mays* yield when using the pre-mix of atrazine, bicyclopyrone, mesotrione, and *S*-metolachlor (ABMS) alone or in combination with other herbicides in Potter County near Bushland during the 2015 and 2016 growing seasons.

			2015	2016				
	Dose[d]		AMAPA[e]		AMAGR	ECHCG	KCHSC	Yield
Treatments[a,b,c]	Kg ai or ae ha^{-1}	Appl	5 WAP[f]	10 WAP				
			% Control					Kg ha^{-1}
(ABMS)	(2.41)	PRE	73	93	95	100	95	8680
(ABMS) + (ABMS)	(1.2) + (1.2)	PRE POST	100	99	100	100	99	10881
(ABMS) + (Df + Di) + G	(1.2) + (0.2) + 1.1	PRE POST	100	-	-	-	-	-
(ABMS) + (S + M + G) + A	(1.2) + (2.17) + 0.56	PRE POST	100	90	100	90	100	10252
Untreated	-	-	0	0	0	0	0	3400
LSD (0.05)			22	5	5	9	5	1466

[a] Abbreviations for herbicides: atrazine (A), bicyclopyrone (B), dicamba (Di), diflufenzopyr (Df), glyphosate (G), mesotrione (M), *S*-metolachlor (S).
[b] These herbicides sold in the US as premixes: A + B + M + S, Acuron®; S + M + G, Halex GT®; Df + Di, Status®. Premixes are noted with parenthesis.
[c] Induce at 0.25% v/v added to all POST treatments.
[d] Herbicide rate expressed as active ingredient or acid equivalent as appropriate.
[e] Bayer code for weeds: AMAPA, *Amaranthus palmeri* S. Watson; *rudis* L.; AMAGR, *Amaranthus graecizans* L.; ECHCG, *Echinochloa crus-galli* (L.) Beauv.; KCHSC *Bassia scoparia* (L.) Scott.
[f] WAP, weeks after planting.

control in cotton (*Gossypium hirsutum* L.) and was the most economical of the over-the-top treatments. Tingle *et al.*, (2003) stated that *C. melo* could be adequately controlled with glyphosate but applications should be made to plants with stem lengths less than 15 cm for optimum control.

Helianthus annuus L. This broadleaf weed was present only in Burleson County in 2014. The herbicide treatment of ABMS at 2.41 kg ha^{-1} applied PRE alone provided 86% control while treatments which also included a POST application of ABMS controlled this weed at least 99% (Table 4). The standards of saflufenacil plus dimethenamid or thiencarbazone-methyl plus isoxaflutole controlled *H. annuus* 100 and 98%, respectively. Al-Khatib *et al.*, (2000) found that atrazine in combination with dicamba and 2,4-D reduced *H. annuus* populations and reduced growth up to 98% while glyphosate was the only herbicide to control this weed in *Glycine max*. Janak and Grichar (2016) reported that atrazine alone controlled *H. annuus* 73% while saflufenacil plus dimethenamid and *S*-metolachlor plus mesotrione controlled this weed at least 97%.

Ipomoea hederacea. *I. hederacea* was present only in Burleson County in 2015. None of the herbicide treatments provided acceptable control of this weed with no treatment providing greater than 71% control (Table 5). Typically, glyphosate provides inadequate control of *Ipomoea* spp. *w*hen applied alone at rates typically used by producers (Norsworthy *et al*., 2001; Shaw and Arnold, 2012; Starke and Oliver, 1998). However, greater than 90% late-season control of *I. purpurea* (L.) (tall morningglory), *I. hederacea* (L.) (ivyleaf morningglory), and *I. hederacea* var. *integriuscula* Gray (entireleaf morningglory) in the field has been documented with 1.12 kg ha^{-1} of glyphosate applied to plants with six true leaves or less (Culpepper *et al*., 2001). Sequential in-season glyphosate applications are often required to provide similar levels of *I. lacunose* control (Norsworthy and Oliver, 2002; Reedy and Whiting, 2000).

