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# Hairy buttercup (*Ranunculus sardous*) and cutleaf evening primrose (*Oenothera laciniata*) control using halauxifen-methyl based programs in Mississippi and Oklahoma winter wheat

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### Abstract

Hairy buttercup and cutleaf evening primrose are winter annual weeds that have become more problematic for winter wheat growers in the southern Great Plains and the midsouthern United States in recent years. Little research exists on which to base recommendations for controlling hairy buttercup in wheat, and little research has been published on cutleaf evening primrose control in recent years. With growing concerns of increased herbicide resistance among winter annual weeds, incorporating new herbicide sites of action has become necessary. The objective of this study was to assess halauxifen-methyl as a novel herbicide to control these two problematic winter annual broadleaf weeds in winter wheat in Mississippi and Oklahoma. Studies were conducted across four site-years in Mississippi and one site-year in Oklahoma comparing 15 herbicide programs with and without halauxifen-methyl. Hairy buttercup and cutleaf evening-primrose control was the greatest when a synthetic auxin was combined with an acetolactate synthase–inhibiting herbicide. Treatments including halauxifen-methyl resulted in the greatest control of hairy buttercup, whereas a synthetic auxin herbicide plus chlorsulfuron and metsulfuron resulted in the greatest control of cutleaf evening primrose. Halauxifen-methyl is an effective addition for control of winter annual broadleaf weeds like hairy buttercup and cutleaf evening primrose in winter wheat.

## Introduction

Winter annual broadleaf weeds pose a threat to winter wheat yields throughout the United States. Yields losses of 13% to 38% have been reported and are dependent on winter annual weed pressure (Conley and Bradley 2005) and timing of weed emergence relative to wheat crop emergence (Stahlman and Miller 1990). In Oklahoma, winter wheat was planted on more than 1.74 million ha in 2020, making it the crop with the greatest area planted in Oklahoma (USDA-NASS 2020). Mississippi winter wheat production is far less than in Oklahoma, accounting for 16,200 ha in 2020, a small fraction of the planted row crop hectares in the state (USDA-NASS 2020). Mississippi and Oklahoma also differ in average temperatures and rainfall received during the typical winter wheat growing season, October to June (Table 1). Mississippi receives more than four times the amount of rainfall and has warmer temperatures during winter months than Oklahoma. Although these states differ in climatic conditions, wheat production between the two states is similar; average yields in Mississippi and Oklahoma are 3,161 kg ha$^{-1}$ and 2,690 kg ha$^{-1}$, respectively (USDA-NASS 2019).

Troublesome weeds are surveyed every 3 yr by the Weed Science Society of America (WSSA); the last survey results available for grass crops were published in 2017 (Van Wychen 2017). Winter broadleaf weeds reported as troublesome by the 23 states responding to the survey included henbit (*Lamium amplexicaule* L.) in 14 states; common chickweed [*Stellaria media* (L.) Vill.] in nine states; horseweed (*Erigeron canadensis* L.) in eight states; cutleaf evening primrose in five states; kochia [*Bassia scoparia* (L.) A. J. Scott] in five states; field bindweed (*Convolvulus arvensis* L.) in five states; flixweed [*Descurainia sophia* (L.) Webb ex Prantl] in five states; wild radish (*Raphanus raphanistrum* L.) in five states; and several weed species were reported as troublesome in fewer than five states (Van Wychen 2017). *Ranunculus* spp. were

**Table 1.** Weather data during the winter wheat growing season for Brooksville, MS, Newton, MS, and Lahoma, OK, during the months of the study from 2018 to 2020.

| | Brooksville, MS[a] | | | Newton, MS[b] | | | Lahoma, OK[b] | | |
|---|---|---|---|---|---|---|---|---|---|
| | Average temperature | | | Average temperature | | | Average temperature | | |
| Year, Month | Min[c] | Max | Total rainfall | Min | Max | Total rainfall | Min | Max | Total rainfall |
| 2018–2019 | C | | mm | C | | mm | C | | mm |
| October | 12 | 27 | 0 | 13 | 27 | 46 | 9 | 21 | 203 |
| November | 5 | 16 | 5 | 6 | 17 | 176 | −1 | 13 | 7 |
| December | 4 | 14 | 267 | 6 | 16 | 254 | −2 | 10 | 48 |
| January | 2 | 12 | 186 | 0 | 14 | 141 | −3 | 8 | 68 |
| February | 7 | 18 | 139 | 6 | 20 | 172 | −3 | 7 | 15 |
| March | 6 | 18 | 64 | 7 | 20 | 78 | 1 | 14 | 65 |
| April | 6 | 19 | 241 | 12 | 25 | 259 | 8 | 21 | 94 |
| May | 19 | 30 | 108 | 17 | 30 | 192 | 13 | 24 | 346 |
| June | 20 | 32 | 123 | 20 | 33 | 87 | 18 | 31 | 180 |
| 2019–2020 | | | | | | | | | |
| November | 4 | 17 | 77 | 4 | 19 | 52 | NA | NA | NA |
| December | 5 | 15 | 171 | 6 | 17 | 101 | NA | NA | NA |
| January | 5 | 15 | 245 | 7 | 16 | 236 | NA | NA | NA |
| February | 4 | 15 | 306 | 6 | 18 | 251 | NA | NA | NA |
| March | 12 | 23 | 158 | 13 | 25 | 165 | NA | NA | NA |
| April | 10 | 22 | 271 | 9 | 25 | 189 | NA | NA | NA |
| May | 15 | 27 | 82 | 15 | 28 | 104 | NA | NA | NA |
| June | 19 | 31 | 66 | 20 | 32 | 178 | NA | NA | NA |

