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Control of American Burnweed (*Erechtites hieraciifolia*) in Bermudagrass Turf

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American burnweed is an early successional summer annual species in the Asteraceae. This weed is a poor competitor; however, it rapidly colonizes disturbed and low-maintenance areas, especially following an environmental disturbance. Recently, turfgrass managers have made adjustments to maintenance practices to satisfy budget requirements and address environmental concerns. This has resulted in reduced mowing frequency in some golf course rough and out-of-play turf areas, and has allowed establishment of broadleaf weed species such as American burnweed which would otherwise be controlled by frequent mowing. The purpose of this study was to evaluate PRE and POST herbicide treatments for American burnweed control in an unmown bermudagrass golf course rough. Single PRE applications of simazine at 2.24 kg ai ha^{-1} and indaziflam at 0.06 kg ai ha^{-1} provided $>$ 80% American burnweed control 24 wk after treatment (WAT) in 2012 and 2013. Sequential combination applications of liquid formulations of dimethenamid-p + pendimethalin (2.24 + 1.68 kg ai ha^{-1}) provided 95% American burnweed control 24 wk after initial treatment in 2012 and 2013. Other PRE treatments did not provide consistent control of American burnweed across rating dates and years. Regardless of year, four POST treatments provided $\geq$ 87% control at 8 and 16 WAT. These included thiencarbazone + foramsulfuron + halosulfuron (0.02 + 0.044 + 0.07 kg ai ha^{-1}), thiencarbazone + iodosulfuron + dicamba (0.02 + 0.15 + 0.005 kg ai ha^{-1}), triclopyr + clopyralid (0.88 + 0.32 kg ai ha^{-1}), and sulfentrazone + metsulfuron (0.4 + 0.04 kg ai ha^{-1}). Several PRE and POST American burnweed control solutions exist for low maintenance bermudagrass areas. Future research should continue to screen other herbicides for control efficacy and focus on application timing to balance season-long control with minimal chemical inputs.

Nomenclature: Clopyralid; dicamba; dimethenamid-p; foramsulfuron; halosulfuron; indaziflam; iodosulfuron; metsulfuron; pendimethalin; simazine; sulfentrazone; thiencarbazone; triclopyr; American burnweed, *Erechtites hieraciifolia* (L.) Raf. ex DC.; bermudagrass, *Cynodon dactylon* (L.) Pers.
Key words: Golf course, turfgrass, weed control.

Erechtites hieraciifolia es una especie anual de verano de sucesión temprana de la familia Asteraceae. Esta maleza es un competidor pobre. Sin embargo, coloniza rápidamente áreas perturbadas y con poco mantenimiento, especialmente después de una perturbación ambiental. Recientemente, especialistas en el manejo de céspedes han hecho ajustes a las prácticas de manejo para satisfacer requisitos de presupuesto y para responder a preocupaciones ambientales. Esto ha resultado en una reducción en la frecuencia de chapia en áreas fuera-de-juego en campos de golf ('rough'), lo que ha permitido el establecimiento de especies de malezas de hoja ancha tales como *E. hieraciifolia*, las cuales serían controladas con una chapia frecuente. El propósito de este estudio fue evaluar tratamientos de herbicidas PRE y POST para el control de *E. hieraciifolia* en un rough de un campo de golf con césped bermuda sin chapia. Aplicaciones PRE simples de simazine a 2.24 kg ai ha^{-1} e indaziflam a 0.06 kg ai ha^{-1} brindaron >80% de control de *E. hieraciifolia* a 24 semanas después del tratamiento (WAT) en 2012 y 2013. Aplicaciones secuenciales de combinaciones de formulaciones líquidas de dimethenamid-p + pendimethalin (2.24 + 1.68 kg ai ha^{-1}) brindaron 95% de control de *E. hieraciifolia* a 24 semanas después del tratamiento inicial en 2012 y 2013. Otros tratamiento PRE no brindaron control consistente de *E. hieraciifolia* al promediar las fechas de evaluación y los años del estudio. Sin importar el año, cuatro tratamientos POST brindaron ≥87% de control a 8 y 16 WAT. Estos incluyeron thiencarbazone + foramsulfuron + halosulfuron (0.02 + 0.044 + 0.07 kg ai ha^{-1}), thiencarbazone + iodosulfuron + dicamba (0.02 + 0.15 + 0.005 kg ai ha^{-1}), triclopyr + clopyralid (0.88 + 0.32 kg ai ha^{-1}), y sulfentrazone + metsulfuron (0.4 + 0.04 kg ai ha^{-1}). Existen varias soluciones PRE y POST para el control de *E. hieraciifolia* para áreas con césped bermuda con bajo mantenimiento. Investigaciones futuras deberían continuar evaluando la efectividad de otros herbicidas y enfocarse en el momento de aplicación para balancear el objetivo de control durante toda la temporada de crecimiento con un mínimo de insumos químicos.

