Efficacy of preemergence herbicides over time[1]

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Abstract

Preemergence herbicides are applied to container-grown nursery crops repeatedly throughout the year, often in 8 to 10 week intervals. Preemergence herbicide efficacy may decline over time, resulting in reduced weed control several weeks after application if weed seed density remains high. The objective of this research is to evaluate efficacy of preemergence herbicides on creeping woodsorrel (*Oxalis corniculata* L.) and flexuous bittercress (*Cardamine flexuosa* With.) by applying weed seed from 0 to 10 weeks after herbicide application. Granular formulations of pendimethalin, prodiamine + isoxaben, oxyfluorfen + pendimethalin, and flumioxazin were applied at their maximum labeled rates to separate groups of containers every two weeks for ten weeks. After the herbicide application at 10 weeks, 40 seeds of creeping woodsorrel and flexuous bittercress each were applied to all containers. All herbicides provided effective control when seed were applied within 2 weeks of herbicide application. Herbicides containing oxyfluorfen or flumioxazin provided effective preemergence bittercress and creeping woodsorrel control when seed were applied up to 8 to 10 weeks after herbicide application. Other herbicide products resulted in reduced control as the time between herbicide and seed application increased.

Index words: weed control, container crops, substrates.

Species used in this study: flexuous bittercress (*Cardamine flexuosa* With.), creeping woodsorrel (*Oxalis corniculata* L.).

Chemicals used in this study: pendimethalin (Pendulum 2G), prodiamine + isoxaben (Gemini G), pendimethalin + oxyfluorfen (OH2), and flumioxazin (BroadStar).

Significance to the Horticulture Industry

There are numerous preemergence herbicide products available for container-grown nursery crops. It has been established that some herbicide active ingredients are more effective at controlling certain weeds than others. This information is used by growers in developing weed management programs. Another factor affecting herbicide performance is how long the product will remain effective on the substrate surface. There is comparatively less information on herbicide longevity. The objective of this research was to provide more information on how long several commonly used herbicides remain effective after application. Herbicides containing oxyfluorfen or flumioxazin provided effective preemergence flexuous bittercress and creeping woodsorrel control even when weed seeds were introduced to the containers up to 8 to 10 weeks after herbicide application. Other herbicide products, including pendimethalin or prodiamine + isoxaben, resulted in reduced control as the time between herbicide and seed application increased. This information provides growers with additional criteria to develop effective weed management programs.

Introduction

Container weeds produce and disperse seed continuously throughout the growing season. Creeping woodsorrel develops lateral shoots from indeterminate stolons that will continue to flower and produce seed as they grow (Doust et al. 1985). Seed of creeping woodsorrel are 90% non-dormant upon dispersal (Holt 1987), can germinate in complete darkness (Altland et al. 2016), and can germinate when temperature ranges between 10 and 30 C (50 and 86 F) (Holt 1987). Creeping woodsorrel can continue to grow and germinate virtually year-round under typical greenhouse conditions. Likewise, Crone and Talyor (1996) describe Pennsylvania bittercress (*Cardamine pensylvanica* Muhl. ex Willd.) as having no specific germination or flowering requirements in a greenhouse environment, and thus is present throughout the year under a wide range of greenhouse conditions. While these and other weeds may be more prolific during some seasons than others, it is reasonable to expect continuous seed production from both species throughout the year, especially in greenhouses and other protected horticulture structures.

Much of the past research on herbicide efficacy in containers involved experiments in which weed seed were applied immediately before or after the time of herbicide application (Derr 1994, Gallitano and Skroch 1993, Ruter and Glaze 1992, Schuett and Klett 1989). Herbicides degrade in soilless substrates by biological, chemical, or photodecomposition processes depending on herbicide type (Monaco et al. 2002). Degradation processes begin almost immediately after application, thus preemergence herbicide concentration near the substrate surface is highest soon after application. In herbicide efficacy experiments, applying weed seed at or near the time of herbicide application makes it more likely the herbicide will be effective. Weed seed applied weeks or months after herbicide application may be less controlled, as the herbicide would have degraded. In herbicide efficacy trials, applying seed near the time of herbicide application is likely to result in an over-estimation of herbicide efficacy. Norcini et al. (1997) reported moderate (87%) and poor (57%) control of hairy bittercress (*C. hirsuta* L.) with oxadiazon after 2 and 3 months, respectively. They noted that this differed from other studies showing excellent

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hairy bittercress control after 2 months (Bachman and Whitwell, 1994) or 6 months (Gallitano and Skroch 1993). They attributed the reduced control in their study to a continuous supply of hairy bittercress seed compared to a single aliquot of seed applied in the other studies.

