From Forest Nursery Notes, Winter 2010

168. Efficacy comparison of some new natural-product herbicides for weed control at two growth stages. Abouziena, H. F. H., Omar, A. A. M., Sharma, S. D., and Singh, M. Weed Technology 23:431-437. 2009.

Weed Technology 2009 23:431–437

Weed Management—Techniques

Efficacy Comparison of Some New Natural-Product Herbicides for Weed Control at Two Growth Stages

Hussein F. H. Abouziena, Ahmad A. M. Omar, Shiv D. Sharma, and Megh Singh*

There is an urgent need to accelerate the development and implementation of effective organic-compliant herbicides that are environmentally safe and that help the producer meet increasing consumer demand for organic products. Therefore, greenhouse experiments were conducted to evaluate the effectiveness of acetic acid (5%), acetic acid (30%), citric acid (10%), citric acid (5%) + garlic (0.2%), citric acid (10%) + garlic (0.2%), clove oil (45.6%), and corn gluten meal (CGM) compounds as natural-product herbicides for weed control. The herbicides were applied to the broadleaf weeds stranglervine, wild mustard, black nightshade, sicklepod, velvetleaf, and redroot pigweed and to narrowleaf weeds crowfootgrass, Johnsongrass, annual ryegrass, goosegrass, green foxtail, and yellow nutsedge. The herbicides were applied POST at two weed growth stages, namely, two to four and four to six true-leaf stages. CGM was applied PPI in two soil types. Citric acid (5%) + garlic (0.2%) had the greatest control (98%) of younger broadleaf weeds, followed by acetic acid (30%) > CGM > citric acid (10%) > acetic acid (5%) > citric acid (10%) + garlic (0.2%), and clove oil. Wild mustard was most sensitive to these herbicides, whereas redroot pigweed was the least sensitive. Herbicides did not control narrowleaf weeds except for acetic acid (30%) when applied early POST (EPOST) and CGM. Acetic acid (30%) was phytotoxic to all broadleaf weeds and most narrowleaf weeds when applied EPOST. Delayed application until the four- to six-leaf stage significantly reduced efficacy; acetic acid was less sensitive to growth stage than other herbicides. These results will help to determine effective natural herbicides for controlling weeds in organic farming.

Nomenclature: Acetic acid; citric acid; citric acid (5%) + garlic (0.2%; Alldown); citric acid (10%) + garlic (0.2%; Groundforce); clove oil (45.6%; Matran II); corn gluten meal (CGM); annual ryegrass, *Lolium multiflorum* Lam.; black nightshade, *Solanum nigrum* L.; crowfootgrass, *Dactyloctenium aegyptium* (L.) Willd; goosegrass, *Eleusine indica* (L.) Gaertn.; green foxtail, *Setaria viridis* (L.) Beauv; Johnsongrass, *Sorghum halepense* (L.) Pers.; redroot pigweed, *Amaranthus retroflexus* L.; sicklepod, *Senna obtusifolia* (L.) H. S. Irwin & Barneby; stranglervine, *Morrenia odorata* (Hook. & Arn.) Lindl.; velvetleaf, *Abutilon theophrasti* Medik; wild mustard, *Brassica kaber* (DC.) L. S. Wheeler; yellow nutsedge, *Cyperus esculentus* L; clove, *Syzygium aromaticum* (L.) Merr. & L. M. Perry; corn, *Zea mays* L.; garlic, *Allium sativum* L.

Key words: Acetic acid, Alldown, broadleaf weeds, citric acid, clove oil, corn gluten meal (CGM), Groundforce, Matran II, narrowleaf weeds, soil type, vinegar, young weeds.

There is increasing public concern about food quality and safety. Organic production is increasing, and there is very little research support for this expanding production system (Derksen et al. 2002). For example, certified organic crops in the United States were grown on 161,000 ha in 1992, but increased to 565,600 ha by 2003 (USDA 2005). Poor weed control is often cited as a major reason for lower yields in organic production (Gianessi and Reigner 2007; Peacock and Norton 1990). Organic crop growers cited weed control as their greatest difficulty in crop production (Stopes and Millington 1991; Walz 1999) because they are not permitted to use synthetic herbicides. Hand-weeding and cultivation are substitutes for herbicides at a greatly increased cost and with reduced effectiveness (Boyd et al. 2006; Gianessi and Reigner 2007). Organic farmers may have to spend up to $2,500/ha to adequately control weeds (Earthbound Organic 2006; Gianessi and Reigner 2007). Recently, some natural herbicides have been produced to control weeds, and the ingredients have been reviewed and approved by the Organic Materials Review Institute for their use in certified organic production (Chase et al. 2004; Ferguson 2004; Young 2004). However, few organically compliant herbicides exist, and even fewer have been tested adequately (Boyd and Brennan 2006; Curran et al. 2005).

