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Evaluation of Alternative Herbicides for Southern Crabgrass (*Digitaria ciliaris*) Control in St. Augustinegrass

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Southern crabgrass is a common turfgrass weed throughout the United States, and in Florida a troublesome problem in St. Augustinegrass lawns. Because of herbicide label changes and lack of herbicide tolerance, no POST herbicides are currently registered for homeowner use for crabgrass control in residential and commercial St. Augustinegrass lawns. Alternative weed control methods, including cultural practices and unconventional herbicides, have been investigated to a limited extent for postemergence crabgrass control. In this study, alternative herbicides evaluated included 30% acetic acid, borax, sodium bicarbonate, and Garden Weasel AG Crabgrass Killer (sodium bicarbonate formulation including cinnamon, wheat and corn flour, and cumin). Treatments were applied to southern crabgrass at three growth stages (one to two leaf, three to four leaf, or one to two tiller). In the greenhouse, 30% acetic acid applied twice at 280 L ha^{-1} and two rates of AG Crabgrass Killer at 976 or 1,465 kg ha^{-1} provided $\geq$ 70% control of one to two–leaf southern crabgrass when evaluated 7 d after initial application (DAIA). No treatment provided $>$ 70% control of three to four–leaf or one to two–tiller southern crabgrass or any size crabgrass beyond 7 DAIA. In field trials, no treatment provided acceptable ($\geq$ 70%) southern crabgrass control at any weed stage. Initial turf injury was unacceptable for most rates of 30% acetic acid, sodium bicarbonate, and AG Crabgrass Killer, causing $>$ 20% St. Augustinegrass injury 7 DAIA. By 21 DAIA, turf injury levels had fallen to $\leq$ 20% for most treatments. Because of high turfgrass injury and little residual control, alternative herbicides tested are not an effective substitute for using preemergence herbicides for southern crabgrass control. If other options are not available, they may have a role as a limited spot treatment in St. Augustinegrass.

Nomenclature: Acetic acid; southern crabgrass, *Digitaria ciliaris* (Retz.) Koel.; St. Augustinegrass, *Stenotaphrum secundatum* (Walt.) Kuntze.

Key words: Organic, natural product herbicides, weed management, baking soda, acetic acid.

Digitaria ciliaris es una maleza común en céspedes a lo largo de los Estados Unidos, y en Florida es problemática en el césped para jardín St. Augustine. Debido a cambios en las etiquetas de herbicidas y la ausencia de tolerancia a herbicidas, actualmente no hay herbicidas POST registrados para uso por parte de los dueños de hogares para el control de *D. ciliaris*, en céspedes St. Augustine en zonas residenciales y comerciales. Métodos de control de malezas alternativos, incluyendo prácticas culturales y herbicidas no convencionales han sido investigados en forma limitada para el control en pos-emergencia de *D. ciliaris*. En este estudio, se evaluaron herbicidas alternativos incluyendo acetic acid al 30%, borax, sodium bicarbonate, y Garden Weasel AG Crabgrass Killer (formulación de sodium bicarbonate incluyendo harinas de canela, trigo y maíz y cumin). Los tratamientos fueron aplicados a *D. ciliaris* en tres estadios de crecimiento (una a dos hojas, tres a cuatro hojas, y uno a dos hijuelos). En el invernadero, acetic acid al 30% aplicado dos veces a 280 L ha^{-1} y dos dosis de AG Crabgrass Killer a 976 ó 1,465 kg ha^{-1} brindaron $\geq$ 70% de control de *D. ciliaris* de una a dos hojas, cuando se evaluó 7 d después de la aplicación inicial (DAIA). Ningún tratamiento brindó $>$ 70% de control en *D. ciliaris* de tres a cuatro hojas o de uno a dos hijuelos, o en ninguno de los estadios de crecimiento más allá de 7 DAIA. En los experimentos de campo, ningún tratamiento brindó un control aceptable ($>$ 70%) de *D. ciliaris* en ninguno de los estadios de crecimiento. El daño inicial en el césped fue inaceptable para la mayoría de las dosis de acetic acid al 30%, sodium bicarbonate, y AG Crabgrass Killer, las cuales causaron $>$ 20% de daño en el césped St. Augustine 7 DAIA. A 21 DAIA, el daño en el césped había caído a $\leq$ 20% en la mayoría de los tratamientos. Debido al alto daño causado al césped y el poco control residual, los herbicidas alternativos evaluados no son un sustituto efectivo para el uso de herbicidas en preemergencia para el control de *D. ciliaris*. Si no hay otras opciones, estos herbicidas alternativos podrían tiene un rol limitado para el control con aplicaciones dirigidas en el césped St. Augustine.

