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Weed Management Programs in Grain Sorghum (*Sorghum bicolor*)

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Abstract: A field study was conducted in Arkansas over three years to evaluate various herbicide treatments, including sequential and tank-mix applications for weed control in grain sorghum (*Sorghum bicolor*). The herbicide treatments used were quinclorac, atrazine + dimethenamid-p, S-metolachlor followed by (fb) atrazine + dicamba, dimethenamid-p fb atrazine, S-metolachlor + atrazine fb atrazine, S-metolachlor + mesotrione, and S-metolachlor fb prosulfuron. All herbicide treatments provided excellent (90% to 100%) control of *Ipomoea lacunosa*, *Ipomoea hederacea* var. *integriuscula*, and *Sida spinosa* by 12 weeks after emergence. Quinclorac and S-metolachlor fb prosulfuron provided the lowest control of *Ipomoea lacunosa*, *Urochloa platyphylla*, *Amaranthus palmeri*, and *Ipomoea hederacea* var. *integriuscula*. Weed interference in the non-treated control reduced grain sorghum yield by 50% as compared to the weed-free control. S-metolachlor + mesotrione and S-metolachlor fb prosulfuron reduced sorghum yields by 1009 to 1121 kg ha^{-1} compared to other herbicide treatments. The five best herbicide treatments in terms of weed control and grain sorghum yield were quinclorac, atrazine + dimethenamid-p, S-metolachlor fb atrazine + dicamba, dimethenamid-p fb atrazine, and the standard treatment of S-metolachlor + atrazine fb atrazine.

Keywords: S-metolachlor; atrazine; quinclorac; dimethenamid-p; mesotrione; prosulfuron; dicamba

1. Introduction

Grain sorghum (*Sorghum bicolor*) is an important cereal and was ranked as the fourth largest crop harvested in the United States in 2016–2017, with more than half of annual production exported to Asian and African countries (United States Department of Agriculture-National Agricultural Statistics Service (USDA-NASS), 2017). Grain sorghum is relatively drought tolerant compared to other grain crops, so it grows well in the dry climates of the United States, ranging from South Dakota to Texas (USDA-NASS 2017) [1]. As a warm-season crop, soil temperatures above 21 °C are considered optimal for planting and subsequent development of grain sorghum [2]. Producers prefer early-season planting of grain sorghum (early- to mid-April) to capture early-season rainfall, which provides adequate moisture for crop growth and development, and to avoid late-season drought during the reproductive stages of sorghum. However, early-season planting may expose the early growth to cold and wet soil conditions in the field, making it sensitive to weed competition. Cool and wet conditions may also increase injury from pre-emergence herbicide applications, resulting in stand loss and delayed growth rate, and finally, decline in the yield [2–4].

Weeds are a serious problem in grain sorghum production in the mid-south United States. For example, studies have reported that most troublesome weeds, including *Amaranthus palmeri* S. Watson (Palmer amaranth), *Sida spinosa* L. (prickly sida), *Urochloa platyphylla* (Munro ex C. Wright) R.D. Webster (broadleaf signalgrass), *Ipomoea lacunosa* L. (pitted morningglory), and *Ipomoea hederacea* var. *integriuscula* A. Gray (entireleaf morningglory), significantly reduce the stand establishment and yields of grain sorghum every year in Texas and Arkansas [2,5]. Moore et al. [6] reported that sorghum grain yield in Oklahoma was reduced by 1.8% to 3.5% due to an increase in the *Amaranthus palmeri* population by one plant in a 15 m row. In the same study, sorghum grain yield decreased by 5.3% to 9.1% with an increase in *Amaranthus palmeri* biomass of one kilogram [6]. *Amaranthus palmeri* reduced grain sorghum harvest efficiency by increasing grain moisture and foreign material in harvested grains [6]. Weeds reduce the yield and quality of grain sorghum by competing with sorghum for nutrients, water, and light [5].

Multiple studies have reported excellent weed control in grain sorghum by chemical control through use of preplant, pre-emergence, early postemergence, or late postemergence herbicides, applied either alone or in combination, during early growth of the grain sorghum [3–5,7,8]. However, excessive and consistent use of the same type of herbicide has developed several weed biotypes resistant to triazine and acetolactate synthase (ALS) inhibitors [4]. As a result, weeds escape, develop, and proliferate in the absence of late-season herbicide application and ultimately hinder harvesting operations. Another constraint with chemical weed control is crop injury due to herbicides, which may also reduce crop yield. The objectives of this research were to evaluate various herbicides and tank-mix combinations for weed control in grain sorghum and their impact on crop injury and yield.

2. Materials and Methods

A three-year (2003 to 2005) field experiment was conducted at the Agricultural Experiment Station, Pine Tree, AR. The research site had Calloway silt loam soil (fine-silty, mixed, active, thermic Aquic Fraglossudalfs) with 7.5% sand, 91% silt, 1.5% clay, and a pH of 6.3. Sorghum hybrid Asgrow A 571 was planted in May and harvested in September in all three years (Table 1). The sorghum seeding rate was 20 seeds m^{-1} row and the row spacing was 76 cm. The previous crop in the study area was soybeans. Plots were fertilized with 181 kg of NPK fertilizer (0-20-20) prior to planting in May. The sorghum plots also received 91 kg N ha^{-1} in June. Plots were irrigated four to five times as needed during the growing season.