Kochia scoparia (L.). This weed was present in Potter County only in 2016. The full rate of ABMS applied PRE provided 95% control while the split rate of ABMS applied PRE and POST provided 99% control. The ½X rate of ABMS applied PRE followed by the premix of *S*-metolachlor plus mesotrione plus glyphosate and atrazine provided 100% control (Table 7).

Annual grass control

Urochloa texana. This annual grass was only present at the Lavaca County location during the 2016 and 2017 growing seasons. Data was combined over years since there was no treatment by year interaction. The ABMS treatments alone, applied either PRE or a combination of PRE and POST, failed to control this grass ($\leq$ 55%) while treatments which included glyphosate provided 79 to 84% control (Table 3). The standard of saflufenacil plus dimethenamid with an additional rate of dimethenamid controlled *U. texana* only 18%. Janak and Grichar (2016) reported in one year, atrazine alone, thiencarbazone-methyl plus isoxaflutole, or saflufenacil plus dimethenamid controlled *U. texana* at least 92% while saflufenacil alone, atrazine plus either *S*-metolachlor, alachlor, or dimethenamid, and the three-way combination of *S*-metolachlor plus atrazine plus mesotrione provided 81 to 89% control. In another year, *S*-metolachlor plus mesotrione controlled this weed at least 95% while isoxaflutole or mesotrione alone and atrazine plus either acetochlor or *S*-metolachlor provided 83 to 89% control.

Typically, *S*-metolachlor alone provides poor control of this weed (Grichar *et al*., 1994; Steele *et al*., 2005). With high populations of *U. texana*, Grichar et al., (1994) reported less than 70% control with 1.7 and 3.4 kg ha^{-1} of metolachlor in dryland peanut (*Arachis hypogaea* L.) and 25 to 76% control under irrigated conditions.

Urochloa fasciculate. This annual grass was only found in Burleson County. Results from 2014 and 2015 were not combined over years because of differences in treatments over the two years.

In 2014, all treatments which included a POST application of glyphosate controlled *U. fasciculate* at least 84% while ABMS applied PRE at 1.2 kg ha^{-1} followed by a POST application of either the premix of *S*-metolachlor plus mesotrione plus glyphosate or ABMS at 1.2 kg ha^{-1} plus glyphosate provided at least 93% control (Table 4). Herbicide treatments which did not include a POST application of glyphosate provided no better than 72% control of *U. fasciculate*. In 2015, all glyphosate POST treatments provided 79 to 85% control while the treatment of ABMS applied PRE at 1.2 kg ha^{-1} followed by a POST application of the premix of *S*-metolachlor plus mesotrione plus glyphosate controlled this weed 85% (Table 5). All ABMS treatments provided at least 76% control while the standard premix of saflufenacil plus dimethenamid controlled this weed 73%.

Results from 2016 and 2018 (Table 6) were combined over years due to a lack of treatment by year interaction. The two treatments which include a POST application of glyphosate and the treatment of ABMS applied PRE at 1.2 kg ha^{-1} plus a POST application of ABMS at 1.2 kg ha^{-1} plus atrazine controlled *U. fasciculate* at least 95%

while either ABMS at 2.41 kg ha^{-1} or the premix of saflufenacil plus dimethenamid with an additional rate of dimethenamid provided 70% control (Table 6).

Janak and Grichar (2016) found that alachlor plus atrazine, *S*-metolachlor plus mesotrione, or *S*-metolachlor plus atrazine plus mesotrione provided 96% or better *U. fasciculate* control while isoxaflutole and *S*-metolachlor alone, and *S*-metolachlor plus atrazine controlled this weed 80 to 88%.

Echinochloa colona. This annual grass was present in Burleson County only in 2017. All ABMS treatments controlled this annual grass at least 98% while the standard of saflufenacil plus dimethenamid with an additional rate of dimethenamid provided 86% control (Table 6).