American burnweed is an early successional summer annual species in the Asteraceae. Native to North America, American burnweed is widely distributed throughout southeastern Canada and

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the eastern United States, from New England south to Florida and west to Minnesota and Texas, and has also been found in Washington, Oregon, and Hawaii (Darbyshire et al. 2012; McCarty et al. 2008). American burnweed is a phenotypically variable plant species, and three varieties are taxonomically recognized. The most commonly observed variety (var. *hieraciifolius*) is distributed throughout North America and was the variety investigated in this research (Barkley 2006; Belcher 1956).

Investigations into American burnweed seed germination characteristics have produced variable results; however, germination of viable seed has occurred across most studies when temperatures are > 20 C (Baskin and Baskin 1996; Lincoln 1983). Growth habit is characterized as erect (up to 2.5 m tall) which disrupts turfgrass quality in unmown areas as plant height quickly reaches above the turf canopy. Plants can also be identified by grooved stems and a short taproot accompanied by fibrous secondary roots or adventitious prop roots (Darbyshire et al. 2012; McCarty et al. 2008). Leaves are alternate, spiraling, and decrease in size up the stem with irregularly toothed margins.

American burnweed is a poor competitor, and thus, occurrence is most often associated with recent disturbance, especially following fire (Boring et al. 1981; Peterson et al. 1990). Hutchinson et al. (2005) reported an increase from $< 10\%$ to $> 70\%$ mean frequency after prescribed burning in an oak–hickory forest in Ohio. American burnweed frequencies returned to preburn levels in years when burning did not occur. Other disturbances such as forest cutting, soil cultivation, and herbicide application also allow rapid colonization of American burnweed. For example, American burnweed was not established in an Appalachian hardwood forest prior to clear-cutting, but generated 59 kg biomass ha^{-1} the year after clear-cutting (Boring et al. 1981). In Canada, American burnweed constituted 13 to 38% of total seed germination along forest clear-cuts (Landenberger and McGraw 2004).

American burnweed is a moderately troublesome weed in North American agricultural crops, forests, pastures, container ornamentals, and turfgrass (Bernard et al. 2012; Britt el al. 1990; Busey and Johnston 2006; Darbyshire et al. 2012; McCarty et al. 2008). As is common with early successional species, rapid establishment of American burnweed follows disturbance with a decline in occurrence correlated with increasing competition and establishment of other species (Boring et al. 1981; Darbyshire et al. 2012; Peterson et al. 1990). American burnweed is not considered a major weed of commercial turfgrass due to its poor tolerance of low mowing heights and frequent mowing (McCarty et al. 2008). However, the recent rise in fuel costs and trends to reduce agronomic inputs has resulted in reduced mowing frequencies and the establishment of low maintenance or natural "out-of-play" areas which consist of turf stands mown only 1 to 2 times yr^{-1} (personal observation). This provides an optimal scenario for American burnweed colonization and has generated an increase in its occurrence in these turfgrass situations.

Relatively few investigations of herbicidal control of American burnweed have been reported. Darbyshire et al. (2012) suggested applications of mesotrione at 101 g ai ha^{-1} or greater provided good control of American burnweed in cranberry (*Vaccinium macrocarpon* Aiton) and blueberry (*Vaccinium* spp.) fields in Canada and Maine, respectively. Gardiner et al. (1991) investigated American burnweed control in pine plantations in Arkansas and reported 94% control 60 d after treatment (DAT) with sulfometuron (168 g ai ha^{-1}) + hexazinone (840 g ai ha^{-1}), which decreased to 80% control 120 DAT. Although several herbicides are labeled for American burnweed control in turfgrass, there have been no peer-reviewed studies to date investigating its control. Thus, the objectives of this research were to evaluate PRE and POST herbicides for control of American burnweed in low-maintenance bermudagrass stands.

