Pelargonic Acid for Weed Control in Organic Vidalia® Sweet Onion Production

Wiley Carroll Johnson III^{1,3,5} and Jerry W. Davis^{2,4}

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SUMMARY. Cultivation using a tine weeder is a proven means to manage weeds in organic Vidalia® sweet onion (*Allium cepa*) production. If the initial cultivation is delayed, emerged weeds are not controlled. In these cases, herbicides derived from natural products could be used to control the emerged weeds before the initial cultivation. Clove oil has been evaluated for this use, but cool-season weed control is inconsistent during the winter season when Vidalia® sweet onion are grown. Pelargonic acid is a herbicide that can be derived from natural sources or synthesized. Field trials were conducted from 2011 through 2013 to determine the efficacy of pelargonic acid for cool-season weed control in organic Vidalia® sweet onion. All possible combinations of four herbicides and three cultivation regimes using a tine weeder were evaluated. Herbicides evaluated were pelargonic acid (3% and 5% by vol.), clove oil [10% by vol. (2011 and 2012)], D-limonene [14% (2013 only)], and a nontreated control. Cultivation regimes were twice (2×) and four times (4×) at 2-week intervals, and a noncultivated control. Main effects of cultivation and herbicides were independent for all parameters, with no improvement when used in combination. Cultivation 2× and 4× controlled cool-season weeds and improved onion yields, which is consistent with previous research. Pelargonic acid (5%) controlled weeds similar to clove oil (2011 and 2012) and D-limonene (2013), with cool-season weed control efficacy being inconsistent among all herbicides. Onion yield response to weed control from any of the herbicides, including pelargonic acid, also was inconsistent. In organic onion production, inconsistent cool-season performance using pelargonic acid is similar to other herbicides derived from natural sources.

Weed management in organic production systems is an integration of cultural, mechanical, and chemical weed control components uniquely tailored for each location and crop. Chemical weed control in certified organic cropping systems allows for use of herbicides that are derived from natural sources. Some are derived from essential oils originating from plants (Dayan et al., 2009; Gaskell et al., 2000; Tworowski, 2002). These are postemergence herbicides that are sprayable, nonsystemic,

and generally nonselective, although crop tolerance varies.

Herbicides derived from natural sources have been investigated for weed control in certified organic crop production with many reports focused on the evaluation of performance on warm-season weeds. These studies evaluated commercial products, rates, times of application, and combinations with mechanical weed control in many cropping systems and regions (Boyd and Brennan, 2006; Boyd et al., 2006; Brainard et al., 2013; Curran et al., 2004; Johnson et al., 2012). Common conclusions drawn from these studies were that none of the essential oil herbicides provided any residual weed

control, small weed size was critical for maximum efficacy, monocots were not controlled, environmental conditions affected herbicide performance, and rates necessary for maximum efficacy made the treatment costly. Additionally, sprayer configuration was reported to be an important consideration to ensure maximum efficacy, with high sprayer output volume necessary to ensure adequate spray coverage of targeted weeds (Boyd and Brennan, 2006; Boyd et al., 2006; Curran et al., 2004; Evans and Bellinder, 2009; Johnson and Davis, 2014; Shrestha et al., 2012; Young, 2004).

Vidalia® sweet onion are a dry-bulb onion grown in Georgia as a cool-season crop and account for the largest portion (17.4%) of the Georgia vegetable crop farm gate value compared with other vegetable crops (Wolfe and Stubbs, 2013). The acreage is stable because plantings are restricted by Federal Marketing Order 955 to a region in southeastern Georgia (U.S. Code of Federal Regulations, 1990). Plantings of Vidalia® sweet onion in 2012 were estimated to be 12,860 acres and the economic impact valued at \$163 million (Wolfe and Stubbs, 2013).

