MANAGING WILD PARSNIP (*PASTINACA SATIVA*) IN TALLGRASS PRAIRIES

by

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Abstract

Pollinators thrive and provide key extensive ecosystem services when provided with sufficient habitat. Tallgrass prairies can provide sufficient habitat as they are often dominated by flowering plants throughout the year that provide resources to the development of pollinators. Wild parsnip (*Pastinaca sativa* L.) is an invasive monocarpic species that is common throughout the midwestern United States. *P. sativa* invades and displaces native forbs within tallgrass prairies which reduces biodiversity of plants and pollinators. While control of *P. sativa* can be easily accomplished with a range of approaches, the presence of native forbs limits methods that can control *P. sativa* to individual plant treatments as this limits injury to desirable forbs. Florpyrauxifen-benzyl is a new herbicide that many native forbs may be tolerant to, allowing it to be broadcasted, but its effectiveness on *P. sativa* is not known. Another approach that could limit native forb injury but control *P. sativa* could be to apply glyphosate to resprouting plants after a spring burn prior to native forb emergence. Studies evaluated the effectiveness of broadcast spraying florpyrauxifen-benzyl and spot treating glyphosate after spring burn as management technique in controlling *P. sativa* in infested tallgrass prairies. Studies also evaluated if techniques could improve native forb populations. Three experiments were conducted over three years to evaluate if 0.9-29.4 g ai ha-1 of florpyrauxifen-benzyl broadcast controls *P. sativa* when applied in spring. One separate experiment was done to assess the benefit in an invaded tallgrass prairie, application of florpyrauxifen-benzyl (14.7 g ai ha-1) alone and or florpyrauxifen-benzyl (11 g ai ha-1) mixed with imazapic (35 g ae ha-1) were compared to a non-treated control. One experiment was conducted in order to evaluate the effectiveness of applying 2% glyphosate after a spring burn. Results found both approaches were successful in reducing *P. sativa* populations, with florpyrauxifen-benzyl removing more (90-

100% reduction) than burn + glyphosate (45-52% density reduction) 2 months after treatment. While, total native forb cover decreased as a result of both approaches, the impact was not severe one year after application (< 25% cover reduction). Given that native forb response was species specific, future research should evaluate the range of tolerances that different species have to inform management approaches of *P. sativa* in tallgrass prairies

Introduction

Tallgrass prairies are an important ecosystem in the United States that provide a myriad of services. Foremost, they are biodiversity hotspots that support rare and endangered plants and animals (Harmon-Threatt & Chin 2016; Swengel *et al.* 2011). Additionally, tallgrass prairies are carbon sinks (Jobbagy' & Jackson' 2000), reduce soil erosion, and provide a space for cultural practices (Bengtsson *et al.* 2019). These services have been reduced on the landscape as >95% of land area that was historically tallgrass prairie has been converted to other ecosystems (e.g., farmland and urban areas) that do not provide these services (Samson *et al.* 2004; Samson & Knopf 1994). To offset this loss, efforts to conserve remnant prairies and creation of new prairies have been occurring over the past 50 years (Bach & Kleiman 2021; Samson & Knopf 1994).

Invasive plant species are a major threat to remnant and new tallgrass prairies and the ecosystem services they provide. They reduce biodiversity in prairies (Vitousek *et al.* 1997) by interfering with the establishment of native plants (Pearson *et al.* 2018). Other ecosystem processes can also be impacted by invasive plants such as soil erosion control (Castro-Díez *et al.* 2019), nutrient cycling (Vilà *et al.* 2011), fire regimes (Brooks *et al.* 2004) and hydrology (Levine *et al.* 2003). Their presence is particularly troublesome when attempting to establish/restore native species to this and other ecosystems (Erskine Ogden & Rejmánek 2005; Paz-Kagan *et al.* 2019).

Wild parsnip (*Pastinaca sativa* L.) is an invasive plant that is problematic to tallgrass prairies of the Midwest. It is a monocarpic perennial, native to Eurasia (Averill & DiTommaso 2007) that is widespread throughout the Midwest with over 23,000 observations documented in public record (EDDMapS 2025). Many habitats are susceptible to invasion, but grasslands are particularly vulnerable, including tallgrass prairies (Jorgensen & Renz 2021). In these areas, it

readily forms large infestations (Thompson & Price 1977; Zangerl & Berenbaum 2005). If *P. sativa* becomes established, it can compete with native species reducing their cover (Cain *et al.* 2010). *Pastinaca sativa* also threatens human health as it can cause phytophotodermatitis when sap comes in contact with skin (Averill & DiTommaso 2007).

There are several management options available to control *P. sativa*. Properly timed mowing and hand-pulling/cutting crowns below the soil surface is effective (Lorenzi & Jeffrey 1987). The high amount of labor required for hand removal/cutting limits the use of this management tool in widespread infestations in tallgrass prairies. While mowing is also effective, it must be repeated for multiple years, reducing desirables forbs. Several herbicides are efficacious on *P. sativa* and can provide multiple years of control with one application. For example, triclopyr, picloram, 2,4-D, dicamba, and glyphosate applied in the spring can control second-year rosettes and seedlings that will flower in subsequent years (Cain *et al.* 2010; Panke & Renz 2012). While these herbicides are effective on *P. sativa* and most will not harm established native grasses, they injure and often eliminate native forbs that are growing nearby (Lym *et al.* 2017). Therefore, herbicides need to be applied to individual plants to minimize injury to desirable forbs. While this may be feasible for small, scattered populations it is not a viable option for prairies that have widespread, dense invasions. Interest exists in finding herbicides that have limited injury to native forbs while providing control of *P. sativa*. If found, broadcast applications in tallgrass prairies could be utilized to minimize the impact of *P. sativa*.

Florpyrauxifen-benzyl is a selective herbicide that may fit this application. This synthetic auxin (group 4) is currently used as a broad-spectrum broadleaf herbicide in rice and aquatic habitats; initial reports suggest it is very selective at low rates (Velásquez *et al.* 2021). Florpyrauxifen-benzyl was recently registered for use in terrestrial areas and is reported to be

effective on plants in the Apiaceae (Carrot Family) at low rates (US EPA 2017). Others have shown variable tolerance of broadleaf plants at low rates (Greene *et al.* 2022) which suggest it may be well suited for tallgrass prairies.

To address the lack of knowledge on the effectiveness of florpyrauxifen-benzyl on *P. sativa* and to test if native forbs are tolerant in infested tallgrass prairies, a series of experiments were conducted between 2022 - 2024. Three experiments were conducted at two locations to test the efficacy of florpyrauxifen-benzyl and determine the minimum rate that is effective at controlling *P. sativa*. An additional experiment was established in an infested tallgrass prairie to determine if broadcast applications of florpyrauxifen-benzyl can increase native forb cover by controlling *P. sativa*.

Materials & Methods

Experiment 1: Florpyrauxifen-benzyl Rate Response

Location

The experiments were conducted at 3 locations within *P. sativa* infested grasslands between 2022-2024. The 2022 experiment was in a 5-year-old planted prairie near New Richmond Wisconsin (45.16°N, -92.49°W) while both the 2023 and 2024 experiments were along an infested roadside near Prairie Du Sac Wisconsin (PDS) (43.34°N, -89.75°W). The predominant soil type at both locations was a silt loam (New Richmond:14% clay, 0.6% organic matter, 5.9 pH; PDS:21% clay, 1.0% organic matter, 6.4 pH. New Richmond and PDS were dominated by smooth brome (*Bromus inermis* Leyss.) and Kentucky bluegrass (*Poa pratensis* L.). Native forbs wild bergamot (*Monarda fistulosa L.*), golden alexanders [*Zizia aurea* (L.) W.D.J. Koch], and yellow coneflower [*Ratibida pinnata* (Vent.) Barnhart] were present at New

Richmond, while only non-native forbs Spotted knapweed (*Centaurea stoebe* L.) and sweetclover [*Melilotus officinalis* (L.) Lam.] were common at PDS. *P. sativa* was widespread at each location with average spring densities of 1.3, 3.9, and 1.5 m^2 at new Richmond, PDS 2023 and PDS 2024 respectively.

Experimental Design

Florpyrauxifen-benzyl was applied at a range of rates in a randomized complete block design, with four replications at PDS and three replications at New Richmond. The plot size for all experiments was 3.0 by 7.6 m (10 by 25 ft). Treatments were applied on May 3rd 2023 and 2024 on at PDS and May 27th at New Richmond using a CO2 pressurized 3-meter (10 foot) boom sprayer at 187 L ha^{-1} (20 GPA) with 8, Teejet XR 11002VS nozzles spaced 381 mm (15-inch) apart. A methylated seed oil was added at 1% v/v to all treatments. The initial experiment (New Richmond) evaluated florpyrauxifen-benzyl at 0, 3.7, 7.4, 11.0 and 14.7 g ai ha^{-1}. Results informed the rates selected for PDS which encompassed 3.7-29.4 and 0.9-29.4 g ai ha^{-1} of florpyrauxifen-benzyl in 2023 and in 2024 respectively (Table 1).

Measurements

P. sativa density and cover were measured at each location to determine the effectiveness of treatments. Density was determined approximately two months after application (July) by counting all plants within each plot. *P. sativa* was categorized as non-flowering or flowering. Cover was visually estimated at this timing at New Richmond and PDS 2024, with the cover separated into *P. sativa*, native broadleaf, non-native broadleaf, native grasses, non-native grasses, woody plants, and litter. Density of flowering *P. sativa* was also evaluated 1 year after treatments to evaluate ability to prevent seed production over a two-year timeframe (New Richmond and PDS 2023 only).

