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Using Quinclorac to Control Annual Grasses and Palmer Amaranth in Grain Sorghum (*Sorghum bicolor* L.)

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Abstract

Field studies were conducted during the 2015 and 2016 growing seasons in south-central Texas to determine control of Palmer amaranth and annual grasses along with grain sorghum tolerance to quinclorac alone and in various combinations when applied to weeds < 5 cm (EPOST) or 10 to 16 cm tall (LPOST). When evaluated late-season quinclorac alone at 0.43 kg ae ha^{-1} controlled broadleaf signalgrass 72% when applied EPOST and 91% when applied LPOST. Combinations of quinclorac with either atrazine, pyrasulfotole + bromoxynil, dicamba, or dimethenamid-P controlled Palmer amaranth 88 to 100% when applied EPOST or LPOST; however, broadleaf signalgrass control with these combination was better when applied LPOST (75 to 95%) compared with EPOST (37 to 72%) applications. Texas millet control with quinclorac was poor in both years and was never greater than 54%. Quinclorac plus either atrazine, pyrasulfotole + bromoxynil, dicamba, or atrazine + dimethenamid-P caused at least 20% sorghum injury at one of three locations. No yield reductions from the untreated check were noted in either year; however, in 2016 all treatments with the exception of quinclorac alone at 0.29 kg ha^{-1} applied EPOST, quinclorac + pyrasulfotole + bromoxynil applied LPOST, quinclorac + atrazine + pyrasulfotole + bromoxynil applied LPOST, and quinclorac + dicamba at either application timing produced yields that were greater than the untreated check.

Keywords: Broadleaf signalgrass, Palmer amaranth, postemergence, Texas millet, yield.

Introduction

Quinclorac is an auxinic herbicide belonging to the quinolinic acid class recommended for control of broadleaf weeds and grass species in rice (*Oryza sativa* L.), corn (*Zea mays* L.), soybean (*Glycine max* L.), sorghum [*Sorghum bicolor* (L.) Moench], and pastures [1] and is readily absorbed by germinating seeds, roots, and leaves [2]. High relative humidity, temperatures, and light intensity plus sufficient soil moisture accelerate uptake and consequently improve herbicide activity [2].

Although quinclorac is selective to relatively well-known species, its mode of action in weeds and mechanism of selectivity for crops are not completely understood [3,4]. However, Zheng and Hall [5] proposed that a group of proteins named ABP (auxin-binding proteins) is the site of the auxin-mimic herbicides. They characterized bio-chemically and physiologically the resistance of a wild mustard [*Brassica kaber* (DC.) L. C. Wheeler] biotype to herbicides presenting this mode of action, finding no differences in the absorption, transport or metabolism of auxin-mimic herbicides between the resistant and susceptible biotypes.

The tolerance of some species to quinclorac is due to smaller herbicide exportation out of the treated leaf [6]. Chism et al. [1] determined that quinclorac metabolism is not involved in the mechanism of crop selectivity, but translocation and exudation of the intact product through the roots may be involved. Thus, the site of action of the herbicides in barnyardgrass [*Echinochloa crus-galli* (L.) P. Beauv] susceptible or resistant biotypes may be a factor that makes this species resistant to quinclorac.

Berghaus and Wuerzer [3] found that quinclorac inhibited root growth of cucumbers (*Cucumis sativus* L.) similar to 2,4-D. It was also discovered when applied to rice and barnyardgrass that rice was able to distribute the herbicide through its root and survive while barnyardgrass was not able to transport it and senesced [3]. Although quinclorac may cause symptoms typical of 2,4-D, such as mesocotyl elongation, the level at which this occurs with quinclorac is significantly less than that of 2,4-D [3,7]. Koo et al. [8] demonstrated on corn roots that quinclorac operates in a unique manner, unlike its structurally similar auxinic counterparts by interfering with cell wall biosynthesis of susceptible grass species. The hemicellulosic and cellulosic portions of the cell wall were rapidly broken down and over increased exposure times and higher herbicide rates, led to root growth inhibition and a decrease in major cell wall constituents such as glucoae [9]. They also found that electrolyte leakage among the susceptible grasses tested was nearly fivefold greater compared to the tolerant grasses or susceptible broadleaf species. This evidence suggested that electrolyte leakage was a secondary effect of cell wall biosynthesis interruption by quinclorac and that a unique mode of action must exist due to the disparities exhibited by quinclorac between susceptible broadleaf and grass species [9].

