Postemergence Control of Seedling Broadleaf Weeds in Containers

MHS Project Report

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Abstract

Experiments were conducted in 2018 and 2019 to evaluate herbicides for postemergence control of common warm-season and cool-season annual weeds in container nursery crop production. The cool-season study was conducted in 2018 and 2019 in Raleigh, NC, USA. Summer studies were conducted in 2019 at two locations, Raleigh NC and Castle Hayne, NC. Weed species for the winter study were common groundsel, common chickweed, and flexuous bittercress . For the summer studies, chamberbitter, eclipta, livid amaranth, rice flatsedge, spotted spurge, and yellow woodsorrel were included. To evaluate the effects of plant age on herbicide efficacy all weeds were surface seeded twice, two weeks apart. Treatments included diquat at 0.56 kg ai/ha, flumioxazin at 0.42 kg ai/ha, flumioxazin + pyroxasulfone at 0.532 kg ai/ha, halosulfuron-methyl at 0.0526 kg ai/ha, indaziflam at 0.049 or 0.0653 kg ai/ha, isoxaben at 1.12 kg ai/ha, bentazon at 1.12 kg ai/ha, sulfentrazone at 0.56 kg ai/ha, glufosinate at 1.12 kg ai/ha, and a nontreated control. Additionally, cloransulam-methyl at 0.0177 kg ai/ha, oxyfluorfen at 0.56 kg ai/ha, saflufenacil at 0.025 kg ai/ha, and topramezone at 0.196 kg ai/ha were included in the summer study. Percent weed control was visually evaluated weekly for 4 and 6 weeks after application for summer and winter studies, respectively. Above-ground fresh weights were measured at 4 or 7 weeks after treatment for summer and winter studies, respectively. In the winter study, diquat, flumioxazin, and flumioxazin + pyroxasulfone provided ≥ 80% control of common groundsel, common chickweed, flexuous bittercress at both ages. Glufosinate controlled common groundsel and common chickweed but did not control flexuous bittercress. In summer studies, flumioxazin provided ≥ 80% control of chamberbitter, eclipta, livid amaranth, rice flatsedge, and yellow woodsorrel. Glufosinate provided ≥ 80% control of chamberbitter, eclipta, and spotted spurge. Other treatments were generally less effective on older weeds and controlled fewer species.

Nomenclature: bentazon; cloransulam; diquat; flumioxazin; flumioxazin plus pyroxasulfone; glufosinate; halosulfuron; indaziflam; oxyfluorfen; saflufenacil; sulfentrazone; topramezone; chamberbitter (*Phyllanthus urinaria*); common chickweed (*Stellaria media* L.); common groundsel (*Senecio vulgaris* L.); eclipta (*Eclipta prostrata* L.); flexuous bittercress (*Cardamine flexuosa* With.); livid amaranth (*Amaranthus blitum* L.); rice flatsedge (*Cyperus iria* L.); spotted spurge (*Euphorbia maculata* L.); yellow woodsorrel (*Oxalis stricta* L.)

Introduction

Nursery crop production is an important industry in the United States with total sales of $5.9 billion in 2017, a 15.7% increase from 2012 sales (USDA Census of Agriculture 2017). One of the major growth areas of ornamental plant production has been in outdoor container nursery production, management, and resource-intensive system that maximizes crop growth and quality and currently accounts for about 69% of nursery crop production (Chappell and Knox 2015, Khachatryan et al. 2020).

Weed management is a troublesome issue in any agricultural system, including container nursery production. Weeds compete for limited resources such as light, nutrients, and water, reducing crop yield and quality. Walker and William (1988) reported as few as one *Echinochloa crus-galli* (barnyardgrass), and *Digitaria sanguinalis* (large crabgrass) can reduce Bailey's red osier dogwood (*Cornus* x Bailey) shoot dry weight by ≥ 50 %. Weed infestations also reduce container nursery crop aesthetics and marketability (Fretz 1972). To eliminate weed competition, nursery producers rely heavily on preemergence (PRE) herbicide applications. Growers typically apply PRE herbicides three to six times annually (Neal et al., 2017). Many PRE herbicides have been registered and reported to control weed effectively in nursery production (Neal. 2017). However, research has shown that the longevity of the PRE herbicides is shorter than the reapplication interval of 8- 10 weeks (Judge et al. 2003, Atwood et al. 2008, Altland. 2019). Consequently, weeds continue to emerge throughout the season and must be manually removed, a labor-intense and expensive task.

