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Strawberry Tolerance to Bed-Top and Drip-Applied Preemergence Herbicides

Nathan S. Boyd and Thomas Reed*

Broadleaf weeds and nutsedge are persistent problems with limited management options for strawberry growers in Florida. Experiments were conducted in 2012 to 2013 (year 1) and 2013 to 2014 (year 2) at the Gulf Coast Research and Education Center in Wimauma, FL, to evaluate tolerance of two strawberry cultivars ('Strawberry Festival' and 'WinterStar'™) to PRE herbicides applied on the bed top or injected through the drip tape. The bed-top herbicides were applied to formed beds following fumigation but prior to laying the plastic mulch. Herbicides evaluated included two rates of EPTC, fomesafen, halosulfuron, and *S*-metolachlor as well as tank mixes of EPTC + *S*-metolachlor, fomesafen + *S*-metolachlor, and napropamide + oxyfluorfen. Drip-applied herbicides were applied through a single drip tape and strawberries were transplanted 1, 7, 15 and 30 d following application. Drip-applied herbicides included two rates of EPTC and fomesafen as well as two rates of a tank mix of napropamide + oxyfluorfen. None of herbicides applied on the bed top except *S*-metolachlor 214 g ai ha^{-1} consistently injured either strawberry cultivar or impacted yields. None of the drip-applied herbicides damaged the strawberry plants or reduced yields at all planting dates. In year 1, EPTC at 229 g ai ha^{-1} and EPTC at 229 g ha^{-1} + *S*-metolachlor at 107 g ha^{-1} resulted in a 70 to 86% reduction in purple nutsedge density compared to the nontreated control. No differences in nutsedge density among treatments were observed in year 2. The herbicides evaluated are safe for use on strawberry and would provide growers with alternative herbicide options, application timings, and application techniques. Further research is needed to evaluate efficacy.
Nomenclature: EPTC; fomesafen; halosulfuron; napropamide; *S*-metolachlor; purple nutsedge, *Cyperus rotundus* L.; strawberry, *Fragaria* × *ananessa* Duchesne 'Strawberry Festival' and 'WinterStar'™.
Key words: Plasticulture, small fruit, soil-active herbicides, weed control.

Malezas de hoja ancha y *Cyperus rotundus* son problemas persistentes con limitadas opciones de manejo para los productores de fresa de Florida. Experimentos fueron realizados desde 2012 a 2013 (año 1) y desde 2013 a 2014 (año 2) en el Centro de Investigación y Educación de la Costa del Golfo, en Balm, FL, para evaluar la tolerancia de dos cultivares de fresa ('Strawberry Festival' y 'WinterStar'™) a herbicidas PRE aplicados sobre la superficie de la cama de siembra o inyectados a través de la cinta de riego por goteo. Los herbicidas sobre la cama de siembra fueron aplicados a camas formadas después de la fumigación pero antes de instalar la cobertura plástica. Los herbicidas evaluados incluyeron dos dosis de EPTC, fomesafen, halosulfuron, y *S*-metolachlor, además de mezclas en tanque de EPTC + *S*-metolachlor, fomesafen + *S*-metolachlor, y napropamide + oxyfluorfen. Los herbicidas aplicados con el sistema de riego fueron aplicados a través de una sola cinta de goteo y las fresas fueron trasplantadas 1, 7, 15, y 30 d después de la aplicación. Los herbicidas aplicados con el riego por goteo incluyeron dos dosis de EPTC y fomesafen además de dos dosis de una mezcla en tanque de napropamide + oxyfluorfen. Ninguno de los herbicidas aplicados sobre la cama, excepto *S*-metolachlor a 214 g ai ha^{-1}, dañó consistentemente a los cultivares de fresa ni impactaron su rendimiento. Ninguno de los herbicidas aplicados con el riego por goteo dañó a las plantas de fresa ni redujo su rendimiento en cualquiera de las fechas de siembra. En el año 1, EPTC a 229 g ai ha^{-1} y EPTC a 229 g ha^{-1} + *S*-metolachlor a 107 g ha^{-1} resultaron en una reducción de 70 a 86% en la densidad de *C. rotundus* al compararse con el testigo sin tratamiento. No se observaron diferencias en la densidad de *C. rotundus* en el año 2. Los herbicidas evaluados fueron seguros para su uso en fresa y brindarían a los productores alternativas de opciones de herbicidas, momentos de aplicación, y técnicas de aplicación. Investigación adicional es necesaria para evaluar la eficacia de estos tratamientos.

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Strawberries are an important winter crop in Florida with almost all of the production occurring in Hillsborough County. In 2013, 3,440 ha of strawberries were harvested with a value in excess of $267 million (Anonymous 2014). Strawberries are

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cultivated as an annual crop in Florida on raised beds that are fumigated and covered with polyethylene mulch. A variety of fumigants are used to control weeds, diseases, and nematodes (Noling and Becker, 1994; Vallad et al. 2014). Fertilizers are typically broadcast-applied during bed formation as well as injected through a single drip tape. Overhead irrigation is used for 10 to 14 d during crop establishment and "if necessary" for frost protection.

