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Herbicide tolerance and weed control for transplanted short-day onion established with PlantTape®

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Abstract

Hand transplanting onion requires significant labor but using PlantTape® could significantly reduce input cost, however production using this method has not been evaluated for herbicide tolerance and weed control. Herbicide options for weed control and transplanted Vidalia onion (*Allium cepa* L.) tolerance using PlantTape® establishment methods were evaluated in Georgia (USA). Using PlantTape® technology and greenhouse grown onion seedlings allowed for rapid field mechanical transplanting. Oxyfluorfen, pendimethalin, and *S*-metolachlor, alone, and in combination, at multiple rates, were applied either on the day of, or 10 d after, transplanting. Either oxyfluorfen alone, regardless of rate, or used in combination with other herbicides, provided 92% to 99% cutleaf eveningprimrose (*Oenothera iaciniata* Hill) season-long control consistently for the day-of, and 10-d after transplant applications. Pendimethalin and *S*-metolachlor control of cutleaf evening primrose was inconsistent, and should not be applied alone for weed control in Vidalia onion. Injury in the form of plant stunting was noted with minor height reduction, but this was transient and did not affect growth. Production was reflective of weed control, with maximum onion bulb count and yield obtained with herbicide combinations of pendimethalin, oxyfluorfen, and *S*-metolachlor. PlantTape® technology can be used to establish Vidalia onion using current registered herbicides, but an emphasis on consistent transplants in the tape to ensure adequate stand is needed.

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Introduction

Vidalia® onion (*Allium cepa* L.) growers have limited ability to directly establish seeds of this crop due to early season weed pressure because of lack of registered herbicides. As a September seeded crop for production (not transplanted), onions grow very slowly, must be irrigated, and fertilized regularly after emergence. This combination of factors can lead to weed infestations that promote insect and pathogen pests. Growers maintain onion production *via* hand transplanting in November and December as a way to ensure crop establishment[1]. This method has its own set of issues with the most recent being labor costs. Vidalia onion producers face annual labor shortages. USDA's Farm Labor Survey reported that from 2002 to 2014, the number of full-time field and crop workers declined by 22%[2].

To combat the shrinking labor force and rising cost, a mechanical method for planting onions is being considered. This mechanical method uses PlantTape® (PlantTape® Inc., Salinas, CA, USA), where seeds are inserted into a peat-based substrate mounted in a tray, germinated, greenhouse grown, and then mechanically transplanted[3,4]. PlantTape® is made of peat moss and vermiculite, which expands when heated, between layers of biodegradable material[4]. There are registered herbicides for onion transplants including pendimethalin, oxyfluorfen, and *S*-metolachlor for applications made within 48 h after transplant. However, since this is a new method where small 1 to 3 leaf onion are mechanically transplanted into soil, there is no information about the crop response or weed control.

Having a relatively small leaf area, onions compete poorly with weeds for light, nutrients, water, and space[5,6]. Onions are a difficult crop to establish in the field because of slow growth, poor competitive morphology, and the potential of reduced growth from herbicide injury[7,8]. Onion morphology plays a large role in weed control because the crop seed germinates and emerges slowly and has a cylindrical upright leaf that does not shade the soil, therefore, weed growth within the row is not suppressed by the crop[9]. For this reason, weeds can become established because there is very little crop canopy[7].

The majority of Vidalia onions are grown from transplants. Onion seeds are sown in bedded soils during September at 4.5 to 5 million seed/ha. Once onion seedlings are large enough to transplant (4 to 8 leaf), they are hand pulled and hand transplanted into holes formed from a pegging machine to ensure uniform stands on preformed beds, in Nov and Dec[10]. This is labor intensive because the entire process, from planting to harvesting, is completed primarily by hand. Planting and harvesting onions are the costliest tasks associated with production. A migrant labor force is relied on for planting and harvesting. A major concern for producers is migrant labor availability, which has become scarce. Starting in 1978, growers knew that the expansion of production would be limited due to the high labor requirement, and with climbing onion acreage in the 1980's, local labor became insufficient. Migrant labor became important after 1982 for onion production in Southeast Georgia (USA)[11].