Gilliam et al. (1990) reported the costs of hand weeding can range from $608 to $1,401 ha^{-1} ($246 to $567 A^{-1}) per year with hourly wages of $3.53 to $3.97. Applying updated agricultural labor costs of $13.25 h^{-1} (USDA ERS 2019) to the Gilliam et al. (1990) data, labor costs would range from $2,148 to $4,950 ha^{-1} ($869 to $2,003 A^{-1}). Yet, depending on the weed species present, Mathers (2003) reported hand weeding costs of up to $9880 ha^{-1}. In a survey of growers, Hall (2017) reported that insufficient labor availability was the number one concern of 39% of growers, and 68% said labor issues were the greatest challenge in their businesses. Therefore, an alternative to control emerged weeds in nursery production with reduced dependence on manual labor is needed.

Previous research has shown that spray formulations of some PRE herbicides, such as Gallery SC (isoxaben) or Marengo SC (indaziflam) had early-POST activity on some common nursery weed species. Altland et al. (2000) reported isoxaben at 1.12 kg ai ha^{-1} provided 90% control of hairy bittercress up to 6 cm in height, but it only 43% control when the weed was larger than 10 cm. Similarly, Marble et al. (2016) reported indaziflam at 0.05 kg ai ha^{-1} provided over 95% control of seedling yellow woodsorrel up to the eight-leaf grow stage. Furthermore, spray formulations of some PRE herbicides are labeled for over the top spray applications. For example: isoxaben is labeled for broadcast applications over many woody nursery crop species (Anonymous, 2018). Yet most residual herbicides with significant postemergence activity are labeled for broadcast applications over very few crop species (Neal et al. 2017).

Many POST herbicides in ornamental and nursery crops are labeled for directed spray applications only, due to the risk of crop injury from foliar applications (Altland, 2003). Spray applications of flumioxazin may be made over several species of coniferous evergreens but directed applications are recommended around broadleaved crops to avoid crop injury (Anonymous 2015). Similarly, broadcast spray application of indizaflam at 0.098 kg ai ha^{-1} have been reported to injure rose, lilac, and potentilla (Barolli, 2014). It is common to perform directed herbicide applications, including broad-spectrum non-selective herbicides, in field-grown nursery crop production. In these crops, crops are tall enough to avoid spray contact with the foliage. Currently such directed applications are not possible in container nurseries due to high crop density of up to 54,400 4L or 19,000 16L pots ha^{-1} (Halcomb 2010) and low crop canopies often only a few inches above the substrate surface. However, research is currently underway to develop a method to make directed herbicide applications to container nursery crops. If successful, such applications underneath the crop could expand the number and type of postemergence herbicides that might be used in container nursery crop production. Yet, limited information is available on the efficacy of postemergence herbicides on weeds in container nursery crops. Therefore, the objectives for this study were to evaluate herbicides for postemergence control of common summer and winter annual weeds in container nursery production and the effects of weed growth stage on herbicide efficacy.

Material and Methods

Studies were conducted in 2018 and 2019 in North Carolina to evaluate herbicides for postemergence control of common annual weeds in container nursery production. Common groundsel (*Senecio vulgaris* L.), common chickweed (*Stellaria media* L.), and flexuous bittercress (*Cardamine flexuosa* With.) are more common in cool-seasons, whereas chamberbitter (*Phyllanthus urinaria* L.), eclipta (*Eclipta prostrata* L.), livid amaranth (*Amaranthus blitum* L.), spotted spurge (*Euphorbia maculata* L.), and rice flatsedge (*Cyperus iria* L.) are common in warm weather (Neal et al. 2017). Therefore, this research was conducted in two parts, one for cool season and another for warm season weeds. The cool-season study was conducted at North Carolina State University's Horticulture Field Lab (HFL) (35.792551° N, 78.698183° W), Raleigh, NC in 2018 and repeated in 2019. The summer study was conducted in 2019 at two sites: HFL and NCSU's Horticultural Crops Research Station in Castle Hayne (CH) NC (34.320158° N, 77.918977° W). Plastic pots were filled with hammer-milled pine bark substrate amended with 4.75 kg m^{-3} lime and 5.93 kg m^{-3} of 18-4-8 (N-P_2O_5-K_2O) slow-release fertilizer (Harrell's, 5105 New Tampa Hwy, Lakeland, FL). In CH tests, 4-L pots were used but at HFL the space available was smaller thus 0.94-L pots were used. Pots were hand watered to settle the substrate and placed in full sun, under overhead irrigation applying about 1.3 cm per day. At CH, the irrigation was applied in a single mid-day cycle; at HFL the volume of water was delivered in 2 equivalent aliquots, morning, and mid-day.