Results of previous research indicated that corn gluten meal (CGM), citric acid (5%) + garlic (0.2%; Alldown), clove oil (45.6%; Matran II), citric acid (10%) + garlic (0.2%; Groundforce), acetic acid (vinegar), and citric acid proved effective as nonsynthetic herbicides for controlling weeds (Curran 2004; Law et al. 2006; Moran 2007; Preston 2003; Quarles 1999; Smith 2006; Zdor et al. 2005). CGM has been used successfully on lawns and high-value crops as a PRE herbicide (Bingaman and Christians 1995; Nonnecke and Christians 1993; Webber and Shrefler 2006). It must be applied just before weed seed germination to be effective and, at 1.61 t/ha, suppressed many common grasses and herba-

DOI: 10.1614/WT-08-185.1

* First author: Visiting Professor, Botany Department, National Research Centre, Dokki, Cairo, Egypt; second author: Assistant Professor, Biochemistry Department, College of Agriculture, Zagazig University, Zagazig 44111, Egypt; second and third authors: Postdoctoral Research Associates, and fourth author: Professor, Institute of Food and Agriculture Science, Horticultural Sciences Department, Citrus Research and Education Center, University of Florida, 700 Experiment Station Road, Lake Alfred, FL 33850-2299. Current address of third author: Reclamation Research Scientist–Weed Control, University of South Florida, Florida Institute of Phosphate Research, 1855 W. Main Street, Bartow, FL 33830. Current address of second author: Assistant professor, Biochemistry Department, Faculty of Agriculture, Zagazig University, Egypt. Corresponding author's E-mail: abouzainah@yahoo.com

Table 1. Summary of active ingredients, product concentrations, and sources used in experimental treatments.

Herbicide (active ingredients)	Product name	Concentration used in spray solution	Rate[a]	Product source or manufacturer
			L/ha	
Acetic acid (5%)	Household vinegar	Undiluted	188	Heinz North America, Pittsburgh, PA; www.heinz.com
Acetic acid (50%)	Acetic acid (60%)	30%	18.7	Ricca Chemical Company, Arlington, TX; www.riccachemical.com
Citric acid (10%)	Citric acid	Undiluted	188	Ricca Chemical Company, Arlington, TX; www.riccachemical.com
Citric acid (5%) + garlic (0.2%)	Alldown	Undiluted	188	Summerset Products, Inc. Bloomington, MN; www.sumrset.com
Citric acid (10%) + garlic (0.2%)	Groundforce	10%	18.8	Abby Laboratories, Inc., Ramsey, MN; www.abbylabs.com
Clove oil (45.6%)	Matran II	20%	37.5	EcoSMART Technologies, Franklin, TN; www.ecosmart.com
Corn gluten meal (CGM)	Corn gluten meal (CGM)	400 g/m^2	4 t	Bioweed, Environmental Factor, Oshawa, ON, Canada; www.environmentalfactor.com

[a] Rate from the commercial product.

ceous weeds (Preston 2003). In addition, Gough and Carlstrom (1999) reported that wheat (*Triticum aestivum* L.) gluten meal inhibited growth in a number of weed species. Acetic acid is an ingredient in several new herbicides on the market today. Researchers in Maryland tested 5% and 10% acetic acid for effectiveness in weed control (Anonymous 2002) and found that older plants required a higher concentration of acetic acid to kill them. At the higher concentration, control was 85 to 100%; however, the solution at lower concentration (5%) burned off the top growth with 100% success. Citric acid (5%) + garlic (0.2%) and 20% of Matran II (clove oil, 45.6%) provided more than 70% weed control within the first week, but control decreased to less than 60% by 3 wk after treatment (WAT; Chase et al. 2004). Natural herbicides can be applied either as formulation without carrier or mixed with different volumes of carriers in the spray solution. In this respect, burning nettle (*Urtica urens* L.) dry weight was reduced by 90% with 12 to 61 L clove oil/ha, whereas 21 to 38 L clove oil/ha was required to reduce common purslane (*Portulaca oleracea* L.) biomass to the same level (Boyd and Brennan 2006). The herbicide efficacy varied according to the growth stage of weeds and the herbicide concentration in spray solution (Boyd et al. 2006; Smith 2004, 2006). Curran (2004) showed 99% control of redroot pigweed (*Amaranthus* spp.) and velvetleaf (*Abutilon theophrasti* Medicus) with 23 to 47% clove oil mixture in a spray volume of 281 L/ha or 12 to 23% clove oil mixture in a spray volume of 562 L/ha when weeds were less than 7.6 cm tall. Clove oil effectively controlled broadleaf weeds when applied at high concentrations but did not effectively control some grass species (Boyd and Brennan 2006). Smith (2004) reported that 76 to 93% and 97 to 99.5% weed control was achieved with 10% and 20% clove oil, respectively, in a spray volume of 337 L/ha. Smith (2004) also noted that the best weed control occurred on small weeds with 1 to 2 leaves. The present study was undertaken to evaluate the efficacy of some nonsynthetic herbicides on six broadleaf weeds and six narrowleaf weeds at two weed growth stages and to examine the performance of corn gluten meal as an herbicide in two soil types.

Materials and Methods

Greenhouse experiments were conducted at the Citrus Research and Education Center (CREC), Lake Alfred, FL, to examine weed control efficacy of some nonsynthetic herbicides on six broadleaf weeds as well as six narrowleaf weeds. Natural herbicide treatments were applied to the broadleaf weeds stranglervine, wild mustard, black nightshade, sicklepod, velvetleaf, and redroot, and to the narrowleaf weeds crowfootgrass, Johnsongrass, annual ryegrass, goosegrass, green foxtail, and yellow nutsedge.