By nature, onion is not competitive against weeds, thus, establishing an effective and safe herbicide program is essential for production. Mechanical weed control practices, such as in row cultivation, are difficult to accomplish due to onions having a shallow rooting system. While there are herbicides registered for early postemergence control, the treatment timings are narrow and limited to four crop stages, loop (crook), flag, one-true-leaf, and two-true-leaf. The narrow application window can be challenging for proper use of the labeled herbicides, not only to comply with the label, but also to prevent crop injury.

Georgia Vidalia onion producers rely on the registered herbicides *S*-metolachlor, pendimethalin, dimethenamid, and oxyfluorfen for residual weed control[5]. While there are several conventional herbicide options for production, none of these programs have been tested using the PlantTape® transplant system. Since PlantTape® onions may be smaller (1 to 3 leaf) than traditional hand transplants (4 to 8 leaf)[4], there is a need to evaluate the tolerance and duration of weed control. Previous research has demonstrated that *S*-metolachlor provided 10 to 14 weeks of control while oxyfluorfen and pendimethalin can range from 2 to 10 weeks.

The main objective of this research was to evaluate pendimethalin, oxyfluorfen, and *S*-metolachlor herbicides for weed control and onion growth responses when using PlantTape® greenhouse grown Vidalia onion transplants. November and December onion planting dates reduce summer annual weed species pressure associated with trying to plant seeded onions in Sept. This method of establishment may provide a greater opportunity for onion to become established without significant weed pressure as an issue, and provide an alternative to hand transplanting slips.

Materials and methods

Field experiments were conducted in Tattnall County Georgia (USA) at the Vidalia Onion and Vegetable Research Center (VOVRC) (32.018801 N, −82.220101 W) and a commercial farm (CF) (32.2567190 N, −82.0722570 W), in autumn to winter of 2017 to 2018. At each location, soil was conventionally tilled by moldboard plowing then a single bed (1.8 m wide, 7.6 m long, 15 cm high) was established with a bed shaper. Soils at VOCRC were Tifton loamy sand (fine-loamy, kaolinitic, thermic Plinthic Kandiudults), and at CF a Fuquay loamy sand (loamy, kaolinitic, thermic Arenic Plinthic Kandiudults).

Prior to field transplanting, Vidalia onion seeds were planted into PlantTape® plugs (www.planttape.com), a combination of peat moss and vermiculite, in Oct 2017. PlantTape® produced onion seedlings were then mechanically transplanted at VOVRC on 14 Nov 2017, and the CF on 5 Dec 2017, with 10 cm in-row spacing, and four rows per 1.8 m wide bed. The short-day cultivar 'Plethora' was planted at VOVRC and the short-day cultivar 'Vidora' was planted at the CF. Two different experiments were conducted at each location, with each experiment replicated in time by location. Each experimental design was a randomized complete block with four replications.

The first experiments examined PlantTape® transplanted Vidalia onion season long tolerance to herbicides. POST-T treatments were oxyfluorfen at 1,121 or 2,242 g/ha, pendimethalin at 1,121 or 2,242 g/ha, or *S*-metolachlor at 1,121 g/ha. Tankmix POST-T treatments included oxyfluorfen plus pendimethalin with both at 1,121 or 2,242 g/ha. Sequential treatments were POST-T oxyfluorfen plus pendimethalin with both at 1,121 g/ha followed POST by oxyfluorfen plus pendimethalin at 1,121 g/ha, POST-T *S*-metolachlor at 560 g/ha followed by POST oxyfluorfen plus pendimethalin with both at 1,121 g/ha, or POST-T *S*-metolachlor at 560 g/ha followed by POST oxyfluorfen plus pendimethalin with both at 2,242 g/ha, and included a nontreated control. For the weed control study there were 11 treatments. Cutleaf evening primrose (*Oenothera iaciniata* Hill) was the predominate species at > 30 plants m^2 at both locations.