Statistical Analysis

Statistical analyses were performed using the open-source statistical software R 4.4.2 (R Core Team, 2024). Dose response curves were initially attempted to be fit to density data using the drc package (Ritz *et al.* 2015). Lack of data surrounding the inflection point and upper plateau for each experiment prevented a good fit and resulted in parameters with confidence intervals an order of magnitude greater than the applied rates. Therefore, a two-way analysis of variance (ANOVA) was used to determine differences in density among treatments ($p<0.05$). If a difference existed, a Fisher Least Significant Difference (LSD) was used to separate means ($p<0.05$). Plant cover was analyzed similarly to the density using data from year of and/or 1 year following application.

Experiment 2: Tallgrass Prairie Florpyrauxifen-benzyl Application

Location

The experiment was conducted from June 2023 through August 2024 (Erikson), in an established 15-year-old planted tallgrass prairie near New Richmond Wisconsin (45.09°N, 92.29°W). The predominant soil type at Erikson Prairie trial is Santiago silt loam and has the same characteristics as the New Richmond site (see above). Erikson prairie contained 27 different native forb species which averaged 64 % of the cover and 6 native grass species which averaged 9% of the cover. The most common native forb species (> 5% cover) were a mixture of Asters (*Aster spp.*), cleavers (*Galium aparine* L.), *M. fistulosa*, *R. pinnata,* black-eyed Susan (*Rudbeckia hirta* L.)*,* cup plant (*Silphium perfoliatum* L.), Canada goldenrod (*Solidago altissima* L.)*, and Z. aurea*. The most common native grasses (> 5% cover) were big bluestem

(*Andropogon gerardii* Vitman) and Indian grass [*Sorghastrum nutans* (L.) Nash]. While non-native forbs were uncommon, *P. sativa* was widespread.

Treatments & Experimental Design

Based on results from New Richmond, florpyrauxifen-benzyl at 14.7 g ai ha^{-1} was evaluated for *P. sativa* control. A lower rate of florpyrauxifen-benzyl (11.0 g ai ha^{-1}) mixed with imazapic (35.0 g ai ha^{-1}) was included as imazapic is often recommended for control in areas that contain native forbs (Anonymous 2023), and florpyrauxifen-benzyl is currently recommended for use only when mixed with other products for terrestrial weed control (personal communication Corteva, J. Crose). These treatments were compared to a non-treated control. The treatments were arranged in a randomized complete block design, with four replications. The plot size was 15.2 by 3 m (50 by 10 ft). Treatments were applied on June 19th using a boomless nozzle (Boom buster 180-10) mounted to an ATV Sprayer (Gator Pros) at 253 L ha^{-1} (27 GPA). A Methylated seed oil at 1% v/v was added to the treatments. Treatments were delayed one month compared to previous experiments as the location was in a severe drought (57 % lower than normal), therefore applications were delayed until precipitation occurred (June 11th, 23 mm) to minimize this impact on results.

Measurements

P. sativa density was evaluated 1 and 13 months after treatment (MAT) and plant cover were measured 12 and 15 MAT to determine the effectiveness of treatments and impact on plants present. While density was estimated similar to experiment 1, percent cover was estimated using the point intercept method where each individual plant intercepting a point is recorded (Elzinga et al. 1998). To accomplish this, fifty points were established at 0.3 m intervals along a 15.2 m transect in each plot. Results are presented for common species that were in high abundance.

Functional groups native forbs, non-native forbs, native woody, non-native woody, native grasses, and non-native grasses were also created from these data and analyzed. We sought to assess if the quality of this native habitat was improved by treatment, so we utilized a floristic quality index called the coefficient of conservatism (CoC). This approach determines a coefficient for each plant species between 0-10 with highly conserved species receiving high values and common/weedy species low values. Non-native species by default receive zero. The mean weighted C-values of the prairie are then calculated by multiplying the cover of each species by the C-value, summing all of these values and then dividing this value by the total cover of all plant species (Rooney and Rogers 2002). A mean weighted C-value was determined for each plot with cover data collected one year after treatment. C-values for each species were taken from the Online Virtual Flora of Wisconsin website (Wisflora 2025).

Statistical Analysis

Two-way ANOVA were performed on the common individual species cover, functional groups cover, C weighted means, *P. sativa* cover and density at each timing similar to experiment 1 with a $p<0.05$ and means separated by LSD if differences existed.

Results/Discussion

Experiment 1: Florpyrauxifen-benzyl Rate Response

While temperatures during both years did not differ from the twenty-year average during the growing season, precipitation was atypical across all three years of the experiments (2022-2024). At New Richmond precipitation was 65% higher in May but 57% less in June-July compared to the twenty-year average. At PDS in 2023 a drought resulted in 81% less

precipitation in May-June, but this location received 40% more precipitation the following spring-summer (May-July) compared to twenty-year averages (Table 2).

Despite the abnormal precipitation patterns observed across locations, *P. sativa* density was reduced to nearly zero with the lowest rate within each of the three experiments. Florpyrauxifen-benzyl applied at 3.7 g ai ha^{-1} resulted in <0.3 *P. sativa* plants m^{-2} at New Richmond and PDS 2023, while 0.9 g ai ha^{-1} had <0.1 *P. sativa* plants m^{-2} at PDS in 2024 two MAT (Table 1). Similar to density, all treatments reduced *P. sativa* cover to <1% 2 MAT (Table 4). These results are similar to reported effectiveness other herbicides used for *P. sativa* control including 2,4-D, aminocyclopyrachlor, dicamba, glyphosate, and metsulfuron (Panke & Renz 2012). While many prefer non-chemical approaches to management, these are less efficacious as it can take up to six years to see a significant effect on *P. sativa* density (Lorenzi & Jeffrey, 1987). As *P. sativa* is a monocarpic perennial, it is dependent on seed production for its populations to persist. It was hypothesized that reduced rates of florpyrauxifen-benzyl may not control all plants but would prevent flowering which would eliminate seed production. Contrary to this hypothesis, the effectiveness was similar at the lowest rate applied between total, rosette, and flowering *P. sativa* plants. As *P. sativa* plants don't flower until at least one year after germination (Baskin & Baskin 1979), it was of interest to determine if broadcast applications that target seedling and > 1 year old plants can prevent seed production for two years from one application. While it took up to 14.7 g ai ha^{-1} to eliminate flowering *P. sativa* at PDS 2023 one year after treatment (YAT), this was accomplished at 7.4 g ai ha^{-1} at New Richmond and was not statistically different than the 3.7 g ai ha^{-1} rate at either location (Table 3). As *P. sativa* seeds have been estimated to persist in the soil bank for at least two years (Hendrix & Trapp 1992) additional control wouldn't be needed until the third year with florpyrauxifen-benzyl broadcasted

treatments and potentially could eliminate populations with that application if no additional seed was introduced to the site. These results agree with other researchers found florpyrauxifen-benzyl controlled other invasive species like Navua sedge [*Cyperus aromaticus* (Ridley) Mattf. & Kukenth] (Chadha *et al.* 2022), yellow floating heart [*Nymphoides peltata* (S. G. Gmel.) Kuntze] (Lam *et al.* 2021), common cattail (*Typha latifolia* L.) (Inci *et al.* 2024), parrotfeather watermilfoil [*Myriophyllum aquaticum* (Vell.) Verdc.] and alligatorweed [*Alternanthera philoxeroides* (Mart.) Griseb.] (Howell *et al.* 2022) respectively, albeit at higher rates. In rice, florpyrauxifen-benzyl has been found to suppress annual grass and broadleaf weeds at higher rates as well (30 g ai ha^{-1}) (Beesinger *et al.* 2022; Miller & Norsworthy 2018). Lower rates similar to what was used in this study (9 g ai ha^{-1}) have been found to be effective at controlling annual broadleaf weeds, but 2,4-D (560 g ai ha^{-1}) was added to this treatment (Greene *et al.* 2022). Given the range of precipitation patterns observed from these three locations (from drought to excess), results provide strong evidence that low rates (0.9 - 3.7 g ai ha^{-1}) would be effective at *P. sativa* control across a wide range of environmental conditions.

Cover of functional groups was not affected by florpyrauxifen-benzyl application at New Richmond or PDS 2024 (Table 4). While florpyrauxifen-benzyl had activity on both grasses and broadleaf weeds in rice (30 g ai ha^{-1}) (Beesinger *et al.* 2022; Miller & Norsworthy 2018), we did not observe any injury to grasses. The reduced rates applied in our experiments in combination with the perennial nature of grasses compared to their results likely both contribute to this difference. Others have shown limited injury to perennial grasses from florpyrauxifen-benzyl (Greene *et al.* 2022; Teló *et al.* 2019). Varying efficacy was expected on perennial forbs based on results from aquatic herbicides trials. Howell *et al.* (2022) found that watermilfoil (*Myriophyllum triphyllum* Orchard) was highly sensitive while species like oxygen-weed [*Lagarosiphon major*

(Ridley) Moss] and Canadian waterweed (*Elodea canadensi*s Michx.) were less sensitive. They also found that Brazilian waterweed (*Egeria densa* Planch.) was very tolerant to florpyrauxifen-benzyl. Broadleaf plant cover was not reduced due to florpyrauxifen-benzyl at new Richmond or PDS in 2023 (Table 4). While species composition was very different at each location (native and non-native perennials new Richmond, invasive perennials PDS 2023) it suggests florpyrauxifen-benzyl may be active on a small subset of broadleaf species (e.g. *P. sativa*) with little to no damage to many. Research is required to determine how consistent this response is among native forb species.

