Effectiveness of PRE herbicides followed by zidua POST for controlling glyphosate-resistant weeds in High Plains sunflower production

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Introduction

Sunflower (*Helianthus annuus* L.) is an important oilseed crop grown in the United States. About 1.32 million acres were planted with sunflower in 2019 with major production in North Dakota, South Dakota, Colorado, Kansas, and Minnesota (USDA NASS 2019). Like other crops, weeds provide a major challenge in successful production of sunflower. Kochia (*Bassia scoparia* L.) and Palmer amaranth (*Amaranthus palmeri*) are two most problematic summer annual weeds in the High Plains region. Season-long interference from both weed species through multiple flushes can reduce sunflower yield and seed quality (Lewis and Gulden 2014). Resistance to glyphosate (group 9) and acetolactate synthase (ALS) inhibiting herbicides (group 2) is fairly common in field populations of both weed species in this region (Godar and Stahlman 2015; Heap 2020; Kumar et al. 2019; Kumar et al. 2020). Because of resistance to group 2 herbicides, Express and Clearfield Sunflowers are no longer effective options for controlling kochia and Palmer amaranth. In addition, multiple resistance to as many as five herbicide modes of action (MOA) in Palmer amaranth and four MOA in kochia has also been reported (Kumar et al. 2020; Varanasi et al. 2015). Due to limited herbicide options, kochia and Palmer amaranth is a serious management concern for sunflower producers in the region.

Previous studies have documented that preemergence (PRE) applied Broadaxe (s-metolachlor/ sulfentrazone) or Spartan Elite (s-metolachlor/sulfentrazone) can provide season-long kochia control and 96% control of Palmer amaranth up to 28 days after treatment (Reddy et al. 2012). However, the longevity and activity of this premix is influenced by available soil moisture (Reddy et al. 2012). Zidua (pyroxasulfone) has emerged as a viable option for extending PRE weed control further into the season, when applied early POST. A combined PRE herbicide program followed by zidua POST can provide effective weed control, but determining the optimal timing of zidua can be difficult as the longevity of PRE herbicides in the soil vary greatly depending on environmental conditions. *The main objectives of this study were to (1) compare the efficacy and longevity of PRE herbicide options in sunflower and (2) determine the optimal timing of zidua POST after PRE herbicide program for season-long weed control.*

Materials and Methods

Field studies were established in two irrigated and three dryland sites across Nebraska, Kansas, and Colorado in 2018 and 2019. The irrigated sites were located in Scottsbluff (Nebraska) and Colby (Kansas), and provided ideal moisture conditions to activate soil applied herbicides. The dryland sites were located in Sidney (Nebraska), Hays (Kansas), and Julesburg (Colorado). All sites had natural infestation of kochia and/or palmer amaranth along with other weeds. Depending upon a herbicide resistance trait in weed populations at each site, a burndown treatment of glyphosate, paraquat, or tillage was used prior to sunflower planting to ensure a weed-free seed bed at planting. Herbicide treatments were applied shortly after planting and irrigation was applied within 24 hours to activate herbicides at the irrigated sites. Layby applications of zidua were applied according to the schedule in Table 1. The recommended agronomic practices (variety, seeding rate, fertilizer, row spacing, diseases and insects control etc.) for sunflower production for each study site were followed.

Data collection and analyses. Data on visual crop injury (%), weed control (%), and weed density were collected at biweekly interval in each growing season. Weed biomass and sunflower yield were recorded at crop harvest. Data collected at each site were separately analyzed in ANOVA using PROC Mixed in SAS and mean separations were performed by Fisher's protected LSD test at $P < 0.05$.

Table 1. Herbicide programs evaluated at each study location in 2018 and 2019.

Trt	Herbicide [1, 2]	Rate, oz/A	Timing
1	Prowl H_2O	32	PRE
2	Prowl H_2O *fb* Zidua	32 *fb* 1.5	PRE *fb* EPOST
3	Prowl H_2O *fb* Zidua	32 *fb* 1.5	PRE *fb* MPOST
4	Prowl H_2O *fb* Zidua	32 *fb* 1.5	PRE *fb* LPOST
5	Broadaxe	19-25	PRE
6	Broadaxe *fb* Zidua	19-25 *fb* 1.5	PRE *fb* EPOST
7	Broadaxe *fb* Zidua	19-25 *fb* 1.5	PRE *fb* MPOST
8	Broadaxe *fb* Zidua	19-25 *fb* 1.5	PRE *fb* LPOST
9	Spartan Charge	3 to 5	PRE
10	Spartan Charge *fb* Zidua	3 to 5 *fb* 1.5	PRE *fb* EPOST
11	Spartan Charge *fb* Zidua	3 to 5 *fb* 1.5	PRE *fb* MPOST
12	Spartan Charge *fb* Zidua	3 to 5 *fb* 1.5	PRE *fb* LPOST
13	Hand weeded check	-	-
14	Nontreated weedy check	-	-