Herbicide efficacy in container substrates with weed seed applied weeks or months after herbicide application has been evaluated by relatively few published reports. Whitwell and Kalmowitz (1989) reseeded prostrate spurge (*Euphorbia humistrata* Engelm. Ex. Gray) and large crabgrass (*Digitaria sanguinalis* L.) at 0, 30, and 60 days after an herbicide application, and found that weed control declined with each successive weed seed application. Altland (2009) found that black cottonwood (*Populus trichocarpa* Torr. & A.Gray ex. Hook.) control with preemergence herbicide declined as the length of time increased between herbicide application and seed fall. Likewise, northern willowherb (*Epilobium ciliatum* Raf.) establishment and growth were greater when seed were introduced just four weeks after herbicide application compared to when seeds were applied immediately after application (Altland and Cramer 2006). In virtually all cases, herbicide efficacy is greatly diminished or completely lacking well before the recommended 75 to 90 day reapplication interval.

Greater knowledge of preemergence herbicide efficacy, as a function of time between application and seed introduction, is needed. Information on herbicide longevity in container substrates will allow more precise recommendations on herbicide selection and reapplication intervals. The objective of this research is to evaluate efficacy of preemergence herbicides on creeping woodsorrel and flexuous bittercress (*Cardamine flexuosa* With.) by applying weed seed from 0 to 10 weeks after herbicide application.

Materials and Methods

On May 25, 2017, a substrate comprised of 80% pine bark (T.H. Blue Inc., Eagle Springs, NC) and 20% peatmoss (Sun Gro Horticulture, Seba Beach, Alberta, CN) amended with 7.1 $kg{\cdot}m^{-3}$ (12 $lb{\cdot}yd^{-3}$) controlled release fertilizer (18N-2.6P-10K-1Mg-2.3S-0.02B-0.05Cu-0.45Fe-0.06Mn-0.02Mo-0.05Zn Osmocote Plus, The Scotts Co., Marysville, OH) and 1.8 $kg{\cdot}m^{-3}$ (3 $lb{\cdot}yd^{-3}$) dolomitic limestone (ECOPHRST, National Lime and Stone Co., Findlay, OH) was blended in a soil mixer (Twister I, Bouldin & Lawson, McMinville, TN).

On June 5, 2017, 25 containers [10 L (#2) Nursery Supplies, Chambersburg, PA] were filled with the substrate and placed outdoors on a gravel nursery production bed (Wooster, OH) under an overhead irrigation system using impact sprinklers (Maxi-bird Impact Sprinkler, Rainbird Corp., Azusa, CA). Approximately 1.2 cm (0.5 in) irrigation was applied daily, split in two cycles. The containers were allowed to settle for one day within the irrigation zone prior to herbicide application. At the time of application, five containers each were treated with one of the following herbicides at their maximum labeled rate: pendimethalin (Pendulum 2G, BASF, Florham Park, NJ) at 224 $kg{\cdot}ha^{-1}$ (200 $lb{\cdot}A^{-1}$), prodiamine + isoxaben (Gemini G, Everris NA Inc., Dublin, OH) at 112 $kg{\cdot}ha^{-1}$ (100 $lb{\cdot}A^{-1}$), oxyfluorfen + pendimethalin (OH2, Everris NA Inc.) at 112 $kg{\cdot}ha^{-1}$ (100 $lb{\cdot}A^{-1}$), and flumioxazin (BroadStar, Valent USA Corp., Walnut Creek, CA) at 168 $kg{\cdot}ha^{-1}$ (150 $lb{\cdot}A^{-1}$). Herbicides were applied with a hand-held granular applicator. A non-treated control group was also maintained. After application, containers were placed back under the overhead irrigation system. Two weeks later, and every two weeks thereafter up to 10 weeks after the initial herbicide application, the process of filling additional containers and treating with herbicides was repeated. Each time a new batch of 25 containers were treated, all containers were rearranged with previously treated containers in a completely randomized design. Following the herbicide application that occurred 10 weeks after the initial application, 40 seed of flexuous bittercress and 40 seed of creeping woodsorrel were applied to the surface of each container. The flexuous bittercress and creeping woodsorrel were applied to separate halves of each container, to facilitate easier counting of weeds later in the experiment. Throughout the experiment, the containers were maintained in a completely randomized design.

Germinated weeds at the cotyledon stage or later were counted at 2 and 4 weeks after seeding (WAS). Weeds were harvested and shoot fresh weight was measured 6 WAS. Data were subjected to analysis of variance (ANOVA) and means were separated with Fisher's protected least significant difference at $\alpha = 0.05$. Weather data was collected by the Ohio State University weather station system (http://www.oardc.ohio-state.edu/weather1/).