A summary of the natural product herbicides and their active ingredients used in this study are presented in Table 1. Some tested herbicides, such as acetic acid (5%; household vinegar), citric acid (10%), citric acid (5%) + garlic (0.2%), and CGM are ready-to-use in concentration without dilution or added to a carrier. Therefore, we used these herbicides without dilution, at a rate of 188 L/ha plus 2 L/ha organic oil. Matran II (clove oil [45.6%]), acetic acid (50%), and Groundforce (citric acid [10%] + garlic [0.2%]) required dilution.

Seeds were sown in plastic trays containing commercial potting medium.[1] Plants were grown in the greenhouse under natural daylight at 25/16 C day/night temperatures and at 70% ± 5% relative humidity. The plants were watered and fertilized with foliar fertilizer[2] containing 20–20–20 (N–P_2O_5–K_2O) to promote optimum growth. The broadleaf plants reached heights of 3 to 5 cm and 6 to 10 cm and grasses were 4 to 7 cm and 8 to 12 cm at the time of spray application for early POST (EPOST) and late POST (LPOST) treatments, respectively. Crop oil was added at 1% (v/v) for all herbicides, except CGM. Plants were sprayed using a chamber track sprayer[3] fitted with a TeeJet 8002 flat-fan spray nozzle,[4] delivering a 190 L/ha at 140 kPa pressure. Each experimental unit was a tray, replicated four times and arranged in a completely randomized-block design. For CGM, the experiments were conducted using two different soils: commercial potting medium and soil from citrus groves at CREC. Citrus grove soil was collected from 0 to 10 cm depth between rows using a stainless steel probe along transects established from a field that had not been treated with herbicides. Soil composition was 97% sand, 1% silt, and 2% clay (with a pH of 7.0 and 1.3% organic matterr).

Visual observations on mortality were recorded at weekly intervals to 5 wk after treatment (WAT). General observation on the efficacy of each herbicide on all weeds at EPOST and LPOST stage was taken at 5 WAT. Visual evaluations were recorded using a 0 to 100 scale, where 0 meant no visible effects and 100 meant complete control. Data expressed as

Table 2. Efficacy of nonsynthetic herbicides applied at two growth stages on six broadleaf weeds at 1 to 4 WAT.[a,b]

Treatments		Stranglervine		Wild mustard		Black nightshade		Sicklepod		Velvetleaf		Redroot pigweed	
		1 WAT	4 WAT	1 WAT	4 WAT	1 WAT	4 WAT	1 WAT	4 WAT	1 WAT	4 WAT	1 WAT	4 WAT
		Efficacy %											
AA (5%)	EPOST	95 b	93 b	63 f	38 e	95 b	98 a	65 d	52 e	95 a	100 a	0 g	0 f
	LPOST	9 h	8 f	17 g	17 f	27 g	18 i	0 i	0 h	38 d	47 d	0 g	0 f
AA (30%)	EPOST	97 ab	99 a	100 a	100 a	100 a	100 a	70 c	62 d	97 a	100 a	93 b	100 a
	LPOST	22 f	20 e	95 a	100 a	68 d	57 d	67 d	20 g	83 c	77 c	75 d	52 d
CA (10%)	EPOST	98 a	98 a	82 d	62 d	85 c	98 a	75 b	72 c	95 a	95 a	50 e	50 d
	LPOST	23 f	0 g	88 c	95 b	30 f	35 g	50 e	18 g	15 g	25 e	0 g	0 f
CA (5%) + G	EPOST	100 a	100 a	100 a	100 a	98 a	100 a	95 a	92 b	90 b	98 a	100 a	100 a
	LPOST	24 f	20 e	95 b	98 a	34 e	45 f	44 f	0 h	21 f	15 f	17 f	18 e
CA (10%) + G	EPOST	75 d	55 d	70 e	60 d	30 f	22 h	25 h	17 g	25 e	0 g	0 g	0 f
	LPOST	10 h	0 g	98 a	100 a	25 g	45 f	0 i	0 h	0 h	0 g	0 g	18 e
Clove oil	EPOST	15 g	0 g	18 g	18 f	0 h	0 j	27 h	27 f	0 h	0 g	0 g	0f
(45.6%)	LPOST	5 i	0 g	80 d	100 a	27 g	50 e	0 i	0 h	0 h	0 g	0 g	0 f
CGM	CPM	80 c	55 d	99 a	95 b	95 b	92 b	73 b	97 a	98 a	83 b	100 a	72 c
	SS	55 e	72 c	88 c	72 c	83 c	87 c	33 g	95 a	97 a	99 a	83 c	93 b

[a] Abbreviations: WAT, weeks after treatment; EPOST, early POST; LPOST, late POST; AA, acetic acid; CA, citric acid; G, garlic (0.2%); CGM, corn gluten meal; CPM, commercial potting medium; SS, sandy soil.

[b] Values within a column followed by a different letter are significantly different at $P = 0.05$.

percentages were arc-transformed before analysis and converted back to percentages for presentation purposes. The experiment was repeated twice under similar conditions, and pooled data were analyzed using Agriculture Research Management[5] software. Means were separated with Fisher's Protected LSD test at P = 0.05.

Results and Discussion

Weed Control Efficacy. Visual observation data were expressed as a percentage of the control treatment and were recorded at 1 to 4 WAT for individual broadleaf weed species (Table 2) and narrowleaf weeds (Table 3). The data were recorded up to 5 WAT; however, there were insignificant differences among observations recorded at 4 and 5 WAT, and, therefore, the data recorded at 5 WAT were excluded. Overall herbicide efficacy at both growth stages on broadleaf weeds is presented in Figure 1 and on narrowleaf weeds in Figure 2.

