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Broadleaf weed control and white clover response to florpyrauxifen-benzyl + 2,4-D and common pasture herbicides

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Abstract

The combination of florpyrauxifen-benzyl + 2,4-D is a new, pre-packaged herbicide mixture for use in pastures and hayfields in the United States. Unlike many other pasture herbicides, florpyrauxifen-benzyl + 2,4-D is reported to preserve white clover. However, limited research exists on the efficacy of florpyrauxifen-benzyl + 2,4-D on common weed species and on the level of tolerance of white clover to it. Field trials were conducted in Virginia in 2018 to 2020 to evaluate control of various broadleaf weeds with florpyrauxifen-benzyl + 2,4-D compared to other commonly used herbicides. Field and greenhouse studies were also carried out to assess white clover tolerance. Weed species evaluated included bulbous buttercup, Canada thistle, horsenettle, and broadleaf plantain. Florpyrauxifen-benzyl + 2,4-D provided 75% to 99% control of all weeds 90 d after application except for horsenettle (56%), while causing the least white clover injury of any herbicide treatment that was evaluated. Spring herbicide applications resulted in greater bulbous buttercup control compared to fall applications, but florpyrauxifen-benzyl + 2,4-D provided greater than 81% control from both application timings. There were no differences in aboveground biomass between white clover varieties; however, all herbicides reduced white clover biomass compared to a nontreated control. This research suggests that florpyrauxifen-benzyl + 2,4-D can improve overall forage quality by controlling broadleaf weeds in mixed grass-legume stands while preserving white clover.

Introduction

Broadleaf weed species are one of the biggest factors limiting forage production (Eagle et al. 2007; Grekul and Bork 2004; Seefeldt et al. 2005). A survey conducted by the Weed Science Society of America reported that of the six most troublesome weed species in pasture, rangeland, and hay, five were broadleaf species. Because of their ability to infest pastures and low palatability to livestock, broadleaf weed species can reduce forage yield, decrease forage quality, contaminate forage with toxic weed species (Cook et al. 2009; Gunning 1949; Welsh et al. 2007), and ultimately, reduce livestock weight gain (Marten et al. 1987). Hartley (1981) showed that when musk thistle (*Carduus nutans* L.) was present at a density of one plant per square meter, sheep weight gain could be reduced by 20%. Additionally, even the presence of certain broadleaf weed species can deter grazing of nearby desirable forage (Tiley 2010), thereby reducing forage utilization.

Because of the perennial nature of pasture systems, a different spectrum of weed species can affect production throughout the year, complicating management efforts. Certain weed species are more susceptible to herbicides at specific times in the growing season. For example, perennial weed species such as horsenettle are best controlled by herbicides applied at the bloom stage, whereas warm-season annuals such as common ragweed (*Ambrosia artemisiifolia* L.) are best controlled by spring and early summer applications (Flessner and Taylor 2021). Additionally, cool-season weed species that emerge in the fall are often targeted with herbicide applications the following spring. Some research suggests that fall herbicide applications can be effective in controlling warm-season perennials (Marshall et al. 2006), however little research exists on the efficacy of fall-applied versus spring-applied herbicides for cool-season perennial weeds. Because many weed species affect pasture productivity, and because these weed species are rarely present at the same time, producers must decide which weeds are the most detrimental to forage production and target those in a single application, because it is rarely economical to apply herbicides multiple times per year in pastures (Gylling et al. 2009).

Another management concern when using herbicides is the elimination of desirable forage legumes such as white clover. Many common and widely available herbicides are frequently used to control broadleaf weeds in pastures and hayfields; however, the majority of these herbicides also kill desirable forage legumes (Beeler et al. 2003; Miller et al. 2020; Payne et al. 2010). Forage legumes in pastures, including white clover, have several benefits such as increased forage quality (Posler et al. 1993), which can ultimately lead to increases in livestock performance (Burns et al. 1973). Compared to grass monocultures, grass-legume mixtures result in a longer grazing season (Gibson and Cope 1985) and lead to greater grass yield through the transfer of nitrogen, fixed through the legumes, to grasses (Sanderson et al. 2005; Sleugh et al. 2000; Wagner 1954).