Echinochloa crus-galli. This weed was present only in Potter County in 2016. All herbicide treatments provided at least 90% control of this weed with ABMS at the split rate of 1.2 kg ha^{-1} applied PRE and POST and the full rate of ABMS at 2.41 kg ha^{-1} providing 100% control (Table 7). Adding the POST premix of *S*-metolachlor plus mesotrione plus glyphosate and atrazine to the 1/2X dose of ABMS provided 90% control.

Brachiaria platyphylla. *B. platyphylla* was present only in Lavaca County in 2018. All ABMS treatments provided perfect control of this annual grass while the standard of saflufenacil plus dimethenamid with an additional rate of dimethenamid provided only 75% control (Table 3).

Corn injury

No corn injury was seen with either PRE or POST treatments of ABMS either alone or in combination with an additional treatment of atrazine at any location (data not shown). Although no crop injury was noted in these studies this is not always true. Armel et al., (2003) reported that atrazine or mesotrione combinations applied PRE did caused 11 to 18% corn stunting when followed by 32 mm of rainfall but that the corn recovered quickly and by four weeks after treatment injury did not exceed 2%. Other studies have reported corn injury more than 50% with isoxaflutole applied POST in field or sweet corn (Grier and Stahlman, 1999; Knezevic et al., 1998; O'Sullivan et al., 2001). In addition, POST herbicides such as dicamba plus diflufenzopyr have shown to cause as much as 15% injury (Sikkema *et al.*, 1999; Sprague *et al.*, 1999). Corn phytotoxicity has been attributed to several factors, including application timing, high use rate, and varied susceptibility of corn hybrids to different herbicides (Sprague et al., 1997; Sprague and Penner, 1998.

Corn yield

Lavaca County locations. Corn yields were not taken in 2018 due to lack of rainfall after the first month of planting which reduced corn growth and ear development. In 2016, all herbicide treatments produced yields that were greater than the untreated check (Table 3). Lower yields were produced with ABMS applied PRE at 2.41 kg ha^{-1} and the standard of saflufenacil plus dimethenamid with an additional rate of dimethenamid which produced yields of 4644 to 4669 kg ha^{-1} while all other herbicide treatments produced yields of over 5000 kg ha^{-1}. In 2017, ABMS at 1.45 kg ha^{-1} plus an additional rate of atrazine at 0.7 kg ha^{-1} produced 4680 kg ha^{-1} and this was not different from the untreated check (Table 3). All other herbicide treatments produced yields that were greater than 5300 kg ha^{-1}.

Burleson County locations. No attempt was made to consolidate data in any year since treatments were not consistent over years. In 2014, no herbicide treatments produced yields that were greater than the untreated check (Table 4). The lowest yield was produced by the premix of atrazine plus *S*-metolachlor applied PRE followed by ABMS plus atrazine applied POST. The herbicide treatments which included a PRE application of ABMS at 2.41 kg ha^{-1} produced the highest yields.

In 2015, all herbicide treatments produced yields that were greater than the untreated check and the PRE application of ABMS at 1.2 kg ha^{-1} plus a POST application of ABMS at the same rate plus glyphosate producing the highest yield (Table 5). All treatments which included glyphosate resulted in yields that were greater than 5500 kg ha^{-1}.

In 2016 and 2018, herbicide systems which did not include a POST herbicide application did not increase corn yield over the untreated check while in 2017 all herbicide treatments with the exception of ABMS at 2.41 kg ha^{-1} applied PRE resulted in a yield increase over the untreated check (Table 6). This lack of a yield increase without a POST application may be explained by the added late-season *A. palmeri* control ($\geq$ 92%) that occurred with a POST herbicide application. However, in 2018, ABMS followed by a POST application of glyphosate plus *S*-metolachlor controlled *A. palmeri* only 75%.