[a]Data accessed from Delta Agricultural Weather Center (2020).
[b]Data accessed from National Oceanographic and Atmospheric Administration (NOAA 2020).
[c]Abbreviations: Max, maximum; Min, minimum; NA, not applicable.

only listed as a major weed problem in Arkansas in 2017 but have been widely reported as a major weed problem in Mississippi pastures (Lemus 2019). *Ranunculus* spp. are often left untouched by cattle because of the toxic oil the plants contain, called protoanemonin (Lemus 2019). Although wheat fields are not commonly grazed in Mississippi, as they are in Oklahoma, many fields in eastern Mississippi currently used for row-crop production were once grazed, leading to a species shift favoring *Ranunculus* spp. populations in Mississippi fields (R. Lemus, personal communication, September 9, 2020). The genus *Ranunculus* comprises winter annual broadleaf species with leaves ranging from entire to deeply lobed. The Ranunculaceae is also known for a prominent tap root and showy yellow flowers, a common sight in fields across eastern Mississippi. Cutleaf evening primrose is a winter annual broadleaf weed species with a basal rosette and deeply lobed leaves. Its flowers can be yellow or red, with a combination of red and yellow flowers and typically is seen in fields. Cutleaf evening primrose has been a problematic weed in winter wheat production in Oklahoma for many years (Klingaman and Peeper 1989; Scott et al. 1995).

Cutleaf evening primrose has been reported to be effectively controlled with acetolactate synthase (ALS) inhibitors (WSSA Group 2) in Oklahoma; control of cutleaf evening primrose with chlorsulfuron was 90% or better (Klingaman and Peeper 1989; Scott et al. 1995). Although ALS-inhibiting herbicides were effective at controlling cutleaf evening primrose, repeated use of ALS-inhibiting herbicides can lead to development of herbicide resistance (Tranel and Wright 2002). The first reported cases of herbicide-resistant weeds in Mississippi and Oklahoma were resistant to ALS-inhibiting herbicides: common cocklebur (*Xanthium strumarium* L.) in Mississippi in 1989 and kochia in Oklahoma in 1992 (Heap 2020a). With increasing instances of ALS-inhibitor resistance reported among broadleaf weeds in Oklahoma and Mississippi, new herbicide options have been sought. Although no confirmations of ALS-inhibitor resistance among cutleaf evening primrose have been documented, *Ranunculus acris* has been determined to be resistant to flumetsulam and thifensulfuron-methyl (both ALS inhibitors) in New Zealand (Heap 2020b). Furthermore, *R. acris* has been found to be resistant to 2-methyl-4-chlorophenoxyacetic acid (MCPA; a Group 4 synthetic auxin herbicide) in New Zealand (Heap 2020b).

In recent years, a new herbicide active ingredient, halauxifen-methyl, was introduced by Dow Agrosciences (now Corteva Agriscience) that was premixed with an ALS-inhibiting herbicide, florasulam, labeled for use to control winter annual weeds in wheat (Anonymous 2018). The synthesis of halauxifen-methyl was aimed at finding an effective auxin herbicide derivative with a short half-life in soils (Schmitzer et al. 2015). Halauxifen-methyl provided effective control of nine broadleaf weed species, with a shorter soil half-life compared with other screened herbicides, which led to the commercialization of this herbicide active ingredient (Schmitzer et al. 2015). Halauxifen-methyl is effective at controlling horseweed (Crose et al. 2020; McCauley et al. 2018; Quinn et al 2020), but little research has been published on control of other winter broadleaf weeds like hairy buttercup or cutleaf evening primrose. The objective of the present study was to assess the effectiveness of halauxifen-methyl plus florasulam herbicide programs to control hairy buttercup and cutleaf evening primrose in Mississippi and Oklahoma.

## Materials and Methods

Field studies were conducted in 2018–2019 and 2019–2020 at two locations in Mississippi: the Mississippi Agricultural and Forestry Experiment Station (MAFES), Blackbelt Branch Experiment Station in Brooksville, MS (33.15°N, 88.33°W; elevation, 85 m), and the MAFES Coastal Plain Experiment Station, in Newton, MS (32.20°N, 89.05°W; elevation, 105 m). The study was also conducted in 2018–2019 at the Oklahoma Agricultural Experiment Station, North Central Research Station, in Lahoma, OK (36.23°N, 98.06°W; elevation, 392 m). Hereafter in this article, site-years in

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**Table 2.** Wheat planting dates, varieties, densities, and harvest dates for all five site-years across Mississippi and Oklahoma.

| Year | Location | Wheat variety | Planting density | Planting date | Herbicide application date | Harvest date |
|---|---|---|---|---|---|---|
| | | | kg ha$^{-1}$ | | | |
| 2018–2019 | Lahoma, OK | Iba | 90 | October 23 | December 5 | June 14 |
| 2018–2019 | Brooksville, MS | TN 902 | 130 | October 29 | December 6 | May 29 |
| 2018–2019 | Newton, MS | TN 902 | 130 | October 22 | December 5 | May 30 |
| 2019–2020 | Brooksville, MS | #Bullet | 130 | November 11 | January 8 | June 17 |
| 2019–2020 | Newton, MS | #Bullet | 130 | November 20 | January 16 | June 11 |

Mississippi are referred to as Brooksville-19, Newton-19, Brooksville-20, and Newton-20. The one site-year in Oklahoma is referred to as Lahoma-19.