Organic Vidalia® sweet onion is a highly profitable segment of the production that is driven by consumer demand. One of the most costly inputs into organic Vidalia® sweet onion is weed control (about \$1500/acre), which is achieved primarily by handweeding (R.L. Torrance, unpublished data). Any strategy that reduces or eliminates the need for handweeding will provide a significant savings directly to growers. Previous research focused on an integrated system of summer solarization, cultivation with a tine weeder, and clove oil (Johnson et al., 2012), with the stated objective to lessen the need for handweeding. Of the weed control

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¹USDA-ARS, Tifton Campus, P.O. Box 748, Tifton, GA 31793-0748

²University of Georgia, Griffin Campus, Griffin, GA 30223

³Research Agronomist

⁴Research Statistician

⁵Corresponding author. E-mail: Carroll.Johnson@ars.usda.gov.

Units

To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
0.4047	acre(s)	ha	2.4711
0.3048	ft	m	3.2808
0.0929	ft ²	m ²	10.7639
9.3540	gal/acre	L·ha ⁻¹	0.1069
2.54	inch(es)	cm	0.3937
25.4	inch(es)	mm	0.0394
1.1209	lb/acre	kg·ha ⁻¹	0.8922
2.2417	ton(s)/acre	Mg·ha ⁻¹	0.4461

tactics studied, cultivation with a tine weeder was the most consistent and effective approach. However, it was noted that timing of the initial cultivation was crucial and delays in the initial cultivation would greatly reduce overall weed control. That research also indicated that clove oil provided inconsistent weed control and its use was not correlated with yield responses. Sprayer output volume and adjuvants were later studied in an attempt to improve clove oil consistency (Johnson and Davis, 2014). None of the adjuvants improved clove oil performance. Higher sprayer output volume increased treatment cost, but was needed for optimum performance. Despite these optimized application factors, clove oil efficacy on cool-season weeds remained inconsistent.

Pelargonic acid is a naturally occurring fatty acid that has herbicidal properties (Vencill, 2002). The herbicide is generally nonselective, applied postemergence, and kills susceptible plants by cell membrane disruption. Symptoms appear quickly, suggesting value as a preharvest crop desiccant. Arboleya et al. (2005) found pelargonic acid to have desiccant properties in onion production, although other herbicides were more effective. Pelargonic acid effectively controlled weeds in squash (*Cucurbita pepo*) when applied with a precision directed sprayer (Webber et al., 2014).

There is a need for an early season herbicide option in organic Vidalia® sweet onion to control emerged cool-season weeds before onset of cultivation with a tine weeder. Clove oil was proposed for this use, but inconsistency in controlling cool-season weeds during winter months negated that possibility (Johnson and Davis, 2014; Johnson et al., 2012). Pelargonic acid might provide a specialized niche in organic Vidalia® sweet onion production if control of emerged early season weeds is better and more consistent than clove oil or other herbicides derived from natural products. Additionally, a commercial product containing pelargonic acid was previously registered for use in certified organic crop production on a limited basis. It is possible that pelargonic acid could become an option in certified organic production if a clear advantage were identified. Therefore, studies were

initiated in 2011 to determine if an integrated system of cultivation with a tine weeder and pelargonic acid can effectively and consistently manage cool-season weeds in organic Vidalia® sweet onion production.

Materials and methods

Field trials were conducted from 2011 through 2013 at the Vidalia Onion and Vegetable Research Center near Lyons, GA (lat. 32.018801°N, long. 82.220101°W). This location is in the defined region where Vidalia® sweet onion are commercially produced (U.S. Code of Federal Regulations, 1990). The soil was a Tifton loamy sand (fine-loamy, kaolinitic, thermic Plinthic Kandiudults), composed of 88% sand, 6% silt, and 6% clay, with 0.5% organic matter. The experimental design was a randomized complete block, with a factorial arrangement of treatments replicated four times. One treatment factor was herbicides derived from natural products. Herbicides evaluated were pelargonic acid (Scythe®, 57% pelargonic acid; Gowan Co., Yuma, AZ) mixed with water to make a 3% and 5% solution by vol. An OMRI-listed herbicide was included for comparison; clove oil (Matratec®, 50% clove oil; Brandt Consolidated, Springfield, IL) at 10% by vol. spray solution (2011 and 2012), D-limonene (Green-Match Burndown Herbicide®, 55% D-limonene; Marrone Bio Innovations, Davis, CA) at 14% spray solution (2013 only). The citrus by-product D-limonene was substituted in 2013 because of unavailability of the clove oil herbicide. Herbicide treatments were applied with a carbon dioxide (CO₂) pressurized tractor-mounted plot sprayer using spray tips with an orifice size suitable to produce an output of 60 gal/acre (Turbo TeeJet® 11006 tips; TeeJet Technologies, Wheaton, IL). Herbicide treatments were applied in late-December each year to weeds ranging in size from cotyledon to one-true leaf stage of growth. At the time of application, onion seedlings had recovered from transplanting and were ≈6 inches tall with a bulb diameter of 10 mm.