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St. Augustinegrass is the most widely used warm-season turfgrass species for residential turf in Florida, where it is grown on 1.2 million home lawns (Hodges et al. 1994). Southern crabgrass is a summer annual found throughout the southeastern United States, and can frequently invade and reduce quality of home lawns (Murphy et al. 2007). Changes in herbicide labels have eliminated late-postemergence (POST) herbicide options for crabgrass control in St. Augustinegrass lawns (Gale 2003). Application of asulam to residential turf was removed from the label in 1995 and asulam is only registered for use on sod farms (Anonymous 2009; Gale 2003). Dithiopyr controls crabgrass species when applied early POST, and is labeled for St. Augustinegrass lawns; however, it is only labeled for control up to the first crabgrass tiller (Anonymous 2012; Reicher et al. 1999).

One option for a substitute to synthetic products may be alternative herbicides, which are often naturally occurring chemicals. These can include common household products such as sodium bicarbonate, vinegar, sodium chloride, and borax. Little information has been published in regards to the use and effectiveness of these products as herbicides (Chase et al. 2004). However, the recent demand for organic products has contributed to exploration of natural products for weed management. This, along with changing public opinion, has led many homeowners to desire organic and nonchemical weed management programs for their lawns (Duke 1986; Ferguson and Chase 2004).

Sodium bicarbonate is a salt derived from the reaction of ammonia, sodium chloride, and carbon dioxide in water (Johnson and Swanson 1987). Commonly known as baking soda, sodium bicarbonate is readily available and easily applied. Although previous research with sodium bicarbonate as an herbicide has been limited, it can be antagonistic when used with synthetic herbicides (Thelen et al. 1995). In a 2004 study, sodium bicarbonate (49 and 98 kg ai ha^{-1}) applied alone provided between 35 and 45% control of southern crabgrass 28 d after initial application (DAIA) when applied at the one to three–leaf growth stage (B.J. Brecke, unpublished data). AG Crabgrass Killer [sodium bicarbonate formulation including cinnamon (*Cinnamomum verum* J. Presl.), wheat (*Triticum* spp.), and corn (*Zea mays* L.) flour, and cumin (*Cuminum cyminum* L.); Garden Weasel, Kansas City, MO 64101], is marketed for crabgrass control with claims of being noninjurious to most warm-season turfgrasses, including St. Augustinegrass (Anonymous 2005).

The aerobic bacterial oxidation of ethanol yields vinegar, which contains acetic acid (Nakayama 1959). Organic growers have expressed interest in acetic acid because it is considered a natural product and can be used for POST weed control. Early research has demonstrated effective control of common lambsquarters (*Chenopodium alba* L.), giant foxtail (*Setaria faberi* Herrm.), redroot pigweed (*Amaranthus retroflexus* L.) and smooth pigweed (*Amaranthus hybridus* L.) at concentrations of acetic acid ranging from 15 to 30% (Evans et al. 2009; Radhakrishnan et al. 2002). An application of 30% acetic acid provided >80% control of large crabgrass [*Digitaria sanguinalis* (L.) Scop.] 1 d after treatment when applied at the two to three–leaf growth stage (Evans and Bellinder 2009). However, application timing was critical because 30% acetic acid acts as a contact material and it was most effective on smaller weeds. Little information exists on turf tolerance to acetic acid used as an herbicide.