Wheat planting densities, varieties, planting dates, and harvest dates are listed in Table 2. Wheat was drilled with a grain drill with disk openers at 19-cm spacing at all five site-years. The Brooksville-19 site was on an Okolona silty clay (fine, smectitic, thermic Oxyaquic Hapluderts) with a pH averaging 5.9. The Brooksville-20 site was on a Brooksville silty clay (fine, smectitic, thermic Aquic Hapluderts) with a pH averaging 6.1. The Newton-19 and Newton-20 sites were in the same field and were on a Prentiss very fine sandy loam (coarse-loamy, siliceous, semiactive, thermic Glossic Fragiudults) with an average pH of 7.1. The Lahoma-19 site was on a Grant silt loam (fine-silty, mixed, superactive, thermic Udic Argiustolls) with an average pH of 6.3.

The same herbicide treatments were applied at all five site-years, except that two treatments differed in the Brooksville-19 and Newton-19 site-years due to a lack of availability of MCPA ester. Herbicide treatments and their rates are listed in Table 3. All applications in Mississippi were applied using a $CO_2$-pressurized backpack sprayer with four nozzles (AIXR 11002; Teejet Technologies, Wheaton, IL) spaced at 48.3 cm at a spray volume of 140 L ha$^{-1}$ and air pressure of 276 kPa. Application equipment at the Lahoma, OK, site was similar with the exception of nozzles. TT 11002 nozzles (Teejet Technologies) were spaced at 45.7 cm and pressure was 214 kPa. Treatments at each site year included 15 herbicide treatments and one untreated control arranged in a randomized complete block design with four replications, except for Brooksville-20, which had eight replications because the field was larger.

Plots were sprayed when cutleaf evening primrose or hairy buttercup rosettes reached 5–10 cm diam. Date of application varied between 2018–2019 and 2019–2020 simply due to later wheat sowing that slowed weed growth in 2019–2020. Hairy buttercup was only present at Mississippi site-years and cutleaf evening primrose was only present at the Lahoma-19 site-year in Oklahoma. Plots in the four Mississippi site-years had hairy buttercup populations averaging 30 plants m$^{-2}$ (5 plants m$^{-2}$ at Brooksville-20, 30 plants m$^{-2}$ at Brooksville-19, and 55 plants m$^{-2}$ at Newton-19 and Newton-20). Plots at the Lahoma-19 site-year had cutleaf evening primrose populations averaging 40 plants m$^{-2}$.

Plot measurements varied by location: 2.1 by 9.1 m at Lahoma-19; 2.3 by 7.6 m at Brooksville-19 and Newton-19; and 1.5 by 4.88 m at Brooksville-20 and Newton-20. Plot width was reduced at Mississippi site locations in 2019–2020 to reduce the unharvested plot area. Plots were visually rated for control (with 0% being no control and 100% being complete death of rated species) at 2, 4, and 8 wk after treatment (WAT). Yield data were recorded at Mississippi locations with an Almaco small plot combine (R1 Rotary Single Plot Combine; Almaco, Nevada, IA) and at the Oklahoma location with a Wintersteiger small plot combine (Wintersteiger Inc., Salt Lake City, UT). The Mississippi locations in 2018–2019 had scattered Fusarium head blight (*Fusarium graminerarum*), but the incidence was not so high as to prevent harvesting any single plot. A different wheat variety, #Bullet, which is highly tolerant to Fusarium head blight was selected for planting at 2019–2020 locations in Mississippi (Anonymous 2019).

Hairy buttercup and cutleaf evening primrose control data (2, 4, and 8 WAT) and wheat yield data were independently subjected to ANOVA using a generalized linear mixed model (PROC GLIMMIX) in SAS, version 9.4 (SAS Institute Inc., Cary, NC). Site-year was analyzed for significance and was separated out by Brooksville-19, Brooksville-20, and the two Newton site-years; pooled as year, these were not significant ($P = 0.24$). The model included the fixed effect of herbicide treatment with replication included as a random effect. Control and yield mean separations were conducted using Fisher protected LSD ($\alpha = 0.05$), which indicated statistical significance. A univariate analysis was performed on all responses to test for stable variance. No data sets were transformed, because transformation did not increase stabilization.