Potter County locations. Grain yield was acquired only in 2016. The untreated check produced the lowest yield. There was no yield differences between the split application of ABMS applied PRE and POST or the ½ dose of ABMS applied PRE followed by the premix of *S*-metolachlor plus mesotrione plus glyphosate and atrazine applied POST (Table 7).

Conclusions

These studies show that ABMS is capable of controlling many of the weeds commonly found in corn production in Texas without any injury to corn. These successful weed control studies with ABMS across diverse Texas corn production environments provides corn producers with valuable information about herbicide performance and application under variable soils and production systems. With glyphosate-resistant *Amaranth* spp. becoming more widespread throughout the state, the use of soil-applied herbicides can not only control resistant weed species in glyphosate-resistant corn production systems but can also reduce the risk of new herbicide-resistant weed species occurring. In general, many treatments with two or three herbicides (and different modes of action) provided better weed control than one herbicide alone and the chance of corn injury appears to be minimal with any herbicide combinations under normal growing conditions.

Data Availability

Any of this data can be obtained from the senior author at w-grichar@tamu.edu.

Conflicts of Interest

There are no conflicts of interest.

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References

1. Al-Khatib, K., Peterson, D. E., and Regehr, D. L. (2000). Control of imazethapyr-resistant common sunflower (*Helianthus annuus*) in soybean (*Glycine max*) and corn (*Zea mays*). Weed Technol. 14: 133- 139.

2. Anonymous. (2009). Monsanto Biotechnology Trait Acres: Fiscal Years 1996-2009. Available: http://www.monsanto.com/investors/documents/2009/q4.biotech.acres. [6 March, 2019].

3. Anonymous. (2018). Acuron® Herbicide Product Label. Syngenta Publication No. SCP 1466A-L1B. Syngenta Crop protection, LLC. Greensboro, NC. Available: Syngenta-us.com/current-label/acuron. [8 March, 2019].

4. Armel, G. R., Wilson, H. P., Richardson, R. J., and Hines, T. E. (2003). Mesotrione, acetochlor, and atrazine for weed management in corn (*Zea mays*). Weed Technol. 17: 284-290.

5. Beckie, H. L. (2006). Herbicide-resistance weeds: management tactics and practices. Weed Technol. 20: 793-814.

6. Beckie H. J. and Reboud, X. (2009). Selecting for weed resistance: herbicide rotation and mixture. Weed Technol. 23: 363-370.

7. Bollman, J. D., Boerboom, C. M., Becker, R. L., and Fritz, V. A. (2008). Efficacy and tolerance to HPPD-inhibiting herbicides in sweet corn. Weed Technol. 20: 267-274.

8. Bradley, P. R., Johnson, W. G., Hart, S. E., Buesinger, M. L., and Massey, R. E. (2000). Economics of weed management in glufosinate-resistant corn (*Zea mays* L.). Weed Technol. 14: 495-501.

9. Burke, I. C., Thomas, W. E., Allen, J. R., Collins, J. and Wilcut, J. W. (2008). A comparison of weed control in herbicide-resistant, herbicide-tolerant, and conventional corn. Weed Technol. 22: 571-579.

10. Culpepper, A. S. (2006). Glyphosate-induced weed shifts. Weed Technol. 20: 277-281.

11. Culpepper, A. S. and York, A. C. (1998). Weed management in glyphosate tolerant cotton. J. Cotton Sci. 2: 174-185.

12. Culpepper, A. S., Gimenez, A. E., York, A. C., Batts, R. B., and Wilcut, J. W. (2001). Morningglory (*Ipomoea* spp.) and large crabgrass (*Digitaria sanguinalis*) control with glyphosate and 2,4-DB in glyphosate resistant soybean (*Glycine max*). *Weed Technol.* 15: 56-61.

13. Dobbels, A. F. and Kapusta, G. (1993). Postemergence weed control in corn (*Zea mays*) with nicosulfuron combinations. Weed Technol. 7: 844-850.

14. Duke, S. O. (2012). Why have no new herbicide mode of action appeared in recent years? Pest Manage. Sci. 68: 505-512.

