Chapter

Using Herbicide Systems for Difficult to Control Weeds in Corn (*Zea mays* L.)

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Abstract

With herbicide-resistant weeds becoming more of an issue, weed control in corn and other crops is becoming more challenging. This requires research to develop herbicide systems that can handle these new challenges. Therefore, field studies were conducted in south-central Texas from 2021 through 2023 to evaluate crop tolerance and efficacy of corn herbicide systems for the control of weeds commonly found in Texas. Herbicide systems, which included the premixes of either atrazine + *S*-metolachlor + mesotrione + bicyclopyrone or *S*-metolachlor + glyphosate + mesotrione + bicyclopyrone, applied either preemergence and/or postemergence, provided the best overall control of annual grasses such as fall panicum (*Panicum dichtomiflorum* Michx.) or Texas millet (*Urochloa texana* Buckl) and broadleaf weeds such as Palmer amaranthus (*Amaranthus palmeri* L.), smellmelon (*Cucumis melo* L.), false ragweed (*Ambrosia tenuifolia* Spreng.), or toothed spurge (*Euphorbia dentate* Michx.). Crop response with the different premixes was not an issue, as injury was seen only at one location under cool, wet conditions. These studies show that effective weed control in corn can be achieved with proper vigilance; however, none of these herbicides are stand-alone products but, in most instances, require using both preemergence and/or postemergence applications to effectively control these problem weeds.

Keywords: annual grasses, broadleaf weeds, fall panicum, false ragweed, palmer amaranth, smellmelon, Texas millet, toothed spurge

1. Introduction

Corn (*Zea mays* L.) is the most cultivated crop grown in the U.S. with over 38 million ha planted in 2023, while over 1 million ha was planted in Texas [1]. During the past 20 years, the use of glyphosate-resistant corn production systems has been used extensively in the corn-growing regions of the U.S. [2]. In 2009, nearly 61 million ha of soybean [*Glycine max* (L.) Merr.], cotton (*Gossypium hirsutum* L) and corn contained the modified 5-enolpyruvylshikimate-3-phosphate synthase (EPSPS) gene that confers resistance to glyphosate [3]. The wide use of glyphosate-resistant row crops, the reduction of traditional herbicide and cultivation practices, and the use of intense weed management with glyphosate as the predominant control strategy have caused a shift in weed populations and created a selective advantage for glyphosate-resistant plants [4, 5].

Developing 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 [6, 7]. Both glyphosate and glufosinate control a wide range of weeds in herbicide-resistant crops [8] with little if any, crop injury [9, 10]. The POST applications of glyphosate or glufosinate provide consistent and greater control of large-seeded broadleaf weed species, including velvetleaf (*Abutilon theophrasti* Medik.), giant ragweed (*Ambrosia trifida* L.), common cocklebur (*Xanthium strumarium* L.), and morning glory spp. (*Ipomoea* spp.), and annual grasses such as Texas millet (*Urochloa texana* Buckl) compared with traditional preemergence (PRE) herbicides [10]. Even though glyphosate and glufosinate performance is similar, glufosinate is less likely to succeed in a single POST application program [8].

Herbicide resistance has become a major issue in many crops including corn. Glyphosate-resistant weeds, specifically *Amaranthus* species, have become an issue across much of the U.S. corn-producing areas as well as in Texas [11]. Also, weed resistance to photosystem II (PSII) inhibiting herbicides, including atrazine, has been documented in seven monocots and 17 dicot species in the corn-producing regions [11, 12]. Populations of tall water hemp [*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. Palmer amaranth populations resistant to ALS, PSII, and HPPD inhibitors have been identified in Kansas [12], indicating the continued need for alternative modes of action in corn to reduce the chance of herbicide resistance. 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 [13–15].

Herbicide resistance complicates weed management in corn and many other crops. Estimates are that more than 1.2 million ha of cropland in the U.S. are now affected by glyphosate-resistant *Amaranthus* species [12]. Since POST herbicides are applied after the weed species and severity are known, growers can assess the problem before making a herbicide application. Therefore, POST herbicides are an essential component of an integrated weed management system to combat herbicide-resistant weeds [16]. In addition, POST herbicides typically do not require rainfall for herbicide activation, making performance less dependent on environmental conditions, and also can reduce the potential for water pollution [17]. In a Minnesota study, atrazine concentrations were reduced in runoff water when applied POST compared with soil-applied, because of the increased plant residue and cover, thus limiting the amount of herbicide reaching the soil [18].