Florpyrauxifen-benzyl + 2,4-D is expected to be commercially available in 2022 and is reported to preserve white clover (Sleugh et al. 2020). However, the weed control spectrum, optimal application timing, and potential varietal response of white clover need further evaluation to make well-informed management decisions regarding applications to pastures and hayfields.

The overall objective of this research was to determine the utility of florpyrauxifen-benzyl + 2,4-D for pasture and hayfield weed management by evaluating its weed control spectrum and white clover response. To do so, four objectives were identified: 1) determine the efficacy of florpyrauxifen-benzyl + 2,4-D on common broadleaf weeds found in pastures and hayfields; 2) compare the efficacy of fall-applied versus spring-applied herbicides for weed control; 3) evaluate the tolerance of white clover to florpyrauxifen-benzyl + 2,4-D; and 4) determine whether white clover varieties differ in sensitivity to florpyrauxifen-benzyl + 2,4-D.

Materials and Methods

Single Application Studies

Field trials were established at six locations in Virginia in 2019 and 2020. All sites contained naturalized weed populations and mixed stands of cool-season grasses such as tall fescue [*Lolium arundinaceum* (Schreb.)] and orchardgrass (*Dactylis glomerata* L.), and legumes such as white clover and red clover (*Trifolium pratense* L.). Treatments were applied at the recommended time based on the Virginia Field Crops Pest Management Guide (Flessner and Taylor 2021) for the weed species being targeted at each location. In general, herbicides were applied in April to control warm-season annual weeds, July to control warm-season perennials, and November and April to control cool-season perennials. Application dates, locations, and weed species at the locations are listed in Table 1.

All studies were designed as a randomized complete block design with four replications. Herbicides were applied using a handheld backpack sprayer with TeeJet (Spraying Systems Co., Wheaton, IL) 11002XR nozzles calibrated to deliver 140 L ha^{-1} at 207 kPa. Treatments were applied to the center 3 m of 3.7 m-wide plots. Plot length was 7.6 m. Treatments are presented in Table 2. A nontreated control was included for comparison.

Following herbicide application, visible weed control and white clover injury were evaluated throughout the growing season on a scale of 0% to 100%, with 0 being no observable injury and 100 being complete plant necrosis relative to the nontreated control as described by Frans et al. (1986). Depending on the study site, trials were either managed for hay production or fenced off for 30 d followed by grazing if cattle were present.

Data were subject to ANOVA and subsequent means were separated using Fisher's protected LSD test ($P \leq 0.05$) to compare across treatments using JMP Pro 15 software (SAS Institute, Inc., Cary, NC). Fixed effects consisted of herbicide treatment. Year, location, and replication nested within year were considered random effects to allow inferences to be made over a range of environments and conditions (Blouin et al. 2011). Visible control data of weed species were analyzed by location for weed species that were present only at certain locations.

Fall Versus Spring Application Timing Study

Field trials were established in Amelia Court House (37.29°N, 77.86°W) and Blacksburg (37.27°N, 80.36°W), Virginia in fall 2018, and in Blacksburg, in fall 2019. All sites contained naturalized weed populations, consisting primarily of bulbous buttercup and mixed stands of cool-season grasses such as tall fescue and orchardgrass, and legumes such as white clover and red clover. Late October/early November was targeted for the fall herbicide application, and late March/early April was targeted for the spring application. Small vegetative bulbous buttercup received a fall application of herbicide and flowering buttercup received a spring application. Application dates and trial locations are listed in Table 1. All trials were fenced off for 30 d following both applications, and then allowed to be grazed by cattle, if they were present.

All sites were established as a factorial design with the first factor being timing and the second factor being herbicide. Treatments were arranged in a randomized complete block design. Treatments were replicated four times at the Amelia Court House site and the Blacksburg site in 2019, while the Blacksburg site in 2018 had three replications. Plot size was 4 m by 9 m in 2018, and 5 m by 7 m in 2019. Herbicides were applied to the middle 3 m of each plot. Herbicides and sources are listed in Table 2. A nontreated control was also included for comparison.

Following herbicide application, visible weed control and white clover injury data were taken at 30-d intervals following the fall application, up until the spring application. Following the spring application, visible weed control data were also taken on 30-d intervals for 120 d.