## Results and Discussion

### *Hairy Buttercup Control and Winter Wheat Yield, Newton 2018–2020*

Hairy buttercup control ranged from 54% to 95% at 4 WAT and 49% to 97% at 8 WAT (Table 4). Herbicide treatment was significant ($P < 0.001$), but not the interaction of treatment by year ($P = 0.201$). Thus, treatments over both years were analyzed across the 2018–2019 and 2019–2020 seasons. The highest performing group of treatments included all treatments containing halauxifen-methyl (hereafter, halauxifen) plus florasulam, as well as MCPA, chlorsulfuron plus metsulfuron, fluroxypyr plus thifensulfuron, and tank mixtures of both dicamba or 2,4-D with chlorsulfuron plus metsulfuron (Table 4). Control with halauxifen plus florasulam alone resulted in 86% and 88% control at 4 and 8 WAT, respectively. Halauxifen plus florasulam treatments, when mixed with ALS-inhibitor herbicides, resulted in at least 91% hairy buttercup control at both 4 and 8 WAT. Treatments with 2,4-D or dicamba alone or in combination with one another resulted in the least hairy buttercup control. Dicamba alone achieved only 54% control at 4 WAT and 49% control 8 WAT; however, control was improved to 78% and 79% when combined with 2,4-D at both 4 and 8 WAT, respectively.

Wheat yields ranged from 1,020 to 2,030 kg ha$^{-1}$ across all plots over both site-years at the Newton location (Table 5). Yields were lower than the other two site-year locations but were consistent over both years of the study. The untreated control plots over both years at Newton had reduced winter wheat yield compared with

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**Table 3.** Herbicide treatments and application rates across the five site-years in Mississippi and Oklahoma from 2018–2020.

| Common name[a] | Trade name | WSSA SOA | Rate | Manufacturer |
|---|---|---|---|---|
| | | | g ae/ai ha$^{-1}$ | |
| 2,4-D amine | Weed Rhap-A 4-D | 4 | 533 | Helena Agri Enterprises, Collierville, TN |
| Dicamba DGA | Clarity | 4 | 140 | BASF, Research Triangle Park, NC |
| MCPA ester | MCPA Ester 4 | 4 | 519 | Albaugh/Agri-Star, Ankeny, IA |
| Chlorsulfuron + metsulfuron[b] | Finesse Cereal and Fallow | 2; 2 | 280 + 56 | FMC Agricultural Solutions, Philadelphia, PA |
| Fluroxypyr + thifensulfuron[b] | Sentrallas | 42 | 159 + 31 | FMC Agricultural Solutions |
| Halauxifen + florasulam[b] | Quelex | 4; 2 | 5.3 + 5.3 | Corteva Agriscience, Indianapolis, IN |
| Halauxifen + florasulam +2,4-D amine | Quelex + Weed Rhap-A 4-D | 4; 24 | 5.3 + 5.3 + 280 | Corteva Agriscience; Helena Agri Enterprises |
| Halauxifen + florasulam +dicamba DGA | Quelex + Clarity | 4; 24 | 5.3 + 5.3 + 140 | Corteva Agriscience; BASF |
| Halauxifen + florasulam +MCPA ester | Quelex + MCPA Ester 4 | 4; 24 | 5.3 + 5.3 + 350 | Corteva Agriscience; Albaugh/Agri-Star |
| Halauxifen + florasulam[b] +chlorsulfuron + metsulfuron | Quelex + Finesse Cereal and Fallow | 4; 22; 2 | 5.3 + 5.3 + 280 + 56 | Corteva Agriscience; FMC Agricultural Solutions |
| Halauxifen + florasulam[b] +fluroxypyr + thifensulfuron | Quelex + Sentrallas | 4; 24; 2 | 5.3 + 5.3 + 114 + 22 | Corteva Agriscience; FMC Agricultural Solutions |
| Dicamba DGA +2,4-D amine | Clarity + Weed Rhap-A 4-D | 44 | 140 + 280 | BASF; Helena Agri Enterprises |
| Dicamba DGA +chlorsulfuron + metsulfuron | Clarity + Finesse Cereal and Fallow | 42; 2 | 140 + 280 + 56 | BASF; FMC Agricultural Solutions |
| Dicamba DGA +fluroxypyr + thifensulfuron | Clarity + Sentrallas | 44; 2 | 140 + 114 + 22 | BASF; FMC Agricultural Solutions |
| 2,4-D amine +chlorsulfuron + metsulfuron | Weed Rhap-A 4-D + Finesse Cereal and Fallow | 42; 2 | 533 + 280 + 56 | Helena Agri Enterprises; FMC Agricultural Solutions |
| 2,4-D amine +fluroxypyr + thifensulfuron | Weed Rhap-A 4-D + Sentrallas | 44; 2 | 280 + 114 + 22 | Helena Agri Enterprises; FMC Agricultural Solutions |
| chlorsulfuron + metsulfuron[b] + fluroxypyr + thifensulfuron | Finesse Cereal and Fallow + Sentrallas | 2; 24; 2 | 280 + 56 + 114 + 22 | FMC Agricultural Solutions; FMC Agricultural Solutions |

[a]Abbreviations: DGA, diglycolamine; MCPA, 2-methyl-4-chlorophenoxyacetic acid; SOA, site of action; WSSA, Weed Science Society of America Herbicide.
[b]Nonionic surfactant was added to all treatments at 0.25% vol/vol, which included an ALS-inhibiting herbicide unless it contained 2,4-D.