Experiment 2: Tallgrass Prairie Florpyrauxifen-benzyl Application

Temperature during both years did not differ from the twenty-year average at Erikson, however precipitation was atypical in both years. In 2023, there was 46% less precipitation in May-June while July received 57% more than the twenty-year average. In 2024, there was 67% more precipitation in May-June while July received 42% less precipitation than the twenty-year average (Table 2).

P. sativa was controlled with florpyrauxifen-benzyl alone and when mixed with imazapic. Both treatments reduced total *P. sativa* density by 55-62% 1 MAT, but flowering *P. sativa* was only reduced from florpyrauxifen-benzyl mixed with imazapic (Figure 1). Both treatments continued to provide control the following year as reductions in density were observed in total (82-90%), rosette (91-95%) and flowering (74-86%) *P. sativ*a compared to the non-treated control (Figure 2). *P. sativa* cover was similarly reduced by both treatments as cover was 1% 1 YAT (Table 5). Control was initially not as effective as results in experiment 1 but results were

similar 1 YAT (Table 1). Treatments were sprayed later in the year when plants were larger and at a different phenological stage (June; bolting) than experiment #1 (May; rosettes) which could account for the reduced effectiveness. Despite the later timing of application (June vs May) and potential drought stress of plants, these results confirm the high level of efficacy of florpyrauxifen-benzyl on *P. sativa*.

Native forbs were injured as a result of treatment. Injury 1 MAT was specific to the species but ranged from 13-100% among common forbs (data not shown). This resulted in a 32% reduction in total native forb cover from florpyrauxifen-benzyl (14.7 g ai ha^{-1}) 1 YAT and a 18% decrease in 1.5 YAT (Table 6). The reduced rate of florpyrauxifen-benzyl (11.0 g ai ha^{-1}) + imazapic (35 g ai ha^{-1}) did not have a reduction in forb cover 1 or 1.5 YAT suggesting reduced rates of florpyrauxifen-benzyl may lessen the impact to native forb cover. Individual native forbs responded differently to treatments 1 and 1.5 YAT. Cover of *R. pinnata and Z. aurea* were greatly impacted (cover reduced by > 60%) in both treatments at both timings *and Solidago spp.* cover was reduced by 49% from florpyrauxifen-benzyl (1 YAT only). *Z. aurea* is a member of the Apiaceae family and therefore is a target species of florpyrauxifen-benzyl. However, *aster spp., G. aparine, M. fistulosa, R. hirta* and *S. perfoliatum* cover was not reduced by either treatment (Table 6). A later spray date could have allowed for more florpyrauxifen-benzyl to be absorbed by native species due to forbs being larger and more established. While there is no research on native forbs that are tolerant to florpyrauxifen-benzyl, varying injury has been observed with other herbicides. Mikkelson and Lym (2013) found that forb tolerance to aminopyralid was species specific. Specifically azure aster [*Symphyotrichum oolentangiense* (Riddell) G.L.Nesom], purple coneflower [*Echinacea purpurea* (L.) Moench], and closed bottle gentian (*Gentiana andrewsii* Griseb.) were the most tolerant to aminopyralid while *r. pinnata*, great blue

lobelia (*Lobelia siphilitica* L.), harebell (*Campanula rotundifolia* L.), and white prairie clover (*Dalea candida* Michx. ex Willd.) were the most susceptible and likely would be killed. Similarly, Carter and Lym (2018) found native forb tolerance to aminocyclopyrachlor also was species specific. Species within the Apiaceae family like *Z. aurea* should be considered when spraying considering this species abundance especially wet-mesic and wet prairies.

As conservation value of native forbs varies among species, we used the mean weighted CoC values to evaluate if treatments impacted the overall floristic quality of this prairie. We found a 26-35% decrease in mean weighted CoC from either treatment compared to the nontreated control (Figure 3). This is likely driven by the reduction of cover of *z. aurea,* as it was common (>15% cover) and its CoC value (7) was the highest of the species observed at the Erikson prairie. While grass cover (native and non-native) was not reduced by treatments, non-native forbs (excluding *P. sativa*) were also reduced (59% 1 YAT) but this did not persist 1.5 YAT (Table 5).

Results demonstrate that florpyrauxifen-benzyl is an effective herbicide that can control *P. sativa* at rates as low as 0.9 g ai ha^{-1}. While applications at rates of 11.0-14.7 g ai ha^{-1} were safe to perennial grasses, some forbs were sensitive to these rates and were reduced in cover. While lowering the rate of florpyrauxifen-benzyl below 11 g ai ha^{-1} applied may mitigate the injury to desirable forbs, altering the application method may also be needed to limit contact to sensitive species. Further research is needed to understand which native forbs are being affected and if rates can be reduced enough to prevent injury while maintaining control of control *P. sativa*. The lack of increase of native forb or native grass cover as a result of one year of *P. sativa* control suggests that this invasive plant is not competing with native forbs/grasses. As results are from one field study with a specific combination of native forbs, and moderate infestation (17%

P. sativa cover), additional research at multiple locations for multiple years is needed to assess the consistency of this response in infested tall grass prairies.

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Tables

Table 1. Density of flowering and non-flowering *Pastinaca sativa* two months after spring treatments of florpyrauxifen-benzyl at three locations in Wisconsin.[a]

	New Richmond 2022						PDS[b] 2023						PDS 2024					
	Rosette		Flowering		Total		Rosette		Flowering		Total		Rosette		Flowering		Total	
Florpyrauxifen-benzyl	*Pastinaca sativa* density																	
g ai ha^{-1}	---------- m^2 ----------																	
NTC	0.43	a	0.79	a	1.23	a	0.48	a	2.80	a	3.28	a	0.33	a	0.47	a	0.80	a
0.9	-		-		-		-		-		-		0.01	b	0.03	b	0.04	b
1.8	-		-		-		-		-		-		0.00	b	0.03	b	0.03	bc
2.8	-		-		-		-		-		-		0.00	b	0.03	b	0.03	bc
3.7	0.12	b	0.09	b	0.21	b	0.12	b	0.04	b	0.16	b	0.00	b	0.01	b	0.01	bc
7.4	0.21	a b	0.09	b	0.30	b	0.08	b	0.03	b	0.11	b	0.00	b	0.00	b	0.00	c
11.0	0.01	b	0.00	c	0.01	c	0.01	b	0.03	b	0.04	b	-		-		-	
12.0	-		-		-		0.03	b	0.03	b	0.05	b	-		-		-	
14.7	0.10	b	0.01	c	0.12	bc	0.03	b	0.00	b	0.03	b	0.02	b	0.00	b	0.02	bc
18.4	-		-		-		0.03	b	0.04	b	0.07	b	-		-		-	
22.1	-		-		-		0.05	b	0.01	b	0.07	b	0.00	b	0.00	b	0.00	c
25.7	-		-		-		0.03	b	0.00	b	0.03	b	-		-		-	
29.4	-		-		-		0.00	b	0.00	b	0.00	b	0.00	b	0.00	b	0.00	c
p-value	0.03		<0.01		0.02		<0.01		<0.01		<0.01		<0.01		<0.01		<0.01	

[a] Means followed by the same letter within a column are not different based on Fisher's LSD (a = 0.05).

[b] PDS, Prairie Du Sac Wisconsin

Table 2. Monthly average temperature and total precipitation and 20-year historical averages at New Richmond (2022-2024) and Prairie Du Sac (2023 and 2024) Wisconsin. Sources: National Weather Service (2024).[a]

	New Richmond [b]								PDS 2023 & 2024 [c]					
	Precipitation				Temperature				Precipitation			Temperature		
	----------mm----------				----------°C----------				----------mm----------			----------°C----------		
Month	Historical average	2022	2023	2024	Historical average	2022	2023	2024	Historical average	2023	2024	Historical average	2023	2024
January	21	11	45	4	-12	-16	-8	-7[a]	33	47	45	-8	-4	-6
February	20	17	54	15	-9	-13	-10	-1[a]	34	76	17	-6	-4	1
March	39	51	57	69	-2	-3	-5	2[a]	49	81	54	1	0	3
April	70	77[a]	75	72	6	3	5	9[a]	98	92	117	7	8	8
May	101	165	58	173	13	13	15	16[a]	110	30	192	14	15	16
June	132	58	67	215	19	19	20	19[a]	135	17	320	20	20	20
July	105	45	165	61	21	21	20	22[a]	108	117	202	22	22	21
August	125	154	59	158	20	19	19	21[a]	105	82	61	21	21	21
September	86	36	90	5	15	15	17	19[a]	100	71	101	16	19	18
October	71	14	124	15	8	9	10[a]	13[a]	61	68	77	10	11	12
November	40	61	1	66	0	0	1[a]	3[a]	57	15	84	2	2	5
December	28	46	47	30	-8	-11	0[a]	-5[a]	39	32	29	-5	1	-4
Total	837	735	842	884	NA	NA	NA	NA	928	726	1300	NA	NA	NA

[a] Data was not available at the closest station therefore was collected from station 23 miles away.

[b] Data taken from a nearby weather station in Baldwin, WI. New Richmond and Erickson experiments were within 1 km of each other

[c] PDS 2023 data was taken from Sauk City WWTP, WI weather station 7 miles away.