Although many relatively new PRE and POST herbicides have been on the market for several years there is little field-based information in the scientific literature on the efficacy of these herbicides on weeds commonly found in the south and central Texas corn-growing regions.

The objective of this research was to evaluate the effect of various PRE and POST herbicides, either alone or in combinations as a systems approach, on crop tolerance and weed control efficacy in the corn-producing regions of the state. The results of this research will provide corn growers with the necessary information to help reduce herbicide resistance issues and improve weed control during the growing season.

2. Strategies for conducting these studies

2.1 Field studies

Field studies were conducted during the 2021 through 2023 growing season at two locations in south-central Texas near Fashing and Yoakum (**Table 1**). Soils at the Fashing location were a Sinton clay loam (fine, smectitic, hyperthermic Typic Haplusterts) with less than 1% organic matter and pH 7.6 while soils at the Yoakum location were a Cuero sandy clay loam (fine-loamy, mixed, superactive, thermic Pachic Argiustolls) with less than 2% organic matter and pH 7.5. Studies were conducted in the same general area (but not the exact location) in each year of the study.

Studies were arranged in a randomized complete block design with three replicates of treatments. Plot dimensions were two rows, spaced 91 cm apart by 9.1 m long. The corn varieties BH 8660 and BH 87213 (BH Genetics, Ganado, TX) were planted from early March through early April depending on location and weather to a depth of approximately 2.5–3.5 cm and at the rate of 8000–10,500 seeds ha^{-1}.

2.2 Herbicide application, weed size, and populations

Herbicides were applied PRE within 3 days of planting while POST herbicide applications were made 27–39 days after planting (DAP), with the exception of Fashing in 2023, when the POST application was delayed to 52 DAP due to extremely dry conditions, which resulted in very little early-season weed growth. Herbicides were applied with a CO_2-pressurized backpack sprayer using Teejet 11002 flat fan nozzles (Spraying Systems Co., North Avenue, and Schmale Road, Wheaton, IL 60188) with a pressure of 180 kPa and calibrated to deliver 187 L ha^{-1}. Herbicide treatments varied from year to year but were consistent across locations. An untreated check was included for comparison at each location. All herbicide rates were based on the U.S. label for that herbicide and POST applications included an adjuvant and either ammonium nitrate or sulfate when recommended according to the label. Weed size at the time of the POST application is shown in **Table 1**.

Weed populations varied from location to location and were from naturally occurring populations. At the Fashing location, *Amaranthus palmeri* populations were moderate (5–7 plants/m^2), *Euphorbia dentate* populations were high (8–10 plants/m^2), *Ambrosia tenuifolia* populations were moderate (4–7 plants/m^2), *Panicum dichtomiflorum* populations were moderate (6–8 plants/m^2), while *Cucumis melo* populations were variable and ranged from 2 to 8 plants/m^2. At the Yoakum location, only *Urochioa texana* developed and populations were high (10–14 plants/m^2).

2.3 Weed control ratings and crop yield

Crop injury and weed control were visually estimated on a scale of 0–100 (0 indicating no control or injury and 100 indicating complete control or plant death) [19]. Corn injury, which consisted of leaf chlorosis and necrosis, was only visible in 2022 and was evaluated at 34 DAP. Mid- to late-season weed control ratings (34–106 DAP) are presented for all weeds. Crop yield was not determined due to time constraints.

Variable	2021	2022	2023	
Location	**Fashing**	**Yoakum**	**Fashing**	**Yoakum**
Coordinates	28.8032o N −98.1445o W	29.2771o N −97.1211o W	28.4821o N −98.0835o W	29.2770oN −97.1222o W
Planting date	March 8	March 17	March 7	April 3
Hybrid	BH 8660	BH 8712	BH 8660	BH 8721
Herbicide application				
Sprayer type	CO_2 backpack	CO_2 backpack	CO_2 backpack	CO_2 backpack
Spray pressure (kPa)	180	180	180	198
Nozzle type	Flat fan	Flat fan	Flat fan	Flat fan
Nozzles tips	DG 11002	DG 11002	DG 11002	Teejet 11,002
Spray volume (L ha-1)	187	187	187	187
PRE	March 10	March 17	March 10	April 5
POST	April 20	April 13	April 28	May 12
Weed size at POST application (cm)				
AMAPA[a]	8–13	—	5–10	—
CUMME	—	—	10–15	—
EPHDE	8–10	—	5–8	—
FRSST	5–30	—	5–8	—
PANDI	5–10	—	8–15	—
UROTE	—	4–6	—	13–18

[a]*Bayer code for weeds: AMAPA, Amaranthus palmeri L. (Palmer Amaranthus); CUMME, Cucumlis melo L. (smellmelon); EPHDE, Euphorbia dentate Michx. (toothed spurge); FRSST, Ambrosia tenuifolia Spreng. (false ragweed); PANDI, Panicum dichtomiflorum Michx. (fall panicum); UROTE, Urochloa texana Buckl. (Texas millet).*

Table 1.
Variables associated with corn herbicide studies in south Texas.