All data were subject to ANOVA and subsequent means were separated using Fisher's protected LSD test ($P \leq 0.05$) to compare across treatments using JMP Pro 15 software. Fixed effects consisted of herbicide treatment. Location and replication, nested within location, were considered random effects. Following spring herbicide application, data were analyzed as a factorial, with herbicide and application timing as fixed effects in order to determine the effect of herbicide timing.

White Clover Response

Established White Clover Response

Field trials were established in 2020 in Raphine (37.93°N, 79.21°W) and Blacksburg (37.23°N, 80.36°W), Virginia. Both locations were seeded with 'Ladino' white clover in previous seasons. Dates of herbicide application are listed in Table 1.

All sites were designed as a randomized complete block design with four replications. Plot size was 3 m by 6 m. Herbicides were applied using a 1.8-m-wide handheld backpack sprayer with four TeeJet (Spraying Systems Co.) 11002XR nozzles calibrated to deliver 140 L ha^{-1} at 207 kPa. Treatments included 1) florpyrauxifen-benzyl + 2,4-D at 9 + 560 g ai/ae ha^{-1}; 2) florpyrauxifen-benzyl + 2,4-D at 18 + 1,120 g ai/ae ha^{-1}; 3) florpyrauxifen-benzyl at 9 g ai ha^{-1}; 4) florpyrauxifen-benzyl at 18 g ai ha^{-1}; 5) 2,4-D at 560 g ae ha^{-1}; 6) 2,4-D at 1,120 g ae ha^{-1}; 7) dicamba + 2,4-D at 560 + 1,120 g ai/ae ha^{-1}; and 8) a mowing to

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Table 1. Site information for broadleaf weed control trials conducted in pastures and hayfields in Virginia from 2018 to 2020.

Location	Coordinates	Application date	Common names	Scientific name
Single application study				
Meadowview, VA	36.7692°N, 81.8691°W	April 22, 2019	Canada thistle; broadleaf plantain	*Cirsium arvense* (L.) Scop.
Glade Spring, VA	36.7745°N, 81.8691°W	April 22, 2019	Canada thistle	*Cirsium arvense* (L.) Scop.
Blacksburg, VA	37.2376°N, 80.4700°W	July 19, 2019	horsenettle	*Solanum carolinense* L.
Raphine, VA	37.9335°N, 79.2109°W	June 4, 2020	horsenettle; white clover	*Solanum carolinense* L.; *Trifolium repens* L.
Raphine, VA	37.9199°N, 79.2217°W	June 4, 2020	white clover	*Trifolium repens* L.
Blacksburg, VA	37.2367°N, 80.4675°W	July 28, 2020	horsenettle; white clover	*Solanum carolinense* L.; *Trifolium repens* L.
Fall versus spring study				
Blacksburg, VA	37.2727°N, 80.3637°	November 16, 2018 & April 24, 2019	bulbous buttercup; white clover	*Ranunculus bulbosus* L.; *Trifolium repens* L.
Amelia Court House, VA	37.2912°N, 77.8683°W	November 19, 2018 & April 17, 2019	bulbous buttercup	*Ranunculus bulbosus* L.
Blacksburg VA	37.2364°N, 80.4676°W	November 26, 2019 & April 6, 2020	bulbous buttercup; white clover	*Ranunculus bulbosus* L.; *Trifolium repens* L.
Established white clover tolerance study				
Blacksburg, VA	37.2365°N, 80.3638°W	September 3, 2020	white clover	*Trifolium repens* L.
Raphine, VA	37.9335°N, 79.2109°W	September 10, 2020		
Greenhouse white clover variety response				
Blacksburg, VA	37.2319°N, 80.4347°W	October 17, 2020, March 1, 2021 & March 16, 2021	white clover	*Trifolium repens* L.

a height of 13 cm in order to mimic the common practice of mowing for pasture weed control.

Following herbicide application, one 0.5-m^2 section of aboveground biomass was collected biweekly for 6 wk from a different area within the treated plots. Additionally, visible injury ratings were taken on a scale of 0% to 100% for 4 wk following herbicide application.

All data were subject to ANOVA and subsequent means were separated using Fisher's protected LSD test ($P \leq 0.05$) to compare across treatments using JMP Pro 15 software. Fixed effects consisted of herbicide treatment. Location and replication, nested within location, were considered random effects. The nontreated control was excluded from visible injury ratings.