Materials and Methods

Two studies were conducted from 2012 to 2013 on common bermudagrass golf course roughs in Greenville, SC to evaluate PRE and POST control of American burnweed. Rough areas were mown once per year resulting in $> 70\%$ infestations of American burnweed. Soil was a Cecil sandy clay loam (fine, kaolinitic, thermic Typic Kanhapludults) with pH of 6.0.

Herbicide treatments and rates are presented in Tables 1 and 2 for PRE and POST studies, respectively. All treatments were applied with a

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Table 1. PRE American burnweed control 8 and 24 wk after initial treatment (WAIT) in a Greenville, SC bermudagrass golf course rough from 2012 to 2013.

Treatment[a]	Rate	American burnweed control[b,c]			
		8 WAIT[d]		24 WAIT	
		2012	2013	2012	2013
	kg ai ha^{-1}	%			
Nontreated control	—	0 c	0 d	0 d	0 d
Dimethenamid-p[e]	1.68	100 a	95 a	58 bc	90 ab
Dimethenamid-p (G)[f]	1.68	67 ab	0 d	52 c	0 d
Dimethenamid-p + pendimethalin	2.24 + 1.68	67 ab	100 a	95 ab	95 a
Dimethenamid-p + pendimethalin (G)	2.24 + 1.68	100 a	45 c	98 a	35 c
Isoxaben	1.12	67 ab	66 bc	60 abc	63 bc
Prodiamine	1.12	33 bc	0 d	0 d	0 d
S-metolachlor	4.28	100 a	0 d	0 d	0 d
Oxadiazon	3.36	100 a	0 d	0 d	0 d
Simazine	2.24	100 a	100 a	95 ab	100 a
Indaziflam	0.06	100 a	87 ab	88 abc	82 ab
$LSD_{0.05}$		59	30	39	31

[a] Herbicide trade names: dimethenamid-p, Tower; dimethenamid-p granular (G), Tower G; dimethenamid-p + pendimethalin, Tower + Pendulum; dimethenamid-p + pendimethalin granular (G), Freehand; isoxaben, Gallery; prodiamine, Barricade; *S*-metolachlor, Pennant Magnum; oxadiazon, Ronstar; simazine, Princep; indaziflam, Specticle.

[b] American burnweed control was evaluated visually on a 0 to 100% scale.

[c] Values in columns followed by different letters are significantly different at $P < 0.05$.

[d] Initial preemergence treatments were made on February 21, 2012 and February 14, 2013.

[e] Treatments containing dimethenamid-p received a sequential application on April 17, 2012 and April 24, 2013.

[f] Granular (G) treatments were applied using a shaker jar.

Table 2. POST American burnweed control 8 and 24 wk after treatment (WAT) in a Greenville, SC bermudagrass golf course rough from 2012 to 2013.

Treatment[a,b,c]	Rate	American burnweed control[d,e]	
		8 WAT	16 WAT
	kg ai ha^{-1}	%	
Nontreated control	—	0 c	0 d
Thiencarbazone + foramsulfuron + halosulfuron	0.02 + 0.044 + 0.07	100 a	98 a
Thiencarbazone + iodosulfuron + dicamba	0.02 + 0.15 + 0.005	100 a	98 a
Triclopyr + clopyralid	0.88 + 0.32	91 a	87 ab
Fluroxypyr	0.42	71 b	75 bc
Carfentrazone + 2,4-D + MCPP + dicamba	1.3 + 0.27 + 0.08 + 0.03	68 b	61 c
Sulfentrazone + metsulfuron	0.4 + 0.04	100 a	99 a
$LSD_{0.05}$		17	21

[a] Herbicide trade names: thiencarbazone + foramsulfuron + halosulfuron, Tribute Total; thiencarbazone + iodosulfuron + dicamba, Celsius; triclopyr +clopyralid, Confront; fluroxypyr, Spotlight; carfentrazone +2,4-D + MCPP + dicamba, Speedzone; sulfentrazone + metsulfuron, Blindside.