Acetic Acid (5%; Household Vinegar). Acetic acid (5%) applied EPOST resulted in 93, 98, and 100% control of stranglervine, black nightshade, and velvetleaf, respectively, at 4 WAT (Table 2). In previous research, Radhakrishnan et al. (2002) reported that herbaceous weeds sprayed with various solutions of acetic acid and concentrations of less than 10% killed the weeds within 2 wks after emergence. Delay of application significantly reduced herbicide efficacy, especially with stranglervine (Table 2). Acetic acid (5%) did not control redroot pigweed (Table 2). Furthermore, acetic acid (5%) gave low efficacy on the narrowleaf weeds when applied at both EPOST and LPOST (Table 3). Our results are in accord

Table 3. Efficacy of nonsynthetic herbicides applied at two growth stages on six narrowleaf weeds at 1 to 4 WAT.[a,b]

Treatments		Crowfootgrass		Johnsongrass		Annual ryegrass		Goosegrass		Green foxtail		Yellow nutsedge	
		1 WAT	4 WAT	1 WAT	4 WAT	1 WAT	4 WAT	1 WAT	4 WAT	1 WAT	4 WAT	1 WAT	4 WAT
		Efficacy %											
AA (5%)	EPOST	0 g	0 c	0 g	0 d	52 b	27 d	0 g	0 e	40 d	28 e	38 d	3 c
	LPOST	0 g	0 c	8 f	0 d	13 e	8 e	0 g	0 e	12 f	12 f	0 f	0 c
AA (30%)	EPOST	35 c	25 b	95 a	95 a	93 a	100 a	97 a	100 a	98 a	100 a	75 c	58 a
	LPOST	20 d	0 c	40 c	0 d	35 d	22 d	98 a	93 b	48 c	50 c	11 e	0 c
CA (10%)	EPOST	13 e	0 c	0 g	0 d	0 f	0 f	0 g	0 e	0 g	0 g	0 f	0 c
	LPOST	0 g	0 c	23 e	0 d	0 f	0 f	23 e	15 d	0 g	0 g	0 f	0 c
CA (5%) + G	EPOST	0 g	0 c	12 f	0 d	43 c	0 f	42 c	0 e	0 g	0 g	0 f	0 c
	LPOST	5 f	0 c	30 d	0 d	10 e	0 f	33 d	0 e	0 g	0 g	0 f	0 c
CA (10%) + G	EPOST	0 g	0 c	20 e	2 d	0 f	0 f	0 g	0 e	0 g	0 g	0 f	0 c
	LPOST	0 g	0 c	10 f	0 d	0 f	0 f	11 f	32 c	0 g	0 g	0 f	0 c
Clove oil (45.6%)	EPOST	0 g	0 c	0 g	0 d	0 f	0 f	0 g	0 e	0 g	0 g	0 f	0 c
	LPOST	10 e	0 c	12 f	0 d	0 f	0 f	11 f	30 c	0 g	0 g	0 f	0 c
CGM	CPM	100 a	97 a	55 b	77 b	90 a	95 b	98 a	97 a	32 e	42 d	83 b	50 b
	SS	90 b	98 a	42 c	32 c	50 b	40 c	47 b	18 d	55 b	65 b	92 a	48 b

[a] Abbreviations: WAT, weeks after treatment; EPOST, early POST; LPOST, late POST; AA, acetic acid; CA, citric acid; G, garlic (0.2%); CGM, corn gluten meal; CPM, commercial potting medium; SS, sandy soil.

[b] Values within a column followed by a different letter are significantly different at $P = 0.05$.

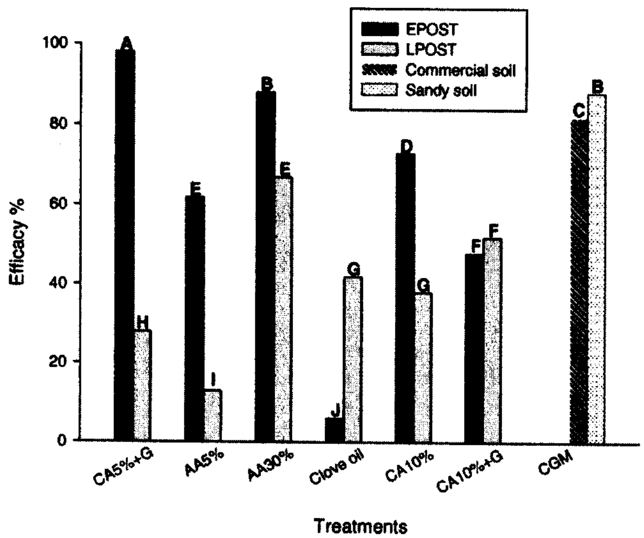

Figure 1. Visual assessments of broadleaf weed injury as affected by the nonsynthetic herbicides at 5 weeks after treatments. Abbreviations: EPOST, early POST; LPOST, late POST; CA, citric acid; AA, acetic acid; G, garlic (0.2%); CGM, corn gluten meal. Columns with the same letters are not statistically different at P = 0.05.