Greenhouse White Clover Varietal Response

Greenhouse trials were established in Blacksburg (37.23°N, 80.43°W), in 2020 and 2021. Four varieties of white clover were seeded into 1.8-L pots at a seeding rate of 5.6 kg ha^{-1}. Varieties included 1) 'Ladino' (Allied Seed LLC, Nampa, ID), 2) 'Durana' (Pennington Seed, Inc., Madison, GA), 3) 'Alice' (Barenbrug USA, Tangent, OR), and 4) 'Patriot' (Pennington Seed). Following seeding, clover was allowed to grow approximately 6 wk until flowering, and then all plants were trimmed to approximately 10 cm in height. Plants were then allowed to regrow for 2 wk before treatments were applied. Herbicides were applied using a 1.8-m-wide handheld backpack sprayer with four TeeJet (Spraying Systems Co) 11002XR nozzles calibrated to deliver 140 L ha^{-1} at 213 kPa. Treatments were arranged in a randomized complete block design with five replications. The trial was replicated three times.

Following herbicide application, plants were allowed to grow for 6wk. Aboveground biomass was then collected from each pot, dried at 52 C for 72 h, and weighed.

All data were subject to ANOVA and subsequent means were separated using Fisher's protected LSD test ($P \leq 0.05$) to compare across treatments using JMP Pro 15 software. Data were analyzed as a factorial with herbicide being Factor A and variety as Factor B. Trial run and replication, nested within run, were considered random effects.

Results and Discussion

Single Application Study

White Clover Injury

By 30 d after application (DAA), white clover injury was greater than 83% in response to all treatments, except for 2,4-D and florpyrauxifen-benzyl + 2,4-D (Table 3). By 60 and 90 DAA, injury from florpyrauxifen-benzyl + 2,4-D and 2,4-D had decreased to 16% and 3%, and to 18% and 9%, respectively. Aminopyralid + 2,4-D, 2,4-D + dicamba, metsulfuron, triclopyr + 2,4-D, and triclopyr + fluroxypyr all resulted in 85% or greater white clover injury 90 DAA.

Canada Thistle Control

Initially, several treatments provided good control of Canada thistle 30 DAA (Table 3). Florpyrauxifen-benzyl + 2,4-D and aminopyralid + 2,4-D resulted in the greatest control 30 DAA. However, control from all treatments declined throughout the growing season. At 90 DAA, aminopyralid + 2,4-D provided the greatest control, followed by florpyrauxifen-benzyl + 2,4-D and 2,4-D + dicamba.

Broadleaf Plantain Control

Except for triclopyr + fluroxypyr, all treatments provided ≥85% control of broadleaf plantain 30 DAA (Table 3). Control levels were similar 60 DAA. By 90 DAA, broadleaf plantain control was greatest with florpyrauxifen-benzyl + 2,4-D, aminopyralid + 2,4-D, and 2,4-D + dicamba.

Horsenettle Control

Aminopyralid + 2,4-D and triclopyr + fluroxypyr provided the greatest horsenettle control 30 DAA. Aminopyralid + 2,4-D, 2,4-D + dicamba, triclopyr + 2,4-D, and triclopyr + fluroxypyr all resulted in 91% control or greater 60 DAA. Aminopyralid + 2,4-D, 2,4-D + dicamba, triclopyr + 2,4-D, and triclopyr + fluroxypyr resulted in the greatest horsenettle control 90 DAA. All other treatments resulted in 56% or less horsenettle control.

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Table 2. Sources of materials.

Treatment	Rate	Trade name	Manufacturer	Location
	g ai/ae ha^{-1}			
Florpyrauxifen-benzyl + 2,4-D[a]	9 + 560	ProClova®	Corteva Agriscience	Wilmington, DE
Aminopyralid + 2,4-D[b]	933 + 115	GrazonNext® HL	Corteva Agriscience	Wilmington, DE
2,4-D + dicamba[b]	1,065 + 560	Shredder® Amine 4 + Clarity®	Winfield Solutions; BASF Corporation	St. Paul, MN; Research Triangle Park, NC
2,4-D	1,065	Shredder® Amine 4	Winfield Solutions	St. Paul, MN
Triclopyr + 2,4-D	560 + 1,121	Crossbow®	Corteva Agriscience	Wilmington, DE
Metsulfuron[b]	7	Cimarron® MAX	Bayer CropScience	St. Louis, MO
Triclopyr + fluroxypyr[b]	631 + 210	PastureGard® HL	Corteva Agriscience	Wilmington, DE

[a]Included methylated seed oil (1% vol/vol).
[b]Included nonionic surfactant (0.25% vol/vol).