**Table 4.** Hairy buttercup control 4 and 8 WAT by site-year in Mississippi 2018–2020.

| | Brooksville 18–19[b] | | Brooksville 19–20[b] | | Newton 18–20[b] | |
|---|---|---|---|---|---|---|
| Herbicide treatment[a] | 4 WAT | 8 WAT | 4 WAT | 8 WAT | 4 WAT | 8 WAT |
| | % | | | | | |
| Untreated control | NA | NA | NA | NA | NA | NA |
| 2,4-D amine | 66 fg | 71 bc | 91 | 92 | 78 b | 79 b |
| Dicamba DGA | 60 gh | 58 d | 96 | 94 | 54 c | 49 c |
| MCPA ester | NA[c] | NA[c] | 88 | 93 | 90 ab | 88 ab |
| Chlorsulfuron + metsulfuron | 86 abc | 94 a | 97 | 91 | 82 ab | 94 a |
| Fluroxypyr + thifensulfuron | 70 ef | 74 bc | 96 | 96 | 85 ab | 89 ab |
| Halauxifen + florasulam | 83 bcd | 91 a | 89 | 91 | 86 ab | 88 ab |
| Halauxifen + florasulam + 2,4-D amine | 86 abc | 89 a | 95 | 98 | 86 ab | 90 ab |
| Halauxifen + florasulam + dicamba DGA | 88 ab | 90 a | 96 | 97 | 88 ab | 89 ab |
| Halauxifen + florasulam + MCPA ester | NA[c] | NA[c] | 97 | 98 | 95 a | 97 a |
| Halauxifen + florasulam + chlorsulfuron + metsulfuron | 91 a | 95 a | 96 | 97 | 91 ab | 93 a |
| Halauxifen + florasulam + fluroxypyr + thifensulfuron | 81 bcd | 93 a | 93 | 95 | 91 ab | 92 a |
| Dicamba DGA + 2,4-D amine | 58 h | 56 d | 93 | 95 | 78 b | 79 b |
| Dicamba DGA + chlorsulfuron + metsulfuron | 89 ab | 95 a | 94 | 98 | 89 ab | 90 ab |
| Dicamba DGA + fluroxypyr + thifensulfuron | 65 fgh | 69 c | 92 | 91 | 88 ab | 89 ab |
| 2,4-D amine + chlorsulfuron + metsulfuron | 88 ab | 95 a | 88 | 92 | 94 a | 95 a |
| 2,4-D amine + fluroxypyr + thifensulfuron | 79 cd | 78 bc | NA[d] | NA[d] | 88 ab | 88 ab |
| Chlorsulfuron + metsulfuron + fluroxypyr + thifensulfuron | 75 de | 79 b | NA[d] | NA[d] | 90 ab | 94 a |
| LSD $P \leq 0.05$ | 8.54 | 9.46 | ns | ns | 15.85 | 12.89 |

[a]Abbreviations: DGA, diglycolamine; MCPA, 2-methyl-4-chlorophenoxyacetic acid; NA, not applicable; ns, not significant; WAT, weeks after treatment.
[b]Means separations were performed using Fisher protected LSD at $\alpha = 0.05$. Means with the same letters are not statistically different.
[c]MCPA and halauxifen + florasulam plus MCPA were not included in the Brooksville 2019 site-year.
[d]2,4-D and fluroxypyr + thifensulfuron; chlorsulfuron and metsulfuron plus fluroxypyr and thifensulfuron were not included in the Brooksville 2020 site-year.

treated plots, showing the negative impact that hairy buttercup can have on winter wheat yields when not managed. This agrees with the findings of Singh (2012), who found that wheat yields were significantly higher when *Ranunculus* spp. were controlled compared with untreated plots (Singh 2012). In addition to affecting yields, the taller hairy buttercup plants could easily get lodged in the header when harvesting, which increases seed contamination with the harvested crop with other species (McWhorter and Hartwig 1972). There were no obvious differences in winter wheat yield with and without halauxifen plus florasulam, but across both years, no crop injury was observed. This was consistent across all four site-years in Mississippi.

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**Table 5.** Winter wheat yields by site-year and herbicide treatment in Mississippi 2018–2020.

| Herbicide treatment[a] | Brooksville 18–19 | Brooksville 19–20 | Newton 18–20[b] |
|---|---|---|---|
| | kg ha$^{-1}$ | | |
| Untreated control | 2,090 | 5,770 | 1,004 b |
| 2,4-D amine | 1,530 | 5,260 | 1,300 ab |
| Dicamba DGA | 2,220 | 6,650 | 1,520 ab |
| MCPA ester | NA[c] | 6,350 | 1,470 ab |
| Chlorsulfuron + metsulfuron | 2,440 | 6,780 | 1,630 ab |
| Fluroxypyr + thifensulfuron | 2,590 | 6,810 | 1,570 ab |
| Halauxifen + florasulam | 2,270 | 6,640 | 1,420 ab |
| Halauxifen + florasulam + 2,4-D amine | 2,560 | 6,600 | 1,660 ab |
| Halauxifen + florasulam + dicamba DGA | 2,300 | 6,320 | 1,840 a |
| Halauxifen + florasulam + MCPA ester | NA[c] | 6,710 | 2,030 a |
| Halauxifen + florasulam + chlorsulfuron + metsulfuron | 2,560 | 6,980 | 1,800 a |
| Halauxifen + florasulam + fluroxypyr + thifensulfuron | 2,730 | 6,720 | 1,660 ab |
| Dicamba DGA + 2,4-D amine | 2,260 | 6,300 | 1,850 a |
| Dicamba DGA + chlorsulfuron + metsulfuron | 2,550 | 6,590 | 1,590 ab |
| Dicamba DGA + fluroxypyr + thifensulfuron | 2,130 | 6,850 | 1,760 a |
| 2,4-D amine + chlorsulfuron + metsulfuron | 2,560 | 6,730 | 1,720 ab |
| 2,4-D amine + fluroxypyr + thifensulfuron | 1,760 | NA[d] | 1,530 ab |
| Chlorsulfuron + metsulfuron + fluroxypyr + thifensulfuron | 2,370 | NA[d] | 1,740 ab |
| LSD P ≤ 0.05 | ns | ns | 720 |