Table 3. Density of flowering Pastinaca sativa 1 year after treatments of florpyrauxifen-benzyl at two locations in Wisconsin[a]

Florpyrauxifen-benzyl	New Richmond 2022	PDS 2023
	Pastinaca sativa flowering density	
g ai ha^{-1}	----------m^2----------	
NTC	0.15 a	0.67 a
3.7	0.01 b	0.07 bc
7.4	0.00 b	0.38 b
11.0	0.00 b	0.04 bc
12.0	-	0.07 bc
14.7	0.00 b	0.00 c
18.4	-	0.00 c
22.1	-	0.01 bc
25.7	-	0.03 bc
29.4	-	0.00 c
p-value	0.04	<0.01

[a] Means followed by the same letter within a column are not different based on Fisher's LSD (a = 0.05).

Table 4. Estimate of relative cover of *Pastinaca sativa* and functional groups 2 months after treatments of florpyrauxifen-benzyl at two locations in Wisconsin. Cover was visually estimated for each functional group and *P. sativa* so that the total cover for any plot equaled 100%.[a]

	New Richmond 2022						PDS 2024[b]					
	Pastinaca sativa	Native broadleaf	Non-native broadleaf	Native grass	Non-native grass	Litter	*Pastinaca sativa*	Native broadleaf	Non-native broadleaf	Native grass	Non-native grass	Litter
Florpyrauxifen-benzyl	Cover											
g ai ha^{-1}	----------%----------											
NTC	4 a	8	38	1	20	29 b	18.0 a	0	5	0	7	15
0.9	-	-	-	-	-	-	0.8 b	0	6	0	9	13
1.8	-	-	-	-	-	-	0.3 b	0	6	0	8	11
2.8	-	-	-	-	-	-	0.8 b	0	6	0	9	6
3.7	1 b	3	17	3	22	54 a	0.3 b	0	6	0	8	14
7.4	1 b	2	12	2	21	63 a	0.0 b	0	7	0	8	18
11.0	0 c	2	19	7	19	53 a	-	-	-	-	-	-
14.7	1 bc	1	12	2	20	65 a	0.3 b	0	10	0	8	15
22.1	-	-	-	-	-	-	0.0 b	0	6	0	9	10
29.4	-	-	-	-	-	-	0.0 b	0	8	0	7	19
p-value	<0.01	0.15	0.26	0.10	1.00	0.02	<0.01	NA	0.83	NA	0.15	0.82

[a] Means followed by the same letter within a column are not different based on Fisher's LSD (a = 0.05).

[b] Cover data was not taken in the 2023 at this location.

Table 5. Estimate of cover of *Pastinaca sativa* and functional groups 1 & 1.5 years after treatments at Erikson prairie in Western Wisconsin. Cover was estimated using the point intercept method. As the prairies consisted of multiple species within different levels of the canopy, total cover can exceed 100%. [a]

Treatment	*Pastinaca sativa*		Native forbs		Non-native forbs		Native woody		Native grasses		Non-native grasses	
	1 YAT[b]	1.5 YAT	1 YAT	1.5 YAT	1 YAT	1.5 YAT	1 YAT	1.5 YAT	1 YAT	1.5 YAT	1 YAT	1.5 YAT
g ai ha^{-1}	----------% Cover----------											
NTC	12 a	21 a	78 a	80 a	29 a	48	7	38	9	25	94	93
florpyrauxifen-benzyl 14.7	1 b	9 b	53 b	66 b	24 ab	30	16	20	14	32	97	93
florpyrauxifen-benzyl 11.0 + imazapic 35.0	1 b	7 b	61 ab	74 ab	12 b	39	3	26	4	18	98	97
p-value	<0.01	<0.01	0.03	0.03	0.04	0.20	0.14	0.05	0.14	0.65	0.20	0.54

[a] Means followed by the same letter within a column are not different based on Fisher's LSD (a = 0.05)

[b] YAT, years after treatment

Table 6. Estimate of cover of individual species 1 &1.5 years after treatments at Erikson prairie. Cover was estimated using the point intercept method. As the prairies consisted of multiple species within different levels of the canopy, total cover can exceed 100%. [aa]

Treatment	*Aster spp.*		*Galium aparine*		*Monarda fistulosa*		*Ratibida pinnata*		*Rudbeckia hirta*		*Silphium perfoliatum*		*Solidago spp.*		*Zizia aurea*	
	1 YAT[b]	1.5 YAT	1 YAT	1.5 YAT	1 YAT	1.5 YAT	1 YAT	1.5 YAT	1 YAT	1.5 YAT	1 YAT	1.5 YAT	1 YAT	1.5 YAT	1 YAT	1.5 YAT
g ai ha^{-1}	----------% Cover----------															
NTC	22	22	1	1	4	4	6 a	10 a	11	8	4	2	39 a	48	23 a	18 a
florpyrauxifen-benzyl 14.7	17	19	2	0	7	7	4 a	0 b	11	9	1	2	20 b	41	2 c	1 b
florpyrauxifen-benzyl 11.0 + imazapic 35.0	14	19	10	0	7	5	0 b	1 b	11	12	3	2	35 ab	48	9 b	5 b
p-value	0.10	0.62	0.08	0.65	0.63	0.73	<0.01	<0.01	0.87	0.48	0.09	0.82	0.04	0.49	<0.01	<0.01

[a]Means followed by the same letter within a column are not different based on Fisher's LSD (a = 0.05).

[b] YAT, years after treatment

Figures

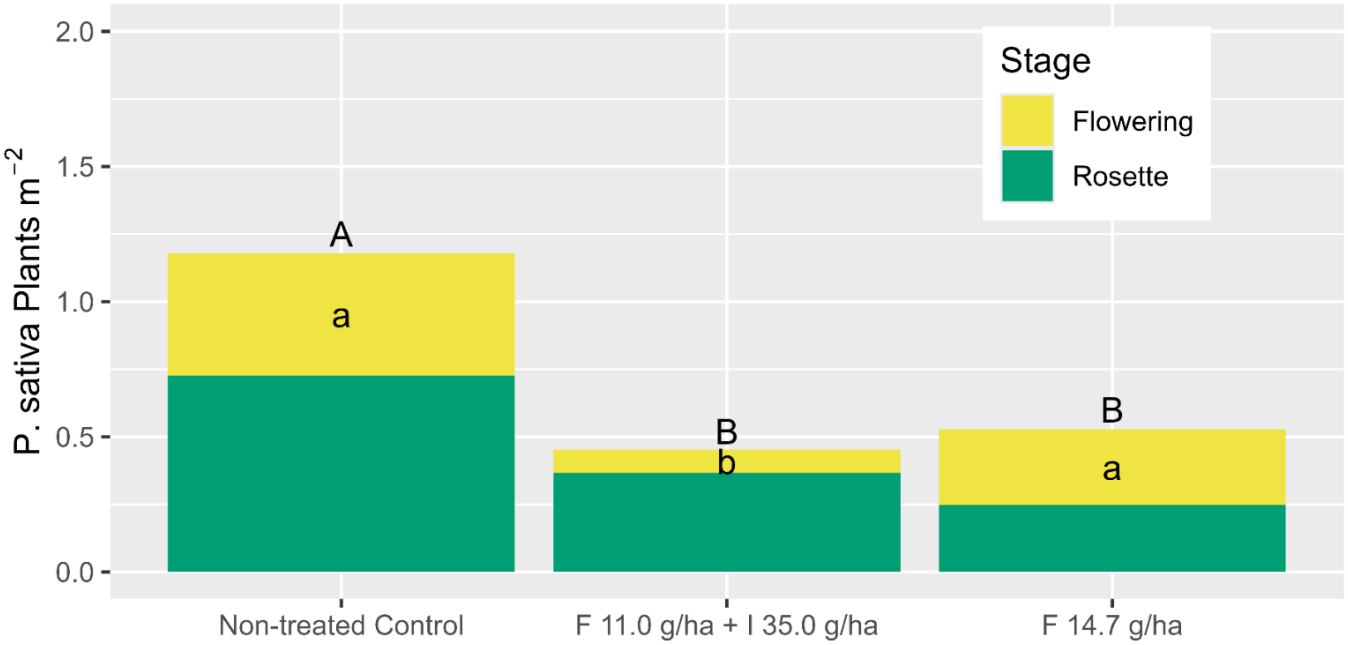

Figure 1. *Pastinaca sativa* average flowering (yellow) and non-flowering (green) density m^{-2} two month after treatment of florpyrauxifen-benzyl (F) and F + imazapic (I). Herbicide treatments were applied in June 2023 when *P. sativa* seedlings, rosettes and bolting plants were present. Letters followed by the same letter within a column are not different within flowering stage (lowercase) or total (uppercase) among treatment means based on Fisher's LSD (a = 0.05). No differences in non-flowering *P. sativa* density were observed (p = XX). Herbicide rates for florpryauxifin were either 11.0 or 14.7 g ai ha^{-1}. When imazapic was included the rate used was 35.0 g ai ha^{-1}.

