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Prickly Sida (*Sida spinosa* L.), Hemp Sesbania [*Sesbania herbacea* (Mill.) McVaugh], and Pitted Morningglory (*Ipomoea lacunose* L.) Response to Selective and Non-Selective Herbicide in Mississippi, USA

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Abstract

Prickly sida (*Sida spinosa*), hemp sesbania (*Sesbania herbacea*), and pitted morningglory (*Ipomoea lacunose*) are becoming problematic weeds in many crops including corn and soybean. Two separate field experiments, under non-crop conditions, were conducted at the Mississippi State University Delta Research and Extension Center, in Stoneville, MS to evaluate the response of these weeds to eight corn selective herbicides and three non-selective herbicides alone or in combination. The herbicides used were Aatrex (atrazine), Clarity (dicamba), 2,4-D (2,4-D amine), Callisto (mesotrione), Enlist Duo (2,4-D choline + dicamba), Capreno (thiencarbazone + tembotrione), Corvus (thiencarbazone + isoxaflutole), Halex GT (mesotrione + *S*-metolachlor + glyphosate), Gramoxone (paraquat), Liberty (glufosinate), and Roundup (glyphosate). Halex GT provided only 86% prickly side control 4-wks after application (WAA). Aatrex + Capreno and Aatrex + Corvus were the only treatments provided 99.5% prickly sida control. Liberty, Callisto, Capreno, and Corvus provided 71, 66, and 51, and 46% control of prickly sida, respectively. Hemp sesbania control was 100% from all herbicide applications except Corvus and Roundup. Hemp sesbania control was not satisfactory from Roundup application since this treatment provided only 72% control. By 4 WAA, all herbicide treatments provided 97 to 100% on pitted morningglory control except Corvus and Capreno treatments (72 to 75%). The herbicide management program should be able to provide acceptable weed control (*i.e.*, greater than 95%) but also to prevent weed seed deposition onto the soil seedbank. Consequently, delaying the evolution of weed herbicide resistance will result in herbicide technology preservation for as long as possible by achieving a long-term weed management program.

Keywords: herbicides, herbicide efficacy, non-selective herbicides, selective herbicides, weed management

1. Introduction

Prickly sida (*Sida spinosa* L.) has become a particularly problematic weed for agronomic cropping systems in the Mid-South region of the United States, especially in cotton (*Gossypium hirsutum* L.), soybean (*Glycine max* L.), corn (*Zea mays* L.), and peanut (*Arachis hypogaea* L.) (Korres et al., 2015a, 2015b, 2017; Webster & Nichols, 2012). The credence of chemical herbicides to control this troublesome weed has decreased with its usage (Webster & Nichols, 2012; Copes et al., 2021). This bothersome weed reduces yields in many crops including soybean (Webster & Nichols, 2012). It has been documented mentioned that prickly sida caused soybean yield reduction by 9-14% (Jeffery et al., 1976). The control of this weed species is difficult, especially in agronomic fields, due to its ability to emerge throughout the growing season, to thrive under crop canopy with reduced light, and its great capacity for seed production after the crop has been harvested (Copes et al., 2021). Currently, the most popular method to control prickly sida is by using chemical herbicides. Field research conducted in 2014 at two locations in Arkansas reported the effectiveness of several herbicide programs in edamame (Salas et al., 2014). According to recent research in Mississippi, USA, a 2 to 3 applications of a wide herbicide programs range was efficient in controlling prickly sida populations in cotton fields (Ferguson et al., 2022). Application timing may be an important factor when applying herbicides to burndown prickly sida populations. In a soybean field study, it was found that late-season control of prickly sida was 93% with herbicide application at-planting and postemergence without the inclusion of any residual herbicide (Copes et al., 2021). In a study on preemergence herbicides and spray nozzle types found that the efficacy of imazethapyr in prickly sida increases under high residue levels (Ferguson et al., 2022).