Additional Weeds

Several treatments resulted in effective plumeless thistle control throughout the season (Table 4). Except for metsulfuron and triclopyr + fluroxypyr, all treatments resulted in 78% control or greater.

There were no differences in wild carrot control at 30 and 60 DAA. Except for metsulfuron, all treatments resulted in 73% or greater control 90 DAA.

All treatments except metsulfuron resulted in 100% control of common ragweed 30, 60, and 90 DAA.

Fall Versus Spring Application Timing Study

White Clover Injury

Florpyrauxifen-benzyl + 2,4-D provided the least white clover injury 30 d after fall application (DAF), followed by 2,4-D, and triclopyr + fluroxypyr (Table 5). Aminopyralid + 2,4-D, 2,4-D + dicamba, and triclopyr + 2,4-D provided the greatest white clover injury 30 DAF. White clover injury increased by 60 DAF to ≥90% in response to all treatments other than florpyrauxifen-benzyl + 2,4-D. At 120 DAF, florpyrauxifen-benzyl + 2,4-D and 2,4-D provided only 2% and 4% white clover injury, respectively, while all other herbicide treatments provided 98% injury or greater.

Following spring applications, data were analyzed as a factorial to determine the effect of application timing. There was a significant interaction between application timing and herbicide treatment ($P = 0.012$), therefore, data were not pooled across timing or herbicides. Herbicide treatments that caused the least white clover injury 90 d following the spring application (90 DAS) included florpyrauxifen-benzyl + 2,4-D applied in the fall and spring, and 2,4-D applied in the fall (Table 6). By 90 DAS, white clover injury ranged from 20% to 36% in response 2,4-D + dicamba applied in the fall, 2,4-D applied in the spring, and triclopyr + 2,4-D applied in the fall. However, all other herbicides and timings resulted in ≥80% injury to white clover 90 DAS.

Bulbous Buttercup Control

Following fall herbicide applications, bulbous buttercup control was 54% or less in response to all the herbicide treatments 30 DAF. For most herbicide treatments, control gradually improved throughout the winter and early spring. By 120 DAF, all treatments provided similar bulbous buttercup control (65% to 81%) except for 2,4-D, which provided only 39% control.

Following spring application, data were analyzed as a factorial in order to determine the effect of application timing. There was a significant interaction between application timing and herbicide treatment ($P = 0.011$), therefore, data were not pooled across timing or herbicide. In general, bulbous buttercup control was better from spring rather than fall application 30 DAS. However, the herbicides that provided significantly less control when applied in the fall versus the spring at 30 DAS were dicamba + 2,4-D, 2,4-D, triclopyr + 2,4-D, and triclopyr + fluroxypyr. The same general trend persisted at 60 DAS. Spring application resulted in greater control compared to fall application for all herbicides except for florpyrauxifen-benzyl + 2,4-D, aminopyralid + 2,4-D, and metsulfuron. At 90 DAS, all herbicide treatments except for aminopyralid + 2,4-D demonstrated greater buttercup control with spring compared to fall applications. Certain herbicides, however, exhibited a greater disparity in control between fall and spring applications. The difference in control between fall and spring applications was greatest with triclopyr + 2,4-D, 2,4-D, and triclopyr + fluroxypyr.

No herbicide provided greater control when applied in the fall compared to the spring, but aminopyralid + 2,4-D provided similar control regardless of application timing, and there were instances when fall applications of specific herbicide treatments would be recommended over spring applications of others. For example, fall applications of aminopyralid + 2,4-D or metsulfuron still provided greater buttercup control than 2,4-D applied in the spring.

Established White Clover Tolerance

Florpyrauxifen-benzyl + 2,4-D applied at 18 g ai ha^{-1} and 1,120 g ae ha^{-1}, respectively, and dicamba + 2,4-D resulted in the most visible injury 1 wk after treatment (Table 7). Visible injury was characterized by lodging and epinasty after both treatments, consistent with auxin herbicide symptomology. For florpyrauxifen-benzyl + 2,4-D at 18 g ai ha^{-1} + 1,120 g ae ha^{-1}, visible injury was greatest 1 wk after treatment (WAT) and declined by 2 and 3 WAT. White clover injury from dicamba + 2,4-D injury was least at 1 WAT, then increased at 2 and 3 WAT and remained ~90% until aboveground biomass was taken.