[b] All POST treatments contained a nonionic surfactant at 0.5% v/v.

[c] POST treatments were applied on April 17, 2012 and April 24, 2013.

[d] American burnweed control was visually evaluated on a 0 to 100% scale.

[e] Values in columns followed by different letters are significantly different at $P < 0.05$.

Table 3. Application dates and atmospheric and soil temperatures for PRE and POST American burnweed control studies in Greenville, SC from 2012 to 2013.

Application timing	Date	Temperature (C)	
		Atmospheric	Soil
PRE	February 21, 2012	11	4
PRE/POST[a]	April 17, 2012	25	11
PRE	February 14, 2013	10	8
PRE/POST	April 24, 2013	20	16

[a] Sequential PRE applications were made for treatments containing dimethenamid-p. POST applications were applied on the same day as the sequential PRE treatments.

CO_2-pressurized backpack sprayer calibrated to deliver 187 L ha^{-1} through 8003 flat-fan nozzles, with the exception of granular treatments that were distributed evenly across plots in two directions using a shaker jar. Plots were not mown for the duration of the study and neither supplemental fertility nor irrigation were applied except where irrigation was required by certain herbicide treatments. POST applications were applied to American burnweed plants 15 to 30 cm tall.

Initial PRE treatments were applied on February 21, 2012 and February 14, 2013. A sequential PRE application was made for treatments containing dimethenamid-p on April 17, 2012 and April 24, 2013. Plots were irrigated with 1.3 cm of water within 12 h after PRE application to ensure movement of applied herbicides to the soil surface. POST applications were made on the same day as sequential PRE treatments. Atmospheric and soil temperatures for each application timing are presented in Table 3. Ratings were taken at various intervals throughout the study and included American burnweed control using a 0 to 100% scale (0 = no control, 100 = complete control) and bermudagrass turf injury using a 0 to 100% scale (0 = no injury, 100 = complete plant death). Control was quantitatively evaluated in both studies by counting the number of American burnweed plants present in each plot at the final rating date in both years. Percent American burnweed control was calculated utilizing plant counts by comparing the number of American burnweed plants in a plot to the number in nontreated control plots in the same replicate.

The experimental design for all studies was a randomized complete block consisting of 2 m by 3 m plots and three replications. American burnweed control and bermudagrass turf injury data were analyzed to evaluate main effects and interaction of treatment and year. Where treatment-by-year interactions were not detected, data were combined for analysis and are presented over years. Mean comparisons between treatments were performed using Fisher's protected LSD. All analyses were conducted using SAS version 9.3 (SAS Institute Inc., Cary, NC) and significant effects and differences were based on $\alpha = 0.05$.

Results and Discussion

Results from this study suggest excellent PRE and POST American burnweed control can be obtained in bermudagrass with several herbicides labeled for turfgrass use. Visual American burnweed control estimates correlated highly with estimates of control via American burnweed plant counts (Table 4). Thus, for brevity, only control estimations will be presented and discussed. No bermudagrass injury was observed after any treatment at any rating date likely due to tall mowing heights; therefore, turf injury data are not presented (Table 4).

Significant treatment-by-year interaction was detected for PRE control at each rating date; therefore, PRE control data were analyzed separately and are presented by year (Table 1). In 2012, little separation between treatments was detected 8 wk after initial treatment (WAIT). All treatments except for prodiamine provided greater American burnweed control compared than the nontreated (Table 1). Application of *S*-metolachlor, oxadiazon, simazine, indaziflam, dimethenamid-p in liquid formulation, and dimethenamid-p + pendimethalin in granular formulation provided 100% American burnweed control 8 WAIT. In 2013, control was not as consistent among treatments 8 WAIT. In contrast to 2012, *S*-metolachlor, oxadiazon, and dimethenamid-p in granular formulation provided no American burnweed control. Only simazine, indaziflam, and liquid formulations of dimethenamid-p or dimethenamid-p + pendimethalin controlled American burnweed > 80% 8 WAIT in 2013 (Table 1). Regardless of year, simazine, indaziflam, and sequential applications of dimethenamid-p in liquid formulation provided >80% control 8 WAIT.