Pitted morningglory (*Ipomoea lacunose*) is a twining annual vine with ovate leaves, pubescent capsules, and white corolla (Radford et al., 1968), and under non-competitive conditions, it can produce up to 15,000 seeds per plant (Senseman & Oliver, 1993; Norsworthy & Oliver, 2002a). Morningglories, mainly pitted morningglory, are one of the most problematic broadleaf weeds in the southeastern and southern Midwest USA (Korres et al., 2015a, 2015b; Dowler, 1995; Uva et al., 1997). These weeds are primarily found in agricultural areas, woodland margins, and roadsides (Korres et al., 2017; Korres et al., 2015a, 2015b; SWSS, 1998). Pitted morningglory is one of the most dominant morningglory species in the Mississippi Delta region (Korres et al., 2015a; Elmore et al., 1982). In crops like corn, cotton, and soybean, it is the second most problematic weed in Mississippi (Webster, 2001) and is among the glyphosate-tolerant weeds (Taylor, 1996). As mentioned by Jordan et al. (1997) morningglories were less effectively controlled by glyphosate compared to other species. Among these species, pitted and entire leaf morningglory were reported to be more glyphosate-tolerant than smallflower and palmleaf morningglory (Norsworthy & Oliver, 2002), hence are becoming more problematic weeds in glyphosate-resistant crops such as soybean and cotton (Chachalis et al., 2000). Mesotrione when used alone showed 51% control in pitted morningglory while when it was used with glyphosate pitted morningglory control increased to 65% (Armel et al., 2003). According to a study by Johnson et al. (2002), a mixture of mesotrione and atrazine was required for effective control of morningglory species as mesotrione alone failed to provide adequate control. Due to its prolific seed production and multiple germination timings, season-long control of pitted morningglory under favorable environmental conditions may not be attained with soil-applied herbicides alone. For example, imazapyr alone at a 7g/ha rate didn't affect pitted morningglory growth and development (Riley & Shaw, 1998).

Hemp sesbania (*Sesbania herbacea*) is an aggressive annual weed that poses threats to rice (*Oryza sativa* L.), corn, cotton, and sunflower (*Helianthus annuus* L.) (Woon, 1987). It commonly grows on uncultivated fields in Mississippi, Arkansas, and Louisiana (Korres et al., 2015a, 2015b) and is very difficult to control (Dowler, 1992). In addition to being prolific (*i.e.*, it produces 21,000 seeds per plant) (Lovelace & Oliver, 2000), it can also grow up to three meters high at maturity (Lorenzi & Jeffery, 1987). Its shading and competitive abilities enable it to reduce crop yields (Norsworthy & Oliver, 2002b; King & Parcell, 1997). Hemp sesbania is known to cause extensive damage to combine blades during crop harvest (Domsch et al., 1980). Leaf and stem compounds found in hemp sesbania are toxic to humans and livestock, with the seeds as the most lethal part of the plant (Everest et al., 1996). The most commonly methods of controlling hemp sesbania in most crops is by a single or multiple herbicide application (Lovelace & Oliver, 2000). Herbicides such as acifluorfen and fomesafen have effectively controlled hemp sesbania (Shaw & Amold, 2002). In soybeans, for example, the minimum effective rates of acifluorfen or fomesafen to suppress 50- to 60-cm tall hemp sesbania were 50 and 140 g ha^{-1}, respectively (Vidrine et al., 1992). Glyphosate combined with acifluorfen and chlorimuron was reported to reduce hemp sesbania fresh weight by almost half in soybean (Norris et al., 2011). Despite the efficacy of herbicides in controlling this weed, it has demonstrated resistance to glyphosate that makes the weed species a significant problem for farmers (Jordan et al., 1997; Norris et al., 2001). Single applications of glyphosate could not adequately control hemp sesbania (Johnson & Young, 2000; Lorenzi & Jeffery, 1987). There is, therefore, a need for additional control options.

The objective of this study is to evaluate a range of selective and non-selective herbicides that are usually used in Mississippi corn for the control of prickly sida, hemp sesbania, and pitted morningglory.