15. Ferrell, J. A. and Witt, W. W. (2002). Comparison of glyphosate with other herbicides for weed control in corn (*Zea mays*): efficacy and economics. Weed Technol. 16: 701-706.

16. Frans, R., Talbert, R., Marx, D., and Crowley, H. (1986). Experimental design and techniques for measuring and analyzing plant responses to weed control practices. In: Camper, N. D., (ed.). Research Methods in Weed Science. 3rd ed. Champaign, IL: Southern Weed Science Society. Pp. 29-46.

17. Grichar, W. J. (2007). Control of smellmelon (*Cucumis melo*) in soybean with herbicides. Weed Technol. 21: 777-779.

18. Grichar, W. J., Colburn, A. E., and Kearney, N. S. (1994). Herbicides for reduced tillage production in peanut (*Arachis hypogaea*) in the Southwest. Weed Technol. 8: 212-216.

19. Grier, P. W. and Stahlman, P. W. (1999). EXP 31130A efficacy and corn (*Zea mays*) response in western Kansas. Weed Technol. 13: 404-410.

20. Heap, I. (2014). The international survey of herbicide resistant weeds. 2014. Available: http://www.weedscience.com.pdf. [7 March, 2019].

21. Janak, T. W. and Grichar, W. J. (2016). Weed control in corn (*Zea mays* L.) as influenced by preemergence herbicides. International Journal of Agronomy, Article ID 2607671, 9 pgs. Available: http://dx.doi.org/10.1155/2016/2607671 [10 March, 2019].

22. Johnson, W, G., Bradley, P. R., Hart, S. E., Buesinger, M. L., and Massey, R. E. (2000). Efficacy and economics of weed management in glyphosate-resistant corn (*Zea mays*). Weed Technol. 14: 578-585.

23. Johnson, B. C., Young, B. G., and Matthews, J. L. (2002). Effect of postemergence application rate and timing of mesotrione on corn (*Zea mays*) response and weed control. Weed Technol. 16: 414-420.

24. Johnson, W. G., Chahal, G. S., and Regehr, D. L. (2012). Efficacy of various corn herbicides applied preplant incorporated and preemergence. Weed Technol. 26: 220-229.

25. Knezevic, S. Z., Sikkema, P. H., Tardif, F., Hamill, A. S., Chandler, K., and Swanton, C. J. (1998). Biologically effective dose and selectivity of isoxaflutole for preemergence weed control in corn (*Zea mays* L.). Weed Technol. 12: 670-676.

26. Livingston, S. D., Janak, J. D., and Matthies, Jr., A. Z. (2004). Early and late-season suppression and control of Texas smellmelon in cotton. Proceed. South. Weed Sci. Soc. 57: 27.

27. Norsworthy, J. K., Burgos, N. R., and Oliver, L. R. (2001). Differences in weed tolerance to glyphosate involve different mechanisms. Weed Technol. 15: 725-731.

28. Norsworthy, J. K. and Oliver, L. R. (2002). Effect of irrigation, soybean (*Glycine max*) density, and glyphosate on hemp sesbania (*Sesbania exaltata*) and pitted morningglory (*Ipomoea lacunosa*) interference with soybean. Weed Technol. 16: 7-17.

29. O'Sullivan, J., Thomas, R. J., and Sikkema, P. H. (2001). Sweet corn (*Zea mays*) cultivar sensitivity to RPA 201772. Weed Technol. 15: 332-336.

30. Owen, M. D. K. (2008). Weed species shifts in glyphosate-resistant crops. Pest Manage. Sci. 64: 377-387.

31. Owen, M. D. K. (2016). Diverse approaches to herbicide resistant weed management. Weed Sci. 64: 570-584.

32. Reedy, K. N. and Whiting, K. (2000). Weed control and economic comparisons of glyphosate-resistant, sulfonylurea-tolerant, and conventional soybean (*Glycine max*) systems. Weed Technol. 14: 204-211.

