Integrated Systems of Weed Management in Organic Transplanted Vidalia® Sweet Onion Production

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SUMMARY. Field experiments were conducted from 2008 through 2010 near Lyons, GA, to develop integrated weed management systems for organic Vidalia® sweet onion (*Allium cepa*) production. Treatments were a factorial arrangement of summer solarization, cultivation with a tine weeder, and a clove oil herbicide. Plots were solarized with clear plastic mulch during the summer fallow period before transplanting onion. Cultivation treatments were twice at 2-week intervals, four times at 2-week intervals, and a noncultivated control. Herbicide treatments were clove oil plus vinegar, clove oil plus an emulsified petroleum oil (EPO) insecticide used as an adjuvant, and a nontreated control. ‘Savannah Sweet’ onions were transplanted in early-December each year, with cultivation and herbicide applications events occurring the following January and February. Onions were harvested the following spring. In addition to yield measurement, a subsample of harvested onion was stored in a controlled atmospheric (CA) storage facility to evaluate treatment effects on diseases of stored onion. Summer fallow solarization did not control the cool-season weeds present in these trials. Cultivating transplanted onion with a tine weeder effectively managed cutleaf eveningprimrose (*Oenothera lacinata*) and swinecress (*Coronopus didymus*) and improved onion yields in 2 of 3 years. There was little difference in overall performance between two cultivations and four cultivations with the tine weeder. The 1 year of marginal weed control with the tine weeder was due to persistently wet soils during winter months that inhibited optimum performance of the implement. Clove oil, combined with vinegar or an EPO insecticide, provided marginal weed control and had no effect on onion yield. Diseases of stored onion were unaffected by any of the treatment combinations, although overall incidence of diseases of stored onion was higher in 2010 compared with other years. This corresponds with the 1 year of marginal weed control with the tine weeder, suggesting that the presence of weeds may be a factor related to disease incidence during storage.

Vidalia® sweet onion is a dry bulb onion grown in Georgia as a cool-season crop. From 2000 to 2009, Vidalia® sweet onion plantings ranged from 12,320 to 17,430 acres, with statewide 2009 crop value estimated at \$126,108,000 (Boatright and McKissick, 2010). The Vidalia® sweet onion name is owned by the Georgia Department of Agriculture and protected by Federal Marketing Order 955 (U.S. Code of Federal Regulations, 1990). For the crop to be sold as a Vidalia® sweet onion, plantings must be an approved cultivar of a yellow Granex-type hybrid and grown in a legally defined region of Georgia. The official Vidalia® sweet onion production region encompasses the entirety of 12 counties and portions of 8 others in southeastern Georgia. Soils in this region

are sandy with low levels of sulfur, which contributes to the lack of pungency and sweet flavor characteristic of Vidalia® sweet onion. Cultivar is another characteristic that affects the lack of pungency, and new onion cultivars are evaluated annually in official trials to maintain the reputation of

the Vidalia® sweet onion (Boyhan and Torrance, 2002).

There have been efforts in recent years to expand the markets of Vidalia® sweet onion and an area of interest is certified organic Vidalia® sweet onion. Growers interested in this production system are largely conventional growers wanting to diversify their enterprise to include organic crop production, with organic Vidalia® sweet onion being the focal point. Acreage of organic Vidalia® sweet onion is volatile. However, in 2007 ≈65 acres were planted, which was the largest planting of any certified organic crop in Georgia.

Crop production budgets exist for organic Vidalia® sweet onion production (R.L. Torrance, unpublished data). The two most costly inputs into organic Vidalia® sweet onion production are cost of transplants (\$1801/acre) and weed control (\$1502/acre), with weed control costs largely because of handweeding. In addition to being costly, relying solely on handweeding is often not feasible because of difficulties in hiring and managing labor to handweed. Any effective weed control system that reduces or eliminates the need for handweeding will provide a significant benefit to the organic onion industry.

The extreme cost of weed control using handweeding is common to all organic crop production systems, particularly organic onion production worldwide (Melander and Rasmussen, 2001; Melander et al., 2005). A basic strategy in successful weed control in organic onion production is the use of transplants, compared with direct seeded systems (Ascard and Fogelberg, 2008; Bond et al., 1998). The best integrated system of weed control in transplanted onion production reduced handweeding by 70%, which resulted in a 96% yield increase compared with

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
1.1209	lb/acre	kg-ha ⁻¹	0.8922
0.0254	mil	mm	39.3701
6.8948	psi	kPa	0.1450
2.2417	ton/acre	Mg-ha ⁻¹	0.4461
(°F – 32) ÷ 1.8	°F	°C	(1.8 × °C) + 32

the same systems used in direct-seeded onion production. A transplanted onion production system gives the crop an advantage over weeds by providing a time-buffer between transplanting the crop and weed emergence.