The other treatment factor was cultivation with a tine weeder (Aerostar Tined Weeder; Einböck, Dorf an der Pram, Austria). The tine weeder uses ground-driven vibrating tines, which are closely spaced in multiple

rows on the implement. The vibrating tines displace seedling weeds (Colquhoun and Bellinder, 1997) and are capable of uprooting 51% of the emerged weed seedlings with a single operation (Kurstjens et al., 2000). Weeds are particularly vulnerable to the tine weeder just before emergence, which is termed “weeds in the white” (Gunsolus, 1990). The tine weeder evaluated in these trials tilled a swath 6 ft wide. All tines were set for maximum downward tension for all cultivations. Onions were cultivated 2× at 2-week intervals, 4× at 2-week intervals, and noncultivated. The initial cultivation was made 1 week after herbicide application, which was also 4 weeks after transplanting.

Approved cultivars for Vidalia® sweet onion production [Candy Kim® (2011), Sapelo Sweet® (2012), Carmelo® (2013)] were grown according to National Organic Standards, although the experimental site was not certified organic because of proximity to conventionally grown crops. Transplants were produced in seedbeds that were direct seeded in September each year. Field sites were fertilized with 6 tons/acre of composted poultry litter (average analysis 3.2N–2.2P–2.6K) in November each year and soil incorporated 3 inches deep with a power tiller. This rate of composted poultry litter was based on previous studies that determined the recommended rates for organic Vidalia® sweet onion (Boyhan et al., 2010). In early December, seedbeds were again freshly tilled with a power tiller that also simultaneously marked transplant holes. Immediately after the final seedbed preparation, onions were transplanted by hand. Plots were 6 ft wide by 20 ft long, with four rows centered on the seedbed and each row 12 inches apart. Within each row, onion transplants were spaced 4 inches apart to achieve the optimum combination of yield and desirable grade (Boyhan and Kelley, 2008; Boyhan et al., 2009). To comply with national organic crop production standards, no additional fertilizer or maintenance pesticides were applied during these trials.

Weed counts were determined mid-March of each year. Weeds were counted by species in two 0.5 m² quadrats (0.5 × 1.0 m) in each plot, centered over an onion row. Onion stand counts were measured midseason

after the last cultivation from two random points in each plot. Onion yields from the entire plot were measured by mechanically undercutting and lifting at physiological maturity in early May each year. After field-curing for 1 week, roots and tops were clipped by hand and onion bulbs graded by size according to established standards (U.S. Department of Agriculture, 1995). Diseased, misshapen, and small onion bulbs were discarded during the grading process. Onion yields were recorded by grade and total yield.

Data were analyzed using a mixed-model analysis. Degrees of freedom were partitioned to test singularly and in combination the effects of cultivation regime and herbicides on weed control and onion yield parameters. Means were separated using Fisher's protected least significant difference test ($P < 0.05$).

Results and discussion

Cutleaf eveningprimrose (*Oenothera laciniata*), lesser swinecress (*Coronopus didymus*), and henbit (*Lamium amplexicaule*) were the predominant weeds present in the study. Additionally, common chickweed (*Stellaria media*) was present in 2012. Analysis of variance indicted no significant interactions among cultivation and herbicides for any of the parameters measured. Therefore, all data are presented as main effects. Additionally, because of differences in growing conditions, cultivars, weed species proportion, and substitution of clove oil with D-limonene in 2013, data were not combined across years and analyzed separately.