33. Ritter, R. L. and H. Menbere. Weed management systems utilizing glufosinate-resistant corn (*Zea mays*) and soybean (*Glycine max*). Weed Technol. 15: 89-94.

34. Sarangi, D. and Jhala, A. J. (2018). Comparison of a premix of atrazine, bicyclopyrone, mesotrione, and *S*-metolachlor with other preemergence herbicides for weed control and corn yield in no-tillage and reduced-tillage production systems in Nebraska, USA. Soil & Tillage Res. 178: 82-91.

35. SAS Institute Incorporated. (2007). SAS/STAT User's Guide: Statistics, Version 9.1, SAS Institute, Cary, NC, USA. 204 pg.

36. Shaw, D. R. and Arnold, J. C. (2002). Weed control from herbicide combinations with glyphosate. Weed Technol. 16: 1-6.

37. Sikkema, P. H.,Knezevic, S. Z., Hamil, A. S., Tardif, F. and Swanton. C. J. (1999). Biologically effective dose and selectivity for SAN 1269H for weed control in corn (*Zea mays* L.). Weed Technol. 13: 283-289.

38. Sprague, C. L., Stoller, E. W., and Hart, S. E. (1997). Preemergence broadleaf weed control and crop tolerance to imidazolinone-resistant and –susceptible corn (*Zea mays*). Weed Technol. 11: 118-122.

39. Sprague, C. L., and Penner, D. (1998). Basis for different corn tolerance of four corn hybrids to Isoxaflutole. Proceed. North Central Weed Sci. Soc. 53: 94.

40. Sprague, C. L., Kells, J. J., and Penner, D. (1999). Weed control and corn (*Zea mays*) tolerance from soil-applied RPA 201772. Weed Technol. 13: 713-725.

41. Starke, R. J. and Oliver, L. R. (1998). Interaction of glyphosate with chlorimuron, fomesafen, imazethapyr, and sulfentrazone. Weed Sci. 46: 652-660.

42. Steele, G. L., Porpiglia, P. J., and Chandler, J. M. (2005). Efficacy of KIH-485 on Texas panicum (*Panicum texanum*) and selected broadleaf weeds in corn. Weed Technol. 19: 866-869.

43. Stephenson IV, D. O. and Bond, J. A. (2012). Evaluation of thiencarbazone-methyl- and isoxaflutole-based herbicide programs in corn. Weed Technol. 26: 37-42.

44. Stephenson, D. O., Bond IV, J. A., Landry, R. L., and Edwards, H. M. (2015). Weed management in corn with postemergence applications of tembotrione or thiencarbazone : tembotrione. Weed Technol. 29: 350-358.

45. Taylor-Lovell, S. and Wax, L. M. (2001). Weed control in field corn (*Zea mays*) with RPA 201772 combinations with atrazine and *S*-metolachlor. Weed Technol. 15: 249-256.

46. Tingle, C. H., Steele, G. L., and Chandler, J. M. (2003). Competition and control of smellmelon (*Cucumis melo* var. *dudaim* Naud.) in cotton. Weed Sci. 51: 586-591.

47. USDA-NASS. (2015). U.S. Department of Agriculture-National Agricultural Statistics Service Acreage. Available: http://usda.mannlib.cornell.edu/usda/current/Acre/Acre-06-30-2015 pdf. [7 March, 2019].

48. Walsh, M. J., Stratford, K., Stone, K., and Powles, S. B. (2012). Synergistic effects of atrazine and mesotrione on susceptible and resistant wild radish (*Raphanus raphanistrum*) populations and the potential for overcoming resistance to triazines herbicides. Weed Technol. 26: 341-347.

49. Wiggins, M. S., McClure, M. A., Hayes, R. and Steckel, L. E, (2015). Integrating cover crops and POST herbicides for glyphosate-resistant Palmer amaranth (*Amaranthus palmeri*) control in corn. Weed Technol. 29: 412-418.