The experiment was designed as a randomized complete block design with four replications. Seeds of *Amaranthus palmeri, Sida spinosa, Urochloa platyphylla, Ipomoea. lacunosa*, and *Ipomoea. hederacea* var. *integriuscula*, and *Sesbania exaltata* (hemp sesbania) were broadcast over the experimental site to obtain a uniform weed population as much as possible and lightly incorporated with the rolling baskets of a field cultivator. Seeds of all weed species used in this study were bought from Azlin seed Service (Leland, Mississippi, USA). The average weed density for *Amaranthus palmeri*, *Sida spinosa*, *Urochloa platyphylla, Ipomoea lacunosa*, and *Ipomoea hederacea* var. *integriuscula*, and *Sesbania exaltata* was 3, 3, 18, 4, 5, and 2 plants m^{-2}, respectively. The plot size was 3.05 m × 7.62 m. The herbicide treatments, their trade names, and manufacturer information are listed in Table 2. The herbicide treatments, their application rate, and timing information are provided in Table 3. The herbicide treatments were sprayed at different times as follows: (a) at planting (pre-emergence; PRE), (b) at emergence (VE), (c) two leaf stage of sorghum (7–8 days after emergence; POST), (d) four leaf stage of sorghum (14–16 days after emergence; POST). The dates for sorghum planting and emergence are provided in Table 1. The herbicide site of action (SOA) classification for the herbicide treatments used in this study are provided in Table 4. S-metolachlor + atrazine (PRE) followed by atrazine + crop oil concentrate (COC) (POST) at four-leaf grain sorghum is the standard herbicide treatment used for weed control in grain sorghum. In the herbicide treatments with both PRE and POST applications in Table 3, the herbicide before the term “fb” (followed by) is pre-emergence herbicide and the herbicide that comes after the term “fb” was applied as post-emergence application (POST). A CO_2-pressurized backpack sprayer with six 8002 flat-fan nozzles (TeeJet Technologies, Springfield, IL, USA) mounted on a handheld boom calibrated to deliver 187 L ha^{-1} at 276 kPa was used. A non-treated control and weed-free control were included in every replication to evaluate the effects of different herbicide treatments on grain sorghum yield. Weeds were removed manually using a hoe in the weed-free control plots.

Control of *Ipomoea lacunosa*, *Ipomoea hederacea* var. *integriuscula*, *Amaranthus palmeri*, *Sida spinosa*, *Sesbania exaltata*, and *Urochloa platyphylla* was measured at 2, 5, and 12 weeks after emergence (WAE) of the sorghum. In addition, grain sorghum injury due to herbicide applications at 2, 5, and 12 WAE and sorghum yield were also measured. Crop injury and weed control were scored on a scale of 0 to 100 (0 being no injury or weed control and 100 being complete crop death or weed control). The visual rating for weed control or crop injury was made based on the whole plot area in comparison to the non-treated control plot. Sorghum yield was adjusted to 13.5% moisture content. Analysis of variance (ANOVA) was conducted using the generalized linear model (GLM) procedure of SAS Statistical Software v 9.3 (SAS Institute, Cary, NC, USA) to analyze the data. Means were separated using Fisher's protected least significant difference (LSD) at the $p < 0.05$ probability level. Data were analyzed separately for each WAE for each weed species. Year was used as a random effect in the analysis.

Table 1. Sorghum planting, emergence, and harvesting dates.

Year	Planting	Emergence	Harvest
2005	17 May	23 May	23 September
2004	26 May	31 May	21 September
2003	27 May	2 June	24 September

Table 2. Herbicide treatments used in this study, their trade names, and manufacturers.

Common Name	Trade Name (Formulation)	Manufacturer
Quinclorac	Facet (75 DF)	BASF Corporation, Research Triangle Park, NC 27,709
Atrazine + Dimethenamid-p	Guardsman (5 L)	BASF Corporation, Research Triangle Park, NC 27,709
S-metolachlor	Dual II Magnum (7.64 EC)	BASF Corporation, Research Triangle Park, NC 27,709
Dimethenamid-P	Outlook (6 EC)	BASF Canada Inc., Mississauga, ON
Atrazine	AAtrex (4 L)	Syngenta Crop Protection, LLC, Greensboro, NC 27,419
Mesotrione	Callisto (4 L)	Syngenta Crop Protection, LLC, Greensboro, NC 27,419
Prosulfuron	Peak (57 DG)	Syngenta Crop Protection, LLC, Greensboro, NC 27,420
Dicamba	Clarity (4 S)	BASF Corporation, Research Triangle Park, NC 27,709

Table 3. Herbicide treatments, their application rate, and application timing used in this study.

Herbicide Treatments	Application Rate	Application Timing
	kg ai ha^{-1}	
Quinclorac	0.42	Pre-emergence
Atrazine + Dimethenamid-p	2.8	Pre-emergence
S-metolachlor fb Atrazine + Dicamba	1.40 fb 1.79 + 0.28	Pre-emergence fb ‡ two-leaf stage of sorghum
Dimethenamid-P fb Atrazine + COC *	0.78 fb 1.79	Pre-emergence fb two-leaf stage of sorghum
S-metolachlor + Atrazine fb Atrazine + COC (standard)	1.42 + 1.12 fb 1.12	Pre-emergence fb four-leaf stage of sorghum
S-metolachlor + Mesotrione + COC	1.42 + 0.14	VE †
S-metolachlor fb Prosulfuron + COC	1.42 + 0.03	Pre-emergence fb two-leaf stage of sorghum

† VE: emergence stage occurs when the coleoptile (spike) pushes through the soil surface. * COC, Crop oil concentrate applied at 1%. ‡ fb, followed by.

Table 4. Herbicide site of action (SOA) classification for herbicides used in this study.