Only dicamba + 2,4-D and florpyrauxifen-benzyl at 9 g ai ha^{-1} resulted in lower white clover biomass than the nontreated control at 2 WAT. By 4 WAT, florpyrauxifen-benzyl + 2,4-D at 9 g ai ha^{-1} + 560 g ai ha^{-1}, florpyrauxifen-benzyl at 18 g ai ha^{-1}, and dicamba + 2,4-D decreased biomass compared to the nontreated control. By 6 WAT all herbicide treatments reduced white clover biomass compared to the nontreated control, while the mowing treatment did not significantly reduce clover biomass. Florpyrauxifen-benzyl + 2,4-D at both rates resulted in 58% reductions in white clover biomass, while florpyrauxifen

Table 3. White clover injury and Canada thistle, broadleaf plantain, and horsenettle control in response to herbicide applications in pastures and hayfields.[a,b,c]

	White clover injury			Canada thistle control			Broadleaf plantain control			Horsenettle control		
Treatment	30 DAA	60 DAA	90 DAA	30 DAA	60 DAA	90 DAA	30 DAA	60 DAA	90 DAA	30 DAA	60 DAA	90 DAA
Florpyrauxifen-benzyl + 2,4-D	30 D	16 B	3 C	89 A	83 AB	75 AB	96 A	99 A	98 A	48 D	71 B	56 C
Aminopyralid + 2,4-D	100 A	99 A	99 A	94 A	89 A	89 A	89 AB	92 AB	93 A	88 A	95 A	89 A
2,4-D + dicamba	86 BC	100 A	98 A	80 AB	78 ABC	73 B	90 AB	91 AB	90 AB	69 B	95 A	81 AB
2,4-D	19 D	18 B	9 C	68 B	60 D	55 CD	85 BC	85 BC	80 C	56 CD	59 C	48 C
Triclopyr + 2,4-D	90 ABC	91 A	85 B	67 B	63 D	58 CD	89 AB	85 BC	83 BC	71 BC	93 A	75 AB
Metsulfuron	84 C	97 A	100 A	69 B	64 CD	50 D	94 AB	90 AB	83 BC	41 D	38 D	26 D
Triclopyr + fluroxypyr	99 AB	99 A	100 A	78 AB	72 BCD	69 BC	75 C	75 C	68 D	85 AB	91 A	74 B

[a]Site years per species: white clover, 3; Canada thistle, 2; broadleaf plantain, 2; horsenettle, 3.
[b]Means followed by the same letter are not significantly different according to Fisher's LSD test ($P < 0.05$), within a column.
[c]Abbreviation: DAA, days after application.

Table 4. Plumeless thistle, wild carrot, and common ragweed control in response to herbicide applications in pastures and hayfields across 2 site years.[a,b]

	Plumeless thistle				Wild carrot		Common ragweed		
Herbicide	30 DAA	60 DAA	90 DAA	120 DAA	60 DAA	90 DAA	30 DAA	60 DAA	90 DAA
					-%-				
Florpyrauxifen-benzyl + 2,4-D	99 A	99 A	100 A	98 A	100 NS	100 A	100 A	100 A	100 A
Aminopyralid + 2,4-D	98 A	100 A	100 A	100 A	96 NS	90 A	100 A	100 A	100 A
2,4-D + dicamba	86 AB	85 B	90 A	100 A	100 NS	73 AB	100 A	100 A	100 A
2,4-D	75 B	75 C	80 A	78 AB	88 NS	74 AB	100 A	100 A	100 A
Triclopyr + 2,4-D	85 AB	85 B	90 A	95 A	95 NS	73 AB	100 A	100 A	100 A
Metsulfuron	65 B	48 C	21 B	23 B	88 NS	49 B	43 B	21 B	8 B
Triclopyr + fluroxypyr	65 B	60 C	55 B	50 B	100 NS	93 A	100 A	100 A	100 A

[a]Means followed by the same letter are not significantly different according to Fisher's LSD test ($P \leq 0.05$), within a column.
[b]Abbreviation: DAA, days after application; NS, not significant.