Mechanical weed control (also called physical weed control) using cultivation is among the most reliable methods of weed control in organic crops, including onion (Ascard and Fogelberg, 2008). While there is no standardized terminology to describe cultivation implements, cultivators that provided the most consistent control with the least amount of damage to onion were those that used vibratory action to displace weed seedlings (Ascard and Fogelberg, 2008; Melander et al., 2005). A single cultivation using a properly operated implement that displaces weed seedlings using vibratory action is capable of uprooting 51% of the emerged weed seedlings (Kurstjens et al., 2000). A single cultivation will not provide successful season-long weed control. However, sequential cultivations at regular intervals may provide the foundation for a successful integrated system of weed control in transplanted onion.

To date, there has been no research on weed management in organic Vidalia® sweet onion. Previous research has been with direct-seeded organic onion grown as a warm-season crop in northern latitudes. Therefore, trials were conducted from Dec. 2007 to Apr. 2010 in southeastern Georgia to develop an integrated system of

weed management for organic Vidalia® sweet onion production.

Materials and methods

Irrigated field trials were conducted from 2007 through 2010 at the Vidalia Onion and Vegetable Research Center near Lyons, GA (lat. 32.018801, long. -82.220101). This site is located in the designated region where Vidalia® sweet onion is commercially produced. 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 split-plot, with treatments replicated four times. Main plots were soil solarized with clear plastic mulch and nonsolarized. Solarized plots were freshly tilled midsummer, irrigated to field capacity, and covered with clear plastic mulch, 6-mil thick. Soil temperatures were measured at 4 inches and recorded using a datalogger (HOBO H8 Series; Onset Computer Corp., Bourne, MA). Soil temperatures were not measured in 2007, but measured during the 2008 and 2009 solarization periods. Daily maximum soil temperature data for solarized and nonsolarized plots are presented in Fig. 1. Solarized plots remained covered for 85, 90, and 120 d in 2007, 2008, and 2009, respectively. Nonsolarized plots remained undisturbed during that time period. The plastic mulch was removed early November and discarded. The entire experiment was shallow-tilled 3 inches deep with a power tiller after mulch removal.

Subplots were a factorial arrangement of three cultivation regimes and three herbicide regimes. The cultivation implement was a tine weeder (Aerostar Tined Weeder; Einböck, Schatzdorf, Austria), which features multiple rows and gangs of flexible steel rod tines with adjustable tine tension according to crop row spacing. Treatments were cultivation twice (2X) at 2-week intervals, four times (4X) at 2-week intervals, and a noncultivated control. An Organic Materials Review Institute (OMRI)-listed clove oil herbicide (Matratec®; Brandt Consolidated, Springfield, IL) was evaluated in these trials; clove oil plus vinegar (containing 30% acetic acid), clove oil plus an EPO insecticide (Saf-T-Side®, Brandt Consolidated), and a nontreated control. Clove oil was chosen based on previous research that indicated the

weed control potential in organic onion (Evans and Bellinder, 2009). Combinations of a clove oil plus vinegar or EPO were based on previous experiences that showed improved weed control efficacy when clove oil was acidified by vinegar or if the petroleum oil insecticide was included as a wetting agent. At the time of trial initiation, there were no OMRI-listed herbicide adjuvants. The clove oil herbicide rate was 10% solution v/v, vinegar rate was 6% solution v/v, and EPO insecticide rate was 1% solution v/v. Herbicide treatments were applied with a carbon dioxide (CO₂)-pressurized tractor-mounted plot sprayer calibrated to apply 50 gal/acre at 60 psi using high volume spray tips (Turbo TeeJet® 11006 tips; Spraying Systems, Wheaton, IL).

Onions ('Savannah Sweet', an approved cultivar for Vidalia® sweet onion production) were grown according to National Organic Standards, although the experimental site was not certified organic because of proximity to conventionally grown crops. Organically grown onion 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 of 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. Other than the weed control treatments being evaluated, there was no supplemental weed control, including handweeding, at any point during these trials.