Borax is a salt of boric acid and has been tested for its weed control properties since the 1940s (Allgaier 1944). The predominant use of borax for weed suppression is to control ground ivy (*Glechoma hederacea* L.). Results varied, but borax provided moderate POST control (20 to 60%) of ground ivy in field trials (Hatterman-Valenti et al. 1996; Rossi et al. 1996). Temporary injury to turfgrass was recorded with all treatments. Because borax is a source of the micronutrient boron, toxicity problems are a concern with continued applications (Rossi et al. 1996). Levels of boron required to create toxic levels to lawn grasses are unclear.

An alternative herbicide that has been used in turfgrass applications is corn gluten meal. It is a natural corn product that is considered a non-synthetic preemergence (PRE) herbicide (Christians 1993). With the use of multiple applications, corn gluten meal provided acceptable control of various crabgrass species (Bingaman and Christians 1995). However, timing is important for PRE herbicides and requires a preemptive weed management program. If PRE materials are not applied in time, weed suppression or control may be limited to using POST herbicides.

Current research with alternative herbicides is largely related to weed control in organic food crop production systems (Chase et al. 2004). More information about the efficacy of these products in turf is needed. The objectives of this research were (1) to evaluate southern crabgrass control provided by alternative herbicides, (2) to determine tolerance of St. Augustinegrass to these products, and (3) to determine the contributions of cinnamon and cumin to sodium bicarbonate in AG Crabgrass Killer for southern crabgrass control.

Materials and Methods

General Conditions. Experimental design for all trials was a factorial structure, and a nontreated check was included. Application rates for borax and vinegar treatments were chosen based on effective treatments used in previous research. AG Crabgrass Killer rates represent the low and high recommended rates, as well as twice and four times the highest recommended rate. Sodium bicarbonate and AG Crabgrass Killer treatments were applied with the use of a shaker can to plots wet from dew or an irrigation event. AG Crabgrass Killer application directions suggest the product be applied to wet foliage, and to let dry for as long as possible for maximum efficacy (Anonymous 2005). Overhead watering for all treatments was withheld for a period of 48 h after herbicide application. Borax and 30% acetic acid were applied to dry foliage with the use of a CO_2-powered backpack sprayer calibrated to deliver 94 L ha^{-1} through flat-fan 11002 nozzles.

Southern crabgrass control was evaluated on a scale of 0 to 100%, where 0 indicated no crabgrass control and 100 complete crabgrass control. Acceptable control for this study was $\geq 70\%$ crabgrass control. Turfgrass injury ratings were based on a scale of 0 to 100%, 0 indicating no turf injury and 100 equaling completely brown turfgrass. Turfgrass injury $< 20\%$ was considered acceptable for all treatments.

Data for all experiments were subjected to an analysis of variance with the use of PROC MIXED with SAS 9.2 (SAS Institute, Inc., Cary, NC 27513). Means were separated with Fisher's Protected LSD at $\alpha = 0.05$. Data were pooled across years to look at more general effects of the treatment. By pooling the years, it is being assumed that the effect of year is only additive, and that because years cannot be repeated, any interaction effects are not of consequence. There was an interaction between weed stages and treatments; therefore, data will be presented separately by weed stage of growth.

Alternative Herbicide Greenhouse Evaluation. Studies to evaluate alternative herbicides were conducted in a greenhouse at the West Florida Research and Education Center (WFREC) in Jay, FL during the summer of 2009 and 2010. Natural lighting was used, and temperatures ranged from 15 C at night to 35 C during the day. Southern crabgrass (Elstel Farm and Seeds, Ardmore, OK 73401) was seeded at a rate of 98 kg ha^{-1} (80% germination rate) on the soil surface in 58-cm^2 plastic pots filled with a peat-based potting media (Fafard Mix No. 42, Fafard, Inc., Agawam, MA 01001) in May 2009 and June 2010. Following emergence, herbicides were applied at three crabgrass growth stages (one to two leaf, three to four leaf, or one to two tiller). For treatments with sequential applications, acetic acid was applied a second time 7 d after initial applications (DAIA). Visual estimates of southern crabgrass control were recorded at 1, 3, 7, 14, 21, and 28 DAIA.