The experiment was repeated in 2018 using the same methods with the following exceptions. The substrate was mixed on May 16, and the first group of containers were filled May 22. Pendimethalin was dropped from the experiment. Oxyfluorfen + prodiamine (Biathlon, OHP, Inc., Bluffton, SC) at 112 $kg{\cdot}ha^{-1}$ (100 $lb{\cdot}A^{-1}$)and oxyfluorfen + oryzalin (Rout, Everris NA Inc.) at 112 $kg{\cdot}ha^{-1}$ (100 $lb{\cdot}A^{-1}$) were added to the experiment.

Results and Discussion

There was a significant herbicide by week interaction for flexuous bittercress number and SFW (Table 1). When counted 2 WAS, non-treated control pots had similar numbers of flexuous bittercress regardless of the time between seeding and herbicide application, ranging from 8.0 to 10.2 seedlings per container. When herbicides were applied 10 weeks before seeding, none reduced flexuous bittercress numbers or SFW compared to non-treated controls (except oxyfluorfen + pendimethalin at 4 WAS). Pendimethalin only reduced flexuous bittercress number when applied immediately after herbicide application (0 weeks before seeding), although it reduced flexuous bittercress SFW when applied as early as 2 weeks before seeding. Davies and Duray (1992) showed that small-flowered bittercress (*Cardamine parvifolia* L.) numbers decreased proportionally with increasing pendimethalin rate when seed were applied at the time of herbicide application. Although higher pendimethalin concentration on the substrate surface will result in greater weed control, control will decrease over time as the herbicide dissipates.

Table 1. **Flexuous bittercress (*Cardamine flexuosa*) number and shoot fresh weight in containers treated with granular preemergence herbicides or non-treated control pots from 0 to 10 weeks prior to weed seed application, 2017.**

		Number		
Weeks before seeding[z]	Herbicide[y]	2 WAS[x]	4 WAS	Shoot fresh weight (g)
10	Control	8.0	13.6	18.9
	Pendimethalin	9.6	12.2	20.2
	Prodiamine + Isoxaben	7.2	10.6	7.5
	Oxyfluorfen + pendimethalin	5.6	7.0	7.1
	Flumioxazin	5.2	9.8	18.3
8	Control	10.8	15.6	28.8
	Pendimethalin	11.4	13.6	27.5
	Prodiamine + Isoxaben	9.2	9.6	12.5
	Oxyfluorfen + pendimethalin	2.2	2.8	0.6
	Flumioxazin	1.4	1.8	2.1
6	Control	10.4	15.2	34.9
	Pendimethalin	9.4	12.4	24.3
	Prodiamine + Isoxaben	7.4	6.0	4.0
	Oxyfluorfen + pendimethalin	1.0	1.0	1.0
	Flumioxazin	0.4	2.0	1.0
4	Control	10.4	16.8	27.2
	Pendimethalin	12.4	16.4	25.4
	Prodiamine + Isoxaben	6.2	7.0	5.8
	Oxyfluorfen + pendimethalin	0.4	0.0	0.0
	Flumioxazin	0.4	0.6	3.4
2	Control	9.0	15.0	37.8
	Pendimethalin	6.2	11.6	6.4
	Prodiamine + Isoxaben	0.4	1.8	0.6
	Oxyfluorfen + pendimethalin	0.0	0.0	0.0
	Flumioxazin	0.0	0.0	0.0
0	Control	8.0	14.2	40.5
	Pendimethalin	3.2	1.8	1.1
	Prodiamine + Isoxaben	0.0	0.0	0.0
	Oxyfluorfen + pendimethalin	0.0	0.0	0.0
	Flumioxazin	0.0	0.0	0.0
$LSD_{0.05}$[w]		4.2	4.0	13.2
Week		0.0001	0.0001	0.0001
Herbicide		0.0001	0.0001	0.1768
Week*Herbicide		0.0001	0.0100	0.0009

[z]Herbicides were applied from 0 to 10 weeks prior to weed seed application.

[y]Herbicides included pendimethalin (Pendulum 2G), prodiamine + isoxaben (Gemini G), oxyfluorfen + pendimethalin (OH2), and flumioxazin (BroadStar). All were applied at the maximum labeled rate.

[x]Weeks after seeding.

[w]Fisher's protected least significant difference where $\alpha = 0.05$.