Grain sorghum is traditionally grown throughout the Sorghum Belt which runs from South Dakota to southern Texas, primarily on dryland acres [10]. In 2018, sorghum was planted on 5.7 million acres and 365 million bushels were harvested. The top two sorghum producing states include Kansas at 2.8 million acres followed by Texas at 1.6 million acres [10]. Because of its drought tolerance, grain sorghum can be grown in areas that are often too hot and dry for other crops [11,12].

Weed competition in grain sorghum reduces yields, causes harvesting losses and increases seed content of the soil seedbank [13-15]. Even light weed infestations in the early growing season will reduce yields significantly. Grain sorghum seedlings grow slowly and are weak competitors with most weeds. One *Amaranthus* spp. plant per meter of row left uncontrolled until sorghum reaches the 3-leaf stage will reduce yields by 10% [14,16,17). Heavy infestations of grassy weeds may cause up to a 20% yield reduction in the first 2 weeks after sorghum germination [12]. Late-season weed infestations have less effect on yields but reduce harvesting efficiency and may reduce harvested yields [18]. There are fewer weed control options in grain sorghum than in cotton *(Gossypium hirsutum* L.), corn, and soybeans. Grain sorghum lacks tolerance to many of the commonly used grass and broadleaf herbicides and is occasionally injured even by herbicides labeled for use in sorghum [19].

Broadleaf weeds may be controlled postemergence (POST) in grain sorghum; however, there are few options for POST grass control. Grassy weeds are most effectively controlled with preemergence (PRE) herbicide applications. Landes et al. [20] found quinclorac to be efficacious in the control of *Echinochloa* spp., large crabgrass [*Digitaria sanguinalis* L. (Scop.)], *Brachiaria* spp., *Aeschynomene* spp., *Ipomoea* spp., and *Sesbania exaltata* in rice. In the south Texas grain sorghum production region, annual grasses such as broadleaf signalgrass [*Urochloa platyphylla* (Nash) R. D. Webster] and Texas millet [*Urochloa texana* (Buckl.) R. Webster] as well as various broadleaf weed species including Palmer amaranth (*Amaranthus palmeri* S. Wats) are a major problem. According to the Facet L label [21] for use on grain sorghum, quinclorac is capable of controlling the following grasses: large crabgrass, barnyardgrass, giant foxtail (*Setaria faberi* L.), green foxtail (*Setaria virdis* L.), yellow foxtail (*Setaria pumila* L.), junglerice [*Echinochloa* colona (L.) Link], and broadleaf signalgrass when applied to plants less than 5 cm in height. Also, Koo et al [7] confirmed efficacy on fall panicum (*Panicum dichotomiflorum* Michx.) and orchargrass (*Dactylis glomerata* L.). However, no mention of Texas millet and Palmer amaranth control with this herbicide could be found on the label and limited research data exists. Quinclorac has been cleared for use in grain sorghum in other states and even the High Plains of Texas for a number of years but only within the last four years has it had clearance for use on grain sorghum in south and central Texas [21]. Therefore, the objective of this research was to determine weed efficacy and crop safety when using quinclorac in the south Texas production area.

Materials and Methods

Field studies were conducted under rain-fed conditions during the 2015 and 2016 growing seasons at the Texas AgriLife Research Site near Yoakum (29.276° N, 97.123° W) and in a producer's field near Ganado, TX (29.047° N, 96.505 ° W) in south-central Texas. Soil type at Yoakum were a Tremona loamy fine sand (thermic Aquic arenic Paleustalfs) with less than 1% organic matter and pH 7.0 to 7.2 while soils at Ganado were a Laewest clay (fine, smectitic, hyperthermic Typic Hapluderts) with less than 1% organic matter and pH of 6.8.

The Yoakum site was infested with a natural population of Texas millet, 10 to 15 plants/m^2, and Palmer amaranth, 20 to 30 plants/m^2, while broadleaf signalgrass populations at the Ganado site ranged from 8 to 12 plants/m^2. The experimental design was a randomized complete block with three replications and a seven (POST herbicides) by two (application timing) factorial arrangement of treatments. Each plot was two rows spaced 97 cm apart by 7.6 m long.