Southern crabgrass shoots were harvested at the end of each experiment and average percent reduction in dry weight compared to nontreated checks was calculated. The experimental design was a two-factor factorial arrangement of treatments with four replications. The factors were three weed growth stages at time of application and 14 alternative herbicide treatments.

Alternative Herbicide Field Evaluation. Southern crabgrass was seeded at a rate of 98 kg ha^{-1} into established 'Raleigh' St. Augustinegrass at the WFREC in Jay, FL during the summer of 2009 and spring of 2010. The soil type was an Orangeburg sandy loam (fine–loamy, kaolinitic, thermic Typic Kandiudults) with pH 5.5 and 1% organic matter. Treatments were applied at the one to two–leaf or one–two tiller crabgrass growth stage on July 9 and August 4 in 2009 and May 5 and June 22 in 2010, respectively. Plots measured 1.5 by 3.0 m. The experimental design was a two-factor factorial with three replications. Factors were two weed growth stages at time of application and 14 alternative herbicide treatments. Turf was managed

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Table 1. Control of greenhouse-grown southern crabgrass using alternative herbicides.

Treatment	Rate	One–two leaf		Three–four leaf		One–two tiller	
		7 DAIA	21 DAIA	7 DAIA	21 DAIA	7 DAIA	21 DAIA
		%					
Nontreated		0	0	0	0	0	0
AG Crabgrass Killer[a]	244 kg ha^{-1}	30	23	6	6	11	4
	488 kg ha^{-1}	51	34	16	6	13	6
	977 kg ha^{-1}	73	66	39	18	20	8
	1,465 kg ha^{-1}	87	69	63	28	23	10
Sodium bicarbonate[a]	1,465 kg ha^{-1}	41	47	20	11	21	6
30% acetic acid[b]	187 L ha^{-1}	52	29	8	3	3	2
	2 × 187 L ha^{-1}[c]	58	29	7	4	10	5
	281 L ha^{-1}	52	25	12	8	11	4
	2 × 281 L ha^{-1}[c]	75	40	14	10	10	10
	374 L ha^{-1}	66	46	16	7	13	8
Borax[b]	15 kg ha^{-1}	11	19	11	3	4	4
	30 kg ha^{-1}	21	16	13	3	6	4
	61 kg ha^{-1}	36	26	13	8	13	7
LSD (0.05)		18	24	9	8	7	5

[a] Applied as a powder with a shaker to moist foliage.

[b] Applied as a spray to dry foliage.

[c] Second application at 7 DAIA (days after initial application).

according to University of Florida/IFAS recommendations (Trenholm and Unruh 2005).

For treatments with two acetic acid applications, the second was applied 7 DAIA. Overhead irrigation was withheld from the plots for 48 h after application of any herbicide, and no precipitation was recorded during that period. Turfgrass injury and southern crabgrass control were visually evaluated 1, 3, 7, 14, 21, and 28 DAIA.

AG Crabgrass Killer Ingredient Evaluation. A study to evaluate ingredients of AG Crabgrass Killer was conducted in a greenhouse at the WFREC in Jay, FL during the summer of 2010. Temperatures in the greenhouse ranged from 15 C at night to 35 C during the day with no supplemental lighting used. Southern crabgrass was seeded at 98 kg ha^{-1} into 58-cm^2 pots containing peat (Fafard Mix No. 42) on July 26. Treatments were applied to southern crabgrass at one to two–leaf and three to four–leaf stages on August 3 and 17. All treatments were applied with a shaker can to wet foliage. Crabgrass control was visually evaluated at 3, 7, 14, 21, and 28 DAIA. At the end of the experiment, southern crabgrass shoots were harvested and oven dried at 65 C for 5 d and shoot dry weights recorded. Four replications were used for the experiment.