2.4 Statistical analysis

Visual estimates of weed control and corn injury were transformed to the arcsine square root prior to analysis of variance, but are expressed in their original form for clarity because the transformation did not alter interpretation. Means were compared with Fisher's Protected least significant difference (LSD) test at the 5% probability level [20]. The non-treated check was included in the weed control analysis.

3. Weed control with herbicide systems

Herbicide treatments varied across years; therefore, no attempt was made to combine data across years. The dates of the evaluations presented also varied across locations. In 2021, evaluations taken 85 DAP are presented, in 2022 evaluations taken 34 and 61 DAP are presented, while in 2023 the evaluation at Yoakum 106 DAP and at Fashing the evaluation 84 DAP are presented.

3.1 2021 Results

When evaluated 85 DAP, *Amaranthus palmeri* control was >90% with atrazine-applied PRE followed by thiencarbazone-methyl plus isoxafluotole applied POST while atrazine alone or atrazine followed by either mesotrione or glyphosate plus diglycolamine salt applied POST provided 60% or less control (**Table 2**). Herbicide systems which included the 4-way combination of atrazine plus *S*-metolachlor plus mesotrione plus bicyclopyrone applied either PRE or POST provided 82–89% control. The lack of *A. palmeri* control with atrazine may be the result of reduced residual activity caused by repeated use of atrazine over years [21]. This lack of effective control is enhanced by atrazine microbial degradation caused by the continuous use of atrazine compared to soils that have not had continuous atrazine usage.

Euphorbia dentate control was ≥70% with all herbicide combinations with the exception of atrazine plus *S*-metolachlor applied PRE followed by the premix combination of *S*-metolachlor plus glyphosate plus mesotrione plus bicyclopyrone applied POST or atrazine alone applied PRE followed by mesotrione applied POST. Atrazine PRE followed by either topramezone, thiencarbazone-methyl plus tembotrione, diglycolamine salt of 3,6-dichloro-o-anisic acid, or glyphosate plus diglycolamine salt of 3,6-dichloro-o-anisic acid applied POST controlled *E. dentate* as well as any of the four-way premixes and this may be because the atrazine rate (2339 ml ha^{-1}) is actually higher than the atrazine rate in any of the premixes. Therefore, it is important to consider the application rate of each herbicide in a premix and how that compares to the same herbicide applied alone [22]. Besides containing the appropriate rates of the multiple modes of action, premixes, and herbicide mixtures should contain active ingredients that have similar efficacy and persistence in the soil to act simultaneously on the same spectrum of weeds [23].

Ambrosia tenuifolia control was <60% with either atrazine alone or atrazine plus pendimethalin while atrazine followed by either diglycolamine salt of 3,6-dichloro-o-anisic acid alone or glyphosate plus diglycolamine salt 3,6-dichloro-o-anisic acid provided perfect control (**Table 2**). This compares with the use of the 4-way premixes applied either PRE or POST which resulted in 78–99% control. Other studies have reported that these premixes provided good (≥72%) [22] to excellent control (95%) [24] of giant ragweed (*Ambrosia trifida* L.).