POST herbicide treatments included quinclorac alone at 0.29 and 0.43 kg ae ha^{-1}, quinclorac at 0.29 kg ha^{-1} plus atrazine at 1.12 kg ai ha^{-1}, quinclorac at 0.29 kg ha^{-1} plus the pre-mix of pyrasulfotole at 0.03 kg ai ha^{-1} plus bromoxynil at 0.2 kg ai ha^{-1}, quinclorac at 0.29 kg ha^{-1} plus atrazine at 1.12 kg ha^{-1} plus the pre-mix of pyrasulfotole at 0.03 kg ai ha^{-1} plus bromoxynil at 0.2 kg ai ha^{-1}, quinclorac at 0.29 kg ha^{-1} plus dicamba at 0.27 kg ae ha^{-1}, and quinclorac at 0.29 kg ha^{-1} plus atrazine at 1.12 kg ai ha^{-1} plus dimethenamid-P at 0.84 kg ai ha^{-1}.

The pre-mixes of pyrasulfotole at 0.03 kg ai ha^{-1} plus bromoxynil at 0.2 kg ai ha^{-1} and atrazine at 1.12 kg ha^{-1} plus dimethenamid-P at 0.84 kg ai ha^{-1} are marketed in the U S as Huskie® and Guardsman Max®, respectively. Application timing included early postemergence (EPOST) when weeds were less than 5 cm in height and late postemergence (LPOST) when weeds were 10 to 16 cm tall. Grain sorghum height at EPOST was 5 to 8 cm tall (3 to 4 leaf stage) while height at LPOST was 15 to 20 cm tall (6 to 8 leaf stage). An untreated check was included for comparison. All POST applications included a petroleum oil adjuvant (Agri-Dex®, a mixture of paraffin base petroleum oil, polyoxyethylate polyol fatty acid ester, and polyol fatty ester; Helena Chemical Co., 5100 Poplar Street, Memphis, TN 38137) at 2.3 L/ha. Herbicides were applied with a CO_2 backpack sprayer using Teejet 11002 flat-fan nozzles (Teejet Spraying Systems Co., P.O. Box 7900, Wheaton, IL 60188) which delivered a spray volume of 190 L/ha at 180 kPa. The sorghum variety BH 4100 was planted both years at the Yoakum location while BH 5350 was planted at the Ganado location at a seeding rate of approximately 198,000 seed ha^{-1}. Weed control and grain sorghum injury was visually estimated on a scale of 0 to 100 (0 indicating no control or plant death and 100 indicating complete control or plant death), relative to the untreated control [22]. Weed control and grain sorghum injury evaluations were recorded 14 days after each POST application. Grain sorghum stunting, and foliar necrosis and chlorosis were used when making the visual estimates of crop injury.

Grain sorghum yield was obtained at Yoakum by hand harvesting each plot separately and then mechanically threshed. No attempt to harvest the Ganado study was made due to time constraints.

An analysis of variance was performed using the ANOVA procedure for SAS [23] to evaluate the significance of herbicides and application timing on weed control, grain sorghum injury, as well as yield. The untreated control was not included in weed control or grain sorghum injury analysis, but was included in the yield analysis. Fishers Protected LSD at the 0.05 level of probability was used for separation of mean differences. Transformation of treatment means for Palmer amaranth, broadleaf signalgrass, and Texas millet control did not change the statistical analysis; therefore, nontransformed data are presented.

Results and Discussion

WEED CONTROL

Broadleaf signalgrass control. This weed was evaluated only in 2015 as a broadleaf signalgrass site could not be located in 2016. When evaluated two weeks after herbicide application only the LPOST applications of quinclorac plus atrazine, quinclorac plus atrazine plus pyrasulfotole plus bromoxynil, and quinclorac plus atrazine plus dimethenamid-P provided 77% or better control. Other herbicide treatments containing quinclorac provided no better than 67% control (Table 1).

Table 1. Weed control with quinclorac alone and in combination two weeks after application.[a]

	Rate		2015		
	Kg ai or ae ha^{-1}	Appl timing[d]	Ganado	Yoakum	
Treatment			UROPL[e]	UROTE	AMAPA
			%		
Untreated	-	-	0	0	0

Quinclorac	0.29	EP	33	38	59
		LP	50	20	61
Quinclorac	0.43	EP	57	54	66
		LP	60	32	61
Quinclorac + atrazine	0.29 + 1.12	EP	48	75	100
		LP	79	48	95
Quinclorac + pyrasulfotole + bromoxynil[b]	0.29 + 0.03 + 0.2	EP	60	62	100
		LP	67	42	93
Quinclorac + atrazine + pyrasulfotole + bromoxynil	0.29 + 1.12 + 0.03 + 0.2	EP	60	73	100
		LP	77	30	100
Quinclorac + dicamba	0.29 + 0.27	EP	27	60	98
		LP	47	32	100
Quinclorac + atrazine + dimethenamid-P[c]	0.29 + 1.63 + 0.84	EP	60	90	100
		LP	83	66	100
LSD (0.05)			18	21	28