The second set of experiments examined weed control when herbicides were applied on the day of transplant (POST-T), and 10-d post (POST). Treatments for the crop tolerance study included POST-T oxyfluorfen at 560, 1,121, or 2,242 g/ha, pendimethalin at 560, 1,121, or 2,242 g/ha, and *S*-metolachlor at 560 or 1,121 g/ha. Tank mixed treatments included POST-T oxyfluorfen at 1,121 g/ha plus pendimethalin at 1,121 g/ha, and POST-T oxyfluorfen at 2,242 g/ha plus pendimethalin at 2,242 g/ha. The crop tolerance study also included the same sequential applications as previously described in the weed control experiment and included a nontreated control, for a total of 14 treatments. Transplanted onions were at the 2-to 3-leaf stage of growth for the POST-T and POST applications. The crop tolerance experiments were maintained weed free by hand. Experiments were maintained according to University of Georgia Extension recommendations for Vidalia onion production for fertilization, irrigation, fungicides, and insecticides[5].

For all experiments, POST-T were applied 16 Nov 2017 at VOVRC and 11 Dec 2017 at CF. POST applications were made on 28 Nov 2017 at VOVRC and 21 Dec 2017 at CF. Herbicides were applied *via* a backpack sprayer with a four nozzle boom, with 45 cm nozzle spacing, calibrated to deliver 187 L/ha at 276 kPa. Weed control ratings were visually estimated using a scale of 0% (no weeds) to 100% (complete weed infestation) multiple times during the season beginning 6 weeks after planting. Plant-stand counts were taken from 1 m of the center two rows on 10 Jan and 28 Feb 2018 for all experiments. Ratings for injury and stunting were visually estimated using a scale of 0% (no injury) to 100% (death) multiple times during the season. Onion plant heights were evaluated at each location on 5 April 2018. On 15 May 2018, final yields were determined by hand harvesting all onions from 3 m of the center two rows of each plot recording bulb number and weight for each experiment. No grading was conducted.

Statistical analysis

For the onion response study, data analysis for injury, height, stand count, and yield were conducted using PROC GLM in SAS 9.4 (SAS Institute, Cary, NC, USA). ANOVA was used to determine herbicide treatment effect on variables, where herbicide treatment and block are two factors in the randomized complete block design. Data means were separated by Fisher's Protected LSD test at 0.05 significance level where appropriate (Table 1).

For weed control data analysis, data were arranged as a split-plot design where fixed effects were location, herbicide treatment and their interaction. Two random effects were block and block by location. PROC MIXED was used to conduct ANOVA, and PROC PLM was applied to test mean differences using Tukey-Kramer test at 0.05 significance level (Table 1).

Results

Treatment by location interactions were noted for Vidalia onion height measures and yield for the weed control and tolerance tests, so data for these variables were analyzed separately by location. There was no treatment by location interactions for injury and cutleaf evening primrose control for the tolerance and weed control experiments, respectively and combined across locations (Tables 1 & 2).

Vidalia onion efficacy for injury was evaluated at 6 weeks after planting. Results indicated that injury was 14% and less in the form of stunting for any POST-T and POST treatment for any herbicide alone or combinations (Table 1). PlantTape® grown Vidalia onion transplant tolerance to these herbicides was excellent for all treatments and foliar injury was transient. Considering all herbicides evaluated in this test, low injury was expected as oxyfluorfen, pendimethalin, and *S*-metolachlor are all registered for dry bulb onions[9]. Herbicide application prior to onion reaching at least 2-true-leaf stage could lead to injury such as stunting and necrotic lesions.

There were no differences for height response by April for the weed control study at VOVRC and CF (Table 1). There were

Table 1. Herbicide treatment effects for tolerance experiments using PlantTape® Vidalia onion transplants* for injury, height, and yield in Tattnall County Georgia.