Common cool- and warm-season broadleaf weeds common to container nursery crop production in the southeastern United States were selected for study (Table 1). To evaluate the effects of growth stage on herbicide efficacy, all weeds were surface seeded twice, two weeks apart. The age from seeding to treatment varied among species due to differential seedling growth rates (see Table 1). Seeding to treatment days for common chickweed were 53 and 39 days in 2018, and 59 and 45 days in 2019, respectively; for common groundsel and flexuous bittercress was 53 and 39 days for both years; for rice flatsedge was 27 and 14 days at CH, and 31 and 18 days at HFL; for chamberbitter was 41 and 27 days at CH, and 39 and 25 days at HFL; for yellow woodsorrel was 34 and 20 days at CH, and 39 and 30 days at HFL; for livid amaranth, spotted spurge and eclipta were 34 and 20 days at CH, and 32 and 18 days at HFL. To simplify discussions, the first and second seeding ages are designated as "old" and "young", respectively. Herbicides and doses applied in the cool-season and warm-season experiments are listed in Table 2. Herbicides included selective and non-selective postemergence herbicides currently labeled for directed applications around woody ornamental plants, as well as spray-applied preemergence herbicides that have been reported to have early postemergence efficacy on some weeds (Neal. 2017). All treatments from the cool-season study were included in the warm-season study. All herbicide applications included manufacturer-recommended spray adjuvants. A single application was made with all herbicides except bentazon (Basagran T&O) which was reapplied two weeks after the initial application as directed by the product label (Anonymous, 2016). A non-treated control was included for comparison in all studies. Treatments were arranged in randomized complete block designs with 5 replications, each experimental unit containing 1 pot of each species at each growth stage. Herbicides were applied with a CO_2 pressurized bottle sprayer equipped with 2-8008 XR flat fan nozzles (Teejet Technologies, Wheaton, IL) and calibrated to deliver 569 L ha^{-1}. Plant foliage was dry at the time of applications and remained dry for at least 12 hours after application.

Percent weed control was visually evaluated (VR) weekly for 6 weeks after treatment (WAT) and 4 WAT in winter and summer experiments, respectively, using a 0 to10 scale where 0 = no control (no difference from the nontreated plants) and 10 = complete (100%) control. For presentation herein, means were multiplied by 10 to convert to percentages. Shoot fresh weights were measured at 4 or 7 weeks after treatments (WAT) for summer and winter studies, respectively. Fresh weight data were converted to percent fresh weigh reductions (FWR) compared to non-treated plants using Equation 1.

Equation 1. % fresh weigh reduction = (FWnon – FWtrt)/FWnon)* 100).

Where: FWnon = above-ground fresh weight of non-treated plants

FWtrt = fresh weight of treated plants

All data were subjected to analysis of variance using SAS [9.4] software (SAS, Cary, NC), and mean separations were conducted using Fisher's protected LSD test at $\alpha = 0.05$.

Table 1. Weed species included in both cool-season and warm-season experiments, along with the growth stages at herbicide application.

Common name	Scientific name	Old	Young
Cool-season weeds			
common groundsel	*Senecio vulgaris* L.	25.4 – 30.5 cm tall; flowering	5 - 7.6 cm tall; ~6 true leaves
common chickweed	*Stellaria media* L.	20.3 – 25.4 cm tall, 25.4 – 30.5 cm in lengths	2.5 – 5 cm tall, ~10 cm in length; 6-8 true leaves
flexuous bittercress	*Cardamine flexuosa* With.	8- 25.4 cm tall, 25.4 – 30.5 cm in lengths	2.5 – 5 cm tall; 2-4 true leaves
Warm-season weeds			
chamberbitter	*Phyllanthus urinaria* L.	7-8 cm tall, 16*16 cm clump, new leaves	~4 cm tall, have no branches
eclipta	*Eclipta prostrata* L.	15-25 cm tall, 3-6 branches, 15- 20 leaf pairs	4-7 cm tall, no branches, 2-4 leaf pairs
yellow woodsorrel	*Oxalis stricta* L.	10- 13 cm tall, flower buds, new leaves	3-5 cm tall
livid amaranth	*Amaranthus blitum* L.	15- 37 cm tall, 5-7 branches, flowering	5-15 cm tall, 2 -6 branches
spotted spurge	*Euphorbia maculata* L.	10-13 cm tall, ~ 25* 25 cm spread, flowering, new leaves,	4- 5 cm tall, 2-4 branches
rice flatsedge	*Cyperus iria* L.	15-25 cm tall, 5-6 branches	3-12 cm tall

Table 2. Herbicides applied cool-season and warm-season experiments.