[a]Abbreviations: DGA, diglycolamine; MCPA, 2-methyl-4-chlorophenoxyacetic acid; NA, not applicable; ns, not significant.
[b]Means separations were performed using Fisher protected LSD at α = 0.05. Means with the same letters are not statistically different.
[c]MCPA and halauxifen + florasulam plus MCPA were not included in the Brooksville 2019 site-year.
[d]2,4-D and fluroxypyr + thifensulfuron; chlorsulfuron and metsulfuron plus fluroxypyr and thifensulfuron were not included in the Brooksville 2020 site-year.

## Hairy Buttercup Control and Winter Wheat Yield, Brooksville-19

Hairy buttercup control ranged from 58% to 91% at 4 WAT, and 56% to 95% control at 8 WAT (Table 4). Treatments with chlorsulfuron plus metsulfuron alone or in combination with halauxifen plus florasulam, dicamba diglycolamine (DGA), or 2,4-D amine resulted in 94% or better control8 WAT (Table 4). The exception was where chlorsulfuron plus metsulfuron was in a tank-mixture with fluroxypyr plus thifensulfuron, which only resulted in hairy buttercup control of 75% and 79% at 4 and 8 WAT, respectively. Halauxifen plus florasulam alone or in combination with other herbicides in a tank mixture resulted in control at or greater than 89% 8 WAT (Table 4). The lowest-performing treatments were dicamba DGA alone or in combination with 2,4-D amine, which only achieved 58% and 56% control, respectively, at 8 WAT. Dicamba DGA, when in a tank mixture with ALS-inhibiting herbicides, drastically improved hairy buttercup control, except when combined with fluroxypyr plus thifensulfuron, which only achieved 69% control 8 WAT. When dicamba was combined with chlorsulfuron plus metsulfuron or halauxifen plus florasulam, hairy buttercup control was 90% or greater 8 WAT (Table 4). Winter wheat yields were not different at Brooksville-19; the average yield was 2,310 kg ha$^{-1}$ (Table 5).

**Table 6.** Preliminary cutleaf evening primrose control data 4 and 8 WAT and winter wheat yield from the Lahoma-19 site-year in Oklahoma 2018–2019.

| Herbicide treatment | 4 WAT | 8 WAT | Wheat yield |
|---|---|---|---|
| | % | | kg ha$^{-1}$ |
| Untreated control | NA | NA | 3,020 abc |
| 2,4-D amine | 36 f | 73 e | 2,650 c–g |
| Dicamba DGA | 13 g | 23 f | 2,800 b–e |
| MCPA ester | 48 e | 78 de | 2,560 d–h |
| Chlorsulfuron + metsulfuron | 76 ab | 89 ab | 2,260 gh |
| Fluroxypyr + thifensulfuron | 75 ab | 75 de | 3,000 abc |
| Halauxifen + florasulam | 74 abc | 84 bc | 3,260 a |
| Halauxifen + florasulam + 2,4-D amine | 71 a–d | 84 bc | 3,120 ab |
| Halauxifen + florasulam + dicamba DGA | 65 d | 76 de | 2,910 a–d |
| Halauxifen + florasulam + MCPA ester | 66 cd | 80 cd | 2,720 b–f |
| Halauxifen + florasulam + chlorsulfuron + metsulfuron | 76 ab | 88 ab | 2,350 fgh |
| Halauxifen + florasulam + fluroxypyr + thifensulfuron | 78 a | 85 bc | 3,040 abc |
| Dicamba DGA + 2,4-D amine | 45 e | 74 e | 2,420 e–h |
| Dicamba DGA + chlorsulfuron + metsulfuron | 71 a–d | 92 a | 2,480 e–h |
| Dicamba DGA + fluroxypyr + thifensulfuron | 69 bcd | 76 de | 2,360 fgh |
| 2,4-D amine + chlorsulfuron + metsulfuron | 79 a | 92 a | 2,190 h |
| LSD P ≤ 0.05 | 8.57 | 5.96 | 420 |

[a]Abbreviations: DGA, diglycolamine; MCPA, 2-methyl-4-chlorophenoxyacetic acid; NA, not applicable; WAT, weeks after treatment.
[b]Means separations were performed using Fisher protected LSD at α = 0.05. Means with the same letters are not statistically different.