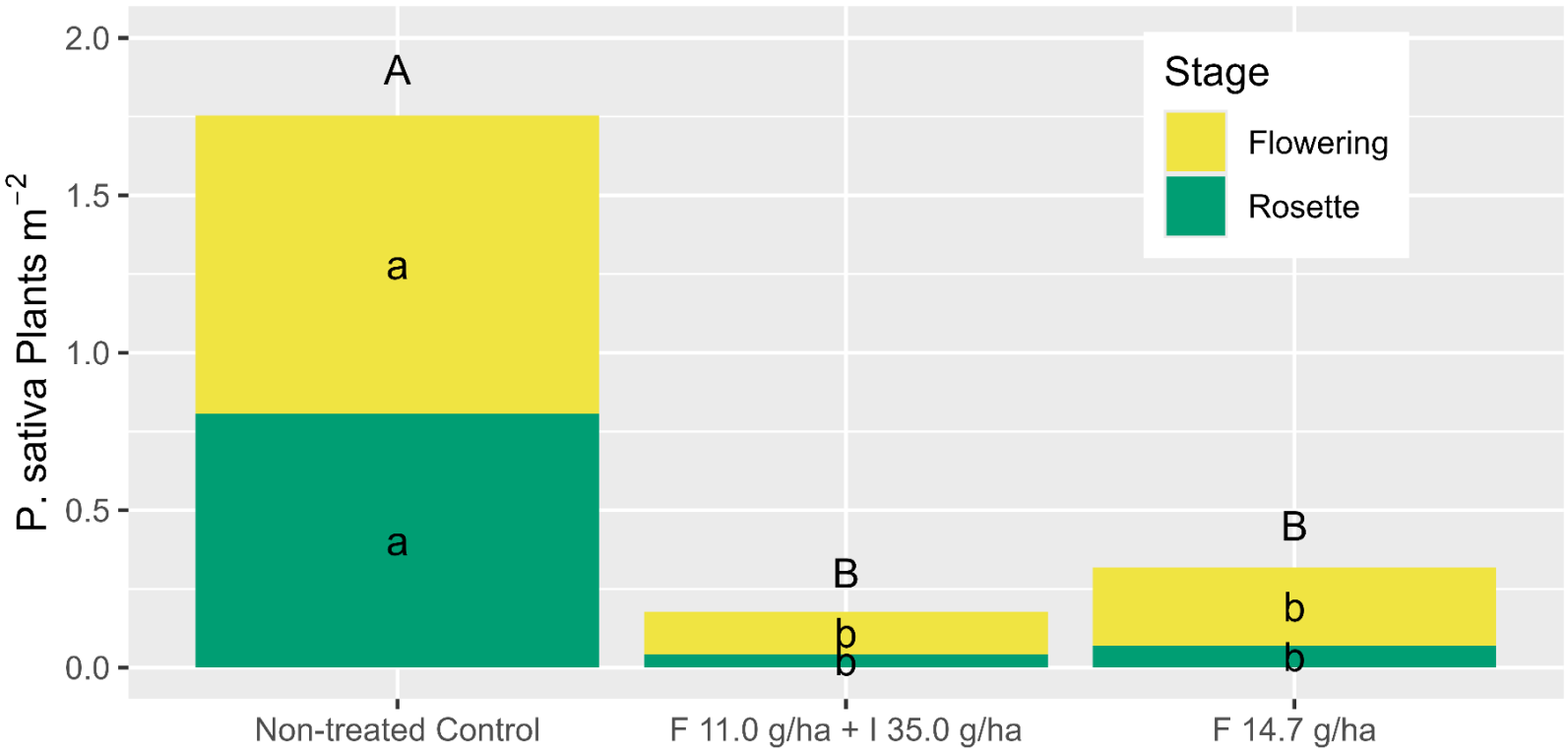

Figure 2. *Pastinaca sativa* average flowering (yellow) and non-flowering (green) density m^{-2} one year after treatment of florpyrauxifen-benzyl (F) and F + imazapic (I). Herbicide treatments were applied in June 2023 when *P. sativa* seedlings, rosettes and bolting plants were present. Letters followed by the same letter within a column are not different within flowering stage (lowercase centered in yellow), non-flowering stage (lowercase centered in green) or total (uppercase) among treatment means based on Fisher's LSD (a = 0.05). Herbicide rates for florpryauxifin were either 11.0 or 14.7 g ai ha^{-1}. When imazapic was included the rate used was 35.0 g ai ha^{-1}.

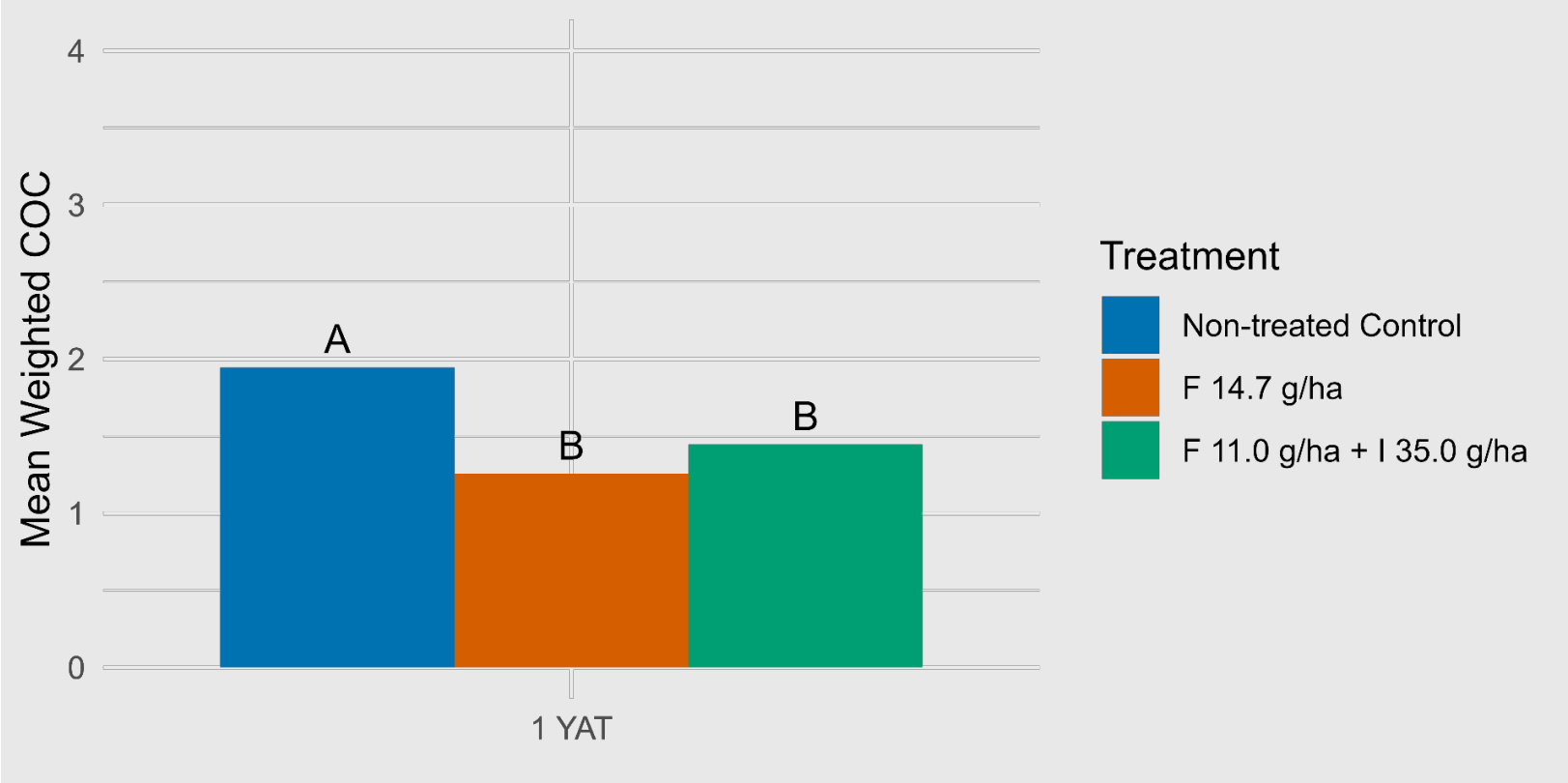

Figure 3. Mean weighted coefficient of conservation one year after treatment of florpyrauxifen-benzyl (F) and F + imazapic (I). Herbicide treatments were applied in June 2023 when *P. sativa* seedlings, rosettes and bolting plants were present. Letters followed by the same letter within a column are not different among treatment means based on Fisher's LSD (a = 0.05). Treatments included a non-treated control (blue), florpyrauxifen at 14.7 g ai ha^{-1} (orange) and florpyrauxifen (11.0 g ai ha^{-1}) + imazapic (35.0 g ai ha^{-1}) (green).

Introduction

Insect pollinators sustain diverse vegetation communities by facilitating reproduction of plants through the transfer of pollen (Michener 2007; Ollerton et al. 2011). However, they are in steep decline due to many factors like climate change, habitat loss and toxic pesticides (Nath *et al.* 2023). Tallgrass prairies are important plant communities that can help to conserve pollinating insect populations in the midwestern United States. They contain a wide range of plant species (up to 58 species m^{-2}) that flower sequentially throughout growing seasons (Soley & Wilsey 2025). This provides pollinators key resources like nectar and pollen that allows populations to flourish and provides services to natural and managed landscapes (Wratten *et al.* 2012). Invasive plants threaten pollinating insects by competing with desired native forbs. They reduce flowering plant diversity and richness of prairies they invade (Wilsey *et al.* 2011), diminishing the resources they provide to pollinating insects.

To counter these impacts invasive plants are actively managed in tallgrass prairies. If detected early, removal, hand pulling and herbicides applied to individual plants are recommended approaches (Byun *et al.* 2024). Many prairies, especially new and reconstructed prairies, have larger populations that require management approaches that are efficient across a larger area. Herbicides are rarely recommended in this situation as they risk widespread injury to native forbs, compromising the overall health of the prairie (Runquist *et al.* 2024). While mowing is common during establishment, it is not recommended in established prairies as it also damages native forb populations (Hassan & Wang 2024). Prescribe fire is a common tool implemented for invasive plant management. Tallgrass prairies evolved with periodic fire and many native prairie plants can benefit from this management approach. Research has demonstrated that burns can increase limiting resources (e.g. nitrogen; Dudley & Lajtha 1993)

which enhances plant and arthropod biodiversity (Van Dyke *et al.* 2007; Reed 1997). It can also reduce native woody populations (Nippert *et al.* 2021) which compete with native forbs.