Treatment	**Rate**	**Treatment**	**Rate**	**Weed control**[a]			
PRE	**Ml ha^{-1}**	**POST**[b]	**Ml ha^{-1}**	**AMAPA**[c]	**EPHDE**	**FRSST**	**PANDI**
				%			
Untreated	—	Untreated	—	0	0	0	0
Atrazine	2339	—	—	60	70	57	27
Atrazine + pendimethalin	2339 2339	—	—	65	72	59	50
Atrazine + S-metolachlor[d]	2109 + 1633	*S*-metolachlor + glyphosate + mesotrione + bicyclopyrone[e]	2042 + 2042 + 204 + 97	85	68	99	79
Pyrosulfone + fluthiacet-methyl[f]	284 + 9	—	—	78	70	86	37
Atrazine	2339	topramezone	2	73	87	91	13
Atrazine + *S*-metolachlor + mesotrione + bicyclopyrone[g]	1670+ 3637+ 408 + 102	—	—	89	78	78	27
Atrazine + *S*-metolachlor + mesotrione + bicyclopyrone	835 + 1819+ 204 + 51	Atrazine + *S*-metolachlor + mesotrione + bicyclopyrone/ Atrazine + glyphosate	835 + 1819 + 204 + 51/1170 + 1608	82	75	97	63
Atrazine	2339	Mesotrione	512	48	60	75	20
Atrazine	2339	Thiencarbazone-methyl + tembotrione[h]	37 + 183	87	87	77	20
Atrazine	2339	Diglycolamine salt of 3,6-dichloro-o-anisic acid	1169	68	87	100	27
Atrazine	2339	Glyphosate + diglycolamine salt of 3,6-dichloro-o-anisic acid	2338 + 1169	47	87	100	32
Atrazine + *S*-metolachlor + Mesotrione[i]	1785 + 4754 + 475	—	—	78	77	82	48

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Treatment	Rate	Treatment	Rate	Weed control[a]			
PRE	**Ml ha^{-1}**	**POST[b]**	**Ml ha^{-1}**	**AMAPA[c]**	**EPHDE**	**FRSST**	**PANDI**
Atrazine	2339	Thiencarbazone-methyl + isoxafluotole[j]	117 + 293	93	80	86	66
LSD (0.05)				32	26	26	25

[a]*Evaluations are taken 85 days after planting (DAP).*
[b]*All POST treatments contained Spectrum (NIS) at 585 ml ha^{-1}.*
[c]*Bayer code for weeds: AMAPA, Amaranthus palmeri L. (Palmer Amaranthus); EPHDE, Euphorbia dentate Michx. (toothed spurge); FRSST, Ambrosia tenuifolia Spreng. (false ragweed); PANDI, Panicum dichtomiflorum Michx. (fall panicum). (https://wssa.net/weed/composite-list-of-weeds/).*
[d]*Premix marketed in the US as Bicep II Magnum® by Syngenta Crop Protection LLC.*
[e]*Premix marketed in the US as Acuron GT® by Syngenta Crop Protection LLC.*
[f]*Premix marketed in the US as Anthem Max® by FMC.*
[g]*Premix marketed in the US as Acuron® by Syngenta Crop Protection LLC.*
[h]*Premix marketed in the US as Capreno® by Bayer CropScience LP.*
[i]*Premix marketed in the US as Lumax® by Syngenta Crop Protection LLC.*
[j]*Premix marketed in the US as Corvus® by Bayer Crop Science.*

Table 2.
Weed control at Fashing in 2021.

Panicum dichtomiflorum control was poor (<70%) with all herbicide systems with the exception of atrazine plus *S*-metolachlor applied PRE followed by *S*-metolachlor plus glyphosate plus mesotrione plus bicyclopyrone applied POST which provided 79% control. This compares with atrazine plus pendimethalin applied PRE which provided only 50% control (**Table 2**). The dinitroaniline herbicides such as pendimethalin usually provide excellent control of annual grasses such as *P. dichtomiflorum* [25–27].

3.2 2022 Results

This study was conducted at the Yoakum location where *Urochloa texana* was the only weed present. Corn injury in the form of leaf burn and chlorosis was present (**Table 3**). When evaluating 34 DAP, corn injury was greatest (22%) with atrazine alone applied POST. Only atrazine plus *S*-metolachlor applied PRE followed by atrazine plus the three-way combination of *S*-metolachlor plus glyphosate plus mesotrione applied POST or the four-way combination of atrazine plus *S*-metolachlor plus mesotrione plus bicyclopyrone applied PRE, followed by atrazine plus the two-way combination of *S*-metolachlor plus glyphosate applied POST caused >2% injury. Corn injury with atrazine is not that common in the south Texas production area but can be an issue under cool, wet conditions which slows plant growth [28]. For March 2022, the average high temperature was 22°C while the average low temperature was 7°C. This compares with a 30-year average for March of 23°C for the high temperature and 12°C for the average low temperature [29]. Rainfall for this time period was 34.0 mm compared with a monthly average of 71.0 mm [29]. Although rainfall was below average, temperatures were considerably below average. Corn injury has also been attributed to several factors, including application timing, high use rate, and varied susceptibility of corn hybrids to different herbicides [28, 30–32].