Common Name	Chemical Family	Group	Site of Action
Quinclorac	Quinoline carboxylic acid	4	Synthetic Auxin
S-metolachlor	Chloroacetamide	15	Mitosis Inhibitor
Dimethenamid-P	Chloroacetamide	15	Mitosis Inhibitor
Atrazine	Triazine	5	Inhibitor of photosynthesis at photosystem II site A
Mesotrione	Triketone	27	Inhibitor of 4-hydroxyphenyl-pyruvatedioxygenase (4-HPPD)
Prosulfuron	Sulfonylurea	2	Acetolactate Synthase (ALS) or Acetohydroxy Acid Synthase (AHAS) inhibitor
Dicamba	Benzoic acid	4	Synthetic Auxin

3. Results

3.1. Weed Control

3.1.1. *Ipomoea lacunosa*

At two WAE, S-metolachlor fb atrazine + dicamba, dimethenamid-p fb atrazine + COC, and S-metolachlor + mesotrione + COC provided 98% control of *Ipomoea lacunosa*, which was significantly higher than all other herbicide treatments (87% to 91%). The lowest control of *Ipomoea lacunosa* was provided by S-metolachlor fb prosulfuron + COC (87%) and quinclorac (89%) at two WAE (Figure 1).

Quinclorac (92%), and S-metolachlor fb prosulfuron + COC (90%) also provided the lowest control of *Ipomoea lacunosa* at five WAE, which was significantly lower than the other herbicide treatments (94% to 99%). Atrazine + dimethenamid-p provided 94% control of *Ipomoea lacunosa*, which was higher than S-metolachlor fb prosulfuron + COC (90%). S-metolachlor fb atrazine + dicamba, S-metolachlor + mesotrione + COC, dimethenamid-p fb atrazine + COC, and S-metolachlor + atrazine fb atrazine + COC provided 98–99% control at five WAE. At 12 WAE, significantly lower control was provided by the quinclorac (91%), atrazine + dimethenamid-p (90%), and dimethenamid-p fb atrazine + COC (90%) as compared to S-metolachlor + atrazine fb atrazine + COC (98%) and S-metolachlor + mesotrione + COC (97%).

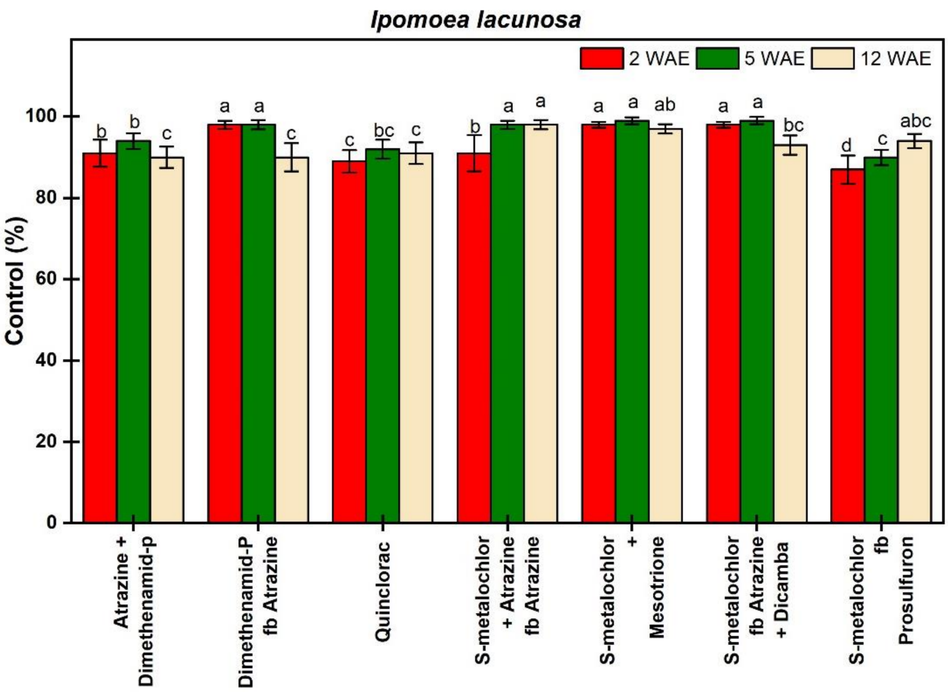

Figure 1. *Ipomoea lacunosa* control with different herbicide treatments at 2, 5, and 12 weeks after emergence (WAE). Data were analyzed separately for each WAE. Data were pooled over three years. The same letters on bars indicate no significant differences at $p < 0.05$, according to Fisher's least significant difference test. The abbreviation "fb" means "followed by".

3.1.2. *Ipomoea hederacea* var. *integriuscula*

S-metolachlor fb atrazine + dicamba (98%), dimethenamid-p fb atrazine + COC (98%), and S-metolachlor + mesotrione + COC (98%) provided 7% to 9% higher control of *Ipomoea hederacea* var. *integriuscula* than all other herbicides (89% to 91%) used at two WAE (Figure 2). All herbicide treatments provided more than 91% control at 5 and 12 WAE. At five WAE, atrazine + dimethenamid-p, quinclorac, and S-metolachlor fb prosulfuron + COC provided 94% to 95% control of *Ipomoea hederacea* var. *integriuscula*, which was significantly lower than the other herbicide treatments (98% to 99%) used in this study. However, the lowest control of *Ipomoea hederacea* var. *integriuscula* at 12 WAE was provided by atrazine + dimethenamid-p (93%), quinclorac (92%), and dimethenamid-p fb atrazine (92%), which was significantly lower than the S-metolachlor + atrazine fb atrazine + COC (99%) and S-metolachlor + mesotrione + COC (98%).