Results and Discussion

Alternative Herbicide Greenhouse Evaluation. Visual evaluations at 7 and 21 DAIA are presented because they represent initial injury and sustained weed control during the experiment (Table 1). When visually evaluated 7 DAIA, 30% acetic acid applied twice at 281 L ha^{-1} and AG Crabgrass Killer applied at the higher two rates provided $>$ 70% control of one to two–leaf southern crabgrass (Table 1). Sodium bicarbonate control of one to two–leaf southern crabgrass averaged $\sim$ 41%. Borax controlled southern crabgrass $\leq$ 36% for all treatments. Control decreased between 7 and 21 DAIA, and no treatment exceeded 63% control of one to two–leaf southern crabgrass 21 DAIA. No treatment achieved $>$ 65% control of three to four–leaf or one to two–tiller stage southern crabgrass and most treatments controlled southern crabgrass $<$ 20% when evaluated 7 or 21 DAIA.

All treatments applied to one to two–leaf southern crabgrass reduced shoot weight 50 to 70% compared to nontreated plants (Table 2). AG Crabgrass Killer at the highest rate and two applications of acetic acid resulted in 70% or greater reduction of one to two–leaf southern crabgrass shoot dry weight.

AG Crabgrass Killer at all rates above 244 kg ha^{-1} and acetic acid at 374 L ha^{-1} also reduced dry

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Table 2. Shoot reduction of greenhouse-grown southern crabgrass using alternative herbicides at 28 days after initial application (DAIA).

Treatment	Rate	Reduction in dry weight relative to nontreated control		
		One–two leaf	Three–four leaf	One–two tiller
Nontreated[a]		–	–	–
AG Crabgrass Killer[b]	244 kg ha^{-1}	70	17	15
	488 kg ha^{-1}	70	21	17
	977 kg ha^{-1}	67	37	20
	1,465 kg ha^{-1}	74	54	34
Sodium bicarbonate[b]	1,465 kg ha^{-1}	67	26	13
	187 L ha^{-1}	50	5	11
	2 × 187 L ha^{-1}[d]	71	13	20
	281 L ha^{-1}	65	8	10
30% acetic acid[c]	2 × 281 L ha^{-1}[d]	75	9	18
	374 L ha^{-1}	59	29	16
	15 kg ha^{-1}	53	0	10
	30 kg ha^{-1}	67	14	7
Borax[c]	61 kg ha^{-1}	72	11	27
LSD (0.05)		50	18	23

[a] Average dry weights totaled 1.8, 2.6, and 2.9 kg m^{-2} for one–two-leaf, three–four-leaf, and one–two-tiller nontreated control, respectively.

[b] Applied as a powder with a shaker to moist foliage.

[c] Applied as a spray to dry foliage.

[d] Second application at 7 DAIA.

weight of three to four–leaf southern crabgrass, but no treatment achieved greater than 54% reduction. Most treatments did not reduce one to two–tiller dry weight with the maximum reduction of only 33% (Table 2).

Products in these trials are generally not manufactured for use as herbicides. Inconsistent control within a growth stage may be the result of the inability of these products to remain on leaf surfaces. Evans et al. (2009) reported increased efficacy of natural products by using adjuvants such as yucca extract. Borax and acetic acid applied as a spray were not mixed with any surfactants, which may have limited the amount of product that remained on the leaf surfaces. When applied to the leaf surface, the products tended to bead up on the cuticle of the southern crabgrass leaf. Surfactants are added to POST herbicide sprays to decrease surface tension of water droplets, leading to more material coming into contact with the leaf surface and possibly increasing control (Jansen et al. 1961). Southern crabgrass injury from acetic acid and sodium bicarbonate products was characterized by leaf necrosis where product contact was observed. Borax injury was observed as necrosis at the leaf tips. This injury appeared consistent with other contact herbicides. The effectiveness of some of the alternative herbicides seemed to correlate with the amount that is retained on the leaf surface. Therefore, differences in control across growth stages may be explained by spray droplet properties and their adherence with the leaf surface.

Alternative Herbicide Field Evaluation. No treatment applied to one to two–leaf or one to two–tiller southern crabgrass in the field provided acceptable ($\geq$ 70%) southern crabgrass control when evaluated 7 or 21 DAIA (Table 3). AG Crabgrass Killer and 30% acetic acid only provided 35 to 60% control regardless of application rate or southern crabgrass size at time of application. Borax provided $<$ 45% control of one to two–tiller southern crabgrass and $<$ 10% control of one to two–leaf southern crabgrass at both 7 and 21 DAIT.