Many studies have evaluated the effectiveness of prescribed fire as an invasive plant management tool. While results vary depending on the species and fire timing, intensity and frequency, annual invasive plants can be effectively controlled (Brancatelli *et al.* 2024; Ditomaso *et al.* 2006) but perennial plants are suppressed and rarely eliminated (Howe 2011). In midwestern United States prairies, early spring burns are most commonly applied prior to growth of native forbs and warm season grasses (Rave *et al.* 2013). These fires can suppress invasive species in prairies, as Ratcliffe *et al.* (2022) found that invasive cool-season grasses Kentucky bluegrass (*Poa pratensis* L.) and smooth brome (*Bromus inermis* Leyss.) were suppressed by repeated annual burns. However, these plants resprouted after the fire and additional management was needed to eradicate populations. Resprouting/growing after a spring burn is common with several invasive plants to midwestern prairies. Many biennial and perennial species like sweetclover (*Melilotus* spp.; Ditomaso *et al*. 2006), leafy spurge (*Euphorbia virgata* Waldst. & Kit.; Jacobs and Sheley 2003), Canada thistle [Cirsium arvense (L.) Scop.; Gramig and Ganguli 2015] and sulfur cinquefoil (Potentilla recta L.; Wolters et al. 1994) were not eradicated after fire.

While spring prescribed fire has limitations in controlling biennial and perennial invasive plants in prairies, they create an opportunity to conduct follow-up treatments with herbicides. This approach has been tested by others with success in controlling invasive plants. King et al. (2015) found that burning a prairie and then applying imazapic at least 2 months after burning controlled invasive plants. While effective, this approach injured many of the existing forbs as they relied on native forbs recovery from seeds, not existing plants. In our management

approach, we are evaluating using herbicide after the fire but prior to native forb and warm season grass emergence with a herbicide that doesn't have residual activity in the soil. While burning is not commonly down every spring in succession, this is experimental technique not intended to mimic historical regimes or common management practices. In this short window some invasive plants emerge prior and allow for a glyphosate application before to native plants emerge. This herbicide, while non-selective, is systemic and rarely taken up from the soil into plants (Vencill 2022), therefore no injury to non-emerged desirable plants is expected. While glyphosate could be broadcasted, some desirable plants may have emerged (native cool season grasses, early emerging native forbs) and could be injured by a broadcast application. Spot treating individual plants, can further minimize injury.

Early and rapid emergence of the invasive plant prior to the native species is important for success of this approach. *P. sativa* is an ideal organism to test this approach. It is a monocarpic perennial, native to Eurasia (Averill & DiTommaso 2007) that is widespread throughout the Midwest and problematic in tallgrass prairies. It competes with native species and reduces their cover (Groh 1944), and its sap can burn the skin of humans if exposed to sunlight (Berenbaum 1995). This species emerges early in the spring (Cain *et al.* 2010) and has been observed to be the first species to resprout after a spring burn in a prairie (personal observation C. Trosen United States Fish and Wildlife Service). As seeds do not persist for long periods in the soil (between 2-4 years; Hendrix & Trapp 1992; Baskin and Baskin 1979) populations could be eradicated with several iterations of this approach, assuming no seed is imported to the site.

The effectiveness of this approach and safety to native forbs has not been evaluated. We sought to quantify if adding glyphosate spot treatments after burning reduces *P. sativa* populations. We hypothesized that spraying will eliminate flowering *P. sativa* but seedlings will

emerge after application and persist. Additionally we wanted to measure the response of vegetation to this approach, specifically native forbs. We hypothesized that total native forb cover would increase as a result of including herbicide, with some species increasing more than others and the level of increase would be related to initial *P. sativa* density. To test these hypotheses we conducted a randomized complete block design in a reconstructed prairie in Western Wisconsin, where treatments were repeated for two years.

Materials & Methods

Location

The experiment was conducted from April 2023 through July 2024, in a planted (10+ years old) tallgrass prairie near New Richmond Wisconsin (45.19°N, -92.46°W). The predominate soil type within the prairie is Sattre silt loam (13.4% clay, 1.14% organic matter, 6.1 pH). Over forty forb species and seven grass species were present at this location (Table 1). The most common native forb species where giant hyssop [*Agastache foeniculum (Pursh) Kuntze*], golden alexanders [*Zizia aurea* (L.) W.D.J.Koch] and goldenrod species (*solidago spp.*). The most common non-native species where alsike clover (Trifolium hybridum L.), lettuce spp. (*Lactuca spp*.) and sulfur cinquefoil (*Potentilla recta* L.), The most common native grasses were big blue-stem (*Andropogon gerardii* Vitman), yellow Indiangrass [*Sorghastrum nutans* (L.) Nash], little blue-stem [*Schizachyrium scoparium* (Michx.) Nash], and Switchgrass (*Panicum virgatum* L.). The most common non-native grass where smooth brome (*Bromus inermis* Leyss.) and Kentucky bluegrass (*Poa pratensis* L.). *P. sativa* was widespread with an average spring density of 2.6 plants m^{-2} and present in 70% of the plots.

Treatment & Experimental Design

The experiment was a randomized complete block design with two treatments: burned vs burned + glyphosate. One hundred 1 m^{-2} (3.3 ft^{-2}) subplots were established within each block in a paired plot design with paired plots separated by 1 m. Within each pair the treatments were randomly assigned. A prescribed fire was conducted across the entire experimental area on April 18th, 2023 and repeated on April 14th, 2024. Due to the high level of fine fuel moisture from grasses the entire areas was completed burned resulting in >99% charred/blackened soil surface data not shown. For the burn done in 2023 ambient air temperature was 8 C, relative humidity was 44% and mean windspeed was 14.5 km hr. Mean fine fuel moisture was 7 g m^{-2} and fuel temperature were 6.7 C. For the burn done in 2024 ambient air temperature was 7 C, relative humidity was 63% and mean windspeed was 0 km hr. Mean fine fuel moisture was 5 g m^{-2} and fuel temperature were 2.2 C. After the burn, *P. sativa* rosettes rapidly resprouted and seedlings emerged. Applications of glyphosate (Roundup Powermax 540 g ae/L) were applied to emerged *P. sativa* plants in the burn + glyphosate treatments 17 and 16 days after prescribed fire in 2023 and 2024 respectively. Plants were spot sprayed to the point of solution runoff with a 2 % solution with the addition of a nonionic surfactant (0.25 % v/v) and Ammonium Sulfate (10.2 g/L) using a CO2 pressurized single nozzle boom sprayer with one Teejet XR 11002VS nozzle. This timeframe was selected as it maximized *P. sativa* emergence and but was prior to emergence of nearly all desirable native forbs and grasses.

Measurements

Density of *P. sativa* was determined just prior to herbicide application (May) and in July of 2023 and 2024 when *P. sativa* was flowering. *P. sativa* plants were categorized as seedlings (2024 only), non-flowering, or flowering. Plant cover (%) was also visually estimated in July of

each year and separated into *P. sativa*, native forbs, non-native forbs (excluding parsnip), native grass, non-native grass, woody plants, and bare ground/litter.

Statistical Analysis

Statistical analyses were performed using the open-source statistical software R 4.4.2 (R Core Team, 2024). Data were found to not be normal, therefore a Wilcoxon signed-rank test was performed on the difference between burn and burn + glyphosate pairs for functional group cover, native forb density, and *P. sativa* density. We excluded plot pairs that did have any *P. sativa* in the spring of each year for these analyses. This resulted in 127 plots in 2023 and 105 plots in 2024. Each response variable was analyzed separately for each evaluation year (2023 and 2024) and the number of instances populations were increasing or decreasing compared ($p<0.05$). Additionally, a Spearman's test was done to evaluate if the response of vegetation was related to initial *P. sativa* density the spring prior to glyphosate application. Cover of functional groups, total native forb density, and density of individual native forbs that were present in at least 15 plots in both years were evaluated (n=198 plot pairs) to determine if relationships existed within each treatment. If significant ($p<0.05$) the corresponding rho value is presented. Rho is the calculated correlation between two variables with values close to 1 or -1 signifying a strong relationship and values close to zero a week relationship.

Results/Discussion

Weather

Temperature during both years was similar to the twenty-year average, however precipitation was atypical in both years. In 2023, large within season fluctuations occurred resulting in drought conditions in May, June and August (42-53% less precipitation than twenty-

year average) and July and October with atypically high precipitation (57-75% greater than twenty-year average). In 2024, high levels of precipitation were observed in May, June and August (26-71% greater than twenty-year average) with below average precipitation in July, September and October (42-94% less precipitation than twenty-year average) (Table 2).