Urochioa texana control at the 34 DAP evaluation (8 days after POST application) was >90% with either atrazine plus *S*-metolachlor or atrazine plus the two-way mix of S-metolachlor plus glyphosate applied PRE, followed by atrazine plus the four-way mix of atrazine plus *S*-metolachlor plus mesotrione plus bicyclopyrone (**Table 3**). Atrazine alone, applied either PRE or POST, provided only 30 and 65% control, respectively. Only herbicide systems that included PRE applications of atrazine plus *S*-metolachlor, atrazine plus the two-way combination of *S*-metolachlor plus glyphosate, the two-way combination of atrazine plus mesotrione and *S*-metolachlor, the four-way combination of atrazine plus *S*-metolachlor plus mesotrione plus bicyclopyrone, or atrazine plus the three-way combination of acetochlor plus mesotrione plus clopyralid provided ≥75% control.

At the 61 DAP evaluation (35 days after POST application), the addition of a total PRE plus POST systems approach is readily noticeable as all such systems provide >90% *U. texana* control, while systems that included a PRE or POST only application provide ≤50% control (**Table 3**). Silva et al. [22] reported that premixes performed better than herbicide systems with a single mode of action for control of giant foxtail (*Setaria faberi* Herrm.). Also, Prostko et al. [33] found that glyphosate applied sequentially was more effective in controlling *U. texana* than either nicosulfuron or foramsulfuron.

3.3 2023 Results

At Yoakum, when evaluating 106 DAP, with only *U. texana* present, all PRE plus POST systems provided 89% or better control of *U. texana* with the exception of

				Injury[b]	UROTE control	
Treatment	**Rate**	**Treatment**	**Rate**	**Days after planting**		
PRE	Ml ha^{-1}	POST[c]	Ml ha^{-1}	34	34	61
					%	
Untreated	—	Untreated	—	0	0	0
Atrazine + *S*-metolachlor + Mesotrione + bicyclopyrone[d]	835 + 1819 + 204 + 51	Atrazine + glyphosate/atrazine + *S*-metolachlor + mesotione + bicyclopyrone	1169 + 1608/835 + 1819 + 204 + 51	2	67	94
Atrazine + *S*-metolachlor[l]	2109 + 1633	Atrazine/*S*-metolachlor + glyphosate + mesotrione + bicyclopyrone[f]	2339/2042 + 2042 + 204 + 97	2	94	95
Atrazine/*S*-metolachlor + glyphosate[g]	2339/2004 + 1503	Atrazine/*S*-metolachlor + glyphosate + mesotione + bicyclopyrone	1169/2042 + 2042 + 204 + 97	2	92	96
Atrazine + *S*-metolachlor	2109 + 1633	Atrazine/*S*-metolachlor + glyphosate + mesotrione[h]	1169/2004 + 2004 + 200	3	78	91
Atrazine + mesotrione[I]/*S*-metolachlor	1516 + 237/1169	Atrazine/*S*-metolachlor + glyphosate + mesotrione + bicyclopyrone	2339/2042 + 2042 + 204 + 97	1	89	94
Atrazine + *S*-metolachlor + mesotrione + bicyclopyrone	835 + 1819 + 204 + 51	Atrazine/*S*-metolachlor + glyphosate	2339/2004 + 1503	3	83	92
Acetochlor + mesotrione + clopyralid[j]	5523 + 533 + 375			0	65	30

				Injury[b]	UROTE control	
Treatment	Rate	Treatment	Rate	Days after planting		
Atrazine/acetochlor + mesotrione + clopyralid	2339/5523 + 533 + 375			0	75	43
		Acetochlor + mesotrione + clopyralid	5523 + 533 + 375	0	53	23
		Atrazine	2339	22	65	48
Atrazine/thiencarbazone-methyl + isoxafluotole[k]	2339 + 117 + 293			0	30	0
Atrazine/thiencarbazone-methyl + tembotrione[l]	2339 + 43 + 220			0	65	50
Atrazine/atrazine + mesotrione	2339/1517 + 237			0	55	7
Atrazine	2339			0	30	0
LSD (0.05)				2	15	24