Treatment	Timing	Rate (g ai·ha^{-1})	Injury (%)	Height (cm/plant)		Yield (kg·ha^{-1})	
				VOVRC**	CF**	VOVRC	CF
Untreated			0 d***	21.8 a	16.5 a	28,090***	8,590 b
Oxyfluorfen	POST-T	1121	9 bc	22.6 a	16.9 a	28,850 c	20,450 a
Oxyfluorfen	POST-T	2242	10 abc	22.2 a	15.7 a	30,030 c	15,020 ab
Pendimethalin	POST-T	1121	11 ab	22.3 a	16.0 a	32,360 bc	13,710 ab
Pendimethalin	POST-T	2242	9 bc	23.2 a	16.9 a	43,540 ab	15,320 ab
S-metolachlor	POST-T	1121	9 bc	22.5 a	16.1 a	30,860 c	15,590 ab
Oxyfluorfen plus pendimethalin	POST-T	1,121 + 1,121	14 a	23.3 a	16.3 a	34,930 bc	11,770 ab
Oxyfluorfen plus pendimethalin	POST-T	2,242 + 2,242	11 ab	22.6 a	14.9 a	33,310 bc	13,620 ab
Oxyfluorfen plus pendimethalin fb Oxyfluorfen plus pendimethalin	POST-T POST	1,121 + 1,121 1,121 + 1,121	6 c	23.4 a	14.7 a	37,370 abc	13,980 ab
S-metolachlor fb Oxyfluorfen plus pendimethalin	POST-T POST	560 1,121 + 1,121	10 abc	22.8 a	16.6 a	48,280 a	15,200 ab
S-metolachlor fb Oxyfluorfen plus pendimethalin	POST-T POST	560 2,242 + 2,242	6 c	22.9 a	14.8 a	37,640 abc	14,240 ab

*, Onion PlantTape® transplanting dates: 14 Nov 2017, VOVRC; 5 Dec 2017, CF. **, Vidalia Onion and Vegetable Research Center, VOVRC; Commercial Farm – Reidsville GA, CF; post applied herbicide on day of transplanting, POST-T; post applied herbicides 10 d after transplanting, POST; followed by, fb. ***, For weed control data analysis, data were arranged as a split-plot design where fixed effects were location, herbicide treatment and their interaction. Two random effects were block and block by location. PROC MIXED was used to conduct ANOVA, and PROC PLM was applied to test mean differences using Tukey-Kramer test at 0.05 significance level, where values followed by the same letter do not differ. Injury data was combined for presentation across locations, taken 6 weeks after planting.

Table 2. Herbicide treatment effects for efficacy evaluation using PlantTape® Vidalia onion transplants* for injury, height, cutleaf eveningprimrose control, and yield in Tattnall County Georgia.