[1] Abbreviations: *fb*, followed by; PRE, pre-crop emergence; EPOST, early postemergence; MPOST, mid postemergence; LPOST, late postemergence

[2] All treatments included glyphosate or paraquat as PRE burndown

Results and Discussion

Due to various reasons (poor crop establishment, inadequate weed population, or hail damage), the data from Hays, Sidney, and Julesburg in 2018 and Colby, Sidney, and Julesburg in 2019 growing season were not collected. This paper reports the weed control efficacy data from Scottsbluff and Colby sites in 2018 and Scottsbluff and Hays sites in 2019.

Colby Site-2018

Among all tested herbicide programs, PRE applied Broadaxe followed by a sequential POST treatment of Zidua (early, mid, or late) provided 88 to 99% control of glyphosate-resistant (GR) Palmer amaranth throughout the season (Table 1). Early-season control of GR Palmer amaranth with PRE applied Prowl and Spartan Charge alone or followed by a sequential POST Zidua ranged from 85 to 95%. However, control with those treatments declined over the season and ranged between 67 to 79% at 10 weeks after crop emergence (WAE). Consistent with percent control, PRE applied Broadaxe alone or followed by sequential POST Zidua treatment had the lowest density (26 to 35 plants per sunflower row) of GR Palmer amaranth.

Scottsbluff Site-2018

No crop injury was observed. Palmer amaranth population at study site was resistant to group 2 herbicides, including Beyond. Weed control was excellent across all treatments, with Prowl, Broadaxe XC, and Spartan Charge alone, all providing >95% control. This high level of control was also reflected in the weed count and weed biomass data, where all herbicide treatments reduced palmer amaranth density and biomass by 90 and 95% respectively (Table 2). No significant differences were observed among herbicide treatments, and there did not appear to be a benefit from adding Zidua POST treatment.

Hays Site-2019

PRE applied Broadaxe alone or followed by a sequential POST (early, mid, or late) application of Zidua provided excellent, season-long control (≥98%) of GR Palmer amaranth and kochia (Table 3). Control of both weed species with PRE Prowl alone or followed by a sequential POST Zidua (early, mid, or late) ranged from 91 to 98% throughout the season. Control of both weed species with Spartan Charge alone or followed by a sequential POST Zidua (early, mid, or late) did not exceed 87% at the final evaluation (Table 3). Consistent with percent control, the PRE applied Broadaxe alone or followed by a sequential POST (early, mid, or late) applications of Zidua prevented any emergence of GR Palmer amaranth and kochia throughout the season.

Scottsbluff Site-2019

Three separate and highly damaging hail events occurred within 10 days in late August that completely destroyed the sunflower crop. The dominate weed species was ALS-resistant Palmer amaranth. All treatments receiving an herbicide had less total weeds than the non-treated check plots. All plots receiving either Broadaxe or Spartan Charge had less weeds than plots receiving Prowl (Figure 1). The performance of Prowl H20 or Spartan Charge was not improved with later applications of Zidua. Total weed control was excellent with Spartan Charge, or Broadaxe followed by Zidua at either 2 or 4 true leaf stage.

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Table 1. Percent visual control and density of Palmer amaranth in sunflower at Colby, KS in 2018.

Herbicide (s) [a]	Rate (oz/a)	2 WAE	4 WAE	6 WAE	8 WAE	10 WAE	Density
		% control					No./sunflower row
Prowl	32	94	91	88	83	79	53
Prowl *fb* Zidua	32 *fb* 1.5	91	85	78	73	69	75
Prowl *fb* Zidua	32 *fb* 1.5	94	89	84	80	77	61
Prowl *fb* Zidua	32 *fb* 1.5	93	88	80	76	67	58
Broadaxe	21	97	95	92	88	83	35
Broadaxe *fb* Zidua	21 *fb* 1.5	98	97	92	90	88	29
Broadaxe *fb* Zidua	21 *fb* 1.5	97	94	92	89	82	40
Broadaxe *fb* Zidua	21 *fb* 1.5	99	98	94	92	89	26
Spartan Charge	5	95	94	86	83	77	50
Spartan Charge *fb* Zidua	5 *fb* 1.5	92	94	87	84	79	51
Spartan Charge *fb* Zidua	5 *fb* 1.5	92	89	85	79	70	71
Spartan Charge *fb* Zidua	5 *fb* 1.5	93	86	74	66	57	65
Hand weeded	–	100	100	100	100	100	0
Nontreated check	–	–	–	–	–	–	153
LSD (0.05)		7	6	11	13	15	32

[a] Abbreviation: PRE, preemergence; EPOST, early postemergence; MPOST, mid postemergence; LPOST, late postemergence; *fb*, followed by; WAE, weeks after sunflower emergence

Table 2. Percent visual control, density, and shoot biomass of Palmer amaranth in sunflower at Scottsbluff, NE in 2018.