[a] *Bayer code for weeds: UROTE, Urochloa texana Buckl. (Texas millet). (https://wssa.net/weed/composite-list-of-weeds/).*
[b] *Injury consisted of leaf necrosis and chlorosis.*
[c] *All POST treatments, with the exception of those with acetochlor + mesotrione + clopyralid or atrazine alone applied POST, contained Induce (NIS) at 0.25% v/v. The acetochlor + mesotrione + clopyralid and atrazine alone treatments included Spectrum at 585 mi ha^{-1} (Spectrum is also a NIS).*
[d] *Premix marketed in the US as Acuron® by Syngenta US Crop Protection.*
[e] *Premix marketed in the US as Bicep II Magnum by Syngenta US Crop Protection.*
[f] *Premix marketed in the US as Acuron GT® by Syngenta US Crop Protection.*
[g] *Premix marketed in the US as Sequence® by Syngenta US Crop Protection.*
[h] *Premix marketed in the US as Halex GT® by Syngenta US Crop Protection.*
[I] *Premix marketed in the US as Callisto Xtra® by Syngenta US Crop Protection.*
[j] *Premix marketed in the US as Resicore® by Corteva Agroscience LLC.*
[k] *Premix marketed in the US as Corvus® by Bayer Crop Science.*
[l] *Premix marketed in the US as Capreno® by Bayer Crop Science.*

Table 3.
Corn injury and Texas millet (UROTE[a]) control at Yoakum in 2022.

				Control	
Treatment	**Rate**	**Treatment**	**Rate**	**Yoakum**	**Fashing**
PRE	Ml ha^{-1}	POST[b]	Ml ha^{-1}	UROTE[c]	PANDI
				%	
Untreated	—	Untreated	—	0	0
Atrazine + *S*-metolachlor	2339 + 1557	*S*-metolachlor + glyphosate + mesotrione + bicyclopyrone[d]/atrazine	2042 + 2042 + 204 + 97/2339	97	99
Atrazine + *S*-metolachlor	2339 + 1557	Atrazine/*S*-metolachlor + glyphosate + mesotrione[e]	2339/2004 + 2004 + 200	89	99
Atrazine/atrazine + *S*-metolachlor + mesotrione + bicyclopyrone[f]	2339/835 + 1819 + 204 + 51	Atrazine + *S*-metolachlor + mesotrione + bicyclopyrone/atrazine + glyphosate	835 + 1819 + 204 + 51/1169 + 2046	97	99
Atrazine/atrazine + *S*-metolachlor + mesotrione + bicyclopyrone	2339/835 + 1819 + 204 + 51	*S*-metolachlor + glyphosate[g]	2004 + 1503	99	100
Atrazine/*S*-metolachlor + mesotrione[h]	2339/2978 + 295	*S*-metolachlor + glyphosate/atrazine	2004 + 1503/2339	95	99
S-metolachlor + mesotrione + pyroxasulfone+ bicyclopyrone[i]/ atrazine	4674 + 538 + 260 + 130/2339	glyphosate	2046	93	99
Pyroxasulfone + carfentrazone[j]	239 + 17			95	95
Atrazine + pendimethalin	2339 + 2339			17	75
Atrazine/thiencarboxone-methyl + isoxafluotole[k]	2339/117 + 293			83	84
Atrazine	2339			7	27
Atrazine + *S*-metolachlor	2339 + 1520			13	83

				Control	
Treatment	**Rate**	**Treatment**	**Rate**	**Yoakum**	**Fashing**
Atrazine + mesotrione[l]	1517 + 237	glyphosate	2046	96	100
Atrazine	2339	tembotrione	219	52	57
LSD (0.05)				27	17

[a]*Evaluations taken 106 days after planting (DAP) at Yoakum and 84 DAP at Fashing.*
[b]*All POST treatments, with the exception of those with glyphosate alone or tembotrione, contained Induce (NIS) at 0.25% v/v. The tembotrione treatment included Agridex (COC) at 0.25% v/v.*
[c]*Bayer code for weeds: PANDI, Panicum dichtomiflorum Michx. (fall panicum); UROTE, Urochloa texana Buckl. (Texas millet). (https://wssa.net/weed/composite-list-of-weeds/).*
[d]*Premix marketed in the US as Acuron GT® by Syngenta US Crop Protection.*
[e]*Premix marketed in the US as Halex GT® by Syngenta US Crop Protection.*
[f]*Premix marketed in the US as Acuron® by Syngenta US Crop Protection.*
[g]*Premix marketed in the US as Sequence® by Syngenta US Crop Protection.*
[h]*Premix marketed in the US as Calibra® by Syngenta US Crop Protection.*
[i]*Premix marketed in the US as Storen® by Syngenta US Crop Protection.*
[j]*Premix marketed in the US as Anthem Flex® by FMC.*
[k]*Premix marketed in the US as Corvus® by Bayer Crop Science.*
[l]*Premix marketed in the US as Callisto Xtra® by Syngenta US Crop Protection.*