Common name	Trade name	Formulation	Rate (kg ai ha^{-1})	Treatments included	
				Winter test	Summer Test
isoxaben	Gallery®	4.16 SC	1.12	X	X
bentazon[b]	Basagran T&O®	2 L	1.12	X	X
sulfentrazone [c]	Dismiss®	SC	0.28	X	X
flumioxazin	SureGuard®	51 WDG	0.42	X	X
diquat	Reward®[c]	L	0.56	X	X
indaziflam	Marengo®	SC	0.049	X	X
			0.0653	X	X
halosulfuron [c]	Sedgehammer®	WDG	0.0526	X	X
flumioxazin + pyroxasulfone	V10233	WDG	0.532	X	X
oxyfluorfen[c]	GoalTender®	EC	0.56		X
cloransulam [c]	FirstRate®	WDG	0.0177		X
saflufenacil [d]	Detail®	WDG	0.025		X
topramezone [d]	Frequency®	SC	0.196		X
glufosinate	Cheetah Pro®	2.34 L	1.12	X[e]	X

[a]Abbrevations: SC, suspension concentration (liquid) formulation; L, liquid formulation; WDG, water-dispersible granular formulation; EC, emusifiable concentrate formulation.
[b]crop oil concentrate at 2.34 L ha^{-1} was added.
[c]non-inonic surfactant at 0.25% by volume was added.
[d]methylated seed oil added at 1% by volume was added.
[e]Based on encouraging results from the summer experiments, glufosinate was added to the 2019 cool-season experiment.

Results

Data for percent FWR and final VR were highly correlated ($0.8 \leq R \leq 0.98$) for all species and plant ages. Therefore, the following presentation and discussion of results focus on FWR data. Main effects of years, plant age, and location, as well as interactions between year and herbicide, age and herbicide, and location and herbicide, were all significant. Therefore, the data are presented separately for locations, years, herbicides, and ages. Overall, young seedling weeds were better controlled by more herbicides than were older weeds ($P < 0.01$). Also, cool-season weeds were better controlled by more treatments than were warm-season weeds. Warm-season weeds grew more rapidly and were generally larger than cool-season weeds.

Cool-season study

The most effective treatments in the cool-season study were diquat, flumioxazin, and flumioxazin plus pyroxasulfone with %FWR > 90% of common groundsel, common chickweed, and flexuous bittercress. There were no differences among these three treatments for the three species in both 2018 and 2019 (Table 3). Isoxaben, bentazon, indaziflam, and sulfentrazone provided overall 23 to 93 % and 31 to 98% FWR of old and young weeds, respectively while most means were between 40 and 70%. Percent FWR of weeds treated with isoxaben, bentazon, indaziflam, and sulfentrazone treatments was less consistent compared to diquat, flumioxazin, and flumioxazin plus pyroxasulfone, with better control in 2018 than 2019. Overall, treatments provided better control of young seedlings than old seedlings.

Diquat provided ≥ 95% FWR of both old and young common groundsel, common chickweed, and flexuous bittercress (Table 3). Foliar necrosis was rapid, with > 60% control 3 days after application (DAA) and >99% control for both young and old seedlings of all species at 22 DAA (data not shown).

Flumioxazin and flumioxazin plus pyroxasulfone reduced fresh weights of old and young common chickweed and bittercress > 95% (Table 3). They both provided ≥ 97% control for young common groundsel in both years but only provided ≥ 80% control of the old seedlings in 2018 and ≥ 95% control in 2019. Symptoms of injury from flumioxazin treatments developed more slowly than from diquat, but by three to five weeks after application, control was > 95% (data not shown).

Glufosinate, included in 2019 only, controlled 100% of old and young common chickweed and common groundsel (Table 3). However, glufosinate did not control young or old flexuous bittercress.

Isoxaben provided ≥ 98% control of young common chickweed and ≥ 85% control of young bittercress; but was less effective on older weeds in one of two years. In 2019 older chickweed was controlled by 77% but 91% in 2018 (Table 3). Similarly, old flexuous bittercress plants were controlled 66 to 86% in 2019 and 2018, respectively. Similarly, Altland et al. (2000) reported isoxaben at 1.12 kg ai ha^{-1} provided 90% control of hairy bittercress up to 6 cm but it only 43% control when weed was larger than 10cm. Isoxaben did not control common groundsel (Table 3).

Bentazon was generally more effective in 2018 than in 2019. It controlled old common groundsel by > 90 %. However, control of young seedlings was 100 % in 2018 but only 59% in 2019 (Table 3). Similarly, bentazon controlled both young and old common chickweed ≥ 98 % in 2018 but provided ≤ 66% FWR in 2019. Both young and old flexuous bittercress plants were controlled 98% in 2018 but < 10% in 2019. Reasons for differential control between years with bentazon are unknown.