2. Materials and Methods

2.1 Field Experiments and Herbicide Treatments

Field studies were conducted in 2020 at the Mississippi State University Delta Research and Extension Center in Stoneville, MS on Sharkey clay (very fine, smectitic, thermic Chromic Epiaquerts) with 2.4% organic matter and pH 7.5. The experimental design was a randomized complete block with three replications. Herbicide treatments were involved eight sites of actions within 13 herbicide treatments. The trade names, site of action, chemical group, manufacturer information and application rates for the herbicides used in this study are listed in Table 1. A non-treated control was also included in the study. The experiment was repeated twice (two runs). Herbicide treatments were applied on July 1 on 3- to 6-leaf prickly sida, 5- to 7-leaf hemp sesbania, and 2- to 4-leaf pitted morningglory. Experiment was conducted on a natural population of prickly sida, hemp sesbania, and pitted morningglory under non-crop conditions. Herbicide applications were made using a CO_2-pressurized backpack sprayer calibrated to deliver 141 L ha^{-1} at 276 kPa. The boom consisted of 51-cm nozzle spacing equipped with Turbo TeeJet (TeeJet Technologies, Springfield, IL) Induction (TTI) 110015 nozzles. Prior to the experiment, a conventional seedbed was prepared by moldboard plowing and tandem disking twice in early April and prickly sida, hemp sesbania and pitted morningglory was allowed to establish a uniform natural population with an average density 97, 2 and 3 plants m^{-2}, respectively. Plot size was 4-m wide and 6-m long.

2.2 Assessment of Herbicide Efficacy and Data Analysis

Visual injury assessments for all weed species were based on 0 to 100% scale relative to the nontreated plots. Zero percentage (0%) indicated no control and 100% being complete plant death. The efficacy of herbicides on these weeds was evaluated weekly from 1 to 4 weeks after herbicide application (WAA). Weekly assessments were analyzed separately using the GlimMix procedure by SAS statistical software (SAS Institute Inc., Cary, NC). Prior to analysis, all data was examined for normality using the univariate procedure in SAS. In addition, the homogeneity of variance was tested with Bartlett's test. The herbicide treatments were considered fixed effects, whereas treatment replication was considered as random. No run (two separate field studies translates to two runs of the experiment) effects were observed, hence data from each run were combined prior to data analysis. Means were separated by t-test at significance level $\alpha = 0.05$.

Table 1. Herbicide treatments for the control of prickly sida, hemp sesbania and pitted morningglory used in this study

Trade name	Active Ingredient	Group*	Site of Action**	Manufacturer	Application Rate (kg a.i. ha^{-1})
Roundup Max	Glyphosate	9	EPSP Synthase inhibitor	Various	1.26
Liberty	Glufosinate	10	Glutamine Synthesis Inhibitor	BASF	0.66
Aatrex	Atrazine	5	Photosystem II Inhibitor	Syngenta	2.24
Enlist Duo	2,4-D Choline+Glyphosate	4+9	T1R1 Auxin Receptors +EPSP Synthase Inhibitor	Corteva	1.85
Capreno	Thiencarbazone+Tembotrione	2+27	ALS Inhibitors+HPPD Inhibitors	Bayer	0.09
Corvus	Thiencarbazone+Isoxaflutole	2+27	ALS Inhibitors+HPPD Inhibitors	Bayer	0.09
Aatrex+Capreno†	Atrazine+ Thiencarbazone+Tembotrione	5+2+27	PS II inhibitors+ALS Inhibitors+HPPD Inhibitors	Bayer	2.24+0.09
Aatrex+Corvus	Atrazine+ Thiencarbazone+Isoxaflutole	5+2+27	PS II inhibitors+ALS Inhibitors+HPPD Inhibitors	Bayer	2.24+0.09
Halex GT	Mesotrione+S-Metolachlor+Glyphosate	27+15+9	HPPD Inhibitors+Long Chain Fatty Acid Inhibitors +EPSP Synthase Inhibitors	Syngenta	2.24
Callisto	Mesotrione	27	HPPD Inhibitors	Syngenta	0.228
2,4-D	2,4-D Amine	4	T1R1 Auxin Receptors	Alligare	1.12
Clarity	Dicamba	4	T1R1 Auxin Receptors	BASF	0.56
Gramoxone	Paraquat	22	PS I Electron Diverter	Syngenta	0.56

Note. *, ** = based on Weed Science Society of America; † = plus induce (nonionic surfactant).