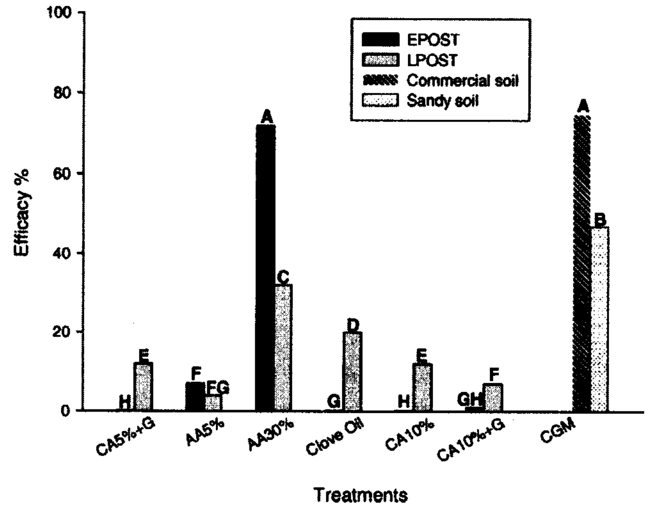

Figure 2. Visual assessments of narrowleaf weed injury as affected by the nonsynthetic herbicides at 5 weeks after treatments. Abbreviations: EPOST, early POST; LPOST, late POST; CA, citric acid; AA, acetic acid; G, garlic (0.2%); CGM, corn gluten meal. Columns with the same letters are not statistically different at P = 0.05.

with Young (2004), who reported that acetic acid (5%) did not adequately control the narrowleaf weeds.

Acetic Acid (30%). As shown in Tables 2 and 3, 30% acetic acid controlled all of the tested broadleaf weeds and most narrowleaf weeds, if applied at the early stage (two to four true leaves or earlier). Increasing the concentration of acetic acid from 5 to 30% in spray solution and applying EPOST provided excellent (95 to 100%) control of tested weeds, except for sicklepod, crowfootgrass, and yellow nutsedge, where the control was 62, 25, and 58%, respectively, at 4 WAT. Two hours after herbicide application, the leaves and shoots of sensitive weeds were killed (personal observation). Comis (2002) and Moran (2007) reported that 10 to 20% acetic acid concentration gave 80 to 100% weed control and was more effective than 5% acetic acid. Treating young weeds increased susceptibility of weed seedlings to acetic acid (30%). LPOST application caused complete growth inhibition (93 and 100%) of wild mustard and goosegrass but had no phototoxic effect on crowfootgrass and Johnsongrass (Tables 2 and 3). Acetic acid (30%) applications provided less than 75% yellow nutsedge control. In previous research, annual grasses were controlled at least 79% with a single application of acetic acid at 9% concentration (Young 2004), whereas Webber and Shrefler (2007) reported that acetic acid was less effective in controlling narrowleaf than broadleaf weeds. Acetic acid application at early weed stages inhibited the growth of all weeds except for crowfootgrass (Tables 2 and 3). These results suggest that among the weeds tested, crowfootgrass is most tolerant to acetic acid. Daniels and Fults (2002) reported from greenhouse and field studies that, although application of acetic acid (5%) solutions did not provide reliable weed control, solutions of 10, 15, and 20% provided 80 to 100% control of certain annual weeds (foxtail, lambsquarters, pigweed, and velvetleaf). In addition, the perennial weed Canada thistle [*Cirsium arvense* (L.) Scop.], treated with 5% acetic acid showed 100% shoot burn down, but roots were unaffected; therefore, shoots always regrew.

Citric Acid (10%). This herbicide was highly effective on stranglervine, black nightshade, and velvetleaf, with control 95% or higher at 4 WAT (Table 2). However, it showed lower activity (< 72% control) when applied to the other broadleaf weeds. Narrowleaf weeds were not substantially affected by citric acid sprayed on either young or taller narrowleaf weeds.

Citric Acid (5%) + Garlic (0.2%; Alldown). Application of this herbicide to younger broadleaf weeds provided 90 to 100% control within 1 WAT. At 4 WAT, the treatment provided similar control of weeds as recorded at 1 WAT (Table 2). Chase et al. (2004) reported that this mixture provided more than 70% weed control within the first week but decreased to less than 60% by 3 WAT. Delayed application of this combination on wild mustard resulted in 95% and 98% control at 1 and 4 WAT, respectively. However, the herbicide phytotoxicity on the other five broadleaf weeds when applied LPOST was significantly less effective (< 67%), and at 4 WAT, the phytotoxicity was reduced, and weeds began to recover from damage.

Crowfootgrass, green foxtail, and yellow nutsedge were not affected by any treatments applied EPOST or LPOST (Table 3). The reason for the reduced control in grasses with contact herbicides may be due to the shielding of the growing point by plant tissue (Boyd et al. 2006), whereas the growing point in broadleaf weeds is much more accessible to herbicides. Among all weeds used in this study at both EPOST and LPOST, wild mustard was more sensitive than other weeds to citric acid (5%) + garlic.