## Hairy Buttercup Control and Winter Wheat Yield, Brooksville-20

Hairy buttercup control was not different for treatments at Brooksville-20, where control ranged from 88% to 97% at 4 WAT and 91% to 98% at 8 WAT (Table 4). The overall population of hairy buttercup plants was the lowest from all site-years in Mississippi, averaging five plants m$^{-2}$. This site was also the most fertile of the four site-years; the average wheat yield was 6,320 kg ha$^{-1}$, which is twice the Mississippi state average for winter wheat yields (USDA-NASS 2019). Wheat yields also did not statistically separate, because this site-year had low buttercup plant populations and high wheat yields, but with little numeric separation between the highest and lowest control and wheat yield data points.

## Preliminary Cutleaf Evening Primrose Control and Winter Wheat Yield, Lahoma-19

Though we had only one site-year of data on for cutleaf evening primrose control, those data are presented as that site-year was sprayed using the same protocol as at the hairy buttercup control site-years. Cutleaf evening primrose control ranged from 13% to 79% at 4 WAT and 23% to 92% control at 8 WAT (Table 6). Treatments with similar control to the best treatment at 8 WAT included chlorsulfuron plus metsulfuron alone and halauxifen plus florasulam plus chlorsulfuron plus metsulfuron. As with hairy buttercup, cutleaf evening primrose control was lowest with 2,4-D and dicamba applied alone or in combination with each other. Cutleaf evening primrose control was 23% to 78% with dicamba and MCPA alone, respectively, at 8 WAT. Mixing dicamba with 2,4-D did not improve weed control compared with 2,4-D alone, showing that dicamba had little effect on cutleaf evening primrose control. The greatest cutleaf evening primrose control was achieved by all treatments that included chlorsulfuron plus metsulfuron, with none of these treatments resulting in less than 88% control (Table 6). Results from this study agree with earlier research showing the effectiveness of chlorsulfuron-containing treatments on the control of cutleaf evening primrose (Klingaman and Peeper 1989; Scott et al. 1995).

Winter wheat yields ranged from 2,190 kg $ha^{-1}$ for 2,4-D amine plus chlorsulfuron plus metsulfuron to 3,260 for halauxifen plus florasulam alone (Table 6). Yield data did not correlate with weed control results; 2,4-D plus chlorsulfuron plus metsulfuron resulted in the greatest percentage of cutleaf evening primrose control yet the lowest wheat yield (Table 6). Yield impacts of cutleaf evening primrose on wheat in this study were consistent with earlier research assessing its effect on wheat yields (Scott et al. 1995). Though cutleaf evening primrose does not appear to affect yields when uncontrolled (yield of 3,020 kg $ha^{-1}$ in this study), the impacts on seed storage and harvesting concerns indicate the necessity of controlling this weed (Scott et al. 1995).

On the basis of results across all five site-years, using multiple herbicide sites of action to achieve sufficient control is necessary, even in a single herbicide product. For example, the combination of two synthetic auxin herbicides did not improve cutleaf evening primrose nor hairy buttercup control, but when synthetic auxin herbicides were added to tank mixtures with an ALS-inhibiting herbicide, control significantly improved (Tables 4 and 6). Halauxifen plus florasulam resulted in similar control to the best-performing herbicide treatments for hairy buttercup control. These results were also observed in other studies assessing control of halauxifen plus florasulam for horseweed control (Crose et al. 2020; McCauley et al. 2018; Quinn et al. 2020) and control of other annual broadleaf weeds (Love et al. 2016; Zimmer et al. 2018). For cutleaf evening primrose control, our preliminary results suggest that using chlorsulfuron plus metsulfuron is highly effective, though overuse of ALS herbicides will increase the likelihood of herbicide-resistance development in cutleaf evening primrose, which has yet to be documented.

Given the necessity to steward herbicides to reduce the likelihood of herbicide-resistance development, incorporation of new herbicide active ingredients is vital (Norsworthy et al. 2012). Halauxifen-methyl plus florasulam in combination with an additional synthetic auxin or other herbicides in this study resulted in effective hairy buttercup and cutleaf evening primrose control. Monitoring use of any of the herbicide sites of action used in this study will be important to ensure that resistance development does not happen in the coming years. Wheat yields were not correlated to hairy buttercup or cutleaf evening primrose control, but given the increased understanding of weed species as alternate hosts to insects and diseases, as well as the potential of additional herbicide-resistance development, allowing populations to go uncontrolled is not wise. Using multiple herbicide sites of action will control other winter weed problems in wheat, ensuring the best return on investment for growers. Hairy buttercup control is greatest when a synthetic auxin herbicide is added to a tank mixture or premixed with an ALS-inhibiting herbicide. Our preliminary results with cutleaf evening primrose suggest this is also true for this species. These treatments may lead to a decreased weed presence, thereby preserving yields for a successful cropping season.