In general, 30% acetic acid treatments applied to the one to two–leaf greenhouse-grown southern crabgrass appeared to provide better control than similar treatments applied in the field. In contrast, control of one to two–tiller southern crabgrass seemed greater in the field. A possible explanation is the height difference between southern crabgrass and St. Augustinegrass at the different weed stages in the field. St. Augustinegrass was maintained at a height of approximately 7.5 cm. At the one to two–leaf stage, southern crabgrass was approximately 4 to 5 cm in height. The taller St. Augustinegrass probably intercepted some of the acetic acid spray before it reached the southern crabgrass foliage, reducing its effectiveness. As with 30% acetic acid, borax treatments were also not as effective against southern crabgrass in field trials as in the greenhouse. For most ratings, control with borax was $<$ 10% for both leaf stages.

Sodium bicarbonate products showed less control in field trials than greenhouse trials at the one to two–leaf stage higher rates, but greater control at the lower rates. These products were applied directly to plant foliage in a powder form and had to remain in contact with the leaf surface to cause injury. Although both greenhouse and field trial had supplemental irrigation withheld for a period of 48 h after application, field conditions tend to have

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Table 3. Effect of alternative herbicides on southern crabgrass control determined visually and St. Augustinegrass injury under field conditions as affected by southern crabgrass growth stage.

Treatment	Rate	Southern crabgrass control (7 DAIA)		Southern crabgrass control (21 DAIA)		Turfgrass injury (7 DAIA)		Turfgrass injury (21 DAIA)	
		One–two leaf	One–two tiller	One–two leaf	One–two tiller	One–two leaf	One–two tiller	One–two leaf	One–two tiller
		%							
Nontreated		0	0	0	0	0	0	0	0
AG Crabgrass Killer[a]	244 kg ha^{-1}	45	38	35	36	23	15	3	7
	488 kg ha^{-1}	53	39	54	36	36	20	7	10
	977 kg ha^{-1}	52	44	50	36	52	31	7	13
	1,465 kg ha^{-1}	55	54	58	50	53	41	7	20
Sodium bicarbonate[a]	1,465 kg ha^{-1}	51	47	44	38	56	46	8	29
30% acetic acid[b]	187 L ha^{-1}	38	33	31	27	52	28	8	23
	2 × 187 L ha^{-1}[c]	41	63	31	35	51	56	28	38
	281 L ha^{-1}	42	38	23	30	53	29	6	13
	2 × 281 L ha^{-1}[c]	42	61	35	23	51	58	31	47
	374 L ha^{-1}	44	47	33	38	50	36	8	14
Borax[b]	15 kg ha^{-1}	8	37	5	36	4	1	1	1
	30 kg ha^{-1}	6	39	2	38	7	5	0	1
	61 kg ha^{-1}	8	38	3	42	10	4	0	2
LSD (0.05)		8	24	15	27	10	20	20	13

[a] Applied as a powder to moist foliage.

[b] Applied as a spray.

[c] Second application at 7 days after initial treatment (DAIA).

greater environmental variability. The product could have been blown or washed off the leaf surface in the field, causing inconsistent control under certain application conditions. Southern crabgrass grown in the greenhouse was probably more succulent than when grown under field conditions because of warmer temperatures and daily watering. This increased susceptibility to injury could have led to higher levels of control in the greenhouse at the one to two–leaf stage.

At 7 DAIA, borax was the only product that caused $\leq$ 10% St. Augustinegrass injury when applied to one to two–leaf stage southern crabgrass (Table 3). All 30% acetic acid, sodium bicarbonate, and AG Crabgrass Killer treatments caused unacceptable levels of turfgrass injury ranging from 23 to 56% when applied at the one to two–leaf stage 7 DAIA. By 21 DAIA, turfgrass injury was $<$ 10% for all treatments except sequential 30% acetic acid applications at the one to two–leaf stage (Table 3). When applied at the one to two–tiller stage of southern crabgrass growth, all rates of 30% acetic acid and higher rates of sodium bicarbonate products caused unacceptable injury when evaluated 7 DAIA (Table 2). By 21 DAIA, St. Augustinegrass injury had fallen below unacceptable levels for most treatments; however, damage from AG Crabgrass Killer (1,465 kg ha^{-1}), sodium bicarbonate, and sequential applications of 30% acetic acid remained unacceptable.