3. Results and Discussion

3.1 Prickly Sida Control

One-week after application (WAA) Aatrex + Corvus and Aatrex + Capreno were the most effective herbicide treatments that provided 99% control of prickly sida (Figure 1). Non-selective herbicides Paraquat and Liberty provided 90 and 93% prickly sida control respectively whereas the percentage control of Roundup PowerMax, Enlist Duo, and Aaartex alone ranged between 80 to 82%. Halex GT, Clarity and 2,4-D provided 72%, 73% and 65% prickly sida control respectively (Figure 1). The lowest percentages of prickly sida control (< 50%) were obtained under Callisto, Corvus, and Capreno treatments (< 50%) (Figure 1). Herbicide activity, as anticipated, increased over time. Two WAA Roundup PowerMax application increased prickly sida control by 17% whereas the percentage control of Aatrex + Corvus, and Aatrex + Capreno remained at the same level as that recorded one WAA (Figure 1). In addition, Aartex and Enlist Duo were also provided high prickly sida control (89 to 91% respectively). However, the effectiveness of Aatrex, Halex GT, Liberty, and Clarity compared with that obtained by the application of Roundup PowerMax and the mix of Corvus and Capreno with Aatrex was recorded at lower levels (Figure 1). Prickly sida control by the application of 2,4-D was slightly increased (75% control) whereas Callisto, Corvus, and Capreno single applications were the weakest treatments as prickly sida control was recorded at < 58% to the untreated check (Figure 1).

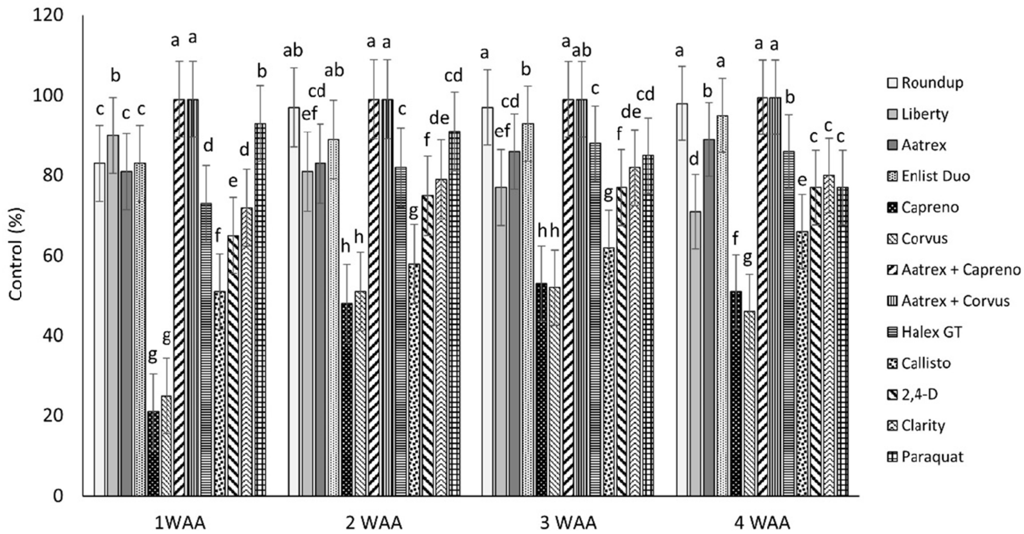

Figure 1. Prickly sida response to herbicide treatments up to four weeks after herbicide application (WAA). Treatments associated with the same letter at each assessment timing (WAA) are not significantly different ($\alpha = 0.05$). Vertical bars indicate two standard errors of the mean