Impact of burning and spray on *P. sativa* density

The addition of an herbicide application after burning reduced *P. sativa* populations compared to control areas that were just burned. Spraying after burning reduced *P. sativa* populations 65% and 63% of the time in 2023 ($p<0.01$) and 2024 ($p<0.01$) respectively (Figure 1a & 1b). Flowering *P. sativa* was nearly eliminated in these areas as 97 and 90% of them had no flowering *P. sativa* in 23 and 24 respectively (data not shown). Thus, spraying after burning effectively eliminated the production of *P. sativa* seeds. While some plots increased or stayed the same in *P. sativa* density, flowering was eliminated in 84 and 47% of these plots in 23 and 24 respectively (data not shown). Others have also had difficulty in eliminating biennial and perennial invasive plants through burning alone. Ratcliffe *et al*. (2022) found burning alone did not remove *P. pratensis* and *B. inermis*. Others have found burning increases invasive species populations as Gates *et al.* (2017) observed yellow sweet-clover [*Melilotus officinalis* (L.) Lam.] populations increasing after a burn. One limitation of this approach is the narrow window of time between the burn and resprouting of native forbs. This window was 18 and 17 days in 2023 and 2024. We hypothesized that the majority of *P. sativa* perennial plants and seedlings would have resprouted/emerged by this timeframe and could successfully be controlled by the spot treatment. Density counts from burn only plots suggest that plants emerged after herbicide applications as densities were 50 and 25% higher in July vs May counts in 23 and 24 respectively. During spring of 2023 there was a drought, followed by more precipitation in early summer. The lack of

precipitation in spring could have delayed resprouting/emergence of *P. sativa* until later precipitation followed in early summer. High spring precipitation in 2024 may have limited this response, but it was still observed.

Impact of burning and spraying on total native forb cover and density

Native forb density was not influenced by including herbicide application after the burn. We found spraying after burning did not increase the chance of reducing total native forb density 2 MAT in 2023 ($p=0.54$) or 2024 ($p=0.89$) (Figure 1c & 1d). Spraying after burning reduced native forb cover 58% of the time in 2023 ($p<0.01$) with an average reduction of 10% compared to burn alone (data not shown). However, this was not observed in 2024 ($p<0.77$) (Table 3). While our approach was successful in maintaining native forb density, native forb cover was reduced in one of the two years evaluated. As 2024 cover was similar between treatments, reductions didn't persist, showing promise that any injury was transient with this approach. Many studies also found glyphosate was effective in controlling invasive or weedy species without harming desirable species through spot spraying (Farooq *et al.* 2019; Mcwhorter & Barrentine 1979; Westerman & Murray 1994).

Contrary to our hypothesis, native forbs were not increased, even when *P. sativa* populations were reduced in areas that include burning and herbicide. Several reasons for this are plausible. A legacy effect of *P. sativa* may be limited recovery of native forbs. While no mechanisms for this have been identified with *P. sativa*, this effect has been observed with other invasive species as Corbin and D'Antonio (2012) found removing invasive plants from an area was not sufficient in restoring native forb populations because of the "legacy" that they leave. A response may not also have been seen because of the timeframe that was observed, and multiple years may be needed in order to see an effect on native forb populations. Alternatively, *P. sativa*

density may have been too low to influence native forbs. Often a threshold exists where low populations of an invasive plant does not reduce native forb cover or density (Panetta & Gooden 2017). We didn't find a relationship between *P. sativa* density prior to herbicide treatment and total native forb density in 2023 ($p = 0.51$) and 2024 ($p = 0.42$), but total native cover was found to be positively correlated in 2023 ($p < 0.01$) and 2024 ($p < 0.01$) (Table 4). The correlations were not considered robust (rho 0.22 and 0.28) and while not directly compared, addition of an herbicide did either had no affect or increased the positive relationship between *P. sativa* and total native forb cover. Another potential explanation of the limited and positive correlation between *P. sativa* and total native forbs is that the responses are specific to individual forbs, with some not affected, and others positively or negatively affected. To assess this, eleven individual forbs correlation with *P. sativa* initial density were also evaluated. Six species (*R hirta, C. canadensis, A. foeniculum, Z. aurea*, *M. fistulosa*, and *R. pinnata*) had no relationship, three had a negative relationship (*S. rigida, S. speciosa,* and *S. canadensis*) and five had positive relationships (*Symphyotrichum spp., A. syriaca, S. arvensis, Solidago* spp., and *Rubus* spp.) (Table 4). While we did not expect *P. sativa* to be positively correlated with individual forb density, others have seen positive relationships between native and invasive plants. Buerdsell *et al.* (2021) found that soil that has been previously invaded by the invasive grass Lehmann lovegrass (*Eragrostis lehmanniana* Nees) increased native grass populations when present. *Solidago* species were the only forbs that was negatively impacted by *P. sativa*. It is unknown why native forbs responded differently to *P. sativa* densities. As these species can vary on the timeframe when they grow and tolerance to prescribed fire (Howe 2011), we hypothesize that these may be involved. Further research is needed to evaluate potential mechanisms for specific forbs.

Impact of burning and spraying on Grasses cover and Density

Total, native or non-native grass cover was not impacted directly by incorporating an herbicide with burning. Cover averaged 21 and 7 % for non-native grasses and 17 and 34 % for native grasses in 2023 and 2024 respectively. This was an expected result as applications were targeted after the burn but prior to development of this functional group and other studies have seen that non-native forbs are more directly impacted than grasses (Link *et al.* 2017). Of interest, was that these functional groups were negatively associated with *P. sativa* density in 2023 ($p<0.01$) and 2024 ($p<0.01$) (Table 4). Although the relationship was not robust (rho -0.161 –-0.359) it suggests that these functional groups are directly competing with *P. sativa.* All but one of the groups (Non-native grass cover 2023) showed a more negative correlation when comparing the burn with the burn + glyphosate in both years. This could be related to the amount of herbicide applied, as higher density plots would have more herbicide applied than lower densities. This higher rate could have increased injury to grasses, especially cool season grasses like *P. pratensis* and *B. inermis* which typically emerge rapidly after a spring burn and could be the reason we observed a more negative correlation when herbicides were used.

Impact of burning and spraying on non-native forb density and cover

While total non-native forb cover was not influenced by including an herbicide application after the burn non-native forb density was in 2024. We found spraying after burning did not increase the chance of reducing total non-native forb cover in 2023 ($p=0.42$) or 2024 ($p=0.49$) (Table 3) or density 2 MAT in 2023 ($p= 0.22$) but did observe an increase in 2024 where 61% of the time this functional group increased ($p=0.02$) (Figure 1e & 1f). We believe this was due to the increased precipitation seen in the second year, allowing weedy non-native forbs to emerge and take advantage of the open niche provided by suppressing *P. sativa.*

Overall, burn + glyphosate was effective in reducing *P. sativa* density compared to just burning. While it didn't eliminate all *P. sativa* plants it prevented any from flowering, thus if repeated annually could eventually eliminate populations. This integrated approach rarely had a significant effect on total native forbs and when observed did not persist, suggesting it has minimal long-term impact. While both native and non-native grasses were not impacted by the addition of an herbicide, they did not increase as a result of treatment either. Additionally grasses and *solidago* spp. were found to be negatively correlated with *P. sativa* spring density, while other individual forbs were either not correlated or had a positive association. Further research is needed to better understand this relationship. Based on our results, applying glyphosate to resprouting *P. sativa* after a spring burn but prior to native plant emergence shows promise as an integrated approach to manage this invasive plant. Further research is needed in additional locations with varying species, however, before widespread adoption of this management approach occurs.

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Tables

Table 1. Species presence at Hamees corner a planted (10+ years old) tallgrass prairie near New Richmond Wisconsin.

Species Common Name	Species Scientific Name	Native Status
alsike clover	*Trifolium hybridum* L.	Non-native
American elm	*Ulmus americana* L.	Native
asparagus	*Asparagus officinalis* L.	Non-native
aster spp.	*Symphyotrichum* spp.	Native
avens	*Geum* spp.	Native
big blue-stem	*Andropogon gerardii* Vitman	Native
black medick	*Medicago lupulina* L.	Non-native
black-eyed Susan	*Rudbeckia hirta* L.	Native
broadleaf plantain	*Plantago major* L.	Non-native
campion spp.	*Silene* spp.	Non-native
Canada goldenrod	*Solidago canadensis* L.	Native
Canada thistle	*Cirsium arvense* (L.) Scop.	Non-native
Canadian horseweed	*Conyza canadensis* (L.) Cronquist	Native
clasping dogbane	*Apocynum cannabinum* L.	Native
common cinquefoil	*Potentilla simplex* Michx.	Native
common milkweed	*Asclepias syriaca* L.	Native

common mountain mint	*Pycnanthemum virginianum* (L.) B.L.Rob. & Fernald	Native
common St. Johnswort	*Hypericum perforatum* L.	Non-native
common tansy	*Tanacetum vulgare* L.	Non-native
common yarrow	*Achillea millefolium* L.	Native
crairie cinquefoil	*Drymocallis arguta* (Pursh) Rydb.	Native
Culver's-root	*Veronicastrum virginicum* (L.) Farw.	Native
curly dock	*Rumex crispus* L.	Non-native
daisy fleabane	*Erigeron annuus* (L.) Pers.	Native
dandelion	*Taraxacum officinale* F. H. Wigg.	Non-native
Deptford pink	*Dianthus armeria* L.	Non-native
dogwood spp.	*Cornus* spp.	Native
European buckthorn	*Rhamnus cathartica* L.	Non-native
false sunflower	*Heliopsis helianthoides* (L.) Sweet	Native
field sow thistle	*Sonchus arvensis* L.	Native
field thistle	*Cirsium discolor* (Muhl. ex Willd.) Spreng.	Native
giant hyssop	*Agastache foeniculum* (Pursh) Kuntze	Native
giant ragweed	*Ambrosia trifida* L.	Native
goat's beard	*Tragopogon dubius* Scop.	Non-native
golden alexander	*Zizia aurea* (L.) W.D.J.Koch	Native
goldenrod Species	*Solidago* spp.	Native
hairy vetch	*Vicia villosa* Roth	Non-native