At 4 and 6 WAS, prodiamine + isoxaben reduced flexuous bittercress number and SFW, respectively, compared to non-treated controls when applied 0 through 8 weeks before seeding. Flexuous bittercress numbers in containers treated with prodiamine + isoxaben were higher than those treated with oxyfluorfen + pendimethalin or flumioxazin when applied 8 to 4 weeks before seeding, although SFW were similar among the three herbicides regardless of application date. Stamps and Neal (1990) reported similar observations in that oxyfluorfen + pendimethalin inhibited hairy bittercress germination, while pendimethalin and prodiamine herbicides only suppressed flexuous bittercress growth. Oxyfluorfen + pendimethalin and flumioxazin provided similar flexuous bittercress control in terms of number and SFW throughout the experiment, and both herbicides reduced numbers and SFW compared to non-treated controls when applied 0 to 8 weeks before seeding. Judge and Neal (2006) also showed that flumioxazin and oxyfluorfen + pendimethalin provided 100% hairy bittercress control when herbicides were applied preemergence. Wehtje et al. (2012) likewise reported that flumioxazin provided excellent hairy bittercress control for 7 to 8 weeks, and diminished control by 10 weeks, using the same rate as applied in this study.

In 2018, flexuous bittercress in non-treated controls ranged from 0.6 to 4.0 seedlings per container (Table 2), compared to much larger numbers of 8.0 to 15.6 seedlings per container in 2017 (Table 1). While many factors can affect weed seed germination, weather was not likely the cause. Weather in both years was typical for this region of Ohio, and similar with a total of 20.9 and 26.0 cm (8.2 and 10.2 in) precipitation and average daily temperature of 21.3 and 21.7 C (70.3 and 71.6 F) in 2017 and 2018, respectively (Fig. 1). Fewer numbers in non-treated controls made comparisons more difficult, although some trends still emerged. When counted 4 WAS, the three products containing oxyfluorfen reduced flexuous bittercress numbers compared to non-treated controls when applied 0 to 10 weeks prior to seed application. These results concur with the 2017 experiment, when oxyfluorfen + pendimethalin also reduced flexuous bittercress numbers 4 WAS regardless of how early the herbicide was applied

Table 2. **Flexuous bittercress (*Cardamine flexuosa*) number and shoot fresh weight in containers treated with granular preemergence herbicides or non-treated control pots from 0 to 10 weeks prior to weed seed application, 2018.**

		Number		
Weeks before seeding[z]	Herbicide[y]	2 WAS[x]	4 WAS	Shoot fresh weight (g)
10	Control	1.2	3.4	1.0
	Prodiamine + isoxaben	0.2	2.6	1.1
	Oxyfluorfen + prodiamine	0.6	1.0	0.2
	Oxyfluorfen + oryzalin	1.2	1.4	0.2
	Oxyfluorfen + pendimethalin	0.4	0.6	0.2
	Flumioxazin	1.2	2.6	2.0
8	Control	0.6	2.6	0.5
	Prodiamine + isoxaben	1.2	2.0	0.3
	Oxyfluorfen + prodiamine	0.0	0.0	0.0
	Oxyfluorfen + oryzalin	0.0	0.2	0.0
	Oxyfluorfen + pendimethalin	0.2	0.4	0.1
	Flumioxazin	0.8	3.8	0.5
6	Control	1.6	4.0	3.3
	Prodiamine + isoxaben	0.6	1.6	0.5
	Oxyfluorfen + prodiamine	0.0	0.0	0.0
	Oxyfluorfen + oryzalin	0.0	0.0	0.0
	Oxyfluorfen + pendimethalin	0.4	0.2	0.0
	Flumioxazin	0.2	0.8	0.0
4	Control	1.6	3.2	1.5
	Prodiamine + isoxaben	0.2	1.6	0.1
	Oxyfluorfen + prodiamine	0.0	0.0	0.0
	Oxyfluorfen + oryzalin	0.2	0.6	0.8
	Oxyfluorfen + pendimethalin	0.2	0.0	0.0
	Flumioxazin	0.2	1.2	0.5
2	Control	0.8	2.6	3.0
	Prodiamine + isoxaben	0.4	3.0	1.7
	Oxyfluorfen + prodiamine	0.2	0.2	0.0
	Oxyfluorfen + oryzalin	0.2	0.0	0.0
	Oxyfluorfen + pendimethalin	0.0	0.0	0.0
	Flumioxazin	0.0	1.0	0.6
0	Control	2.0	3.0	2.0
	Prodiamine + isoxaben	0.0	0.2	0.0
	Oxyfluorfen + prodiamine	0.0	0.0	0.0
	Oxyfluorfen + oryzalin	0.0	0.0	0.0
	Oxyfluorfen + pendimethalin	0.0	0.0	0.0
	Flumioxazin	0.0	0.0	0.0
$LSD_{0.05}$[w]		0.8	1.4	1.4
Week		0.0001	0.0001	0.0001
Herbicide		0.0504	0.0002	0.2249
Week*Herbicide		0.0195	0.0117	0.0748

[z]Herbicides were applied from 0 to 10 weeks prior to weed seed application.