Prickly sida control remained high by the application of Aatrex + Corvus, Aatrex + Capreno, and Roundup PowerMax 3 WAA along with Paraquat, Aatrex, and Halex GT, the application of which resulted at 85 to 88% control of the weed (Figure 1). Liberty and Clarity did not provide sufficient control of prickly sida control (< 85%) whereas Callisto, Corvus, and Capreno remained the weakest treatments despite the slight increases of their efficacy compared to previous assessment (< 62% control) (Figure 1).

As it was expected, prickly sida control was slightly improved over time compared to previous assessment at 4 WAA. Liberty, Paraquat, 2,4-D, and Clarity failed to provide sufficient control of prickly sida (< 80%) (Figure 1). However, Callisto, Capreno, and Corvus provided the weakest control (*i.e.*, < 66%). In general, tank mixture of Aatrex with Corvus and Capreno resulted in high prickly sida control. Similar results were obtained by Schwartz-Lazaro et al. (2022) when the same combination of herbicides was used in a three-year crop rotation program including corn. Halex Gt and Atrazine may provide acceptable level of prickly sida control (86 to 89%), although given the high fecundity of this species (*i.e.*, between 3000-8000 seeds per plant; Copes, 2016) escapees will produce and deposit enough seeds onto the soil seedbank, which will cause problems the following year. The aim of a long-term prickly sida management program should aim to prevention of the seed deposition to the soil seedbank. Consequently, less seed inputs results into less weed presence, hence reduced risks for the development of herbicide-resistant weeds. Therefore, if we wish to preserve current herbicide technology a long term weed management program needs to be adopted. Thus, weed management programs must provide both an optimum and effective (> 95%) level of weed control resulting in less weed seed production and deposition to the soil seed bank.

3.2 Hemp Sesbania Control

One-week after application (WAA) Aatrex + Capreno, Aatrex + Corvus, Liberty, and Paraquat provided 100% control of hemp sesbania (Figure 2). The efficacy of Callisto, Halex GT, 2,4-D, Aatrex, Enlist Duo, and Clarity alone was also recorded at acceptable levels between 93 to 95% compared to untreated checks. Capreno, Roundup, and Corvus applications provided 89, 73 and 72% control of hemp sesbania, respectively (Figure 2). As it was expected the efficacy of herbicides was increased 2 WAA as all herbicide applications tested provided 98 to 100% control of the weed except Capreno alone the application of which recorded at 95% control of hemp sesbania. Corvus and Roundup application were the weakest treatments 2 WAA (Figure 2). The same hemp sesbania control level was recorded 3 and 4 WAA for all herbicide treatments except Corvus and Roundup (Figure 2). Hemp sesbania was difficult to control by Roundup application, as this treatment provided only 72% control of hemp sesbania.