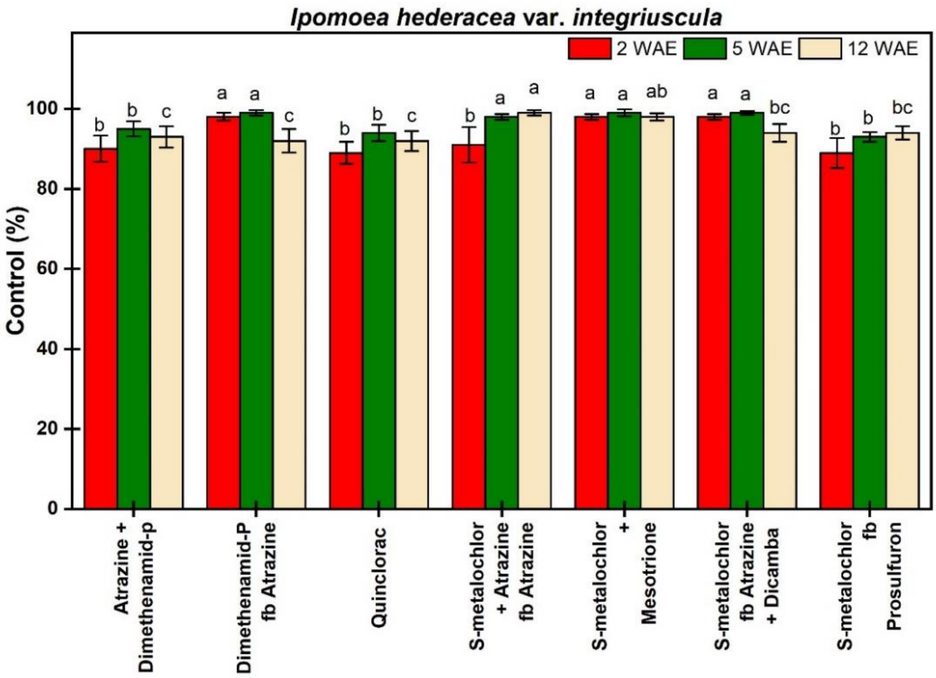

Figure 2. *Ipomoea hederacea* var. *integriuscula* control with different herbicide treatments at 2, 5, and 12 weeks after emergence (WAE). Data were analyzed separately for each WAE. Data were pooled over three years. The same letters on bars indicate no significant differences at $p < 0.05$, according to Fisher's least significant difference test.

3.1.3. *Amaranthus palmeri*

S-metolachlor fb atrazine + dicamba, dimethenamid-p fb atrazine + COC, and S-metolachlor + mesotrione + COC provided 100% control of *Amaranthus palmeri* throughout the growing season at 2, 5, and 12 WAE. S-metolachlor + atrazine fb atrazine + COC provided 98% control of *Amaranthus palmeri* at two WAE; however, they provided 100% control at 5 and 12 WAE (Figure 3). At each evaluation timing, the lowest control was provided by quinclorac (78% to 85%). All the other herbicide treatments provided more than 90% control of *Amaranthus palmeri* at each WAE.

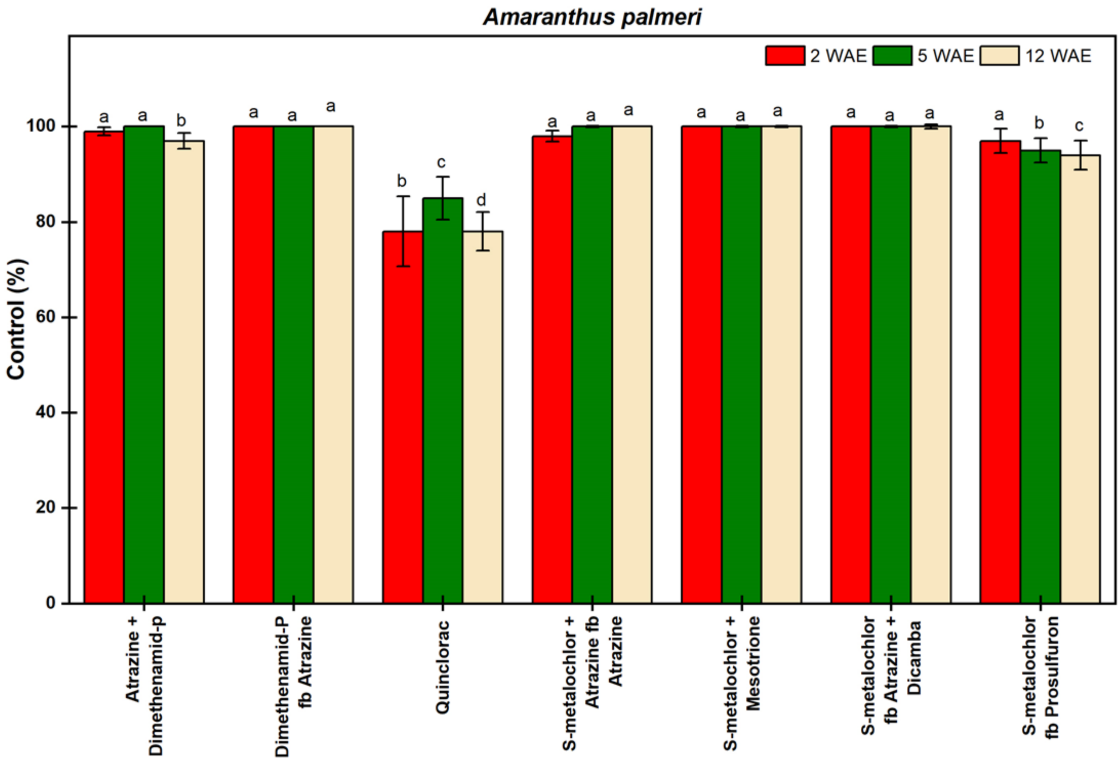

Figure 3. *Amaranthus palmeri* control with different herbicide treatments at 2, 5, and 12 weeks after emergence (WAE). Data were analyzed separately for each WAE. Data were pooled over three years. The same letters on bars indicate no significant differences at $p < 0.05$, according to Fisher's least significant difference test.

3.1.4. *Sesbania exaltata*

All herbicides provided 100% control of *Sesbania exaltata* at 2, 5, and 12 WAE in this study (data not presented).