Visual estimates of weed control and weed counts were determined mid-March of each year. Weeds were

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Fig. 1. Daily maximum 4-inch (10.2 cm) soil temperature comparisons between fallow plots solarized preplant and plots nonsolarized at Lyons, GA, 2008 and 2009. Soil temperature data were not measured in 2007; $(1.8 \times ^\circ\text{C}) + 32 = ^\circ\text{F}$.

counted in two 0.5-m² quadrats (0.5 × 1.0 m) in each plot, centered over a pair of onion rows. Onion yields were measured by mechanically undercutting and lifting onion 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. A subsample of 20 randomly selected medium-size onion bulbs were collected from each plot and stored for 120 d at 1 °C in CA cold storage conditions (3% oxygen, 5% CO₂, 70% relative humidity). At the conclusion of the storage period, bulbs were removed and placed under

ambient conditions (≈ 21 °C) for 14 d of a simulated shelf life period, at which time individual bulbs were examined for symptoms of fungal and bacterial diseases common to stored onion.

Data were analyzed using a mixed model analysis. Degrees of freedom were partitioned to test singularly and in combination the effects of summer solarization, cultivation regime, and herbicide treatment on weed control, onion yield parameters, and incidence of diseases of stored onion. Means were separated using Fisher's protected least significant difference test at $P \leq 0.05$.

Results and discussion

Growing conditions varied among the 3 years, which prevented combining of data across years (data not shown). Specifically, extreme cold temperatures

in Dec. 2009 alternating with periods of excessive rainfall directly affected crop growth and ability to implement weed control practices, particularly cultivation. Therefore, all data are presented by year. Analysis of variance indicated no interactions among solarization, cultivation regimes, and herbicide treatments for any of the parameters evaluated. Therefore, all data are presented as main effects.

WEED CONTROL. Predominant weeds were cool-season species; cutleaf eveningprimrose and swinecress, with cutleaf eveningprimrose being the more common species each year of the study. Solarization during the preceding summer did not affect either of the cool-season weeds present in these trials (data not shown). Previous studies (Johnson et al., 2007) in the same region demonstrated that solarization during summer fallow periods controlled the warm-season perennial weed yellow nutsedge (*Cyperus esculentus*). It was speculated that summer fallow solarization controlled yellow nutsedge by trapping emerging weeds under clear plastic that scorched emerging weeds and created conditions conducive for diseases of weeds, not outright heating the soil to temperature lethal to weed propagules. In our trials, soil temperatures at 4 inches routinely exceeded 50 °C and occasionally 60 °C in 2009 (Fig. 1), which was similar to soil temperatures reported in earlier solarization trials that controlled yellow nutsedge. Since seeds for the cool-season weeds cutleaf eveningprimrose and swinecress were likely dormant during the summer, it appears that dormancy protected the cool-season weeds from summer solarization.

Cultivation with a tine weeder consistently reduced densities of cutleaf eveningprimrose and swinecress compared with the noncultivated control (Table 1). Each year, there was no difference in overall effectiveness in cutleaf eveningprimrose control between cultivation with a tine weeder 2X at 2-week intervals and 4X at 2-week intervals, based on weed counts and visual estimates of control. Considering that cutleaf eveningprimrose densities ranged from 47 to 87 plants/m² in the noncultivated control in 2008 and 2010, respectively, the performance of the tine weeder in controlling this weed was impressive. Cultivating with the tine weeder also effectively

controlled swinecress compared with the noncultivated control, with cultivating 2X generally effective as cultivating 4X.

Across the 3 years of this study, performance of the tine weeder was directly related to the presence and size of weed seedlings at the initial cultivation. Of equal importance was the tith and moisture status of soil. The best overall performance of the tine weeder was in 2008. The initial cultivation was just before weed emergence and the soil was neither excessively wet nor crusty from being too dry. In contrast, the 2010 growing season featured extreme cold temperatures after transplanting in Dec. 2009 and then periods of prolonged rainfall through Jan. 2010, which delayed field operations and forced cultivation when soils were too wet. The tine weeder simply did not perform according to expectations because of wet soils during in the 2010 season. We observed that the cultivator tines cut season-lasting grooves in the wet soil during the initial cultivation that unfortunately served as guides for the tines during

the remaining cultivations. In effect, this reduced the vibratory action of the tines and lessened the effectiveness of cultivation. Despite the reduced performance of the implement and weeds escaping control, cultivating onion in 2010 with the tine weeder significantly reduced cutleaf eveningprimrose densities compared with the noncultivated control.

Organic cropping systems have few remedial weed control options on which to rely if the primary means of weed control fails, which adds to the intrinsic risk of organic crop production. This is the case when a tine weeder is the primary means of weed control in organic onion. Delays due to weather conditions, as seen in Jan. 2010, reduced efficacy of cultivation, and there was no other option to control escapes—other than costly handweeding.

Clove oil plus EPO and clove oil plus vinegar reduced densities of cutleaf eveningprimrose compared with the nontreated control (Table 1), with little difference in overall efficacy between the two clove oil treatments.