AG Crabgrass Killer Ingredient Evaluation. At the one to two–leaf stage, both rates of AG Crabgrass Killer and sodium bicarbonate applied at 967 kg ha^{-1} provided $\geq$ 70% southern crabgrass control (Table 4). For most treatments, control was less when applied at the three to four–leaf stage than the one to two–leaf stage. AG Crabgrass Killer and sodium bicarbonate did not provide acceptable control when applied to three to four–leaf stage southern crabgrass. Cinnamon and cumin provided $<$ 25% southern crabgrass control when applied to either growth stage, but cinnamon reduced dry weight for both growth stages when applied at 9.3 kg ha^{-1} (Table 4). Although control was not observed, the significant reduction in southern crabgrass dry weight could be due to herbicidal

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Table 4. Effect of AG Crabgrass Killer components on greenhouse-grown southern crabgrass.

Treatment	Rate	Crabgrass control (14 DAIA[a])		Reduction in dry weight relative to nontreated control (28 DAIA)	
		One–two leaf	Three–four leaf	One–two leaf	Three–four leaf
	kg ha^{-1}	%			
Nontreated		0	0	0	0
Cinnamon	4.6	0	3	37	5
	9.3	0	0	54	32
Sodium bicarbonate	484	33	19	73	4
	967	70	11	70	5
AG Crabgrass Killer[b]	488	75	29	86	45
	977	84	28	90	28
Cumin	9.3	23	0	50	0
LSD (0.05)		37	10	29	29

[a] Abbreviation: DAIA, days after initial application.

[b] Active: cinnamon—0.95%; inert: sodium bicarbonate, corn, and wheat flour, cumin—99.1%.

properties in cinnamon. AG Crabgrass Killer and sodium bicarbonate reduced shoot dry weight $\geq$ 70% when applied to one to two–leaf southern crabgrass, but $\leq$ 45% at the three to four–leaf stage (Table 4).

Cinnamon is labeled as the active ingredient in AG Crabgrass Killer, and all other materials tested are listed as inert ingredients (Anonymous 2005). Only sodium bicarbonate and AG Crabgrass Killer provided acceptable southern crabgrass control at either stage of growth. Cumin and cinnamon alone provided little southern crabgrass control and generally had limited effect on crabgrass shoot dry weight.

The flour components of AG Crabgrass Killer may have been added to improve handling characteristics and improve application efficiency of the product. When sodium bicarbonate was applied alone, it tended to clump with moisture and not adhere well to the leaf surface. In contrast, AG Crabgrass Killer adhered to the leaf surface well, even when moisture was present. The addition of flour in the formulation appears to improve the ability of AG Crabgrass Killer to stick to the leaf, which may have led to increased efficacy of AG Crabgrass Killer over sodium bicarbonate alone due to increased surface contact.

For southern crabgrass, alternative herbicides are ineffective at offering sustained commercially acceptable (> 70%) control. Although initial weed injury is high at small weed stages, reduction in southern crabgrass incidence is short lived as crabgrass regrowth occurs rapidly. High initial injury to turfgrass from these chemicals would also limit their potential for use in homeowner situations.

Although southern crabgrass control was not commercially acceptable (> 70%) in the field with the tested alternative materials, the lack of other herbicide management options available for POST southern crabgrass control in St. Augustinegrass lawns may necessitate the need for some of these products for southern crabgrass suppression. If high initial turfgrass injury is accepted, sodium bicarbonate products could potentially be used as a spot treatment if a natural product is desired or the timing to apply PRE herbicides has expired.