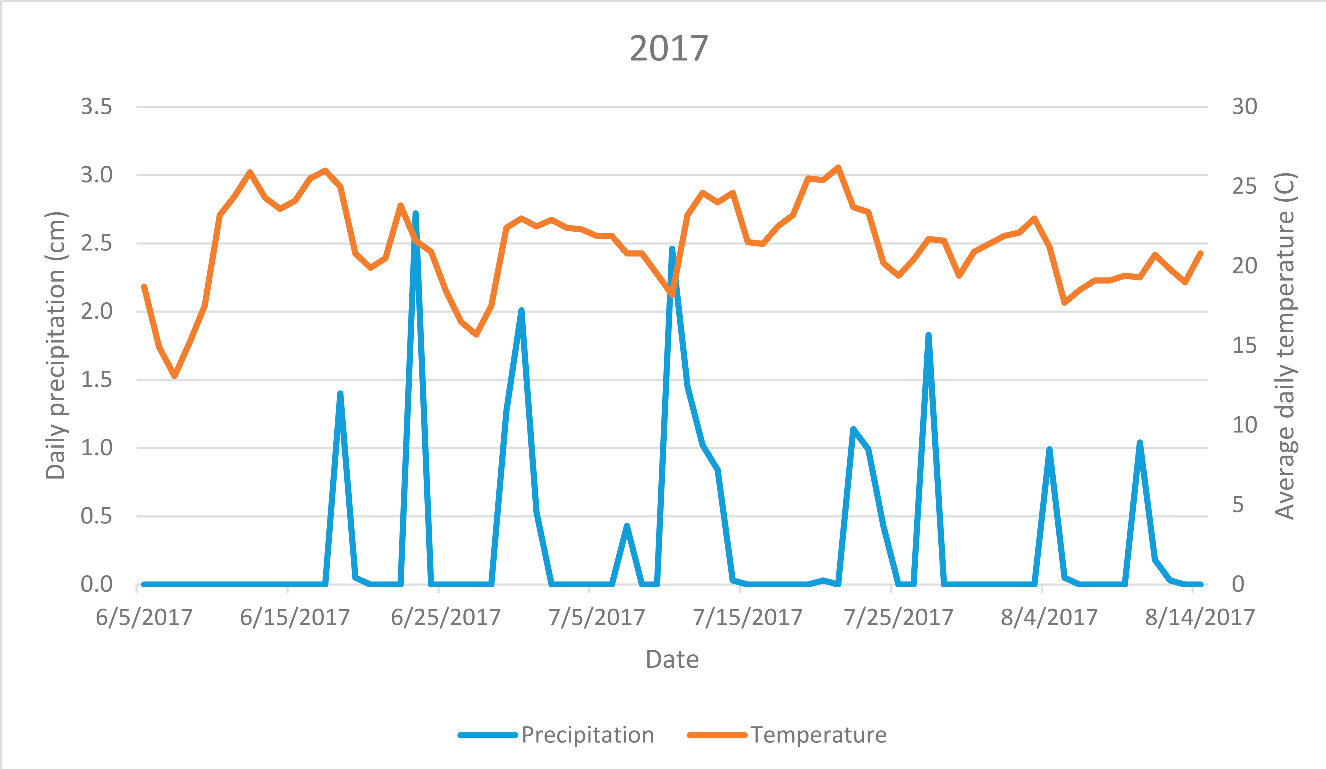
[y]Herbicides included pendimethalin (Pendulum 2G), prodiamine + isoxaben (Gemini G), oxyfluorfen + pendimethalin (OH2), and flumioxazin (BroadStar). All were applied at the maximum labeled rate.

[x]Weeks after seeding.

[w]Fisher's protected least significant difference where $\alpha = 0.05$.

(0 to 10 weeks prior to seed application). At 4 WAS, prodiamine + isoxaben reduced flexuous bittercress numbers compared to non-treated controls when applied 0, 4, or 6 weeks prior to seeding and only reduced bittecress SFW if applied immediately before seeding. Oxyfluorfen + prodiamine reduced bittecress numbers 4 WAS compared to prodiamine + isoxaben with each herbicide timing treatment except 0 weeks. Due to percent active ingredient and application rates, both products resulted in similar amounts of prodiamine application [0.84 $kg·ha^{-1}$ (0.75 $lb·A^{-1}$) in oxyfluorfen + prodiamine and 0.89 $kg·ha^{-1}$ (0.79 $lb·A^{-1}$) in prodiamine + isoxaben], yet control was improved with oxyfluorfen + prodiamine considering the totality of the data. This further suggests that the oxyfluorfen is the active ingredient providing most of the flexuous bittercress control. In 2018, flumioxazin reduced bittecress numbers and SFW compared to non-treated controls when applied up to 6 before seeding, while it reduced numbers and SFW as early as 8 weeks before seeding in 2017. Containers treated with flumioxazin also had greater SFW than non-treated controls when applied 10 weeks before seeding. Control from flumioxazin may have been slightly reduced from 2017 to 2018, although differences in results between the two years might also be related to the aforementioned lower germination rates in 2018.