3.1.5. *Urochloa platyphylla*

The S-metolachlor + mesotrione + COC application provided excellent control (98–99%) of *Urochloa platyphylla* at 2, 5, and 12 WAE (Figure 4). Quinclorac provided the lowest control (80% and 87%) of *U. platyphylla* at two and five WAE compared to the other herbicide treatments. S-metolachlor fb prosulfuron + COC also provided only 89% control of *Urochloa platyphylla* at two and five WAE, which was significantly higher than quinclorac (80% to 87%). However, S-metolachlor fb prosulfuron + COC provided the lowest control (86%) at 12 WAE as compared to the other herbicide treatments.

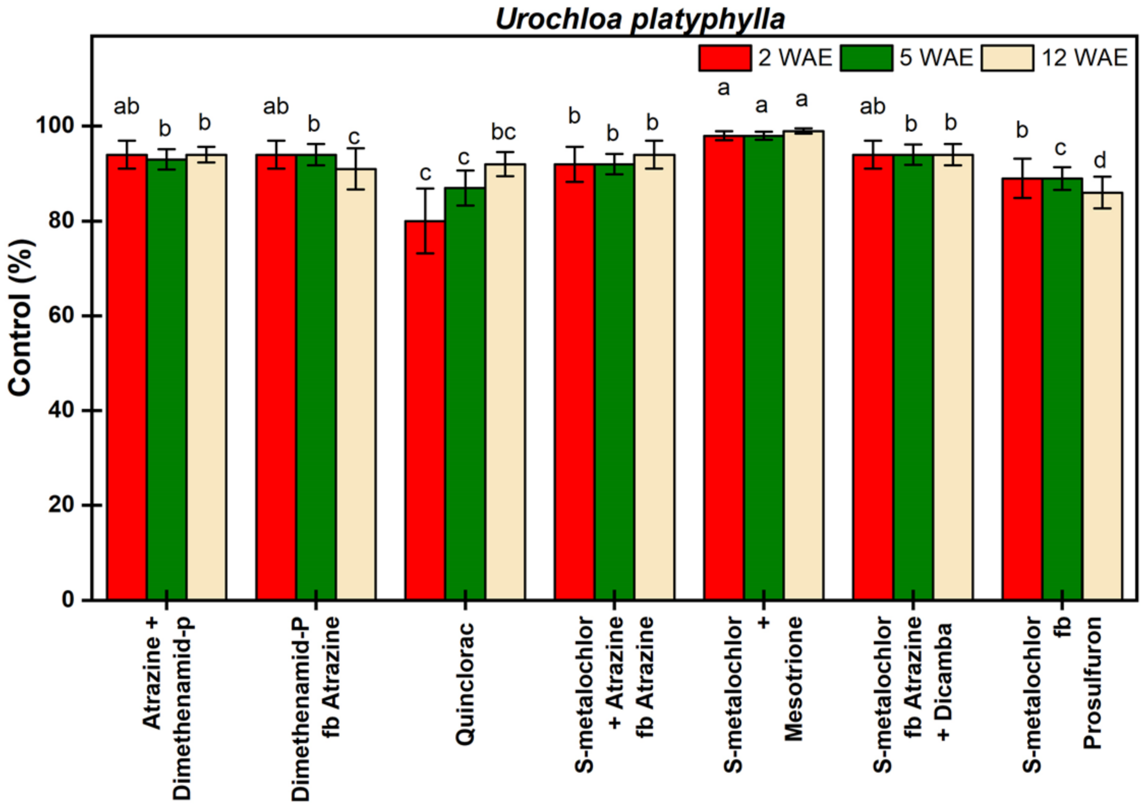

Figure 4. *Urochloa platyphylla* control with different herbicide treatments at 2, 5, and 12 weeks after emergence (WAE). Data were analyzed separately for each WAE. Data were pooled over three years. The same letters on bars indicate no significant differences at $p < 0.05$, according to Fisher's least significant difference test.

3.1.6. *Sida spinosa*

All herbicide treatments provided more than 90% control of *Sida spinosa* (Figure 5). Quinclorac provided 95% control at 2, 5, and 12 WAE. S-metolachlor fb atrazine + dicamba, dimethenamid-p fb atrazine + COC, and S-metolachlor + mesotrione + COC provided 100% control of *S. spinosa* at two WAE, but the control was reduced at 5 and 12 WAE. At two WAE, quinclorac, S-metolachlor fb prosulfuron, and S-metolachlor + atrazine fb atrazine + COC provided 95% to 96% control of *Sida spinosa*, which was 4% to 5% less than the control provided by the other herbicide treatments. Quinclorac (95%) and S-metolachlor fb prosulfuron + COC (97%) provided significantly lower control than S-metolachlor + atrazine fb atrazine and S-metolachlor + mesotrione (99%) at five WAE. At 12 WAE, S-metolachlor fb prosulfuron + COC (98%) provided significantly higher control of *Sida spinosa* than all other herbicide treatments.