Treatment	Timing	Rate (g ai·ha^{-1})	Injury (%)	Height (cm/plant)		Cutleaf (%)	Yield (kg·ha^{-1})	
				VOVRC**	CF**	Eveningprimrose	VOVRC	CF
Untreated			0 e***	22.3 cde	15.8 b	0 d	19,788 f	8,109 bc
Oxyfluorfen	POST-T	560	8 bcd	24.3 ab	18.8 a	92 a	33,278 a-f	21,205 a
Oxyfluorfen	POST-T	1,121	8 bcd	23.2 a-d	19.1 a	96 a	27,520 c-f	19,267 a
Oxyfluorfen	POST-T	2,242	8 bcd	23.0 a-d	18.4 ab	99 a	42,697 ab	19,752 a
Pendimethalin	POST-T	560	10 abc	23.3 a-d	18.3 ab	41c	28,201c-f	8,360 bc
Pendimethalin	POST-T	1,121	8 bcd	22.8 a-e	16.3 ab	42 c	22,102 ef	9,562 bc
Pendimethalin	POST-T	2,242	11 ab	23.9 abc	18.0 ab	78 ab	32,686 a-f	16,128 ab
S-metolachlor	POST-T	560	10 abc	21.9 de	16.9 ab	48 ab	24,255 ef	5,047 c
S-metolachlor	POST-T	1,121	13 a	21.1 e	17.4 ab	53 bc	29,421b-f	14,585 ab
Oxyfluorfen plus pendimethalin	POST-T	1,121 + 1,121	4 de	24.5 a	17.0 ab	97 a	35,341a-e	14,460 ab
Oxyfluorfen plus pendimethalin	POST-T	2,242 + 2,242	10 abc	23.2 a-d	18.4 ab	99 a	36,687 a-d	15,431 ab
Oxyfluorfen plus pendimethalin fb Oxyfluorfen plus pendimethalin	POST-T POST	1,121 + 1,121 1,121 + 1,121	8 bcd	22.5 b-e	16.4 ab	99 a	32,148 a-f	9,544 bc
S-metolachlor fb Oxyfluorfen plus pendimethalin	POST-T POST	560 1,121 + 1,121	6 de	24.1 a-c	17.3 ab	99 a	45,137 a	13,180 abc
S-metolachlor fb Oxyfluorfen plus pendimethalin	POST-T POST	560 2,242 + 2,242	9 abc	23.4 a-d	18.9 a	99 a	40,436 abc	16,523 ab

*, Onion PlantTape® transplanting dates: 14 Nov 2017, VOVRC; 5 Dec 2017, CF. Six weeks after establishment, maintained weed free for the remainder of the season by hand weeding. **, VOVCR = Vidalia Onion and Vegetable Research Center, Commercial Farm – Reidsville GA, CF; post applied herbicide on day of transplanting, POST-T; post applied herbicides 10 days after transplanting, POST; followed by, fb. ***, For weed control data analysis, data were arranged as a split-plot design where fixed effects were location, herbicide treatment and their interaction. Two random effects were block and block by location. PROC MIXED was used to conduct ANOVA, and PROC PLM was applied to test mean differences using Tukey-Kramer test at 0.05 significance level, where values followed by the same letter do not differ. Injury data was combined for presentation across locations, taken 6 weeks after planting. Injury data at 6 weeks after application, and cutleaf eveningprimrose data taken prior to harvest. Data were combined for presentation.

significant treatment differences for height at VOVRC and CF for the 14-treatment efficacy study (Table 2), but this varied with no specific trend for any herbicide or rate. While early season foliar injury was noted (Tables 1 & 2), it resulted in no height reductions up to 4 months after the POST-T and POST treatments for PlantTape® grown onion transplants.

Stand counts were taken 13 and 10 weeks after planting at VOVRC and CF, respectively (data not shown). Individual analyses were conducted for stand counts due to differences in location, cultivar, and treatment. Typical transplanted stand counts should be between 150,000 to 200,000 onion per hectare[9]. Variable stand counts (71,000 to 150,00) in this experiment were due to missed and multiple seed planted in each PlantTape® plug (data not shown). For PlantTape® Vidalia onion production, there must be consistency in transplant establishment to prevent multiple seed per plug, as multi-bulb plugs will reduce overall shape and quality of Vidalia onion. Ensuring single seed per plug will improve adoption of these technologies.

Cutleaf evening primrose was the predominate species, and is a common and troublesome weed of winter crops of Georgia and Alabama[1,12]. Prior to harvest, all POST-T and POST treatments that contained 560 to 2,242 g/ha of oxylfuorfen provided 92% and greater control of cutleaf eveningprimrose (Table 2). Oxyfluorfen control of cutleaf eveningprimrose has been previously reported[13,14], and it is the standard for transplant Vidalia onion weed control, but must be applied prior to weed emergence[5]. Multiple rates of oxyfluorfen were applied in this test to establish how long weed control would be maintained. At harvest any treatment containing oxyfluorfen at any rate-maintained season-long control of cutleaf eveningprimrose. This was not observed with pendimethalin or *S*-metolachlor POST-T only treatments in that by the end of the season, cutleaf eveningprimrose control was 78% and less for these two herbicides (Table 2). There is always a need to combine herbicides with different mechanisms of action to broaden control as there is often a complex of weed species present in onion production[5].