Creeping woodsorrel numbers were affected by the interaction between week and herbicide product ($P < 0.0176$), while SFW was affected by both main effects but not their interaction (Table 3). Pendimethalin reduced weed numbers when applied 8 weeks prior to seeding, but control was still less than that provided by oxyfluorfen +



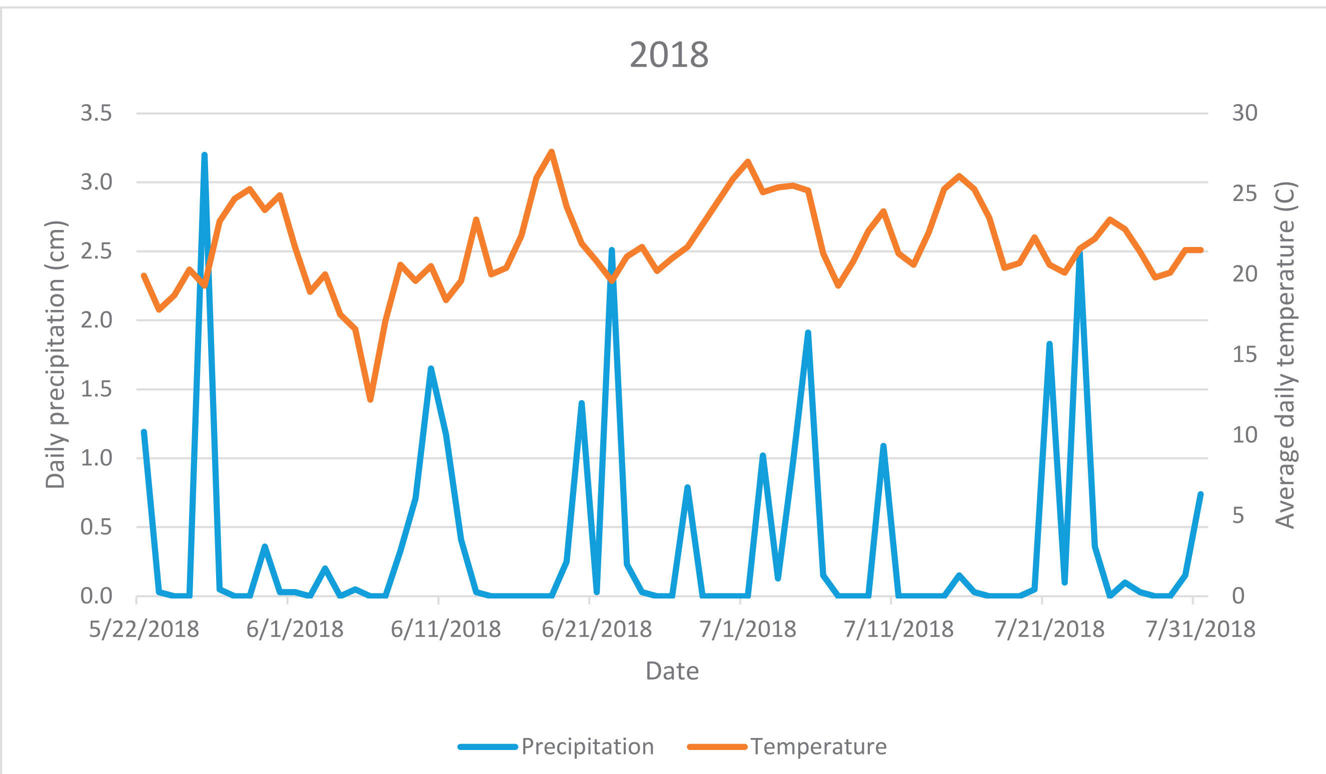


Fig. 1. Daily precipitation and average daily air temperature of the experimental plot in which herbicides were evaluated for efficacy over a 10 week period in 2017 (top) and 2018 (bottom).

Table 3. Creeping woodsorrel (*Oxalis corniculata*) number and shoot fresh weight in containers treated with granular preemergence herbicides or non-treated control pots from 0 to 10 weeks prior to weed seed application, 2017.