[a] Texas millet and Palmer amaranth data combined over years
[b] Pyrasulfotole plus bromoxynil marketed as Huskie® (Bayer CropScience).
[c] Dimethenamid-P plus atrazine marketed as Guardsman Max® (BASF Corporation).
[d] Abbreviations: EP, early postemergence; LP, late postemergence.
[e] Bayer Code for Weeds: UROPL, Urochloa platyphylla (Nash) R. D. Webster (broadleaf signalgrass); AMAPA, *Amaranthus palmeri* S. Wats (Palmer amaranth); UROTE, *Urochloa texana* (Buckl.) R. Webster (Texas millet).

When evaluated eight weeks after treatment, LPOST applications of quinclorac alone at 0.43 kg ha^{-1}, quinclorac plus atrazine, quinclorac plus pyrasulfotole plus bromoxynil, quinclorac plus atrazine plus pyrasulfotole plus bromoxynil, and quinclorac plus atrazine plus dimethenamid-P controlled broadleaf signalgrass at least 89% while EPOST applications of quinclorac alone at 0.43 kg ha^{-1} and quinclorac plus atrazine plus dimethenamid-P controlled this weed 72% (Table 2). Many studies have reported on the effectiveness of quinclorac on barnyardgrass [8,9,24,25]; however, little data is available on the efficacy on other annual grasses such as broadleaf signalgrass [26]. Berghaus and Wuerzer [27] reported that after a foliar application to barnyardgrass, approximately 75% of the applied quinclorac was taken up within 8 h. Most of the absorbed quinclorac remained in the treated leaf but 15 to 25% of the compound was transferred basipetally to the root or acropetally into the upper parts of the shoot [27].

Table 2. Weed control with quinclorac alone and in combination eight weeks after application.[a]

Treatment	Rate		Ganado		Yoakum	
	lb ai or ae/acre	Appl timing[d]	2015	Yoakum	AMAPA	
			UROPL[e]	UROTE	2015	2016
			%			
Untreated	-	-	0	0	0	0
Quinclorac	0.25	EP	47	37	77	33

		LP	79	24	93	37
Quinclorac	0.43	EP	72	39	53	77
		LP	91	34	67	50
Quinclorac + atrazine	0.29 + 1.12	EP	68	48	100	100
		LP	91	35	100	88
Quinclorac + pyrasulfotole + bromoxynil[b]	0.29 + 0.03 + 0.2	EP	67	31	100	100
		LP	89	31	100	98
Quinclorac + atrazine + pyrasulfotole + bromoxynil	0.29 + 1.12 + 0.03 + 0.2	EP	62	45	100	100
		LP	94	34	100	100
Quinclorac + dicamba	0.29 + 0.27	EP	37	43	93	100
		LP	75	19	100	100
Quinclorac + atrazine + dimethenamid-P[c]	0.29 + 1.63 + 0.84	EP	72	74	100	100
		LP	95	54	100	98
LSD (0.05)			17	21	29	29

[a] Texas millet data combined over years.
[b] Pyrasulfotole plus bromoxynil marketed as Huskie® (Bayer CropScience).
[c] Dimethenamid-P plus atrazine marketed as Guardsman Max® (BASF Corporation).
[d] Abbreviations: EP, early postemergence; LP, late postemergence.
[e] Bayer Code for Weeds: UROPL, *Urochloa platyphylla* (Nash) R. D. Webster (broadleaf signalgrass); AMAPA, *Amaranthus palmeri* S. Wats (Palmer amaranth); UROTE, *Urochloa texana* (Buckl.) R. Webster (Texas millet).

Vincent [26] also reported that broadleaf signalgrass control were significantly improved when applications were made to signalgrass 2.5 cm tall compared to later growth stages.