Table 4.
Late-season annual grass control in 2023 at Yoakum and Fashing.[a]

Treatment	Rate	Treatment	Rate	Control			
PRE	Ml ha^{-1}	POST[b]	Ml ha^{-1}	AMAPA	CUMME	EPHDE	FRSST
				%			
Untreated	—	Untreated	—	0	0	0	0
Atrazine + *S*-metolachlor	2339 + 1557	*S*-metolachlor + glyphosate + mesotrione + bicyclopyrone[d]/ atrazine	2042 + 2042 + 204 + 97/2339	100	100	98	100
Atrazine + *S*-metolachlor	2339 + 1557	Atrazine/*S*-metolachlor + glyphosate + mesotrione[e]	2339/2004 + 2004 + 200	99	100	89	100
Atrazine/atrazine + *S*-metolachlor + mesotrione + bicyclopyrone[f]	2339/835 + 1819 + 204 + 51	Atrazine + *S*-metolachlor + mesotrione + bicyclopyrone/atrazine + glyphosate	835 + 1819 + 204 + 51/1169 + 2046	100	100	99	100
Atrazine/atrazine + *S*-metolachlor + mesotrione + bicyclopyrone	2339/835 + 1819 + 204 + 51	*S*-metolachlor + glyphosate[g]	2004 + 1503	98	95	84	98
Atrazine/*S*-metolachlor + mesotrione[h]	2339/2978 + 295	*S*-metolachlor + glyphosate/atrazine	2004 + 1503/2339	100	99	99	98
S-metolachlor + mesotrione + pyroxasulfone+ bicyclopyrone[i]/ atrazine	4674 + 538 + 260 + 130/2339	glyphosate	2046	100	99	99	100
Pyroxasulfone + carfentrazone[j]	239 + 17			97	96	81	98

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Treatment	Rate	Treatment	Rate	Control			
PRE	Ml ha^{-1}	POST[b]	Ml ha^{-1}	AMAPA	CUMME	EPHDE	FRSST
Atrazine + pendimethalin	2339 + 2339			89	94	60	95
Atrazine/ thiencarboxone-methyl + isoxafluotole[k]	2339/117 + 293			91	99	86	100
Atrazine	2339			63	65	23	57
Atrazine + *S*-metolachlor	2339 + 1520			93	96	71	57
Atrazine + mesotrione[l]	1517 + 237	glyphosate	2046	79	96	73	100
Atrazine	2339	tembotrione	219	98	100	69	99
LSD (0.05)				21	19	18	22

[a] *Evaluations are taken 84 days after planting (DAP).*
[b] *All POST treatments, with the exception of those with glyphosate alone or tembotrione contained Induce (NIS) at 0.25% v/v. The tembotrione treatment included Agridex (COC) at 0.25% v/v.*
[c] *Bayer code for weeds: AMAPA, Amaranthus palmeri L. (Palmer Amaranthus); CUMME, smellmelon (Cucumis melo L.); EPHDE, Euphorbia dentate Michx. (toothed spurge); FRSST, Ambrosia tenuifolia Spreng. (false ragweed). (https://wssa.net/weed/composite-list-of-weeds/).*
[d] *Premix marketed in the US as Acuron GT® by Syngenta US Crop Protection.*
[e] *Premix marketed in the US as Halex GT® by Syngenta US Crop Protection.*
[f] *Premix marketed in the US as Acuron® by Syngenta US Crop Protection.*
[g] *Premix marketed in the US as Sequence® by Syngenta US Crop Protection.*
[h] *Premix marketed in the US as Calibra® by Syngenta US Crop Protection.*
[i] *Premix marketed in the US as Storen® by Syngenta US Crop Protection.*
[j] *Premix marketed in the US as Anthem Flex® by FMC.*
[k] *Premix marketed in the US as Corvus® by Bayer Crop Science.*
[l] *Premix marketed in the US as Callisto Xtra® by Syngenta US Crop Protection.*

Table 5.
Late-season broadleaf weed control in 2023 at Fashing.[a]

atrazine applied PRE, followed by tembotrione applied POST which provided only 52% control (**Table 4**). The PRE only system of pyroxasulfone plus carfentrazone provided 95% control while atrazine plus the two-way mix of thiencarboxone-methyl plus isoxafluotole provided 83% *U. texana* control. In other studies, pyroxasulfone controlled *Amaranthus* spp., *Lolium* spp., *Urochloa* spp., goosegrass, (*Eleusine indica* L.), crowfootgrass (*Dactyloctenium aegyptium* L.), and *Digitaria* spp. [34–38]. The PRE treatments of atrazine alone and atrazine plus either pendimethalin or *S*-metolachlor provided <20% control.