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Table 5. White clover injury in response to fall and spring herbicide applications in pastures across 4 site years.[a,b]

Treatment	Timing	White clover injury											
		30 DAF		60 DAF		120 DAF		30 DAS		60 DAS		90 DAS	
		%											
Florpyrauxifen-benzyl + 2,4-D	Fall	15	D	12	C	2	B	0	E	0	E	0	E
	Spring	—		—		—		0	E	0	E	0	E
Aminopyralid + 2,4-D	Fall	65	A	93	A	100	A	95	A	95	A	93	A
	Spring	—		—		—		100	A	100	A	100	A
2,4-D + dicamba	Fall	63	A	93	A	100	A	34	D	25	D	20	DE
	Spring	—		—		—		100	A	100	A	95	A
2,4-D	Fall	33	C	68	B	4	B	11	E	0	E	0	E
	Spring	—		—		—		88	AB	55	CD	29	D
Triclopyr + 2,4-D	Fall	55	AB	93	A	98	A	67	C	50	CD	36	D
	Spring	—		—		—		100	A	100	A	100	A
Metsulfuron	Fall	48	B	90	A	98	A	79	BC	80	B	85	B
	Spring	—		—		—		100	A	100	A	100	A
Triclopyr + fluroxypyr	Fall	35	C	90	A	100	A	69	C	75	BC	80	BC
	Spring	—		—		—		100	A	100	A	100	A

[a]Means followed by the same letter are not significantly different according to Fisher's LSD test ($P \leq 0.05$), within a column.
[b]Abbreviations: DAF, days after fall treatment; DAS, days after spring treatment.

Table 6. Bulbous buttercup control in response to fall and spring herbicide applications in pastures across 4 site years.[a,b]

Treatment	Timing	Bulbous buttercup control													
		30 DAF		60 DAF		90 DAF		120 DAF		30 DAS		60 DAS		90 DAS	
		%													
Florpyrauxifen-benzyl + 2,4-D	Fall	38	BC	70	A	81	AB	68	A	93	AB	87	AB	82	CD
	Spring	—		—		—		—		99	A	99	A	96	AB
Aminopyralid + 2,4-D	Fall	54	A	74	A	89	A	81	A	91	AB	90	AB	90	ABC
	Spring	—		—		—		—		100	A	100	A	99	A
2,4-D + dicamba	Fall	50	AB	71	A	64	BC	75	A	81	BC	72	C	71	DE
	Spring	—		—		—		—		95	A	93	A	89	ABC
2,4-D	Fall	24	D	56	B	56	C	39	B	60	D	48	D	38	F
	Spring	—		—		—		—		73	C	77	BC	70	E
Triclopyr + 2,4-D	Fall	31	CD	65	AB	66	BC	71	A	70	CD	70	C	60	E
	Spring	—		—		—		—		97	A	98	A	98	A
Metsulfuron	Fall	26	D	57	B	82	AB	70	A	93	AB	91	A	84	BC
	Spring	—		—		—		—		99	A	99	A	97	A
Triclopyr + fluroxypyr	Fall	41	BC	55	B	69	ABC	65	A	59	D	48	D	44	F
	Spring	—		—		—		—		95	A	96	A	94	ABC

[a]Means followed by the same letter are not significantly different according to Fisher's LSD test ($P \leq 0.05$), within a column.
[b]Abbreviations: DAF, days after fall treatment; DAS, days after spring treatment.

Table 7. Established white clover injury and aboveground biomass in response to postemergence herbicides across 2 site years.[a,b]