Texas millet control. Both early-season and late-season efficacy data were combined over years since there was not a treatment by year interaction. The EPOST application provided better control of this weed than LPOST applications when evaluated two weeks after herbicide application with the exception of quinclorac at 0.29 kg ha^{-1} and quinclorac plus pyrosulfotole plus bromoxynil applications where there was no difference in control with either application timing (Table 1). Only quinclorac plus atrazine plus dimethenamid-P applied EPOST provided acceptable Texas millet control (90%) while EPOST applications of quinclorac plus atrazine or quinclorac plus atrazine plus the premix of pyrasulfotole plus bromoxynil provided marginal control (73-75%). No other herbicide treatments provided better than 66% control.

At the late-season evaluation, only quinclorac plus atrazine plus dimethenamid-P applied EPOST provided control > 70% while all other herbicide treatments provided $\leq$ 54% control (Table 2). Vincent [26] reported that adding atrazine to quinclorac significantly improved Texas millet control over quinclorac or atrazine alone. Dowler and Wright [28] found that crowfootgrass [*Dactyloctenium aegytium* (L.) Willd] and Texas millet could be sufficiently controlled (>80%) with POST applications of atrazine in pearl millet [*Pennisetum glaucum* (L.) R. Br]. Vincent [26] also reported that Texas millet should be considered moderately tolerant to quinclorac as the weed species shows symptoms of temporary height reduction with the magnitude dependent upon the growth stage at which it is applied. He stated that if quinclorac was sprayed at 2.5 cm height, Texas millet dry weight was reduced 80% when compared with the untreated check but quinclorac applications made to plants taller than 2.5 cm were not as efficacious.

The stage of growth of weeds at the time of herbicide application can affect control [29]. Weeds generally are more susceptible to POST herbicides in the early seedling stage than in advanced stages of growth [30]. Zawierucha and Penner [29] reported that goosegrass [*Eleusine indica* (L.) Gaertn] was more susceptible to quinclorac applied preemergence or EPOST at the one- to two-leaf stage than at the later more mature stages. Quinclorac may have an additional mode of action in grasses besides auxinlike activity [3]. Koo et al. [7-9] suggested that quinclorac acts as a cell-wall biosynthesis inhibitor in susceptible grasses that leads to loss of membrane integrity and root injury. This conclusion was drawn from experiments using intact roots of corn and different grasses, which showed that quinclorac at 10 µM reduced [14C]-glucose incorporation into distinct cell-wall fractions within 6 h of treatment, particularly in the herbicide-susceptible grass species [8,9].

Ethylene and cyanide are produced in roots of barnyardgrass treated with quinclorac [31,32]. Cyanide was shown to inhibit root growth [31] while ethylene is able to reduce cell-wall deposition by inhibiting the activities of cell-wall synthesizing enzymes [33] and root elongation [34]. Grossman [2] concluded that the inhibition of cell-wall synthesis in root tissue appears to be a side effect of quinclorac and not the primary mode of action responsible for the selective effects in grasses.

Palmer amaranth control. Since there was not a treatment by year interaction at the early-season rating, the data were combined over years. However, at the late-season rating there was a treatment by year interaction; therefore, that data are presented separately by years

When evaluated two weeks after herbicide application, quinclorac alone at either rate failed to effectively control ($\leq$ 66%) Palmer amaranth (Table 1). However all combination treatments provided effective control ($\geq$ 93%) of this weed. When evaluated eight weeks after treatment in 2015, all herbicide treatments, with the exception of quinclorac alone at 0.26 kg ha^{-1} applied EPOST and quinclorac at 0.43 kg ha^{-1} applied either EPOST or LPOST controlled Palmer amaranth at least 93% (Table 2). In 2016, quinclorac alone failed to control (33-77%) this weed while all quinclorac combination treatments provided at least 88% control.

Vincent [26] reported that the addition of atrazine to quinclorac and quinclorac plus pyrasulfotole plus bromoxynil improved Palmer amaranth control to that seen with a PRE followed by POST applications. A major benefit of growing grain sorghum is the ability to integrate several modes of action into a weed management plan that cannot be used in sensitive crops such as cotton and soybean to eliminate tough to control weeds.

GRAIN SORGHUM INJURY

Injury evaluations were taken fifteen days after herbicide application. Injury symptoms for quinclorac alone consisted of plant stunting while quinclorac combination treatments exhibited stunting as well as foliar chlorosis and necrosis. The dicamba treatment exhibited the typical epinasty commonly seen with hormonal herbicides [35]. Since there was a treatment by year interaction for injury no attempt was made to combine data over years. In 2015 at Ganado grain sorghum injury was readily seen with the EPOST herbicide applications and seen less consistently on LPOST applications (Table 3). The most severe injury was noted with EPOST applications of quinclorac plus pyrasulfotole plus bromoxynil with or without the addition of atrazine (22 to 25%) while the LPOST applications of these treatments resulted in 15% injury. These injury symptoms were typically leaf margin necrosis and interveinal chlorosis.