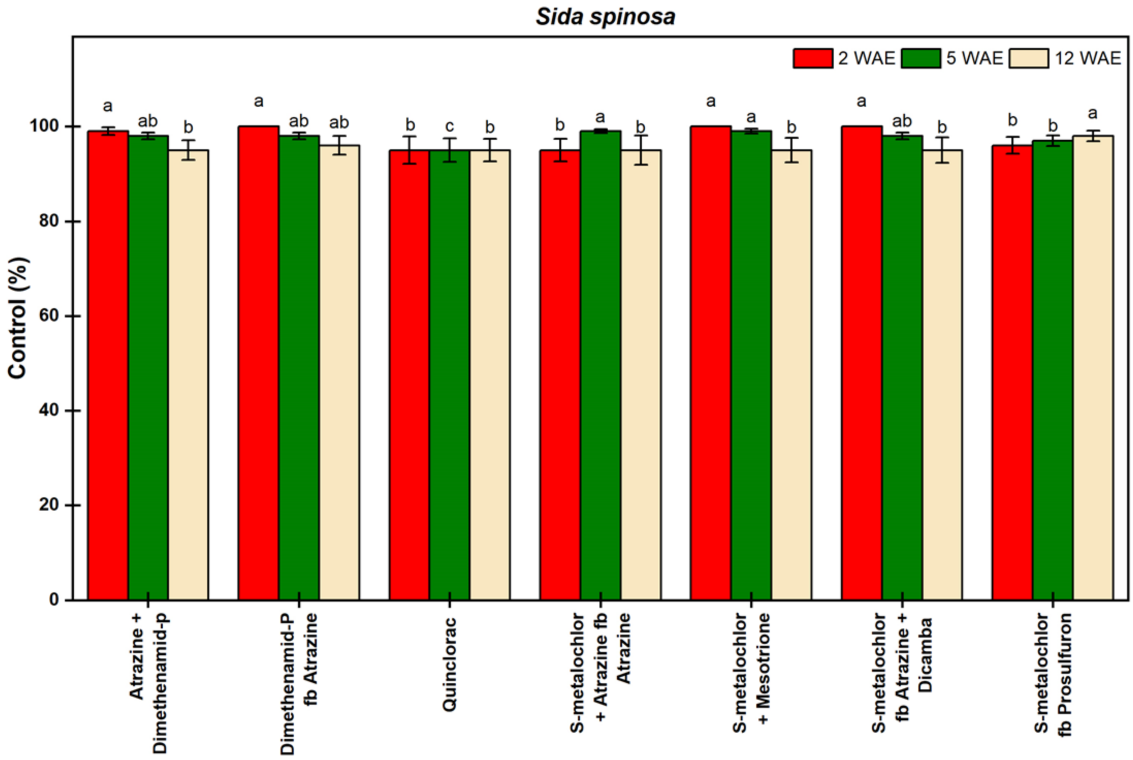

Figure 5. *Sida spinosa* control with different herbicide treatments at 2, 5, and 12 weeks after emergence (WAE). Data were analyzed separately for each WAE. Data were pooled over three years. The same letters on bars indicate no significant differences at $p < 0.05$, according to Fisher's least significant difference test.

3.2. Grain Sorghum Injury and Yield

Among all the herbicide treatments used, maximum injury to sorghum plants was caused by *S*-metolachlor + mesotrione (57%, 30%, and 15% at 2, 5, and 12 WAE, respectively) and *S*-metolachlor fb prosulfuron (6%, 16%, and 7% at 2, 5, and 12 WAE, respectively) (Figure 6). S-metolachlor+ mesotrione (VE) caused the greatest injury, 57% at two WAE, with the level of injury declining to 15% at the end of the season (12 WAE). The use of dimethenamid-p fb atrazine + COC caused only 2% injury at five WAE, and no injury (0%) was present on sorghum plants at 12 WAE. In general, the injury caused by different herbicide treatments reduced with time. No significant differences were obtained for sorghum injury between the following treatments at two WAE: atrazine + dimethenamid-p (4%), quinclorac (2%), S-metolachlor fb atrazine + dicamba (2%), and S-metolachlor + atrazine fb atrazine + COC (2%). At five WAE, quinclorac, atrazine + dimethenamid-p, and S-metolachlor fb atrazine +dicamba resulted in only 2% to 5% injury to sorghum. Quinclorac and S-metolachlor fb atrazine + dicamba treatments had only 1% injury present on sorghum plants at 12 WAE.