WEED CONTROL. In 2011, there was no difference in cutleaf eveningprimrose density among cultivation treatments (Table 1). Lesser swinecress densities were lower when cultivated 4× with a tine weeder compared with the noncultivated control, with no difference in lesser swinecress density between cultivation 2× and the control. Both cultivation regimes reduced density of henbit, with cultivation 4× being more effective than cultivation 2×. Cultivation 4× was the most effective cultivation regime in reducing the total weed density. Cutleaf eveningprimrose and lesser swinecress densities were unaffected by herbicides in 2011 (Table 1). Pelargonic acid (5%) and clove oil reduced densities of henbit compared

with the nontreated control, with no difference between the two herbicides. Additionally, henbit densities did not differ between pelargonic acid (3%) and the nontreated control. When summed across all weed species, pelargonic acid (5%) and clove oil were the most effective herbicides in reducing the total weed density.

In 2012, cutleaf eveningprimrose, henbit, and common chickweed were the predominant species (Table 2). Both cultivation regimes reduced densities of cutleaf eveningprimrose and common chickweed compared with the nontreated control, with no difference in densities of those weeds when cultivated 2× or 4×. Cultivation had no effect on density of lesser swinecress and henbit. Both cultivation regimes reduced total weed density over the noncultivated control, with no difference in total weed density when cultivated 2× or 4×. In 2012, pelargonic acid (5%) reduced cutleaf eveningprimrose and common chickweed density compared with the nontreated control (Table 2), but there were no differences in densities of either species among both rates of pelargonic acid and clove oil. Lesser swinecress and henbit densities were unaffected by herbicides. Total weed density was reduced by all of the herbicides compared with the nontreated control, with no differences among the three herbicides evaluated.

In 2013, cutleaf eveningprimrose and lesser swinecress were the predominant species (Table 3). Cultivation reduced densities of cutleaf eveningprimrose, lesser swinecress, henbit, and the total weed density compared with the noncultivated control, with cultivation 2× and cultivation 4× being equally effective. In 2013, herbicides had no effect on densities of cutleaf eveningprimrose or lesser swinecress (Table 3). Pelargonic acid at 3% and 5% reduced henbit density compared with the nontreated control. However, both rates of pelargonic acid were equally effective as D-limonene. When densities of all species were totaled, there were no differences among herbicide treatments.

ONION STAND COUNTS. There was no effect of cultivation and herbicide treatment on midseason onion stand counts (data not shown). This indicates that cultivation with a tine

weeder does not reduce onion stand. Similarly, transient injury from herbicides (foliar necrosis) did not cause onion mortality.

ONION YIELD. In 2011, cultivation 2× or 4× increased onion yield over the noncultivated control for jumbo- and colossal-size onion, along with total onion yield (Table 1). Yield of medium-size onion (the smallest size) was greatest in the noncultivated control compared with either of the cultivation regimes. There were no differences in any onion yield parameter between cultivation 2× and cultivation 4×. Weed control success with cultivation skewed onion sizes, with poorer weed control making smaller onion bulbs (medium-size onion) compared with treatments with better weed control, as evidenced by more medium-size onion bulbs in the noncultivated compared with plots cultivated with the tine weeder. Yield of larger onion bulbs and total yield were greater when cultivated compared with the noncultivated control, presumably due to better weed control. The same general response of onion size distribution to weed control with herbicides was observed in 2011 (Table 1). Medium-size onion bulbs were greatest in the nontreated control compared with onion treated any of the herbicides. However, yield of jumbo, colossal, and total onion yield were greater when treated with either rate of pelargonic acid or clove oil compared with the nontreated control. Among the herbicides, yield of jumbo- and colossal-size onion, along with total onion yield, were similar between treatment with pelargonic acid (5%) and clove oil.

In 2012, yield of medium-, jumbo-size, and total yield across all sizes were increased by both cultivation regimes compared with the noncultivated control (Table 2). There was no difference in medium, colossal, and total onion yield between cultivation with a tine weeder 2× and 4×, although jumbo yield was greater when cultivated 2×. Medium and total onion yield were greatest in 2012 when treated with either rate of pelargonic acid compared with the nontreated control (Table 2), while yield of jumbo- and colossal-size onions were unaffected by herbicide treatment. When compared with clove oil, yield of medium-size onion

Table 1. Main effects of cultivation with a tine weeder and pelargonic acid on weed control and organic Vidalia® sweet onion yield at Lyons, GA in 2011.