Discussion

Weeds can act as insect or disease hosts that can be detrimental to the crop. Bacterial streak [*Pseudomonas viridiflava* (Burkholder)] is a common bacterium that affects onions with the greatest severity occurring between Jan and March and extended rainy periods[15]. Cutleaf evening primrose acted as an alternate host for bacterium survival[16]. The disease organism, causal agent of center rot (*Pantoea ananatis*) can survive on weeds. Weed infestations are common in onion production and can occur as either summer or winter annuals depending on planting date. Predominant weed species associated with Georgia onion production include cutleaf evening primrose, lesser swinecress (*Coronopus didymus* L.), and henbit (*Lamium amplexicaule* L.) as previous studies have reported[1,17].

Cutleaf evening primrose seed germinate and form a rosette in autumn, plants grow slowly until spring, then rapidly expand and bolt, flowering, ending with seed production by the beginning of summer[18]. Cutleaf evening primrose can also serve as an overwintering host for western flower thrips [*Frankliniella occidentalis* (Pergrande)], which is a known vector for tomato spotted wilt virus (genus *Topsovirus*, family *Bunyaviridae*, TSWV)[19] and center rot of onion. Oxyfluorfen alone, or in combination with pendimethalin or *S*-metolachlor, provided excellent control of cutleaf evening primrose (Table 2).

There were no treatment trends detected for the tolerance and weed control test for number of harvested bulbs/ha (Tables 1 & 2). While there were significant differences, this was attributed to variability in number of bulbs per plug that lead to variations in number of harvested bulbs·ha^{-1} (data not shown).

There were large differences in yield between tolerance and weed control tests at VOVRC and the CF (Tables 1 & 2). The difference in yield can be attributed to a difference in cultivar. In the 2018 Vidalia onion variety trial conducted at VOVRC, after evaluation of 38 cultivars, *Plethora* had greater yield than *Vidora* at 64 and 56 kg/plot, respectively[20]. While yield differences were not great in the 2018 variety trial, the results are similar to what was reported in the tolerance and weed control tests for this research.

Vidalia onions are a high value vegetable crop for Georgia. Traditionally, onions are hand transplanted in the field, which is a time consuming and costly process. The advent of PlantTape® technology could reduce cost associated with the planting process. The use of current registered herbicides would allow a smooth transition for those growers that would like to switch from traditional transplanting methods to PlantTape®.

Conclusions

This research demonstrated that application of registered herbicides in Georgia for seeded and transplant onion production can also be used for PlantTape® onions. While PlantTape® onions are smaller than those traditionally used for hand transplanted onions at time of herbicide application, there was only minor and transient injury for these experiments. The differences seen in onion height and total yield in kg/ha can likely be attributed to the onion cultivars used, with 'Plethora' being taller and having greater yield than 'Vidora'. In all experiments, superior weed control was accomplished when oxyfluorfen was applied. Upon harvest the peat-based substrate had not biodegraded by the end of the season. This could become an issue when the onions are harvested and taken for processing. Further research of PlantTape® onions in side-by-side comparison with transplanted onions would provide a better understanding of the injury caused by herbicides on such young onions. This type of study could also help establish trends for percent injury based on herbicide treatment.

Author contributions

The authors confirm contribution to the paper as follows: study conception and design: Grey TL, Couch AD; data collection: Couch AD, Grey TL; analysis and interpretation of results: Couch AD, Grey TL, Swartz BM, Coolong T; draft manuscript preparation: Couch AD, Grey TL, Swartz BM, Coolong T. All authors reviewed the results and approved the final version of the manuscript.

Data availability

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

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Conflict of interest

The authors declare that they have no conflict of interest. The mention of commercial products in the article is for methodological purposes and does not represent endorsement by the authors or their respective institutions.

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