hoary alyssum	*Berteroa incana* (L.) DC.	Non-native
Kentucky blue	*Poa pratensis* L.	Non-native
lettuce spp.	*Lactuca* spp.	Non-native
little blue-stem	*Schizachyrium scoparium* (Michx.) Nash	Native
mullein	*Verbascum thapsus* L.	Non-native
mustard spp.	*Brassicaceae* spp.	Non-native
orange hawkweed	*Hieracium aurantiacum* L.	Non-native
purple prairie-clover	*Dalea purpurea* Vent.	Native
red clover	*Trifolium pratense* L.	Non-native
redtop	*Agrostis gigantea* Roth	Non-native
round-headed bush-clover	*Lespedeza capitata* Michx.	Native
rubis spp.	*Rubus* spp.	Native
serviceberry spp.	*Amelanchier* spp.	Native
showy goldenrod	*Solidago speciosa* Nutt.	Native
smooth brome	*Bromus erectus* Huds.	Non-native
smooth penstemon	*Penstemon digitalis* Nutt. ex Sims	Non-native
stiff goldenrod	*Solidago rigida* L.	Native
stiff Sunflower	*Helianthus pauciflorus* Nutt.	Native
sulfur cinquefoil	*Potentilla recta* L.	Non-native
sweet clover sp.	*Melilotus* spp.	Non-native
sweet-scented bedstraw	*Galium triflorum* Michx.	Native

switch grass	*Panicum virgatum* L.	Native
tall cinquefoil	*Drymocallis arguta* (Pursh) Rydb.	Native
thimbleweed	*Anemone cylindrica* A.Gray	Native
white avens	*Geum canadense* Jacq.	Native
white clover	*Trifolium repens* L.	Non-native
wild bergamot	*Monarda fistulosa* L.	Native
wild Carrot	*Daucus carota* L.	Non-native
wild grape	*Vitis riparia* Michx.	Native
wild parsnip	*Pastinaca sativa* L.	Non-native
wood violet	*Viola sororia* Willd.	Native
yellow avens	*Geum aleppicum* Jacq.	Native
yellow coneflower	*Ratibida pinnata (Vent.)* Barnhart	Native
yellow Indian grass	*Sorghastrum nutans* (L.) Nash	Native

Table 2. Monthly 2023-2024 weather and 20-year historical averages at Hamees corner. Data was taken from Baldwin, WI weather station 20 miles away. Sources: National Weather Service (2024).[a]

	New Richmond & Erikson					
	Precipitation			Temperature		
	----------mm----------			----------°C----------		
Month	Historical average	2023	2024	Historical average	2023	2024
January	21	45	4	-12	-8	-7[a]
February	20	54	15	-9	-10	-1[a]
March	39	57	69	-2	-5	2[a]
April	70	75	72	6	5	9[a]
May	101	58	173	13	15	16[a]
June	132	67	215	19	20	19[a]
July	105	165	61	21	20	22[a]
August	125	59	158	20	19	21[a]
September	86	90	5	15	17	19[a]
October	71	124	15	8	10[a]	13[a]
November	40	1	66	0	1[a]	3[a]
December	28	47	30	-8	0[a]	-5[a]
Total	837	842	884	NA	NA	NA

[a] Data was not available at the closest station therefore was collected from station 23 miles away.

Table 3. Data was found to not be normal, therefore a Wilcoxon signed-rank test was performed on the difference between burn and burn + glyphosate pairs for functional group cover. Plot pairs were excluded if no *P. sativa* was present in the spring of each year for these analyses. 2023 n=127. 2024 n=105

	Native forbs		Non-native forbs		Native grasses		Non-native grasses		Total Grasses	
Treatment	2023	2024	2023	2024	2023	2024	2023	2024	2023	2024
	----------# of plots----------									
Decreasing	72	52	64	44	48	36	51	44	54	53
Increasing	35	47	53	39	15	12	51	39	66	50
No Change	20	6	10	22	64	57	25	22	7	2
p-value	<0.01	0.77	0.42	0.49	0.16	0.09	0.63	0.49	0.38	0.39

Table 4. Spearman test of cover, density classes, and individual native forbs. Rho values show relationship between initial p. sative and target species/class. Rho values closer to 1.0 signify a strong relationship between p. sative and target. Positive values signify that as p. sative increases so does the target while negative values signify that as p. sativa increases the target decreases. Rho was calculated if found to be significant ($p<0.05$).

	2023		2024	
Species	Burn	Burn + Herbicide	Burn	Burn + Herbicide
	----------rho----------			
Total native forb density	ns[b]	ns	ns	ns
Total native forb cover	0.22	0.28	0.28	0.42
Total non-native forb density	0.37	0.29	0.46	0.46
Total non-native forb cover	ns	ns	0.45	0.23
Total native grass cover	-0.16	-0.18	-0.36	-0.44
Total non-native grass cover	-0.25	-0.19	-0.17	-0.38
Total grass cover	-0.30	-0.32	-0.44	-0.50
Symphyotrichum spp.	ns	0.17	ns	ns
Rudbeckia hirta L.	ns	ns	ns	ns
Solidago canadensis L.	*	*	-0.20	-0.18
Conyza canadensis (L.) Cronquist	*	*	ns	*
Asclepias syriaca L.	*	0.15	0.17	ns
Sonchus arvensis L.	*	*	0.18	ns
Agastache foeniculum (Pursh) Kuntze	ns	ns	ns	ns
Zizia aurea (L.) W.D.J.Koch	ns	ns	ns	ns
Unidentifiable *Solidago* spp.	0.25	0.22	0.37	0.39
Rubus spp.	*	*	0.31	0.21
Solidago speciosa Nutt.	*	*	-0.18	ns

Solidago rigida L.	-0.19	ns	-0.30	-0.28
Monarda fistulosa L.	ns	ns	ns	ns
Ratibida pinnata (Vent.) Barnhart	ns	ns	ns	ns

[ns] Species were not found to be significant, and rho was not calculated.

[*] Species that did not meet threshold for analysis.

Figures

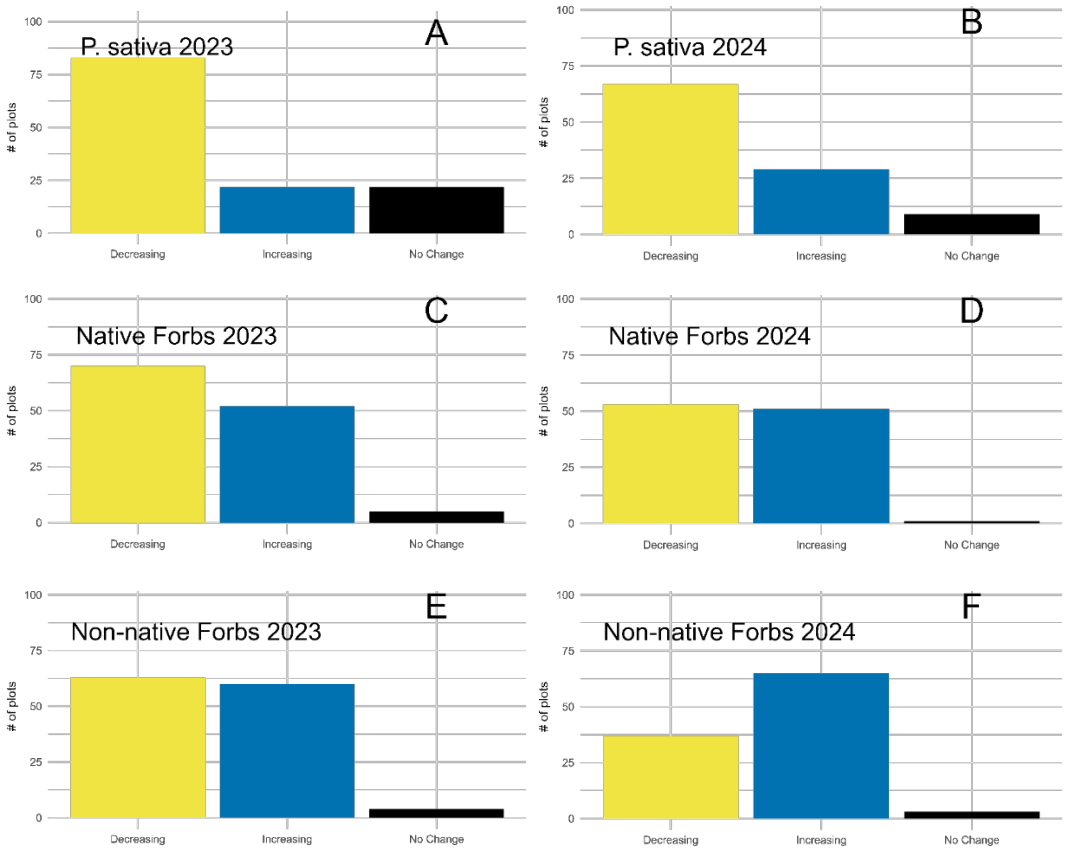

Figure 1. Number of plots of *P. sativa* (A, B), native forbs (C, D) and non-native forbs (E, F) and respective changes in density when spray was included after burn. 2023 (A, C, E) and 2024 (B, D, F). Significance was found in *P. sativa* density was found to be significant in both years 2023 ($p<0.01$) (A) and 2024 ($p<0.01$) (B) and non-native forb density ($p<0.01$) (2024). All other density classes were found to not be significant ($p>0.05$). 2023 n=127. 2024 n=105.