Table 3. Grain sorghum injury fifteen days after herbicide application and yield with quinclorac alone and in combination.

	Rate		Injury			Yield	
	Kg ai or	Appl	Ganado	Yoakum		Yoakum	
Treatment	ae ha^{-1}	timing[c]	2015	2015	2016	2015	2016

			%			Kg ha^{-1}	
Untreated	-	-	0	0	0	2318	3337
Quinclorac	0.29	EP	5	7	0	3348	3902
		LP	0	3	0	2987	4518
Quinclorac	0.43	EP	5	20	7	3090	4877
		LP	0	4	0	3451	4782
Quinclorac + atrazine	0.29 + 1.12	EP	5	37	7	3451	4672
		LP	0	4	0	3400	4518
Quinclorac + pyrasulfotole + bromoxynil[a]	0.29 + 0.03 + 0.2	EP	25	30	0	2987	4518
		LP	15	6	0	3503	3627
Quinclorac + atrazine + pyrasulfotole + bromoxynil	0.29 + 1.12 + 0.03 + 0.2	EP	22	37	9	3657	4518
		LP	15	7	0	3297	4474
Quinclorac + dicamba	0.29 + 0.27	EP	10	20	12	2976	4210
		LP	10	10	20	3451	2241
Quinclorac + atrazine + dimethenamid-P[b]	0.29 + 1.63 + 0.84	EP	5	48	13	3605	4620
		LP	0	13	0	3400	4827
LSD (0.05)			3	8	7	1760	1141

[a] Pyrasulfotole plus bromoxynil marketed as Huskie® (Bayer CropScience).
[b] Dimethenamid-P plus atrazine marketed as Guardsman Max® (BASF Corporation).
[c] Abbreviations: EP, early postemergence; LP, late postemergence.

In 2015 at Yoakum, as was seen at the Ganado location, the EPOST applications resulted in the greatest injury. Quinclorac plus atrazine plus dimethenamid-P applied EPOST resulted in the greatest injury (48%); however, all EPOST applications with the exception of quinclorac alone at 0.29 kg ha^{-1} resulted in at least 20% injury (Table 3). In 2016, grain sorghum injury was less severe. Quinclorac plus dicamba applied LPOST resulted in the greatest injury (20%). Other studies have reported that quinclorac alone is safe on grain sorghum [7,26] while Ramakrishna et al. [36] found that atrazine reduced the height of grain sorghum regardless of application rate (0.5, 0.75, and 1.0 kg ha^{-1}) compared to other herbicide treatments. Phillips [37] reported that dicamba can be safely applied to grain sorghum less than 30 cm in height.

GRAIN SORGHUM YIELD

Yields were not obtained at the Ganado location due to the grower harvesting the area before we were able to harvest the plots. At the Yoakum location, data were not combined over years due to a treatment by year interaction. In 2015, none of the herbicide treatments were different from the untreated check (Table 3). Although significant injury was noted with several herbicide treatments this did not translate to a reduction in yield from the untreated check.

In 2016, several herbicide treatments produced yields that were significantly better than the untreated check. Only quinclorac alone at 0.29 kg ha^{-1} applied EPOST, quinclorac plus pyrasulfotole plus bromoxynil or quinclorac plus atrazine plus pyrasulfotole plus bromoxynil applied LPOST, and quinclorac plus dicamba applied either EPOST or LPOST were not greater than the untreated check. Quinclorac plus dicamba applied EPOST provided an 88% yield increase over the same treatment applied LPOST (Table 3).

Conclusions

Control of broadleaf signalgrass later in the growing season with quinclorac at 0.29 kg ha^{-1} alone applied LPOST was moderate (79%) but improved to >90% for the LPOST application when rate was increased. Quinclorac alone or in various combinations failed to provide season-long control of Texas millet at any application timing. Quinclorac alone failed to consistently control Palmer amaranth; however, quinclorac applied in combination with atrazine, dicamba, dimethenamid-P, or pyrasulfotole plus bromoxynil at any application timing provided excellent season-long control of Palmer amaranth.

Data Availability

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

Conflicts of Interest

There are no conflicts of interest.

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