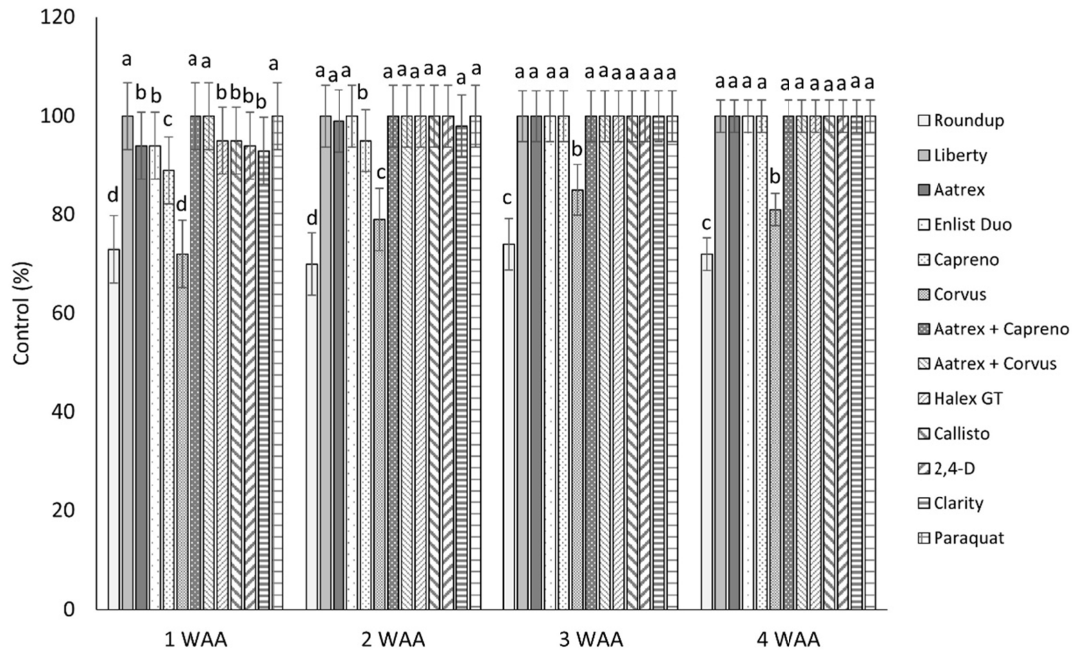

Figure 2. Hemp sesbania response to herbicide treatments up to four weeks after herbicide application (WAA). Treatments associated with the same letter at each assessment timing (WAA) are not significantly different ($\alpha = 0.05$). Vertical bars indicate two standard errors of the mean

All herbicide treatments, except Corvus and Roundup provided 100% hemp sesbania control, consequently preventing seed production and further seed inputs into the soil seedbank. Preventing weed seed deposition into the soil seedbank results in reduction of increases of soil seedbank inventory, which possibly will delay the evolution of herbicide resistance and preserve herbicide technology for longer time periods.

3.3 Pitted Morningglory Control

The application of Liberty, Paraquat, Aatrex + Capreno, and Aatrex + Corvus 1 WAA resulted in 99% pitted morningglory control (Figure 3). The phenoxy herbicides such as Clarity and 2,4-D were less effective and provide sufficient control of pitted morningglory by 81 to 82% of the untreated check. The application of Capreno and Corvus resulted in the least control of the weed, *i.e.*, 40 and 29%, respectively. The efficacy of all herbicide treatments, as anticipated, was increased two-weeks after application. Most herbicide products provided greater than 98% control except Clarity, 2,4-D, Roundup, and Capreno (Figure 3) whilst Capreno and Corvus rated as the weakest treatments since they were resulted only 52 and 53% of pitted morningglory control. Roundup, Clarity, and 2,4-D efficacy in controlling pitted morningglory increased with time as weed control recorded between 89 to 96% 3 WAA (Figure 3). However, Corvus and Capreno, despite improvements on morningglory control, remained the weakest treatments with 60 and 62% control, respectively. Four WAA, all herbicide treatments provided 97 to 100% pitted morningglory control except Corvus and Capreno treatments (Figure 3).