Weeks before seeding[z]	Herbicide[y]	Number		Shoot fresh weight (g)
		2 WAS[x]	4 WAS	
10	Control	10.2	11.2	8.7
	Pendimethalin	9.0	10.6	7.3
	Prodiamine + Isoxaben	8.2	6.4	0.5
	Oxyfluorfen + pendimethalin	2.4	5.2	4.1
	Flumioxazin	6.6	6.0	2.7
8	Control	15.4	17.8	12.6
	Pendimethalin	9.8	13.2	10.2
	Prodiamine + Isoxaben	9.2	5.6	0.0
	Oxyfluorfen + pendimethalin	4.4	4.4	1.0
	Flumioxazin	2.2	1.6	0.8
6	Control	7.4	10.4	6.2
	Pendimethalin	9.6	8.4	3.2
	Prodiamine + Isoxaben	4.4	3.2	0.0
	Oxyfluorfen + pendimethalin	2.2	1.4	0.2
	Flumioxazin	1.4	2.2	0.9
4	Control	11.6	12.0	7.4
	Pendimethalin	13.6	12.6	6.2
	Prodiamine + Isoxaben	3.4	2.6	0.0
	Oxyfluorfen + pendimethalin	3.4	1.0	0.3
	Flumioxazin	0.6	0.8	0.1
2	Control	7.2	13.2	11.9
	Pendimethalin	5.6	3.4	0.6
	Prodiamine + Isoxaben	3.6	3.0	0.0
	Oxyfluorfen + pendimethalin	0.4	0.8	0.0
	Flumioxazin	0.2	0.0	0.0
0	Control	7.6	12.4	9.5
	Pendimethalin	1.6	2.0	0.0
	Prodiamine + Isoxaben	0.0	0.0	0.0
	Oxyfluorfen + pendimethalin	0.4	0.2	0.1
	Flumioxazin	0.0	0.0	0.0
$LSD_{0.05}$[w]		4.4	4.4	4.7
Week		0.0001	0.0001	0.0001
Herbicide		0.0001	0.0001	0.0130
Week*Herbicide		0.0092	0.0176	0.0763

[z]Herbicides were applied from 0 to 10 weeks prior to weed seed application.

[y]Herbicides included pendimethalin (Pendulum 2G), prodiamine + isoxaben (Gemini G), oxyfluorfen + pendimethalin (OH2), and flumioxazin (BroadStar). All were applied at the maximum labeled rate.

[x]Weeks after seeding.

[w]Fisher's protected least significant difference where $\alpha = 0.05$.

pendimethalin or flumioxazin. Pendimethalin reduced creeping woodsorrel number and SFW compared to non-treated controls when applied 0 or 2 weeks before seeding, but failed to reduce SFW if applied 4 weeks or more before seeding. Using the same herbicide and rate, Altland (2015) showed that pendimethalin provided creeping woodsorrel control across several substrate types when seed was applied up to 4 weeks after herbicide application. Likewise, Derr (1997) showed that pendimethalin and prodiamine (alone) provided excellent yellow woodsorrel (*O. stricta* L.) control when seed were applied near the time of herbicide application. Creeping woodsorrel numbers in containers treated with prodiamine + isoxaben were erratic (with respect to non-treated controls) when counted 2 WAS; however, the herbicide reduced creeping woodsorrel number regardless of application timing at 4 WAS and provided the greatest reduction in SFW. Oxyfluorfen + pendimethalin and flumioxazin provided similar control in both creeping woodsorrel numbers and SFW throughout the study. Both products reduced numbers and SFW applied as early as 8 weeks before seeding.

In 2018, creeping woodsorrel germination ranged from 7.4 to 13.1 seedlings per container in non-treated controls, compared to 10.4 to 17.8 seedlings in 2017. While numbers were somewhat reduced compared to the previous year, germination was still high enough to discern significant differences. All herbicides reduced creeping woodsorrel numbers and SFW when applied as early as 8 weeks before seeding (with the exception of SFW from flumioxazin 8 weeks before seeding). There were few and minor differences between the herbicide products from 0 to 8 weeks before seeding, with all treatments providing effective control. The three products containing oxyfluorfen provided excellent control. Beste and Frank also reported that oxyfluorfen at 2.2 to 4.5 $kg \cdot ha^{-1}$ (2.0 to 4.0 $lb \cdot A^{-1}$) provided excellent woodsorrel (*O. stricta* L.) control, although no details were provided on how seed were applied in that experiment. In contrast to our results, Berchielli et al. (1988) showed that oxyfluorfen, oryzalin, or the combination of the two herbicides provided excellent preemergence oxalis (*O. dillenii* Jacq.) control when seed were applied to containers immediately after herbicide

Table 4. Creeping woodsorrel (*Oxalis corniculata*) number and shoot fresh weight in containers treated with granular preemergence herbicides or non-treated control pots from 0 to 10 weeks prior to weed seed application, 2018.