Citric Acid (10%) + Garlic (0.2%; Groundforce). This herbicide is similar to the previous herbicide discussed above, but the concentration of citric acid is higher. In most cases, increasing citric acid from 5 to 10% in this herbicide did not enhance herbicide phytotoxicity but had low efficiency compared with the herbicide containing citric acid (5%) + garlic (0.2%). Delayed application of citric acid (10%) plus garlic (0.2%) can effectively control wild mustard (100% control) but provided less than 60% control of stranglervine and wild mustard when applied EPOST (Table 2). Application of this herbicide either EPOST or LPOST had no effect upon velvetleaf, redroot pigweed, and all narrowleaf weeds except goosegrass, where control was 32% with the LPOST application (Tables 2 and 3). Poor control of black nightshade and sicklepod was recorded with this formulation (Table 2).

Results indicate that the citric acid (5%) + garlic (0.2%) has good potential for use as a natural herbicide. This herbicide caused 98% mortality of broadleaf weeds (Figure 1) and exhibited lower efficiency or no effect against narrowleaf weeds (Figure 2). The active ingredients of Alldown and Groundforce are citric acid and garlic but the difference between them is the concentration of citric acid, where its concentration in Alldown is half of that in Groundforce. Surprisingly, the efficacy of Alldown (citric acid [5%] + garlic [0.2%]) was better than that of Groundforce (citric acid [10%] and garlic [0.2%]) as shown in Figures 1 and 2. Johnson (2005) reported that citric acid (10%) plus garlic did not effectively control any of the weeds present in his trials. However, others have reported satisfactory weed control with clove oil and citric acid (10%) + garlic (Boyd et al. 2006; Smith 2006; Tworkoski 2002).

Clove Oil (45.6%; Matran II). Clove oil provided poor control (0 to 35%) of all weeds except wild mustard and black nightshade, where complete (100%) and 50% control was achieved with this treatment at 4 WAT, respectively (Table 2). Ferguson (2004) reported that weed control with Matran II at recommended and higher concentrations was inconsistent, ranging from 10 to 40%, compared with 100% control with glyphosate. However, Smith (2006) showed that Matran II at 12.5 gallons/ha applied in more dilute solution (5.4%) provided excellent weed control. Chase et al. (2004) reported that 20% concentration of Matran II, provided better than 70% weed control within the first week, which decreased to less than 60% by 3 WAT.

The herbicidal activity of clove oil may be due to a significant loss of foliar membrane integrity (Bainard et al. 2006). According to Bainard et al. (2006), the presence of leaf epicuticular wax in weeds tolerant to clove oil may possibly protect their leaves from herbicide damage. Boyd et al. (2006) reported that clove oil controlled 95 to 97% of all tested broadleaf weeds.

Corn Gluten Meal. CGM reduced germination and seedling survival of all weeds (Tables 2 and 3). These results support previously reported data that a high rate of CGM (4 t/ha) maintained 72% total weed control and 83% broadleaf weed control until 46 d after planting (Webber and Shrefler 2006; Zdor et al. 2005). Sicklepod germinated in the sandy soil treated with CGM, but at 4 WAT, 97% of seedlings were dead (Table 2). In general, CGM caused 70 to 90% weed control, the lowest for stranglervine and the highest for velvetleaf and crowfootgrass (Tables 2 and 3). Kuk et al. (2001) reported that CGM caused 32, 94, and 64% reduction in plant stands of velvetleaf, sicklepod, and goosegrass, respectively, compared with control.

Data in Tables 2 and 3 and Figures 1 and 2 indicate that CGM was less effective in controlling narrowleaf weeds than broadleaf weeds, particularly in sandy soil. However, application of CGM provided complete control (95 to 97%) of crowfootgrass, annual ryegrass, and goosegrass; substantial inhibition (83%) of green foxtail; and moderate control (less than 77%) of Johnsongrass and yellow nutsedge. Application of CGM in sandy soil resulted in 90 and 98% control of crowfootgrass and yellow nutsedge at 1 WAT, whereas the phytotoxicity was reduced on yellow nutsedge at 4 WAT (Table 3). Similar findings were reported by Bingaman and Christians (1995), Chase et al. (2004) and Zdor et al. (2005).

The efficacy of CGM was significantly affected by the soil type, where the percentage of control of wild mustard, velvetleaf, pigweed, annual ryegrass, and goosegrass at 4 WAT were 95, 83, 72, 95, and 97% in commercial potting medium, compared with 72, 99, 93, 40, and 18% for the same weeds germinated in sandy soil, respectively (Tables 2 and 3). The results in Figures 1 and 2 indicated that the control of broadleaf and narrowleaf weeds at 5 WAT were 82 and 75% in commercial potting medium, compared with 88 and 47% for the same weeds germinated in sandy soil, respectively.

It has been previously reported by Liu and Christians (1997) that CGM applied PRE inhibits seed germination and seedling growth for more than 4 WAT. Bingaman and Christians (1995) reported that application rates of CGM at 3.2, 6.4, and 9.6 t/ha reduced black nightshade survival by 82, 88, and 99%, respectively.

CGM inhibits root growth of germinating seeds but does not damage plants that have formed a mature root system, and this inhibition may be attributed to the presence of root-inhibiting dipeptides in CGM (Liu and Christians 1997). It could be concluded that CGM can be used as PPI herbicide for organic crop production (Webber and Shrefler, 2006). However, McDade and Christians (2000) advised against using incorporated CGM for direct-seeded vegetables.