At Fashing, when evaluated 84 DAP, *A. palmeri* control was 89% or better with all herbicide systems with the exception of atrazine alone applied PRE, which provided 63% control, and atrazine plus mesotrione applied PRE followed by glyphosate applied POST which provided 79% control (**Table 5**). Again, the lack of *A. palmeri* control with atrazine may be attributed to the continuous use of atrazine over years [21].

C. melo control was ≥94% with all systems with the exception of atrazine alone which provided 65% control. *E. dentate* control was at least 80% with all herbicide systems with the exception of atrazine-applied PRE alone, atrazine plus either pendimethalin or *S*-metolachlor applied PRE, atrazine plus mesotrione applied PRE followed by glyphosate applied POST, or atrazine-applied PRE followed by tembotrione applied POST which provided 23–73% control (**Table 5**). *A. tenuifolia* control was 95% or better with all systems with the exception of PRE applications of atrazine alone or atrazine plus *S*-metolachlor. Single herbicides alone typically do not provide effective weed control [22, 39, 40]. Armel et al. [39] reported improved weed control with mixtures of mesotrione plus acetochlor or atrazine over that of mesotrione alone.

P. dichtomiflorum control was at least 99% with all herbicide systems, which included glyphosate applied POST (**Table 4**). Pyroxasulfone plus carfentrazone applied PRE provided 95% control, while atrazine plus either *S*-metolachlor or the two-way combination of thiencarboxone-methyl plus isoxaflutole controlled this weed 83 and 84%, respectively. Atrazine alone only provided 27% control. The added control noted with pyroxasulfone can be attributed to the extended residual activity of this herbicide [41]. Steele et al. [42] reported that pyroxasulfone applied preemergence, at a 10-fold lower use rate than *S*-metolachlor, controlled *U. texana* 84–96% while *S*-metolachlor provided 75–85% control when rated 9 weeks after treatment.

4. Conclusions

The benefit of a systems approach to corn weed control is clearly evident in this study. Results of this study provide insight into PRE and POST herbicide options to improve weed control in conventional tillage corn production. The use of both PRE and POST herbicide treatments provided excellent season-long control of problem weeds found in the south Texas corn production area. Using PRE herbicides for early-season weed control in corn provides an extended period of weed control, protecting crop yields during their most important and vulnerable corn developmental stages. Group 3 (pendimethalin), Group 5 (atrazine), Group 15 (pyroxasulfone, *S*-metolachlor), and Group 27 (mesotrione) herbicides, applied PRE in a systems approach, can reduce the weed density and delay the time to POST applications, thus lowering the selection pressure for further resistance to POST herbicides. Also, including PRE herbicides as part of a systems approach brings more diversity to effective modes of action and provides the opportunity for broad-spectrum chemical weed control.

Preemergence herbicide premixes, containing multiple effective modes of action, reduce the risk of early-season weed control failures and the development of any herbicide resistance issues. These premix herbicides with multiple modes of action can expand the spectrum of weed control compared to a single mode of action herbicide. Besides providing broader spectrum control, herbicides with multiple modes of action that also target the same weed spectrum reduce the selection intensity for the formation of herbicide-resistant weed biotypes. For example, the four-way combination of atrazine plus *S*-metolachlor plus mesotrione plus bicyclopyrone applied either PRE or POST effectively controlled broadleaf weeds such as *Amaranthus palmeri*, *Ambrosia tenuifolia, C. melo*, *Euphorbia dentate* and annual grasses such as *Urochioa texana* and *Panicum dichtomiflorum*.

The use of PRE herbicide premixes is usually more effective than the same active ingredients applied alone when weather conditions are not favorable. However, the result of this effect may vary according to the water solubility and soil sorption of each herbicide in the mixture. Each herbicide has a unique behavior in the soil depending on edaphoclimatic conditions.

This research shows that using PRE herbicide premixes that contain multiple modes of action may provide more consistent early-season weed control due to the widespread occurrence of herbicide resistance across the U.S. Also, the more variable and extreme weather conditions experienced in the south Texas production area, which usually include heat and drought conditions, can cause herbicides to not perform as expected and premixes can provide a safeguard against individual herbicide failures. Also, dominant weed species and rainfall amount and pattern are still essential factors to be considered when selecting herbicide options.

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