Simazine, indaziflam, and sequential applications of dimethenamid-p + pendimethalin in both

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Table 4. Analysis of variance (ANOVA) for PRE and POST American burnweed control and bermudagrass injury studies in Greenville, SC from 2012 to 2013 and correlation between visual and plant count control ratings.[a]

		American burnweed control					Bermudagrass injury	
		PRE			POST		PRE	POST
Source	df	8 WAIT	24 WAIT	df	8 WAIT	16 WAIT	8 WAIT	8 WAIT
Treatment	9	*	*	6	*	*	ns	ns
Year	1	*	ns	1	ns	ns	ns	ns
Treatment by year	9	*	*	6	ns	ns	ns	ns
		2012	2013					
Correlation coefficient[b]		0.88971*	0.87823*		0.97446*			

[a] Abbreviations: df, degrees of freedom; ns, nonsignificant; WAIT, weeks after initial treatment.

[b] Correlation coefficients separated for 2012 and 2013 PRE control due to significant treatment-by-year interaction.

* Significant at $P < 0.05$.

granular and liquid formulation provided > 80% American burnweed control 24 WAIT in 2012 (Table 1). Isoxaben and sequential applications of dimethenamid-p in liquid and granular formulation provided ≤ 60% American burnweed control compared to the nontreated 24 WAIT. In 2013, simazine, indaziflam, and liquid formulations of dimethenamid-p and dimethenamid-p + pendimethalin provided > 80% control 24 WAIT, whereas all other treatments provided < 65% control at this time. Overall, simazine and indaziflam provided > 80% American burnweed control regardless of year or rating date, suggesting these treatments are good PRE options for inclusion in a PRE American burnweed control program.

Treatment-by-year interaction was not detected for POST control data at any rating date, therefore, data from 2012 and 2013 were combined prior to analysis and are presented across years (Table 2). Thiencarbazone + iodosulfuron + dicamba, thiencarbazone + foramsulfuron + halosulfuron, sulfentrazone + metsulfuron, and triclopyr + clopyralid provided > 90% control 8 WAT (Table 2). Fluroxypyr and carfentrazone + 2,4-D + MCPP + dicamba provided < 80% American burnweed control at this rating date. Similar levels of control were observed 16 WAT (Table 2). Greater than 85% control was achieved with thiencarbazone + iodosulfuron + dicamba (98%), thiencarbazone + foramsulfuron + halosulfuron (98%), sulfentrazone + metsulfuron (99%), and triclopyr + clopyralid (87%), whereas fluroxypyr and carfentrazone + 2,4-D + MCPP + dicamba provided 75% and 61% control, respectively. American burnweed plants were large (15 to 30 cm) at the time of treatment. Applications were made at later growth stages to ensure adequate weed pressure at time of application. It is possible that greater POST control might be achieved if applications are made to less mature plants.

Simazine and indaziflam provided extended (up to 24 wk) American burnweed control (> 80%) regardless of year. Most PRE herbicide applications in managed turfgrass are applied for control of annual grasses such as crabgrass (*Digitaria* spp.), goosegrass [*Eleusine indica* (L.) Gaertn.], and annual bluegrass (*Poa annua* L.); thus, less research has focused on PRE broadleaf control in turfgrass. Simazine is often used for POST winter weed control prior to bermudagrass greenup in the spring. In field nurseries, fruit tree orchards, and vineyards, simazine is an effective PRE herbicide for control of troublesome broadleaf weeds such as horseweed [*Conyza canadensis* (L.) Cronq.] and other large-seeded species (Abit et al. 2012; Altland et al. 2003). Results from PRE simazine application in this study suggest an additional benefit of excellent American burnweed control in low-maintenance bermudagrass areas. Indaziflam is mostly applied for PRE crabgrass, goosegrass, and annual bluegrass control in bermudagrass (Brosnan et al. 2011, 2012; Perry et al. 2011), but others have noted extended control of certain broadleaf weed species as well (Perry et al. 2011). Where control of annual grassy weeds is required, indaziflam can also provide the benefit of controlling American burnweed.