Treatment	Rate (oz/ac)	Timing	Palmer amaranth control			Density			Shoot biomass
			24-Jul	20-Aug	11-Sep	24-Jul	20-Aug	11-Sep	11-Sep
			% control			plants per m^2			g per m^2
Non Treated Check			0 c	0 b	0 b	22.2 a	17.6 a	17.4 a	185.12 a
Prowl H2O	32	PRE	97 ab	95 a	95 a	1.4 b	1.6 b	1.4 b	3.8 b
Prowl H2O Zidua	32 1.5	PRE EPOST	96 ab	95 a	95 a	0.6 b	0.8 b	1.4 b	2.73 b
Prowl H2O Zidua	32 1.5	PRE MPOST	97 ab	99 a	99 a	1.6 b	1.3 b	1.5 b	2.58 b
Prowl H2O Zidua	32 1.5	PRE LPOST	94 b	99 a	99 a	0.9 b	0.7 b	0.9 b	2.37 b
Broadaxe	19	PRE	99 ab	99 a	99 a	0.3 b	0 b	0 b	0 b
Broadaxe Zidua	19 1.5	PRE EPOST	99 ab	99 a	99 a	0 b	0 b	0 b	0 b
Broadaxe Zidua	19 1.5	PRE MPOST	99 ab	99 a	99 a	0.2 b	0 b	0 b	0 b
Broadaxe Zidua	19 1.5	PRE LPOST	99 ab	99 a	99 a	0.2 b	0.3 b	0.2 b	0.8 b
Spartan Charge	3	PRE	99 ab	98 a	98 a	1.1 b	0.5 b	0.2 b	0.74 b
Spartan Charge Zidua	3 1.5	PRE EPOST	99 ab	99 a	99 a	0.3 b	0.4 b	0.3 b	1.88 b
Spartan Charge Zidua	3 1.5	PRE MPOST	98 ab	99 a	99 a	0.9 b	2.4 b	1.5 b	9.51 b
Spartan Charge Zidua	3 1.5	PRE LPOST	97 ab	99 a	99 a	0.3 b	1.1 b	0.7 b	0.89 b
Handweeded Check			100 a	100 a	100 a	0 b	0 b	0 b	0 b

Means within the same column which share the same letter, are not statistically different.

Table 3. Percent visual control and density of Palmer amaranth and kochia in sunflower at Hays, KS in 2019.

Herbicide (s)	Timing	Rate (oz/a)	July-12		Aug-16		Sep-10		Density (plants/row)	
			Palmer amaranth	Kochia	Palmer amaranth	Kochia	Palmer amaranth	Kochia	Palmer amaranth	Kochia
Prowl	PRE	32	94 ab	96 a	93 ab	94 a	92 ab	94 a	4	1
Prowl *fb* Zidua	PRE *fb* EPOST	32 *fb* 1.5	98 a	94 a	98 a	92 ab	96 a	91 ab	2	1
Prowl *fb* Zidua	PRE *fb* MPOST	32 *fb* 1.5	92 ab	95 a	92 ab	94 a	92 ab	93 ab	1	1
Prowl *fb* Zidua	PRE *fb* LPOST	32 *fb* 1.5	94 ab	92 ab	94 a	91 ab	93 ab	91 ab	3	2
Broadaxe	PRE	25	98 a	98 a	99 a	99 a	99 a	99 a	0	0
Broadaxe *fb* Zidua	PRE *fb* EPOST	25 *fb* 1.5	96 a	99 a	98 a	99 a	99 a	98 a	0	0
Broadaxe *fb* Zidua	PRE *fb* MPOST	25 *fb* 1.5	97 a	98 a	99 a	98 a	99 a	99 a	0	0
Broadaxe *fb* Zidua	PRE *fb* LPOST	25 *fb* 1.5	96 a	99 a	99 a	98 a	99 a	98 a	0	0
Spartan Charge	PRE	5	87 b	89 b	85 b	86 b	85 b	82 b	5	2
Spartan Charge *fb* Zidua	PRE *fb* EPOST	5 *fb* 1.5	89 b	91 b	88 b	88 b	87 b	86 b	4	2
Spartan Charge *fb* Zidua	PRE *fb* MPOST	5 *fb* 1.5	86 b	88 b	85 b	85 b	84 b	83 b	6	3
Spartan Charge *fb* Zidua	PRE *fb* LPOST	5 *fb* 1.5	83 b	86 b	82 b	84 b	82 b	82 b	5	3
Hand weeded	–	–	100 a	100 a	100 a	100 a	100 a	100 a	0	0
Nontreated	–	–	–	–	–	–	–	–	10	7

[a] Abbreviation: PRE, preemergence; EPOST, early postemergence; MPOST, mid postemergence; LPOST, late postemergence; *fb*, followed by; WAE, weeks after sunflower emergence. Means within a column with similar letters are not significantly different based on Fisher's protected LSD test ($\alpha = 0.05$).