		Number		
Weeks before seeding[z]	Herbicide[y]	2 WAS[x]	4 WAS	Shoot fresh weight (g)
10	Control	6.2	7.4	5.7
	Prodiamine + isoxaben	3.0	2.0	2.1
	Oxyfluorfen + prodiamine	2.6	1.0	0.4
	Oxyfluorfen + oryzalin	3.8	6.4	3.8
	Oxyfluorfen + pendimethalin	2.6	4.0	1.5
	Flumioxazin	4.0	6.6	0.9
8	Control	5.6	7.8	3.7
	Prodiamine + isoxaben	2.0	0.8	0.1
	Oxyfluorfen + prodiamine	0.2	0.2	0.0
	Oxyfluorfen + oryzalin	0.6	1.6	0.0
	Oxyfluorfen + pendimethalin	0.6	1.2	0.1
	Flumioxazin	2.6	3.0	1.7
6	Control	6.4	10.6	9.9
	Prodiamine + isoxaben	1.8	0.6	0.4
	Oxyfluorfen + prodiamine	0.4	0.4	0.1
	Oxyfluorfen + oryzalin	1.0	0.4	0.1
	Oxyfluorfen + pendimethalin	1.0	2.2	1.0
	Flumioxazin	0.8	1.2	0.0
4	Control	8.4	9.6	6.4
	Prodiamine + isoxaben	1.2	0.0	0.0
	Oxyfluorfen + prodiamine	0.4	0.0	0.0
	Oxyfluorfen + oryzalin	1.0	1.8	0.3
	Oxyfluorfen + pendimethalin	1.2	2.0	0.3
	Flumioxazin	1.0	1.0	0.1
2	Control	8.2	13.0	9.8
	Prodiamine + isoxaben	3.4	2.2	1.5
	Oxyfluorfen + prodiamine	1.2	1.0	0.3
	Oxyfluorfen + oryzalin	1.2	0.0	0.0
	Oxyfluorfen + pendimethalin	0.6	0.0	0.0
	Flumioxazin	0.8	1.6	0.1
0	Control	5.2	8.4	12.4
	Prodiamine + isoxaben	0.6	0.2	0.1
	Oxyfluorfen + prodiamine	0.4	0.8	0.4
	Oxyfluorfen + oryzalin	0.0	0.0	0.0
	Oxyfluorfen + pendimethalin	0.0	0.2	0.0
	Flumioxazin	0.6	0.6	3.8
$LSD_{0.05}$[w]		2.8	2.9	3.3
Week		0.0001	0.0001	0.0001
Herbicide		0.0008	0.0002	0.0712
Week*Herbicide		0.7951	0.0009	0.0105

[z]Herbicides were applied from 0 to 10 weeks prior to weed seed application.

[y]Herbicides included pendimethalin (Pendulum 2G), prodiamine + isoxaben (Gemini G), oxyfluorfen + pendimethalin (OH2), and flumioxazin (BroadStar). All were applied at the maximum labeled rate.

[x]Weeks after seeding.

[w]Fisher's protected least significant difference where $\alpha = 0.05$.

application. However, none of these herbicides at the labeled rates (rates similar to those used in our study) provided effective control when weed seeds were applied 7 weeks after herbicide application.

In summary, herbicides containing oxyfluorfen or flumioxazin provided effective preemergence flexuous bittercress and creeping woodsorrel control for up to 8 to 10 weeks after application. Other herbicide products resulted in reduced control, or variable control between years, as the time between herbicide and seed application increased. All herbicides provided effective control when seed were applied within 2 weeks of herbicide application. Davies and Duray (1992) showed that small-flowered bittercress (*Cardamine parvifolia* L.) numbers decreased proportionally with increasing pendimethalin rate when seed were applied at the time of herbicide application. Berchielli et al. (1988) likewise showed that increasing rates of oxadiazon, oryzalin, or oxyfluorfen + oryzalin resulted in reduced southern yellow woodsorrel (*Oxalis dillenii* Jacq.) numbers or shoot dry weights. Thus higher concentrations of herbicide on the substrate surface at the time of application will result in greater weed control and conversely, herbicide control will decrease over time with herbicide dissipation. The objective of this research is to evaluate efficacy of preemergence herbicides on creeping woodsorrel and flexuous bittercress, and how long those herbicides would remain effective over time with consistent weed seed presence. Based on these data, herbicides containing oxyfluorfen or flumioxazin should be applied for controlling populations of flexuous bittercress and creeping woodsorrel in crops that are labeled for these chemicals. Applications should be made every 8 weeks while seed presence from these weeds are high. It is possible that the duration between herbicide applications could be extended once sanitation efforts reduce seed presence of flowering weeds, thus reducing seed production.

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