There was no dose response for indaziflam on flexuous bittercress, common chickweed, or common groundsel FWR in 2018 (Table 3). But, increasing the dose of indaziflam from 0.049 to 0.0653 kg ai ha^{-1} improved FWR of both young and older common groundsel in 2019. It controlled > 90 % of young common chickweed, 80% and 73% of old common chickweed in 2018 and 2019, respectively, but < 65% of young or old flexuous bittercress. Control of old common groundsel was < 40% in 2018. In 2019 control of old common groundsel was 17% and 76% for the low and high dose, respectively.

Sulfentrazone provided 67 to 77% and 87 to 98% FWR on old and young common groundsel, respectively (Table 3). It did not control old common chickweed, and flexuous bittercress but it did show 82% FWR on young common chickweed and 62% FWR on flexuous bittercress in 2018, and < 15% FWR in 2019 (Table 3).

Warm-season study

When averaged across species, flumioxazin, and flumioxazin plus pyroxasulfone provided $\geq$ 80 % FWR of warm-season weeds. (Table 4). Diquat and glufosinate provided > 95 % FWR of young seedlings in both sites, and $\geq$ 89% FWR of old seedlings at CH. However, at HFL diquat and glufosinate provided only 68% and 78% FWR, respectively. Topramezone, saflufenacil, indaziflam, and oxyfluorfen controlled young seedlings 77 to 92% (Table 4). However, older weeds were not as well controlled by these treatments. Topramezone provided 52 and 72% FWR of old seedlings. . Halosulfuron, cloransulam, bentazon, saflufenacil, indaziflam, oxyfluorfen and isoxaben provided $\leq$ 60% average FWR (Table 4).

Flumioxazin and flumioxazin plus pyroxasulfone provided 100% control of both old and young rice flatsedge, livid amaranth, and chamberbitter, and young seedlings of yellow woodsorrel, and eclipta. (Table 5). Both treatments include flumioxazin, thus similarities in weed control are to be expected. But there were a few differences between these treatments on old eclipta and spotted spurge in the HFL experiment. Flumioxazin alone provided better control of old eclipta compared to flumioxazin plus pyroxasulfone. In contrast, flumioxazin plus pyroxasulfone controlled spotted spurge better than flumioxazin in the same study. These observations are consistent with the Sureguard herbicide label that lists chamberbitter, eclipta and spotted spurge as controlled by POST applications (Anonymous, 2015). However, results from this study also showed POST efficacy on rice flatsedge, yellow woodsorrel, and livid amaranth with flumioxazin, suggesting there is potential for label expansion.

Diquat was generally more effective on young weeds than on older plants (Table 5). Among older weeds, control with diquat was more variable with complete control of rice flatsedge and >90% control of yellow woodsorrel, but less and more variable control of other species. Diquat provided 75 to 81% control of old chamberbitter and 56 to 78% control of old spotted spurge. Diquat provided >90 % control of old livid amaranth and eclipta in the CH study but was less effective at the HFL site with only 21 to 58% control of these species, respectively.

Glufosinate provided > 90 % control of young and old chamberbitter, spotted spurge, and eclipta; and >90% control of young rice flatsedge, yellow woodsorrel, and livid amaranth. It also provided > 73 % control of old rice flatsedge and 57 to 79% control on old yellow woodsorrel, and 54 to 74% control on old livid amaranth (Table 5).

Topramezone provided > 95 % control on young yellow woodsorrel and eclipta. It provided 63 to 76% control on old chamberbitter, 54 to 65% control on old yellow woodsorrel, 64 to 96% control on young spotted spurge, 78 to 95% control on old eclipta and young chamberbitter (Table 5). Topramezone provided 85% cotnrol on old livid amaranth and spotted spurge at HFL location, but < 50% FWR at CH. It provided < 50% control of old rice flatsedge.

Saflufenacil provided > 90 % control on young rice flatsedge, chamberbitter, yellow woodsorrel, and eclipta (Table 5). It provided > 79% control of old chamberbitter, young livid amaranth, and old eclipta, 56 to 64 % control of young spotted spurge, and 48 to 78% control of old rice flatsedge. It provided< 50% control of old yellow woodsorrel, livid amaranth, and spotted spurge.

Increasing the dose of indaziflam from 0.049 and 0.0653 kg ai ha^{-1} improved suppression of old yellow woodsorrel in both CH and HFL (Table 5). But, for most species there was not a significant difference between the two indaziflam doses. Indaziflam provided > 85 % control of young eclipta, ~ 80% control of both old and young yellow woodsorrel seedlings, ~ 75% control of young chamerbitter. Variable responses were observed with rice flatsedge. At CH, > 85 % control of old rice flatsedge and > 95 % control of young rice flatsedge were observed. But at HFL the 0.049 kg ai ha^{-1} dose provided only 71% control, while 0.0653 kg ai ha^{-1} provided 100% control of rice flatsedge.