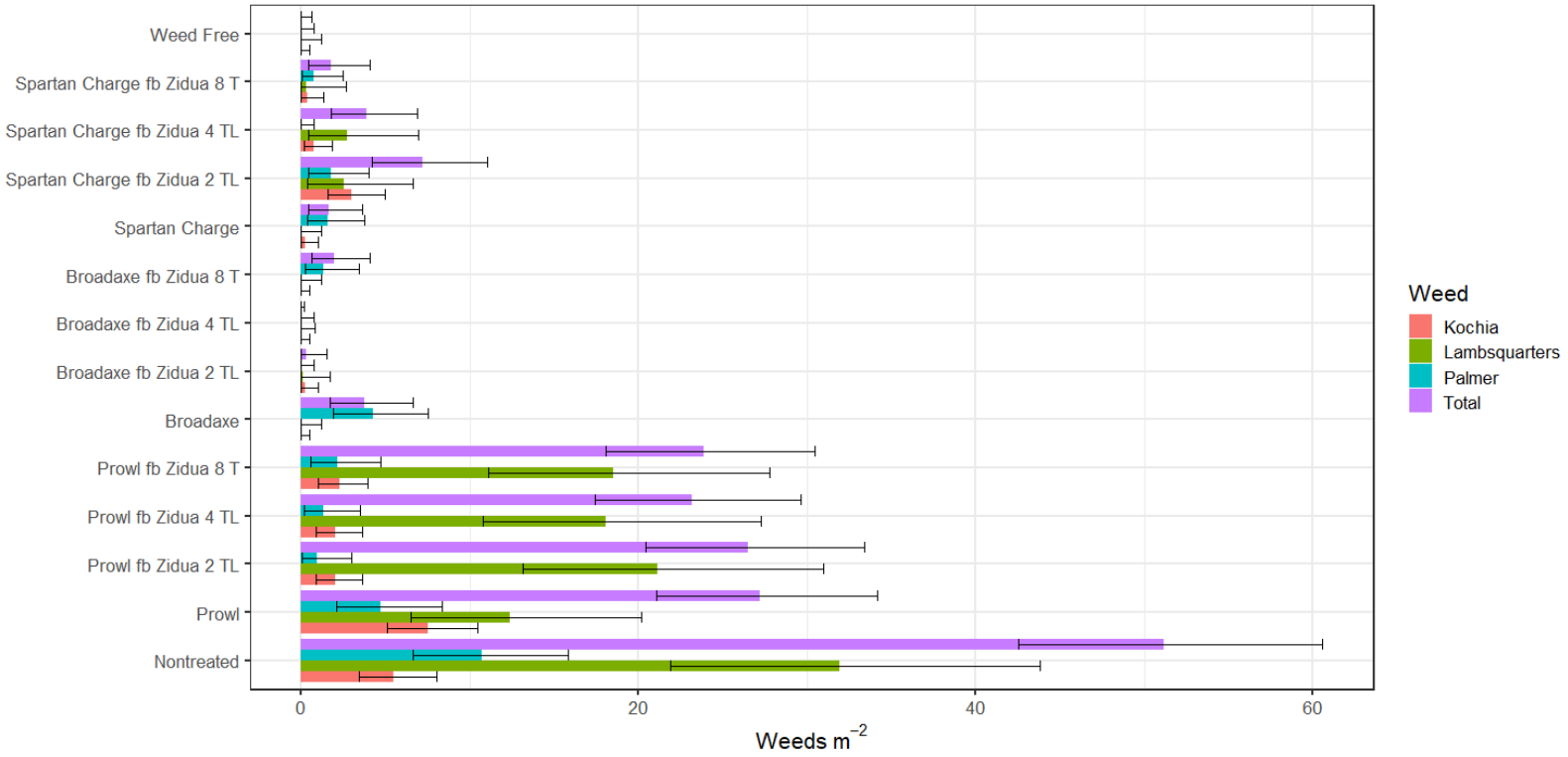

Figure 1. Effect of various PRE and PRE *fb* POST herbicide programs on weed density in sunflower at Scottsbluff, NE in 2019.