Main effect	Cutleaf	Lesser	Henbit	Total weeds	Onion yield			
	eveningprimrose	swinecress			Medium	Jumbo	Colossal	Total
	(no./m ²) ^z				(kg·ha ⁻¹) ^z			
Cultivation ^y								
Cultivation 2×	1.9 a ^x	8.9 ab	9.1 b	22.0 b	14,060 b	22,480 a	206 a	36,750 a
Cultivation 4×	1.8 a	6.8 b	4.9 c	13.4 c	13,660 b	21,340 a	262 a	35,270 a
Noncultivated	5.4 a	14.1 a	13.2 a	32.6 a	15,610 a	11,930 b	0 b	27,540 b
Herbicides ^w								
Pelargonic acid (3%)	5.5 a	8.3 a	10.3 ab	24.1 b	13,910 b	18,440 b	108 ab	32,460 b
Pelargonic acid (5%)	1.9 a	8.3 a	5.1 c	15.3 c	13,930 b	21,530 ab	241 a	35,700 ab
Clove oil (10%)	0.8 a	8.6 a	7.8 bc	17.1 c	13,650 b	25,040 a	274 a	38,970 a
Nontreated	3.9 a	14.6 a	13.1 a	31.6 a	16,300 a	9,310 c	0 b	25,610 c

^z1 weed/m² = 0.0929 weed/ft², 1 kg·ha⁻¹ = 0.8922 lb/acre.

^yCultivation data are main effects, combined across herbicides.

^xWithin each main effect, means in a column followed by the same letter are not different according to Fisher's protected least significant difference test at $P < 0.05$.

^wHerbicide treatment data are main effects, combined across cultivations.

Table 2. Main effects of cultivation with a tine weeder and pelargonic acid on weed control and organic Vidalia® sweet onion yield at Lyons, GA in 2012.

Main effect	Cutleaf	Lesser	Henbit	Common	Total	Onion yield			
	eveningprimrose	swinecress				chickweed	weeds	Medium	Jumbo
	(no./m ²) ^z					(kg·ha ⁻¹) ^z			
Cultivation ^y									
Cultivation 2×	2.2 b*	0.6 a	6.4 a	2.1 b	11.3 b	7,250 a	5,360 a	53 a	12,670 a
Cultivation 4×	2.7 b	0.4 a	6.5 a	2.4 b	11.9 b	7,400 a	3,460 b	0 a	10,860 a
Noncultivated	10.1 a	1.6 a	3.9 a	6.4 a	22.0 a	3,680 b	1,170 c	0 a	4,850 b
Herbicides ^w									
Pelargonic acid (3%)	4.2 ab	0.8 a	6.2 a	1.4 b	12.5 b	6,700 ab	3,620 a	34 a	10,360 ab
Pelargonic acid (5%)	3.8 b	0.7 a	5.8 a	2.1 b	12.3 b	7,810 a	3,620 a	0 a	11,430 a
Clove oil (10%)	4.5 ab	1.4 a	4.9 a	3.5 b	14.3 b	5,530 bc	3,240 a	37 a	8,810 bc
Nontreated	7.5 a	0.6 a	5.6 a	7.4 a	21.1 a	4,400 c	2,850 a	0 a	7,240 c

^z1 weed/m² = 0.0929 weed/ft², 1 kg·ha⁻¹ = 0.8922 lb/acre.

^yCultivation data are main effects, combined across herbicides.

^xWithin each main effect, means in a column followed by the same letter are not different according to Fisher's protected least significant difference test at $P < 0.05$.

^wHerbicide treatment data are main effects, combined across cultivations.

Table 3. Main effects of cultivation with a tine weeder and pelargonic acid on weed control and organic Vidalia® sweet onion yield at Lyons, GA in 2013.