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## References

Anonymous (2019). #Bullet characteristic sheet. Wynne, AR: Erwin Keith Inc. 1 p. https://www.progenyag.com/site/assets/files/1096/bullet-1.pdf. Accessed: September 1, 2020

Anonymous (2018). Quelex® herbicide label. Dow AgroSciences Publication No. D01-411-003. Indianapolis, IN: Dow AgroSciences. 5 p

Conley SP, Bradley KW (2005) Wheat (*Triticum aestivum*) yield response to henbit (*Lamium amplexicaule*) interference and simulated winter kill 1. Weed Technol 19:902–906

Crose JA, Manuchehri MR, Baughman TA (2020) Horseweed (*Conyza canadensis*) management in Oklahoma winter wheat. Weed Technol 34: 229–234

Delta Agricultural Weather Center, Mississippi State University Extension (2020) Daily report Brooksville Station (10/29/18-05/29/2019) and (11/11/19-06/17/20). http://deltaweather.extension.msstate.edu/report. Accessed: September 1, 2020

Heap I (2020a) Herbicide resistance in Mississippi and Oklahoma, USA. http://weedscience.org/Pages/filter.aspx. Accessed: September 1, 2020

Heap I (2020b) Herbicide-resistant Ranunculaceae globally (*Ranunculus* spp.). http://weedscience.org/Pages/filter.aspx. Accessed: September 1, 2020

Klingaman TE, Peeper TF (1989) Weed control in winter wheat (*Triticum aestivum*) with chlorsulfuron and CGA 131036 and comparison of modes of action. Weed Technol 3:490–496

Lemus R (2019) Identifying and controlling common winter weeds in your pastures. Mississippi State Extension update, December 12, 2019.http://extension.msstate.edu/newsletters/forage-news/2019/identifying-and-controlling-common-winter-weeds-your-pastures. Accessed: September 3, 2020

Love CO, Plater CL, Lines MD, Wells GS, Nott PJ (2016) Combination of Arylex (halauxifen-methyl) + fluroxypyr for broadleaf weed control in winter cereals and fallow. Pages 341–346 *in* Twentieth Australasian Weeds Conference. http://caws.org.nz/old-site/awc/2016/awc201613411.pdf. Accessed: September 3, 2020

McCauley CL, Johnson WG, Young BG (2018) Efficacy of halauxifen-methyl on glyphosate-resistant horseweed (*Erigeron canadensis*). Weed Sci 66:758–763

McWhorter CG, Hartwig EE (1972). Competition of johnsongrass and cocklebur with six soybean varieties. Weed Sci 20:56–59

[NOAA] National Oceanic and Atmospheric Administration, National Centers for Environmental Information (2020) Climate data online search [custom global summary of the month: Lahoma, OK and Newton, MS]. https://www.ncdc.noaa.gov/cdo-web/search. Accessed: September 1, 2020

Norsworthy JK, Ward SM, Shaw DR, Llewellyn RS, Nichols RL, Webster TM, Bradley KW, Frisvold G, Powles SB, Burgos NR, Witt WW, Barrett M (2012) Reducing the risks of herbicide resistance: best management practices and recommendations. Weed Sci 60:31–62.

Quinn J, Soltani N, Ashigh J, Hooker DC, Robinson DE, Sikkema PH (2020) Halauxifen-methyl controls glyphosate resistant horseweed (*Conyza canadensis*) but not giant ragweed (*Ambrosia trifida*) in winter wheat. Weed Technol 34:607–612

Schmitzer PR, Balko TW, Daeuble JF, Epp JB, Satchivi NM, Siddal TL, Weimer MR, Yerkes CN (2015) Discovery and SAR of halauxifen methyl: a novel auxin herbicide. Pages 247–260 *in*: Maienfisch P, Stevenson TM, eds. Discovery and Synthesis of Crop Protection Products. ACS Symposium Series. Vol. 1204. Washington, DC: American Chemical Society Publications

Scott RC, Peeper TF, Koscelny JA (1995) Winter wheat (*Triticum aestivum*) yield response to winter annual broadleaf control. Weed Technol 9:594–598

Singh RJ (2012) Weed management in irrigated wheat (*Triticum aestivum*) with special reference to buttercup weed (*Ranunculus* spp) in north-west Himalayas. Ind J Agric Sci 82:706–710

Stahlman PW, Miller SD (1990) Downy brome (*Bromus tectorum*) interference and economic thresholds in winter wheat (*Triticum aestivum*). Weed Sci 38:224–228

Tranel PJ, Wright TR (2002) Resistance of weeds to ALS-inhibiting herbicides: what have we learned? Weed Sci 50:700–712

[USDA-NASS] U.S. Department of Agriculture, National Agricultural Statistics Service (2020) Acreage. June 30, 2020. 50 p. https://www.nass.usda.gov/Publications/Todays_Reports/reports/acrg0620.pdf. Accessed: September 1, 2020

[USDA-NASS] U.S. Department of Agriculture, National Agricultural Statistics Service (2019) Small Grains. 2019 Summary. 27 p. https://downloads.usda.library.cornell.edu/usda-esmis/files/5t34sj573/ms35tp36v/3197z0970/smgr0919.pdf. Accessed: August 27, 2020

Van Wychen L (2017) 2017 Survey of the most common and troublesome weeds in grass crops, pasture and turf in the United States and Canada. Weed Science Society of America National Weed Survey Dataset. http://wssa.net/wp-content/uploads/2017-Weed-Survey_Grass-crops.xlsx. Accessed: August 25, 2020

Zimmer M, Young BG, Johnson WG (2018) Weed control with halauxifen-methyl applied alone and in mixtures with 2,4-D, dicamba, and glyphosate. Weed Technol 32:597–602

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