Onion were moderately injured by both clove oil treatments, with foliar necrosis being transitory (data not shown). Clove oil herbicides were applied in January each year and great care was taken to apply the herbicides to seedling weeds and when weather conditions were not overly cold. This proved to be challenging, considering the rapid growth of these cool-season weeds and highly variable winter weather conditions.

ONION YIELD. Neither summer fallow solarization nor clove oil herbicides affected onion yield (data not shown). The only factor that affected onion yield was cultivation with a tine weeder (Table 2). Overall, noncultivated controls tended to have lower yield and smaller onion bulbs, as noted by the greater number of medium-sized onion bulbs, compared with plots that were cultivated. We attribute this to poor weed control in noncultivated plots. Conversely, plots that were cultivated with the tine weeder had better weed control and yielded more jumbo- and colossal-size onion bulbs than the noncultivated control. When yields

Table 1. Effects of cultivation with a tine weeder and clove-oil herbicide treatment on weed control in organic onion at Lyons, GA, in 2007–10.

Cultivation regime ^z	Cutleaf eveningprimrose density (no./m ²) ^y			Visual estimate of cutleaf eveningprimrose control (%)			Swine cress density (no./m ²) ^z		
	2008	2009	2010	2008	2009	2010	2008	2009	2010
Cultivation 2X	7.6 b ^x	2.2 b	28.5 b	80 a	89 a	80 a	0.4 b	1.5 ab	0.1 b
Cultivation 4X	6.3 b	1.4 b	37.0 b	77 a	91 a	77 a	0.5 b	0.7 b	1.3 ab
Non-cultivated	46.8 a	5.3 a	86.6 a	64 b	66 b	64 b	4.5 a	2.1 a	3.0 a
Herbicide treatment^w									
Clove oil + EPO ^v	14.3 a	2.4 b	47.5 b	76 a	88 a	78 a	1.6 a	1.1 b	0.5 b
Clove oil + vinegar ^v	26.4 a	2.2 b	42.4 b	77 a	87 a	79 a	2.3 a	0.6 b	0.9 ab
Nontreated control	19.0 a	4.3 a	62.3 a	67 b	70 b	64 b	1.6 b	2.6 a	3.0 a

^zCultivation regime data are main-effects, combined across solarization and herbicide treatment regimes.

^y1 weed/m² = 0.0929 weed/ft².

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

^wHerbicide treatment data are main-effects, combined across solarization and cultivation regimes. Clove oil applied at 10% v/v.

^vEmulsified petroleum oil (EPO) insecticide used as a spray adjuvant (applied at 1% solution v/v); vinegar containing 30% acetic acid (applied at 6% solution v/v).

Table 2. Effects of cultivation regime with a tine weeder on graded organic onion yield at Lyons, GA, 2007 to 2010.

Cultivation regime ^z	Medium-size onion bulbs ^y (kg·ha ⁻¹) ^x			Jumbo-size onion bulbs ^y (kg·ha ⁻¹)			Colossal-size onion bulbs ^y (kg·ha ⁻¹)		
	2008	2009	2010	2008	2009	2010	2008	2009	2010
Cultivation 2X	4,040 b ^w	11,390 b	6,900 a	21,160 a	44,650 a	19,190 a	2,870 a	3,680 a	90 a
Cultivation 4X	3,410 b	11,300 b	7,800 a	23,220 a	42,230 ab	15,780 a	2,870 a	1,610 b	90 a
Non-cultivated	5,290 a	15,240 a	8,070 a	8,430 b	36,220 b	10,400 b	360 b	1,350 b	90 a

^zCultivation regime yield data are main-effects combined across solarization and herbicide treatment regimes.

^yMedium = 2.0 to 3.0 inches diameter, jumbo >3.0 to 3.75 inches diameter, colossal >3.75 inches diameter (1 inch = 2.54 cm). Onion bulbs <2.0 inches diameter were discarded.

^x1 kg·ha⁻¹ = 1.1209 lb/acre.

^wMeans in a column followed by the same letter are not different according to Fisher's protected least significant difference test at $P \leq 0.05$.

Table 3. Effects of cultivation with a tine weeder on total yield and diseases of stored organic onion at Lyons, GA, 2007 to 2010.