The results in Tables 1 and 2 indicate that the tested herbicides provided better weed control with early application than late application, and the potential for this response varies among weeds and herbicides (Tables 2 and 3). These results coincide with those reported by Chase et al. (2004) and Ferguson (2004). Delaying the application allowed growth of weeds to increase twofold or threefold. Thickness, chemical composition, and ultrastructure of the epicuticular wax differ among plant species and with the age of the plants (Holloway 1970). These results also give anecdotal support to the concept that the morphological and physicochemical characteristics of leaves of various weed species influence the behavior of herbicides on the leaf surface and may lead to differential activity of a given herbicide from one weed species to another (Sanyal et al. 2006; Young 2004). None of the herbicides provided satisfactory control of narrowleaf weeds, except for acetic acid 30%, EPOST, and CGM. The difference between broadleaf and narrowleaf weeds partially occurs because all tested herbicides, except CGM, are contact herbicides, and the growing point for broadleaf weeds is above the ground, whereas the growing point for grasses remains below ground in the early growth stages (Boyd et al. 2006).

Wild mustard and black nightshade were more sensitive to the herbicides tested, whereas redroot pigweed was difficult to control with clove oil, acetic acid (5%), and citric acid (10%) + garlic (0.2%) treatments. The differences in leaf-surface morphology between these species could be responsible for this mortality difference (Sanyal et al. 2006).

Overall, results presented in Figure 1 indicate that citric acid (5%) + garlic (0.2%), citric acid (10%), and CGM were efficacious against broadleaf weeds tested in this study, when compared with untreated weeds. Acetic acid (30%) was more effective on all tested broadleaf weeds and most narrowleaf weeds if applied at an early stage (two to four true leaves or before). It provided 88 and 72% control of broadleaf and narrowleaf weeds, respectively (Figures 1 and 2). This treatment could be used to control weeds in the stale-seedbed technique for organic vegetable production.

We conclude that citric acid (5%) + garlic (0.2%) and acetic acid (30%) could be applied before planting to control weeds, as a stale-seedbed technique, in directed sprays between crop plants, between orchard trees, and in wide-row plantations. In addition, citric acid + garlic may also be applied POST in some crop species (Smith 2004; Evans and Bellinder 2009). CGM is effective as a PPI herbicide and could be combined with citric acid (5%) + garlic (2%) or acetic acid (30%) to improve weed management in organic cropping systems.

Sources of Materials

[1] Commercial potting medium. Metro-Mix500, Grace-Sierra Horticultural Products Company (now Scotts Company), 14111 Scottslawn Road, Marysville, OH 43041.

[2] Tracite foliar fertilizer. Helena Chemical Co., 7664 Moore Road, Memphis, TN 38120.

[3] Allen track sprayer. Allen Machine Works, 607 E. Miller Road, Midland, MI 48640.

[4] Teejet 8003 flat-fan nozzles, Spraying Systems Co., North Ave., Wheaton, IL, 60788.

[5] Pesticide Research Manager Software. Gylling Data Management Inc., 405 Martin Boulevard, Brookings, SD 57006.

Acknowledgments

The authors wish to thank Dr. Carlene A. Chase, Assistant Professor, Horticulture Sciences Department, University of Florida, for providing the Alldown, Groundforce, and Matran II herbicides. Appreciation also is expressed to the All Star Trading Company for providing CGM. We also thank Mr. Gary Test for his assistance in the greenhouse work.

Literature Cited

Anonymous. 2002. Vinegar wipes out thistles organically. Stockman Grass Farmer. July, p. 1.

Bainard, L. D., M. B. Isman, and M. K. Upadhyaya. 2006. Phytotoxicity of clove oil and its primary constituent eugenol and the role of leaf epicuticular wax in the susceptibility to these essential oils. Weed Sci. 54:833–837.

Bingaman, B. R. and N. E. Christians. 1995. Greenhouse screening of corn gluten meal as a natural control product for broadleaf and grassy weeds. Hortscience 30:1256–1259.

Boyd, N. S. and E. B. Brennan. 2006. Burning nettle, common purslane, and rye response to a clove oil herbicide. Weed Technol. 20:646–650.

Boyd, N. S., E. B. Brennan, and S. A. Fennimore. 2006. Stale seedbed techniques for organic vegetable production. Weed Technol. 20:1052–1057.

Chase, C. A., A.J.M. Scholberg, and G. E. Macdonald. 2004. Preliminary evaluation of nonsynthetic herbicides for weed management in organic orange production. Proc. Fla. State Hortic. Soc. 117:135–138.

Comis, D. 2002. Spray weeds with vinegar. http://www.ars.usda.gov/is/pr/2002/020515.htm. Accessed: December 12, 2008.

Curran, W. S. 2004. Soybean trial: Matran II study (RSSYNP60204). Pages 200–206 *in* W. S. Curran, D. D. Lingenfelter and C. B. Muse, eds. The Pennsylvania State University 2004 Herbicide Field Trials: Final Report. Volume 4. University Park, PA: Pennsylvania State University.

Curran, W. S., D. D. Lingenfelter, and C. B. Muse. 2005. Effectiveness of vinegar and clove oil for control of annual weeds. Proc. Weed Sci. Soc. Am 45:16. [Poster].

Daniels, C. H. and J. Fults. 2002. Fact Sheet for Vinegar/Acetic Acid Recommendations. http://www.barc.usda.gov/anri/sasl/vinegar.html. Accessed: December 12, 2008.