Treatment	Rate	Visible injury										Aboveground biomass					
		1 WAT		2 WAT		3 WAT		4 WAT		6 WAT		2 WAT		4 WAT		6 WAT	
	g ai/ae ha^{-1}	%										kg ha^{-1}					
Nontreated		0		0		0		0		0		647	A	1,736	A	2,102	A
Florpyrauxifen-benzyl + 2,4-D	9 + 560	46	B	38	C	37	BC	25	BC	11	CD	548	AB	823	BC	883	C
Florpyrauxifen-benzyl + 2,4-D	18 + 1,120	63	A	56	B	46	B	36	B	25	B	511	AB	893	ABC	891	C
Florpyrauxifen-benzyl	9	25	D	24	D	15	E	8	D	4	E	312	BC	880	ABC	883	BC
Florpyrauxifen-benzyl	18	36	C	39	C	33	CD	23	C	14	C	390	ABC	748	BC	1,095	BC
2,4-D	560	21	D	19	D	23	DE	14	CD	6	DE	622	AB	1442	AB	1,251	BC
2,4-D	1,120	36	C	41	C	33	CD	23	C	15	C	440	ABC	1,119	AB	708	C
Dicamba + 2,4-D	560 + 1,120	65	A	84	A	89	A	94	A	96	A	135	C	172	C	0	D
Mowing												519	AB	1,598	AB	1,583	AB

[a]Means followed by the same letter are not significantly different according to Fisher's LSD test ($P \leq 0.05$), within a column.
[b]Abbreviation: WAT, weeks after treatment.

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Table 8. White clover aboveground biomass in response to postemergence herbicides in greenhouse experiments.[a]

Treatment	Rate	Aboveground biomass	
	g ai/ae ha^{-1}	kg ha^{-1}	
Nontreated	——-	3,892	A
Florpyrauxifen-benzyl + 2,4-D	9 + 560	1,315	C
Florpyrauxifen-benzyl + 2,4-D	18 + 1,120	599	D
2,4-D	560	2,543	B
2,4-D	1,120	1,940	BC
Dicamba + 2,4-D	560 + 1,120	539	D

[a]Means followed by the same letter are not significantly different according to Fisher's LSD test (P ≤ 0.05).

resulted in 48% to 58% reductions, and 2,4-D resulted in 40% to 66% reductions in white clover biomass. Dicamba + 2,4-D eliminated all white clover.

Greenhouse White Clover Varietal Tolerance

Herbicide treatment was significant (P = 0.002), but there was no significant difference between white clover varieties (P = 0.820) or no interaction between the two factors (P = 0.800). Therefore, results were pooled across variety. All herbicide treatments reduced white clover biomass compared to the nontreated control (Table 8). The greatest biomass reductions occurred when florpyrauxifen-benzyl + 2,4-D was used at 18 + 1,120 g ai ha^{-1}, and dicamba + 2,4-D, which reduced biomass by 85% and 86%, respectively. Florpyrauxifen-benzyl + 2,4-D at 9 + 560 g ae ha,[1] resulted in a 66% decrease in white clover biomass.

Research Implications

Our findings on the efficacy of florpyrauxifen-benzyl + 2,4-D to control broadleaf weed species are similar to those reported by Perry et al. (2015) who found that florpyrauxifen-benzyl did provide control of broadleaf weed species such as *Amaranthus* spp., *Ambrosia* spp., and *Conyza* spp., which can also be found in pastures and hayfields. When considering fall versus spring herbicide applications, producers need to consider the weed species present to determine proper application timing, but also the specific herbicide to be used.

Additionally, our findings are similar to those of other authors who have reported that commonly used pasture herbicides can result in high levels of desirable forage legume injury, and even death as was observed with aminopyralid (Beeler et al. 2003; Harrington et al. 2014; Mikkelson and Lym 2013; Miller et al. 2020), aminopyralid + 2,4-D (Enloe et al. 2014; Payne et al. 2010), 2,4-D (Payne et al. 2010), 2,4-D + dicamba (Payne et al. 2010), and metsulfuron (Payne et al. 2010.) Although herbicides that contain florpyrauxifen-benzyl did significantly injure established white clover, the clover was not eliminated and recovery occurred during the trial period, indicating that this herbicide may be used in pastures containing white clover. Although the higher rate of florpyrauxifen-benzyl + 2,4-D caused greater visible injury and lodging than the lower rate, there were no differences in clover biomass. Mowing remained the safest weed management option if the primary objective is to maintain white clover while employing a weed control tactic.

In conclusion, our research findings demonstrate the ability of herbicides that contain florpyrauxifen-benzyl to add value to forage systems through 1) controlling certain broadleaf weed species with the flexibility to apply across timings and 2) preserving established white clover. Future research should investigate the weed spectrum of florpyrauxifen-benzyl–containing herbicides, and evaluate the effect of various environmental factors, application timings, and clover growth stages on white clover injury.

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