Literature Cited

Allgaier BE (1944) The chemical control of klamath weed. I. Application of ecological methods in determining the herbicidal and fertilizing properties of ammonium sulfamate and commercial borax. Ecology 25:424–432

Anonymous (2005) Garden Weasel® AG Crabgrass Killer product label. Kansas City, MO. 1 p

Anonymous (2009) Asulox® product label. EPA Registration No. 70506-139. King of Prussia, PA: United Phosphorous, Inc. 1–5 p

Anonymous (2012) Dimension® 2EW product label. EPA Registration No. 62719-542. Indianapolis, IN: Dow Agrosciences, LLC. 1–5 p

Bingaman BR, Christians NE (1995) Greenhouse screening of corn gluten meal as a natural control product for broadleaf and grass weeds. HortScience 30:1256–1259

Chase CA, Scholberg JM, MacDonald GE (2004) Preliminary evaluation of nonsynthetic herbicides for weed management in organic orange production. Proc Fla State Hort Soc 117:135–138

https://doi.org/10.1614/WT-D-14-00094.1 Published online by Cambridge University Press

Christians NE (1993) The use of corn gluten meal as a natural preemergence weed control in turf. Intl Turfgrass Soc Res J 7:284–290

Duke SO (1986) Naturally occurring chemical compounds as herbicides. Champaign, IL: Weed Science Society of America. Rev Weed Sci 2:17–44

Evans GJ, Bellinder RR (2009) The potential use of vinegar and a clove oil herbicide for weed control in sweet corn, potato, and onion. Weed Technol 23:120–128

Evans GJ, Bellinder RR, Goffinet MC (2009) Herbicidal effects of vinegar and a clove oil product on redroot pigweed (*Amaranthus retroflexus*) and velvetleaf (*Abutilon theophrasti*). Weed Technol 23:292–299

Ferguson JJ, Chase CA (2004) Status and preliminary research on non-synthetic herbicides for organic production. Gainesville, FL: University of Florida. EDIS Factsheet HS1003. p 1–10

Gale TW (2003) Prohibition of asulam use on residential turf. Tallahassee, FL: Florida Department of Agriculture and Consumer Services, Memorandum 760. 1 p

Hatterman-Valenti H, Owen MDK, Christians NE (1996) Ground ivy (*Glechoma hederacea* L.) control in a Kentucky bluegrass turfgrass with borax. Environ Hort 14:101–104

Hodges AW, Haydu JJ, van Blokland PJ, Bell AP (1994) Contribution of the Turf Grass Industry to Florida's Economy, 1991/92: A Value Added Approach. Gainesville, FL: University of Florida Food & Resource Economics Department Economic Report ER 94-1. 6–11 p

Jansen LL, Gentner WA, Shaw WC (1961) Effects of surfactants on the herbicidal activity of several herbicides in aqueous spray systems. Weeds 9:381–405

Johnson W, Swanson K (1987) Final report on the safety assessment of sodium sesquicarbonate, sodium bicarbonate and sodium carbonate. J Am Coll Toxicol 6:121–138

Murphy TR, Colvin DL, Dickens R, Everest JW, Hall D, McCarty LB (2007) Weeds of Southern Turfgrasses. Gainesville, FL: University of Florida; IFAS. 38 p

Nakayama T (1959) Studies on acetic acid–bacteria I. Biochemical studies on ethanol oxidation. J Biochem 46:1217–1225

Radhakrishnan J, Teasdale JR, Coffman CB (2002) Vinegar as a potential herbicide for organic agriculture. [Abstract] Proc Northeast Weed Sci Soc 56:100

Reicher ZJ, Weisenberger DV, Throssell CS (1999) Turf safety and effectiveness of dithiopyr and quinclorac for large crabgrass (*Digitaria sanguinalis*) control in spring-seeded turf. Weed Technol 13:253–256

Rossi F, Sausen A, Berg H (1996) Effective timing for postemergence ground ivy control. Wisconsin Turf Research Results of 1995 Studies 9:90–93

Thelen KD, Jackson EP, Penner D (1995) 2,4-D interactions with glyphosate and sodium bicarbonate. Weed Technol 9:301–305

Trenholm LE, Unruh JB (2005) Florida Lawn Handbook. 3rd ed. Gainesville, FL: University of Florida Press. 172 p

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