Derksen, D. A., R. L. Anderson, R. E. Blackshaw, and B. Maxwell. 2002. Weed dynamics and management strategies for cropping systems in the Northern Great Plains. Agron. J. 94:174–185.

Earthbound Organic. 2006. Organic Farming 101: Controlling Weeds Without Chemical Herbicides. http://www.ebfarm.com/WhyOrganic/Organic101.aspx. Accessed: January 15, 2008.

Evans, G. J. and R. R. Bellinder. 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.

Ferguson, J. 2004. Evaluation of organic herbicides. Hortscience. 39:876.

Gianessi, L. P. and N. P. Reigner. 2007. The value of herbicides in U.S. crop production. Weed Technol. 21:559–566.

Gough, R. E. and R. Carlstrom. 1999. Wheat gluten meal inhibits germination and growth of broadleaf and grassy weeds. Hortscience. 34:269–271.

Holloway, P. J. 1970. Surface factors affecting the wetting of leaves. Pestic. Sci. 1:156–163.

Johnson, W. C. 2005. Starting from scratch: Growing peanut without herbicides. Page 92 *in* SWSS Looking to the Future: Proceedings of 58th Annual Meeting of the Southern Weed Science Society, Charlotte, North Carolina. Madison, WI: Omnipress, http://swss.omnibooksonline.com/. Accessed: March 17, 2009.

Kuk, Y., R. Burgos, and R. E. Talbert. 2001. Evaluation of rice by-products for weed control. Weed Sci. 49:141–147.

Law, D. M., A. B. Rowell, J. C. Snyder, and M. A. Williams. 2006. Weed control efficacy of organic mulches in two organically managed bell pepper production systems. Horttechnology 16:188–375.

Liu, D. and N. Christians. 1997. Inhibitory activity of corn gluten hydrolysate on monocotyledonous and dicotyledonous species. Hortscience 32:243–245.

McDade, M. C. and N. E. Christians. 2000. Corn gluten meal—a natural preemergence herbicide: effect on vegetable seedling survival and weed cover. Am. J. Altern. Agric. 15:189–191.

Moran, P. J. 2007. Use of Fungal Bioherbicides and Vinegar to Control Pigweeds in South Texas. Page 199 *in* Proceeding of the Weed Science Society of America. Champaign, IL: WSSA. [Abstract].

Nonnecke, G. R. and N. E. Christians. 1993. Evaluation of corn gluten meal as a natural, weed control product in strawberry. Acta Horticulture 348:315–320.

Peacock, L. and G. A. Norton. 1990. A critical analysis of organic vegetable crop protection in the U.K. Agric. Ecosyst. Environ 31:187–197.

Preston, S. 2003. Principles of Sustainable Weed Management for Croplands. http://attra.ncat.org/attra-pub/PDF/weed.pdf. Accessed: December 12, 2008.

Quarles, W. 1999. Non-toxic weed control in the lawn and garden. Common Sense Pest Control Q. Pp. 4–14.

Radhakrishnan, J., J. R. Teasdale, and B. Coffman. 2002. Spray Weeds with Vinegar. http://www.ars.usda.gov/is/pr/2002/020515.htm. Accessed: January 15, 2008.

Sanyal, D., P. C. Bhowmik, and K. N. Reddy. 2006. Influence of leaf surface micromorphology, wax content, and surfactant on primisulfuron droplet spread on barnyardgrass (*Echinochloa crus-galli*) and green foxtail (*Setaria viridis*). Weed Sci. 54:627–633.

Smith, R. 2004. Post emergence organic weed control in onions and broccoli. Crop Notes, pp. 10–12.

Smith, R. 2006. Broccoli: Organic Weed Control Trials. http://ucce.ucdavis.edu/files/filelibrary/1598/29476.pdf. Accessed: December 12, 2008.

Stopes, C. and S. Millington. 1991. Weed control in organic farming systems. Pages 185–192 *in* Proceedings of the Brighton Crop Protection Conference. Brighton, UK: Brighton Crop Production Council.

Tworkoski, T. 2002. Herbicide effects of essential oils. Weed Sci. 50:425–431.

[USDA] U.S. Department of Agriculture. 2005. Economic Research Service: Organic Production Data Sets. Available at: http://www.ers.usda.gov/Data/Organic. Accessed: December 12, 2008.

Walz, E. 1999. Final Results of the Third Biennial National Organic Farmers' Survey. https://ofrf.org/publications/pubs/4thsurvey_results.pdf.

Webber, C. L., III, and J. W. Shrefler. 2006. Corn gluten meal and spring-transplanted onions (*Allium cepa* L.): crop safety, weed control, and yields. Pages 87–97 *in* National Allium Research Conference. College Station, TX: Texas A&M.

Webber, C. L., III, and J. W. Shrefler. 2007. Organic weed control with vinegar: application volumes and adjuvants. Proc. Hortic. Ind. Show 26:149–151.

Young, S. L. 2004. Natural product herbicides for control of annual vegetation along roadsides. Weed Technol. 18:580–587.

Zdor, R. E., C. M. Alexander, and R. J. Kremer. 2005. Weed suppression by deleterious Rhizobacteria is affected by formulation and soil properties. Commun. Soil Sci. Plant Anal. 36:1289–1299.

Received December 24, 2008, and approved March 27, 2009.