Sulfentrazone, oxyfluorfen, halosulfuron, cloransulam, bentazon, and isoxaben were ineffective on spotted spurge, applied at either growth stage (Table 5). Sulfentrazone provided 100% control of young and old rice flatsedge, 100% control of young chamberbitter, and > 90% control of young yellow woodsorrel, livid amaranth, and eclipta. Oxyfluorfen provided > 95% control of young rice flatsedge, 100% control of young livid amaranth, ≥ 85% control of young chamberbitter, and 71% and 100 % control of young yellow woodsorrel at CH and HFL, respectively (Table 5). Halosulfuron provided > 90% control of both young and old rice flatsedge, and young eclipta. Bentazon provided > 75% and > 90% control of old and young rice flatsedge, respectively, and 99% control of young eclipta, but < 50% control of chamberbitter, < 30% control of yellow woodsorrel, livid amaranth, and spotted spurge in both old and young seedlings . Isoxaben did not provide notable control on any weeds in the summer study.

Conclusions

Both cool-season and warm-season studies showed treatments provided better control when the weeds are younger. In the cool-season experiment weeds were less than 5 weeks from seed; in the warm-season experiment the young plants were 2 to 4 weeks old. Once cool-season weeds were greater than 7 weeks old, or warm-season weeds were greater than 5 weeks old, control was generally lower. This was especially apparent with warm-season weeds.

Of the herbicides and weeds tested, diquat and flumioxazin treatments controlled the most warm-season and cool-season weeds. Glufosinate provided > 90% control of many warm-season weeds. Of particular note is that glufosinate was the only treatment that provided > 90% control of old spotted spurge, which is one of the most common summer weeds in container nurseries. Glufosinate was included in only one year of the cool-season experiment but was less effective on flexuous bittercress compared to diquat or flumioxazin.

To avoid crop injury POST herbicides labeled for broadleaf weed control in ornamental plantings are generally applied as directed sprays. This is especially important for non-selective or broad spectrum herbicides like diquat, sulfentrazone and glufosinate (Neal et al., 2017). However, some POST herbicides, including bentazon, sulfentrazone, oxyfluorfen, and flumioxazin are labeled for broadcast applications over some nursery crop species. For example, bentazon is labeled for over the top broadcast applications to *Hemerocallis*, *Ilex*, and *Ajuga* species but not on *Juniperus*, and *Magnolia* species (Anonymous, 2016; Neal et al., 2017).

Similarly, flumioxazin may be applied over the top of several *Thuja*, *Juniperus* and *Pinus* species but directed applications are required to avoid injury to broadleaf woody shrub species (Anonymous, 2015).

These data show that certain problem weeds can be controlled in some crop species using selective postemergence herbicides. Additionally, these data show that broad spectrum postemergence herbicides are effective on common nursery weeds. However, utilization of broad-spectrum postemergence herbicides in containers will require the development of innovative ways to perform directed spray applications, avoiding contacting the crop canopies.

Table 4. Average fresh weight reduction (FWR) % of all warm-season weeds for each treatment at two locations, Castle Hayne, NC (CH) and Raleigh NC (HFL).

Average FWR % across species[a]									
Treatments		**Old[b]**				**young**			
	(kg ai ha^{-1})	**CH[c]**		**HFL[d]**		**CH**		**HFL**	
flumioxazin	0.42	89	a	92	a	98	a	100	a
flumioxazin + pyroxasulfone	0.532	88	a	80	ab	99	ab	97	abc
diquat	0.56	90	a	68	b	97	a	99	ab
glufosinate	1.12	89	a	78	b	96	a	97	abc
topramezone	0.196	52	bc	72	b	82	bc	92	cd
saflufenacil	0.025	57	b	46	c	88	b	93	bcd
indaziflam	0.0653	48	bc	44	c	85	bc	93	bcd
	0.049	35	de	41	c	77	c	86	d
sulfentrazone	0.28	40	cde	43	c	89	b	89	d
oxyfluorfen	0.56	44	cd	21	de	84	bc	77	e
halosulfuron	0.0526	29	ef	27	d	58	d	57	f
cloransulam	0.0177	19	f	17	de	56	d	58	f
bentazon	1.12	44	e	35	f	23	f	35	g
isoxaben	1.12	-7	g	-2	f	34	f	34	g

[a]Means within a column followed by the same letter were not significantly different (α = 0.05) based on Fisher's protected LSD ($P \leq 0.05$).