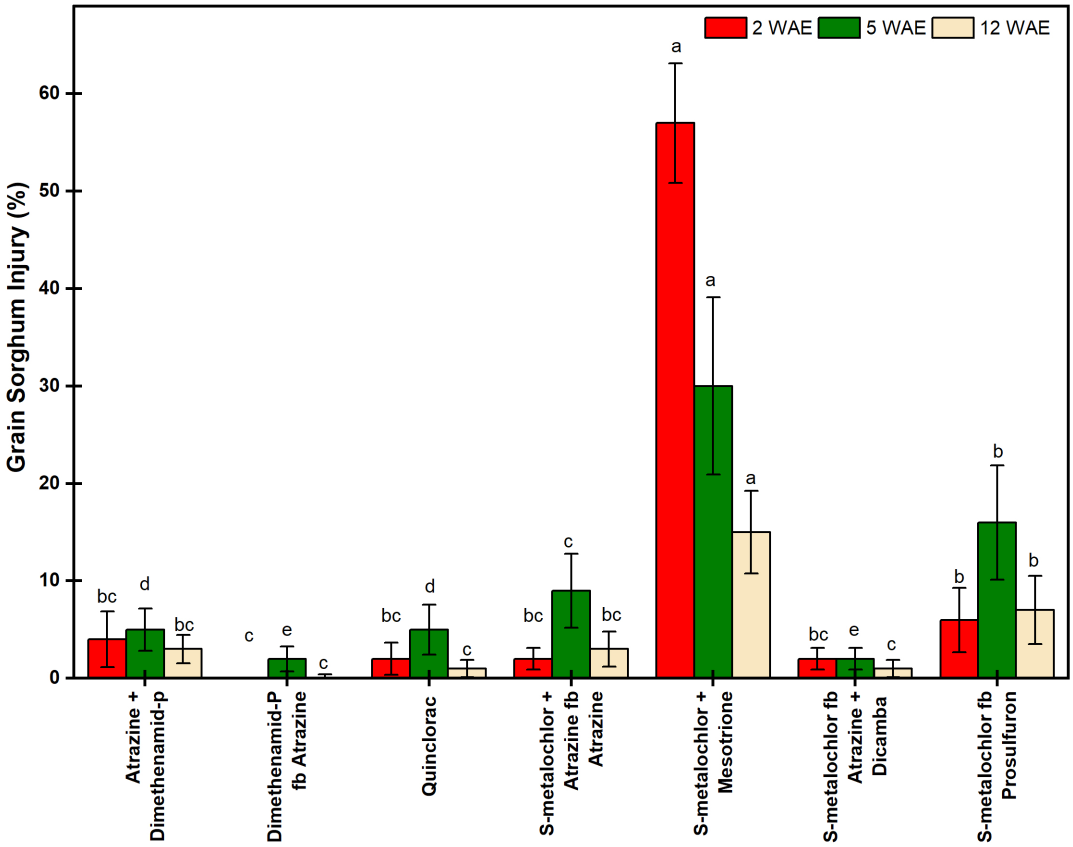

Figure 6. Injury to grain sorghum plants due to different herbicide treatments at 2, 5, and 12 weeks after emergence (WAE). Data were analyzed separately for each WAE. Data were pooled over three years. The same letters on bars indicate no significant differences at $p < 0.05$, according to Fisher's least significant difference test.

Amaranthus palmeri, Sida spinosa, Urochloa platyphylla, Ipomoea lacunosa, and *Ipomoea hederacea* var. *integriuscula* interference reduced grain sorghum yield in the non-treated control (2130 kg ha^{-1}) by 55% as compared to the standard herbicide treatment (4708 kg ha^{-1}) (Figure 7). S-metolachlor + mesotrione (3699 kg ha^{-1}) and S-metolachlor fb prosulfuron (3587 kg ha^{-1}) provided significantly lower sorghum yields than S-metolachlor + atrazine pre-emergence followed by atrazine + COC (4708 kg ha^{-1}) at four-leaf grain sorghum, by 1,009 and 1,121 kg ha^{-1}, respectively. The five best herbicide treatments in terms of grain sorghum injury, yield, and weed control were quinclorac (PRE) (4876 kg ha^{-1}), atrazine + dimethenamid-p (PRE) (4932 kg ha^{-1}), S-metolachlor (PRE) fb atrazine + dicamba (at two-leaf grain sorghum) (4708 kg ha^{-1}), dimethenamid-p (PRE) fb atrazine + COC (at two-leaf grain sorghum) (4708 kg ha^{-1}), and S-metolachlor + atrazine (PRE) fb atrazine + COC (at four-leaf grain sorghum) (4708 kg ha^{-1}). The weed-free control had 100% yield increase as compared to the non-treated control. All herbicide treatments except S-metolachlor + mesotrione and S-metolachlor fb prosulfuron, provided significantly similar yields compared to the weed-free control.

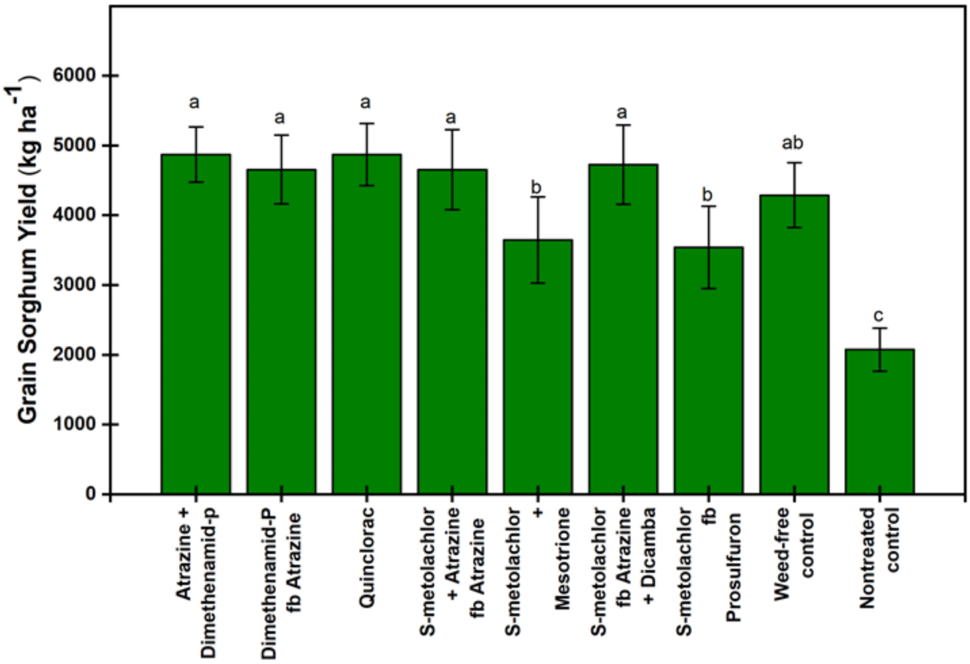

Figure 7. Grain sorghum yield as affected by different herbicide treatments. Data were pooled over three years. The same letters on bars indicate no significant differences at $p < 0.05$, according to Fisher's least significant difference test.

4. Discussion

Atrazine is commonly used to control several annual broadleaf and grass weeds in PRE or early post applications. Prosulfuron is a sulfonylurea herbicide and is characterized by a low use rate, short half-life, low volatility, and relatively low water solubility, which minimize injury to non-target crops and movement into surface or groundwater [9,10]. Mesotrione is a selective herbicide which controls many broad leaves and some grass weeds [4]. Mesotrione inhibits the hydroxyphenylpyruvate dioxygenase (HPPD) enzyme which disrupts carotenoid biosynthesis and results in plastoquinone synthesis inhibition [11,12]. Plastoquinone is part of the phosphorylation process as well as a cofactor for the phytoene desaturase enzyme needed for carotenoid synthesis [4]. Mesotrione is currently labeled for preplant non-incorporated or PRE weed control in sorghum [4]. Mesotrione needs adequate moisture to be activated for PRE herbicide applications [13].