American burnweed control with liquid formulations of dimethenamid-p and dimethenamid-p + pendimethalin was not consistent across rating dates. Except for dimethenamid-p alone at 24 WAIT in 2012 and the dimethenamid-p + pendimethalin combination at 8 WAIT in 2013, these treatments provided ≥ 95% American burnweed control. Dimethenamid-p has a shorter half-life (< 21 d) than other PRE herbicides, and this possibly contributed to decreased control at 24 WAIT in 2012. Granular treatments with these compounds were much less consistent, although the combination of dimethenamid-p + pendimethalin increased control compared to dimethenamid-p alone at all rating dates except 8 WAIT in 2012. Dimethenamid-p is often applied as a tank-mixture with other herbicides for improved weed control in potato (*Solanum tuberosum* L.) (Hutchinson 2012), but further research is required to determine if there is a benefit to tank-mixing other compounds with dimethenamid-p for American burnweed control because our results were not conclusive.

Other PRE herbicide treatments either provided inconsistent or ineffective American burnweed control. Isoxaben can provide good control of certain broadleaf weeds in turfgrass (Proctor and Reicher 2013), but provided only fair (60 to 67%) PRE American burnweed control in this study. Prodiamine, oxadiazon, and *S*-metolachlor did not adequately control American burnweed.

Four POST herbicide treatments provided > 85% American burnweed control 8 and 16 WAT. Haines et al. (1985) investigated the effects of leaf surface characteristics, water-holding capacity, and leaf surface–water droplet contact angles of six plant species on simulated acid rain damage. Of the six species studied, American burnweed had the lowest leaf surface-water droplet contact angle (70.1°) and a relatively high water-holding capacity (25 mg H_2O cm^{-2}). Additionally, electron micrographs revealed that American burnweed leaves are glabrous and lack epicuticular wax. Excellent POST control from several herbicides might be attributed to these leaf characteristics. Low leaf surface–water droplet contact angle and the absence of epicuticular wax allows for greater herbicide retention and subsequent penetration into the leaf (Darbyshire et al. 2012).

Fluroxypyr provided ~73% POST American burnweed control at 8 and 16 WAT. Fluroxypyr is a pyridine herbicide which provides effective broadleaf weed control in most warm- and cool-season turfgrasses. However, fluroxypyr efficacy is improved in some species by application to plants grown in high soil moisture and high relative humidity. For example, control of kochia [*Kochia scoparia* (L.) Schrad.] was greater when plants were grown in moist soil than in dry soil and control of Palmer amaranth (*Amaranthus palmeri* S. Wats.) was greater when plants were grown at 90% relative humidity than plants grown at 35% relative humidity (Lubbers et al. 2007). Adequate soil moisture at the time of application might not have been present due to the lack of irrigation at the study site and might have contributed to reduced fluroxypyr efficacy. Further research is required to evaluate the interaction of environmental conditions and control of American burnweed with fluroxypyr.

The combination product of carfentrazone + 2,4-D + MCPP + dicamba controlled American burnweed < 70% at both rating dates. Hanson (1962) made one of the first reports of herbicide tolerance when he noted a significant decrease in American burnweed susceptibility to 2,4-D after 10 yr of application in Hawaiian sugarcane (*Saccharum officinarum* L.). This phenomenon is often observed with repeated applications of the same herbicide over a period of time, but it is possible that American burnweed has some tolerance to 2,4-D, resulting in reduced level of control in our study.

The research presented here illustrates several PRE and POST American burnweed control solutions for out-of-play or low-maintenance bermudagrass areas. Low-maintenance turfgrass areas are not always bermudagrass; thus, these control options should be evaluated individually and turfgrass managers are always advised to check label recommendations for turfgrass safety prior to herbicide application. Nontraditional turfgrass weed species will continue to invade these areas as decreases to maintenance practices are made to satisfy budget requirements and environmental awareness concerns. Improving the understanding of chemical control options for these species, along with identification of their biological and ecological characteristics, will help turf managers improve the overall effectiveness of their holistic weed management program. Future research concerning American burnweed should continue to screen old and new herbicide chemistries for control efficacy and focus on application timing to balance season-long control with minimal chemical inputs.

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