[b]Weeds were seeded two weeks apart to observe the age effects from treatments; the first and second seedling ages were designated as old and young, respectively. Exact ages varied between species and years due to different rates of germination and seedling growth.

[c]CH = NCSU Castle Hayne Research Station, Castle Hayne, NC.

[d]HFL = NCSU Horticultural Field Lab, Raleigh, NC

Table 3. Percent Fresh weight reduction averaged across species and for each species, by seedling age and year in cool-season studies evaluated 7 weeks after the first application.

Treatments		Averaged across species				common chickweed[a]			
		old[b]		young		old		young	
		2018	2019	2018	2019	2018	2019	2018	2019
	(kg ai ha^{-1})								
diquat	0.56	100 a	100 a	100 a	100 a	100 a	100 a	100 a	99 a
flumioxazin + pyroxasulfone	0.532	95 a	99 a	99 a	99 a	99 a	100 a	100 a	100 a
flumioxazin	0.42	92 a	100 a	99 a	100 a	99 a	100 a	100 a	100 a
isoxaben	1.12	61 b	46 bc	71 c	70 b	91 ab	77 b	98 a	99 a
bentazon	1.12	93 a	51 b	98 a	36 cd	99 a	50 c	100 a	66 b
indaziflam	0.0653	55 b	24 c	77 bc	44 cd	85 b	73 b	100 a	97 a
	0.049	50 b	41 bc	76 bc	53 c	78 b	73 b	100 a	93 a
sulfentrazone	0.28	32 c	23 c	84 b	31 d	-7 c	15 d	82 b	12 c
Glufosinate	1.1	--	77 b	--	65 b	--	100 a	--	100 a

Treatments		common groundsel				flexuous bittercress			
		Old[b]		young		old		young	
		2018	2019	2018	2019	2018	2019	2018	2019
diquat	0.56	99 a	100 a	100 a	100 a	100 a	100 a	100 a	96 a
flumioxazin + pyroxasulfone	0.532	87 ab	96 a	98 a	97 a	99 a	100 a	100 a	100 a
flumioxazin	0.42	80 ab	100 a	98 a	98 a	97 a	100 a	100 a	100 a
isoxaben	1.12	7 d	-4 b	28 c	26 d	86 a	66 a	88 a	85 a
bentazon	1.12	92 ab	96 a	100 a	59 bc	98 a	7 b	98 ab	-15 b
indaziflam	0.0653	39 c	17 b	76 b	43 cd	42 b	-18 b	53 d	-8 b
	0.049	38 c	76 a	69 b	64 b	33 b	-25 b	62 cd	1 b
sulfentrazone	0.28	67 b	77 a	98 a	87 a	35 b	-23 b	72 c	-1 b
Glufosinate	1.1	--	100 a	--	100 a	--	30 bc	--	4 b

[a]Means within a column followed by the same letter were not significantly different ($\alpha = 0.05$) based on Fisher's protected LSD ($P \leq 0.05$).

[b]Weeds were seeded two weeks apart to observe the age effects from treatments; the first and second seedling ages were designated as old and young, respectively. Exact ages varied between species and years due to different rates of germination and seedling growth.

Table 5. Percent fresh weight reduction (FWR) for the summer study, by species, plant age and location. Evaluated four weeks after herbicide applications.

		rice flatsedge[a]				chamberbitter			
		old[b]		young		old		young	
Treatments		CH[c]	HFL[d]	CH	HFL	CH	HFL	CH	HFL
	(kg ai ha^{-1})								
flumioxazin	0.42	100 a	100 a	100 a	100 a	100 a	100 a	100 a	100 a
flumioxazin + pyroxasulfone	0.532	100 a	100 a	100 a	100 a	100 a	100 a	100 a	100 a
diquat	0.56	100 a	100 a	89 a	100 a	81 b	75 b	100 a	100 a
glufosinate	1.12	82 b	73 c	90 a	94 a	99 a	96 a	99 a	99 a
topramezone	0.196	33 c	49 d	61 b	64 b	63 cd	76 b	88 ab	98 a
saflufenacil	0.025	78 b	48 d	91 a	100 a	85 ab	100 a	100 a	100 a
indaziflam	0.0653	99 a	87 abc	99 a	100 a	35 e	12 d	84 ab	74 b
	0.049	91 ab	90 ab	98 a	71 b	29 e	22 d	75 b	74 b
sulfentrazone	0.28	100 a	100 a	100 a	100 a	56 d	80 b	100 a	100 a
oxyfluorfen	0.56	89 ab	29 e	100 a	97 a	76 bc	57 c	85 ab	97 a
halosulfuron	0.0526	100 a	93 a	100 a	100 a	3 fg	8 d	37 c	45 c
cloransulam	0.0177	75 b	94 a	93 a	100 a	10 f	22 d	40 c	62 b
bentazon	1.12	89 ab	76 bc	93 a	100 a	5 fg	7 d	40 c	45 c
isoxaben	1.12	17 c	12 f	40 c	15 c	-7 g	15 d	28 c	21 d