In our study, the use of mesotrione or prosulfuron with S-metolachlor caused maximum injury to sorghum compared to the other herbicides used, and consequently, reduced the sorghum yield. Similarly, post applications of mesotrione at 70.5 g ai ha^{-1} were shown to provide consistent weed control, but also caused 20% chlorosis in grain sorghum [14]. A study by Miller and Regehr [15] showed severe plant injury ranging from 40% to 60% bleaching with early post application of mesotrione, whereas later post applications caused less injury to sorghum. Abit et al. [4] reported no reduction in sorghum yield with the use of foliar-applied mesotrione, although visible injury to sorghum was observed. Abit et al. [4] found that sorghum yield was not well correlated with visible mesotrione injury and suggested that sorghum can tolerate some level of injury without affecting the yield. They also suggested that sorghum plants recovered from mesotrione injury as the growing season progressed, thus, resulting in a poor correlation of sorghum injury with sorghum yield [4]. However, application of mesotrione with S-metolachlor provided more than 90% control of the weeds evaluated in this study. Similar to our study, Kaczmarek (2017) also recorded the best weed control with the use of a mesotrione tank mixture with S-metolachlor [16].

Dimethenamid is a chloroacetamide herbicide and is soil-applied to selectively control grass and certain broadleaf weeds [17]. In a study conducted by Mueller and Steckel [18], the herbicide dissipation rates of dimethenamid and S-metolachlor were 5 and 8.8 days, respectively, whereas the half-lives of these herbicides were 9 and 27 days, respectively, and dissipation rates were slower during a dry year. The chloroacetamide herbicide dimethenamid provided 87–100% and 78–90% control of *Amaranthus albus* (prostrate pigweed) and *Panicum texanum* (Texas panicum), respectively, when applied pre-emergence at 0.56–0.12 kg ha^{-1}. In our study, dimethenamid-p use with atrazine provided 97% to 100% control of *Amaranthus palmeri* resulting in a similar yield as with the standard herbicide treatment. However, Grichar et al. reported that use of dimethenamid and atrazine, alone or together, did not result in a higher yield than the non-treated control [19].

Control of *Amaranthus palmeri* with quinclorac, atrazine + dimethenamid-p, and S-metolachlor declined over time from 2 to 12 WAE in our study. *Amaranthus palmeri* has a comparatively faster growth rate and produces more branches, leaf area, and biomass than other *Amaranthus* spp. including common waterhemp (*Amaranthus tuberculatus*), redroot pigweed (*Amaranthus retroflexus*), and tumble pigweed (*Amaranthus albus*) [20,21], and it has 6% to 13% of the plant's total dry matter in its roots [22]. *Amaranthus palmeri* is also a prolific seed producer, resulting in more generation per growing season [22], and consequently, its control by some herbicides reduces with time after herbicide application. However, the use of herbicides including S-metolachlor fb atrazine + dicamba, dimethenamid-p fb atrazine + COC, S-metolachlor + atrazine fb atrazine +COC, and S-metolachlor + mesotrione + COC did not show any decline in the control of *Amaranthus palmeri* over time in our study. Similarly, Pannacci and Bartolini also found 96% to 100% control of *Amaranthus retroflexus* with the use of S-metolachlor or dicamba mixed with Terbuthylazine [23].

The best herbicide treatments in terms of grain sorghum injury, yield and weed control were the following: (1) quinclorac (site of action (SOA) group 4) (PRE); (2) atrazine (SOA group 5) + dimethenamid-p (SOA group 15) (PRE); (3) S-metolachlor (SOA group 15) (PRE) fb atrazine + dicamba (SOA group 4) (at two-leaf grain sorghum); (4) dimethenamid-p (PRE) fb atrazine + COC (at two-leaf grain sorghum); (5) the standard treatment of S-metolachlor + atrazine (PRE) fb atrazine + COC (at four-leaf grain sorghum). These treatments provided the highest grain sorghum yield of 4708–4932 kg ha^{-1}.

Herbicide-resistant (HR) weeds are a worldwide problem. The use of herbicide programs with the same site of action, may increase the evolution of HR weeds. One of the best management strategies to delay the onset of HR weeds is to rotate herbicide programs and/or incorporate multiple mode of action [24]. The findings of this research show that weed control can be achieved with four additional herbicide programs that contain different sites of action as compared to the local standard herbicide program (S-metolachlor + atrazine (PRE) fb atrazine + COC (four-leaf stage of sorghum)) in grain sorghum. The addition of quinclorac, dicamba, mesotrione, and prosulfuron to herbicide programs adds three additional sites of action (Table 4) for control of HR weeds without affecting grain sorghum yield.

5. Conclusions

Weeds are a serious problem in grain sorghum production. *Amaranthus palmeri*, *Sida spinosa*, *Urochloa platyphylla*, *Ipomoea lacunosa*, and *Ipomoea hederacea* var. *integriuscula* interference can significantly reduce grain sorghum yield. Our study evaluated multiple herbicide options for the control of broadleaf and grass weeds in grain sorghum in Arkansas. Herbicide mixtures, such as the use of mesotrione or prosulfuron with S-metolachlor, which injures sorghum plants, also reduces grain sorghum yield. The herbicide efficiency for weed control varies with weed species. Our results show that quinclorac PRE, atrazine + dimethenamid-p PRE, S-metolachlor PRE fb atrazine + dicamba at two-leaf grain sorghum, dimethenamid-p PRE fb atrazine + COC at two-leaf grain sorghum, and S-metolachlor + atrazine PRE fb atrazine + COC at four-leaf grain sorghum are the most effective options in terms of grain sorghum injury and yield, as well as weed control, in Arkansas grain sorghum production. These five herbicide programs provide multiple options to the farmer to rotate herbicide programs with different sites of action in order to prevent or delay the evolution of herbicide-resistant weeds, which is a serious problem worldwide.

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