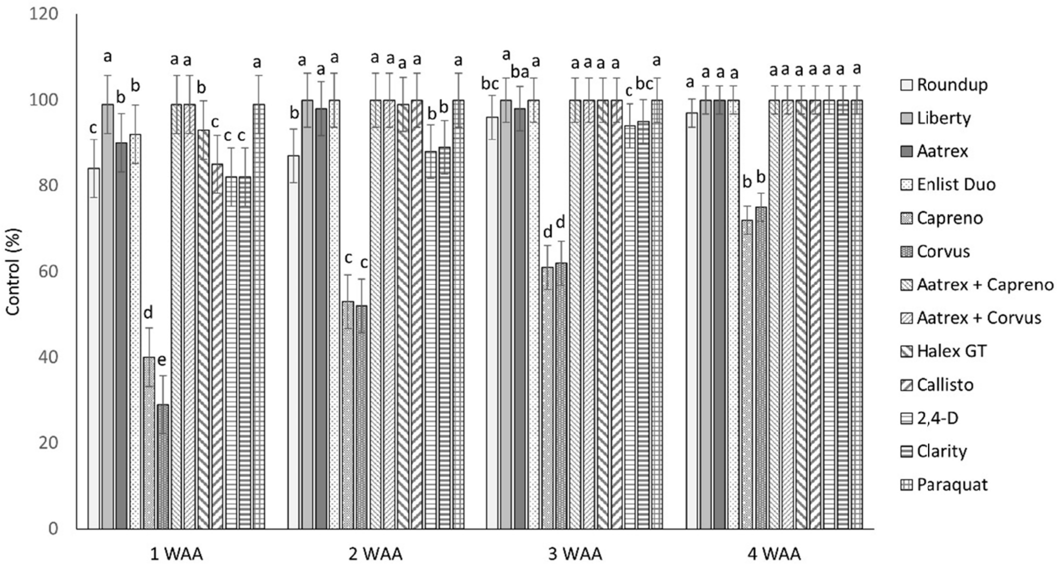

Figure 3. Pitted morningglory response to herbicide treatments up to four weeks after herbicide application (WAA). Treatments associated with the same letter at each assessment timing (WAA) are not significantly different (α = 0.05). Vertical bars indicate two standard error of the mean

All herbicide treatments, except Corvus and Capreno, provided 97 to 100% pitted morningglory control, therefore reductions of future seed deposition onto the soil surface. This is of particular interest given the fact that one herbicide application was used in this work. As stated by Joseph et al. (2017) one postemergence application of various herbicides active ingredients including glyphosate, dicamba and S-metolachlor, alone or in mixtures, provided similar levels of pitted morningglory control as two postemergence applications. In addition, Schwartz-Lazaro et al. (2022) reported similar effects on morningglory by the application of pre-mix herbicides such as S-metolachlor, mesotrione and glyphosate. According to Armel et al. (2007) the addition of atrazine to mesotrione applied postemergence improved *Ipomoea coccinea* (red morningglory) control. Furthermore, atrazine added to PRE applications of isoxaflutole also increased control of ivyleaf morningglory (Stephenson & Bond, 2012). Johnson et al. (2002) and Breeden et al. (2001) reported increased control of ivyelaf morningglory and pitted morningglory by the addition of atrazine to mesotrione. Therefore, the co-application of various herbicide families such as HPPD or ALS-inhibiting with PSII-inhibiting herbicides is well documented as a practice that can increase overall herbicidal activity and broaden the weed control spectrum.

4. Conclusions

Only four herbicide applications of Atrazine + Capreno, Atrazine + Corvus, Roundup, and Enlist Duo provided greater than 95% control of prickly sida. Capreno and Corvus were the weakest herbicide applications, but when they tank-mixed with Aatrex increased the activity of the later significantly. All herbicide treatments provided greater than 96% pitted morningglory control except Corvus and Capreno. Roundup, a non-selective herbicide, failed to provide acceptable control of hemp sesbania whereas all other herbicide treatments, except Corvus, provided 100% hemp sesbania control. Late-season herbicide applications were shown to reduce seed production of several weed species including prickly sida, pitted morningglory (Joseph et al., 2017). It is known that reductions in weed infestation are followed by reductions in seed production (Walker & Oliver, 2008; Korres & Froud-Williams, 2002), hence reduced inputs in the soil seedbank. However, current knowledge of the efficacy of early, single, post-emergence herbicide applications is needed for making suitable recommendations. The research presented here allows us, through the long-term evaluation on the effects of early, single application of various herbicides to recommend effective herbicide programs; this could aid in reductions of weed seed production, hence inputs onto the soil seedbank, a valuable information for integrated weed management systems.

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