Main effect	Cutleaf eveningprimrose	Lesser swinecress	Henbit	Total weeds	Onion yield			
		(no./m ²) ^z			Medium	Jumbo	Colossal	Total
(kg·ha ⁻¹) ^z								
Cultivation ^y								
Cultivation 2×	1.9 b*	1.4 b	4.1 b	10.8 b	12,770 a	9,870 a	58 a	22,690 a
Cultivation 4×	1.4 b	0.1 b	2.4 b	7.6 b	12,510 a	9,420 a	102 a	22,040 a
Noncultivated	16.5 a	15.0 a	7.1 a	39.8 a	7,380 b	1,130 b	0 a	8,510 b
Herbicides ^w								
Pelargonic acid (3%)	12.2 a	4.0 a	3.0 b	20.3 a	10,560 ab	6,150 ab	75 a	16,790 b
Pelargonic acid (5%)	1.8 a	5.8 a	3.0 b	13.3 a	11,810 a	8,610 a	41 a	20,470 a
D-Limonene (14%)	4.0 a	5.8 a	5.8 ab	22.5 a	11,350 ab	5,710 b	30 a	17,090 b
Nontreated	8.3 a	6.3 a	6.3 a	21.3 a	9,820 b	6,750 ab	68 a	16,640 b

^z1 weed/m² = 0.0929 weed/ft², 1 kg·ha⁻¹ = 0.8922 lb/acre.

^yCultivation data are main effects, combined across herbicides.

^xWithin each main effect, means in a column followed by the same letter are not different according to Fisher's protected least significant difference test at $P < 0.05$.

^wHerbicide treatment data are main effects, combined across cultivations.

and total onion yield were greater when treated with pelargonic acid (5%). Additionally, there was no difference in any of the onion yield

parameters between pelargonic acid at 3% and 5%.

In 2013, yield of medium, jumbo, and total onion yield were

increased by cultivation using a tine weeder compared with the noncultivated control (Table 3). There was no difference in any of the onion yield

parameters between cultivation 2× or 4×. Compared with the nontreated control, yield of medium-size onion and total onion yield were greater when treated with pelargonic acid at 5% (Table 3). Onion treated with pelargonic acid at 5% also yielded more jumbo-size onion and had greater total onion yield than onion treated with D-limonene. Additionally, total onion yield was lower when treated with pelargonic acid at 3% compared with pelargonic acid at 5%, while there was no difference among the medium-, jumbo-, and colossal-size onion yields.

Previous research clearly showed the value of cultivation with a tine weeder for weed control in organic onion (Johnson et al., 2012). In these experiments, cultivation improved weed control and increased onion yield, which agrees with the earlier study. Earlier studies also included clove oil for weed control and the herbicide did not consistently improve weed control and onion yield (Johnson and Davis, 2014; Johnson et al., 2012). In our experiments, pelargonic acid at 5% controlled weeds comparable to clove oil (2011 and 2012) and D-limonene (2013). Onion yield response to pelargonic acid for weed control was inconsistent, which is similar to yield response to clove oil and D-limonene in the earlier studies. It appears that pelargonic acid at 5% is not an improvement over the other herbicides derived from natural products.

The lack of an interaction between cultivation regimes and herbicides derived from natural sources is also in agreement with the earlier studies. In this experiment, performance of cultivation with a tine weeder was independent of herbicides, indicating that pelargonic acid did not improve overall performance of cultivation. One of the underlying objectives of this experiment was to determine if pelargonic acid would be useful to control emerged broadleaf weeds in organic sweet onion if early season cultivations were delayed. Clove oil has been evaluated for similar uses and performance was also independent of cultivation (Johnson et al., 2012). This was attributed to difficulties in controlling cool-season weeds during the winter using a postemergence herbicide. Pelargonic acid at 5% was more effective in controlling

cool-season weeds and protecting onion yield than pelargonic acid at 3%, but no better than either clove oil or D-limonene. To date, the inconsistencies in herbicides derived from natural products on cool-season weeds has been attributed mainly to difficulties in scheduling applications during winter months when weeds are small and conditions are optimal. These results indicate that pelargonic acid has the same limitation as clove oil in organic Vidalia® sweet onion production, offering no advantage. For this reason, cultivation with a tine weeder remains the preferred tool to control cool-season weeds in organic Vidalia® sweet onion in Georgia. Herbicides derived from natural sources cannot be considered a viable option to control emerged weeds during winter months in organic Vidalia® sweet onion, regardless of the circumstances. With this severe limitation, it is prudent that cultivation using a tine weeder be initiated before weeds emerge.

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