Cultivation regime ^z	Total onion yield (kg·ha ⁻¹) ^y			Botrytis neck rot ^x (%)			Center rot ^x (%)	
	2008	2009	2010	2008	2009	2010	2008	2009
Cultivation 2X	28,064 a ^w	59,714 a	26,271 a	11.8 b	4.3 a	74.0 a	21.0 ab	9.6 a
Cultivation 4X	29,498 a	55,142 a	23,671 a	10.1 b	5.4 a	71.4 a	15.2 b	7.2 a
Non-cultivated	14,256 b	52,810 a	18,400 b	20.1 a	6.1 a	73.5 a	23.8 a	8.5 a

^zCultivation regime yield data are main-effects combined across solarization and herbicide treatment regime.

^y1 kg·ha⁻¹ = 1.1209 lb/acre.

^xBotrytis neck rot incited by the fungus *Botrytis allii*; center rot incited by the bacterium *Pantoea ananatis*. Disease incidence based on a sample of 20 medium-size onion bulbs stored for 120 d.

^wMeans in a column followed by the same letter are not different according to Fisher's protected least significant difference test at $P \leq 0.05$.

were totaled across all onion sizes (Table 3), weed control using the tine weeder increased onion yield over the noncultivated control in 2 of 3 years. Overall, there was no difference in total onion yield between plots cultivated with a tine weeder 2X or 4X. It is worth noting that the state yield average for graded onion for 2008, 2009, and 2010 was 32,000, 23,000, and 20,050 lb/acre, respectively (U.S. Department of Agriculture, 2010). Overall average graded organic onion yields in our study were 21,620, 49,880, and 20,330 lb/acre for 2008, 2009, and 2010, respectively.

INCIDENCE OF DISEASES OF STORED ONION. Incidence of two diseases of stored onion was measured in this study; the fungal disease botrytis neck rot incited by *Botrytis allii* and center rot, a bacterial disease incited by *Pantoea ananatis* (Table 3). There was no effect of summer solarization and clove oil herbicide treatment on incidence of either disease of stored onion (data not shown). Incidence of both diseases was affected by cultivation with a tine weeder, but only 1 out of 3 years. Interestingly, in the 1 year with significant cultivation effects on stored diseases of onion, incidence of botrytis neck rot was greater in the noncultivated control compared with either cultivation regime in 2008. In the remaining years, cultivation had no effect on botrytis neck rot. Center rot incidence in the noncultivated control was less than cultivation 4X with the tine weeder in 2008 and unaffected by any cultivation regime in 2009. These results suggest that multiple cultivations using a properly adjusted tine weeder do not damage onion enough to increase incidence of diseases of stored onion. However, we observed that functionality of standard onion harvesting implements that undercut and lift onion plants is inhibited

by heavy weed infestations. It is plausible that the poor harvesting conditions because of weeds caused damage to onion bulbs and subsequently increased disease susceptibility of stored onion.

Organic Vidalia[®] Sweet Onion can be a profitable cropping system, provided that there is less reliance on costly handweeding. Current production budgets project handweeding costs at \$1502/acre. In our trials, handweeding was not used at any phase of the research. We were able to manage heavy infestations of cutleaf eveningprimrose and swinecress using cultivation with a tine weeder. The cost to cultivate organic peanut with a tine weeder in 2008 was estimated at \$10.52/acre (D. Kaiser and N. Smith, personal communication). Using that assumption, cultivating organic onion with a tine weeder 2X will cost ≈\$21.04/acre, which is a substantial savings over the projected cost of using handweeding as the sole means of weed control. It should be noted that the weed control data clearly show weeds escaping control by cultivating with a tine weeder and weed escapes should not be ignored. However, cultivating organic onion with a tine weeder will relegate handweeding to a means of controlling weed escapes, not the primary method of weed control. It is plausible that there will still be a significant saving to organic onion growers by reducing the time and frequency of handweeding.

Solarization during summer fallow periods does not have a role in organic onion production. Weed control was not improved and onion yields were unaffected. In 2007 and 2008, our solarization periods were 85 and 90 d, respectively. In an effort to enhance solarization effects, we extended the solarization period in 2009 to 140 d and there was still no effect of solarization on any parameter. Clove

oil herbicide treatments provided some weed control, but there was no effect on onion yield. In addition, clove oil herbicides are very costly and the high rates applied with a high-output sprayer lessen opportunities to reduce treatment cost. Therefore, clove oil herbicide treatment has little role in organic onion production.

Vidalia[®] sweet onion production is based on using transplants and this is also the case with organic Vidalia[®] sweet onion production. Our research trials were based on a transplanted onion production system. It is doubtful that these research results are applicable to direct-seeded onion production because of direct-seeded onion having a longer growing season, needing to control both warm- and cool-season weeds, and tiny onion seedlings not tolerating cultivation with a tine weeder. From a weed control perspective, organic Vidalia[®] sweet onion production should remain a transplanted production system.

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