		yellow woodsorrel				livid amaranth			
		old		young		old		young	
		CH[b]	HFL[c]	CH	HFL	CH	HFL	CH	HFL
flumioxazin	0.42	94 a	99 a	100 a	100 a	100 a	100 a	100 a	99 a
flumioxazin + pyroxasulfone	0.532	81 ab	96 a	100 a	100 a	100 a	100 a	100 a	100 a
diquat	0.56	92 a	96 a	99 a	100 a	95 a	21 cde	100 a	95 a
glufosinate	1.12	79 ab	57 b	96 a	99 a	74 a	54 b	90 abc	97 a
topramezone	0.196	54 b	65 ab	99 a	96 a	36 b	85 a	86 abc	96 a
saflufenacil	0.025	19 c	-9 cde	98 a	100 a	23 b	42 bc	79 bc	95 a
indaziflam	0.0653	100 a	90 ab	100 a	100 a	19 bc	36 bcd	75 c	100 a
	0.049	85 ab	79 ab	100 a	98 a	-25 e	20 de	51 d	100 a
sulfentrazone	0.28	14 c	21 c	100 a	93 ab	10 bcd	6 ef	94 ab	99 a
oxyfluorfen	0.56	58 b	3 cd	100 a	71 bc	17 bcd	31 cd	100 a	100 a
halosulfuron	0.0526	0 cd	-18 de	79 b	55 c	-10 de	-9 fg	4 e	21 bc
cloransulam	0.0177	14 c	-36 e	82 b	52 c	-10 de	-9 fg	5 e	1 c
bentazon	1.12	-18 d	-84 f	26 d	-45 e	-9 cde	7 ef	10 e	-12 c
isoxaben	1.12	-12 cd	-40 e	63 c	20 d	-36 e	-26 g	1 e	56 ab

Table 5. (cont.)

Treatments		spotted spurge								eclipta							
		old				young				old				young			
		CH[b]		HFL[c]		CH		HFL		CH		HFL		CH		HFL	
	(kg ai ha^{-1})																
flumioxazin	0.42	48	bcd	58	c	83	b	100	a	92	abc	94	ab	100	a	100	a
flumioxazin + pyroxasulfone	0.532	69	abc	80	ab	88	ab	100	a	75	cd	51	c	100	a	100	a
diquat	0.56	78	ab	56	c	92	ab	100	a	94	abc	58	c	100	a	98	a
glufosinate	1.12	98	a	91	a	100	a	96	a	100	a	97	a	100	a	99	a
topramezone	0.196	46	cde	61	bc	64	c	96	a	78	bcd	95	ab	95	abc	100	a
saflufenacil	0.025	39	def	13	d	56	cd	64	c	97	ab	79	b	99	a	100	a
indaziflam	0.0653	16	efg	8	de	50	cd	79	b	20	fg	34	de	99	a	100	a
	0.049	9	fg	4	de	45	de	75	bc	20	fg	30	de	88	bc	99	a
sulfentrazone	0.28	16	efg	1	de	42	def	41	d	41	e	51	c	97	ab	100	a
oxyfluorfen	0.56	8	g	-1	de	28	fgh	27	e	17	fg	7	f	89	bc	67	c
halosulfuron	0.0526	16	fg	2	de	33	efg	42	d	68	d	85	ab	92	abc	100	a
cloransulam	0.0177	-5	g	-12	e	25	gh	43	d	34	ef	45	cd	87	c	97	a
bentazon	1.12	4	g	6	de	-1	i	22	e	67	d	55	c	99	a	99	a
isoxaben	1.12	-11	g	9	d	14	h	15	e	6	g	22	ef	56	d	77	b

[a]Means within a column followed by the same letter were not significantly different ($\alpha = 0.05$) based on Fisher's protected LSD ($P \leq 0.05$).

[b]Weeds were seeded two weeks apart to observe the age effects from treatments; the first and second seedling ages were designated as old and young, respectively. Exact ages varied between species and years due to different rates of germination and seedling growth.

[c]CH = NCSU Castle Hayne Research Station, Castle Hayne, NC.

[d]HFL = NCSU Horticultural Field Lab, Raleigh, NC.

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