A variety of PRE herbicides are registered for grass and broadleaf weed control in strawberries. Daugovish et al. (2008) found that oxyfluorfen applied pretransplant at 0.3 and 0.6 kg ha^{-1} reduced broadleaf weeds such as California burclover (*Medicago polymorpha* L.), hairy nightshade (*Solanum physalifolium* Rusby), little mallow (*Capsella bursa-pastoris* L.), and shepherd's purse (*Malva parviflora* L.) by 70 to 100% compared to the nontreated control. Samtani et al. (2012) reported that labelled PRE rates of oxyfluorfen and flumioxazin were safe to use on multiple strawberry cultivars. In Florida, Stall et al. (1995) reported strawberry tolerance to clopyralid, metolachlor, napropamide, oxyfluorfen, pendimethalin, prodiamine, simazine, and terbacil applied to the bed top prior to laying the plastic mulch. Research conducted by Gilreath et al. (2003) in Florida found that napropamide at 4.5 kg ha^{-1} + oxyfluorfen at 0.57 kg ha^{-1} resulted in greater fruit numbers and weights compared to either product alone and also had the best grass and broadleaf weed control. As a result, this tank mix is used by growers in Hillsborough County more than any other herbicide combination. It is applied on the bed tops following fumigation and covered immediately with plastic mulch.

In recent years, Florida growers have reported increased issues with grass and broadleaf weeds emerging in the planting holes. Black medic (*Medicago lupulina* L.), Carolina geranium (*Geranium carolinianum* L.), cutleaf evening primrose (*Oenothera laciniata* Hill), and Florida pusley [*Richardia scabra* (Moq.) Gomez] are especially problematic and difficult to control. There are very few POST herbicides that are safe for use on strawberries (Manning and Fennimore 2001) and in Florida, clopyralid is the only POST herbicide registered (Vallad et al. 2014) with efficacy on broadleaf weeds.

Purple nutsedge and yellow nutsedge (*Cyperus esculentus* L.) are also problematic in plasticulture strawberry production systems due to their ability to penetrate the plastic mulch. In recent years, several PRE herbicides with activity on nutsedge, including *S*-metolachlor, fomesafen, and EPTC have been registered for use in vegetable crops. Boyd (2015) found that *S*-metolachlor, fomesafen, and EPTC applied alone or as tank mixes can reduce nutsedge density but control levels achieved are inconsistent over time and space. Dittmar (2013) found that fomesafen and *S*-metolachlor provided short-term nutsedge suppression with no control observed 60 d after application. Several authors have indicated that a posttransplant herbicide applied in conjunction with a PRE herbicide may be needed to achieve season-long control (Adcock et al. 2008; Dittmar et al. 2012). There are no herbicides with activity on nutsedge registered for use in strawberry, but McGuire and Pitts (1991) demonstrated strawberry tolerance to post-transplant applications of fomesafen.

There is a need to identify herbicides and application techniques for control of nutsedge and problematic broadleaf weeds. Herbicides are typically applied to the bed top immediately following fumigation, which is often 21 to 30 d before transplant. Drip-applied herbicides have been evaluated in vegetable crops and may be an alternative application technique for strawberry growers, which would allow herbicide application much closer to the transplant date. Santos (2009) found that drip-applied napropamide + *S*-metolachlor in tomato did not effectively control a mixed stand of yellow and purple nutsedge. Dittmar et al. (2012) found that drip-applied herbicides may be a beneficial component of a yellow nutsedge control program but additional POST herbicides would be needed for season-long control. In strawberries, drip application may be an alternative option allowing growers to apply herbicides much closer to the transplant date after drip tape and plastic mulch have been installed. Research is needed to identify herbicides that can be safely injected through the drip tape without damaging the transplants.

The objectives of these experiments were to (1) evaluate the tolerance of two strawberry cultivars to PRE herbicides and tank mixes applied under the plastic mulch and (2) evaluate strawberry tolerance

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Table 1. Herbicide treatments applied under the plastic following fumigation at the Gulf Coast Research and Education Center in Wimauma, FL, in 2012 and 2013.

Common name	Trade name	Rate	Manufacturer, city, state
		g ai ha^{-1}	
Nontreated control	Nontreated control	—	—
EPTC	Eptam	229	Gowan Company, Yuma, AZ (http://www.gowanco.com)
EPTC	Eptam	458	Gowan
Fomesafen	Reflex	42	Syngenta Crop Protection Inc., Greensboro, NC (http://www.syngentacropprotection.com/)
Fomesafen	Reflex	84	Syngenta
Halosulfuron	Sandea	5	Gowan
Halosulfuron	Sandea	10	Gowan
S-metolachlor	Dual Magnum	107	Syngenta
S-metolachlor	Dual Magnum	214	Syngenta
EPTC + *S*-metolachlor	Eptam + Dual Magnum	229 + 107	Gowan and Syngenta
Fomesafen + *S*-metolachlor	Reflex + Dual Magnum	42 + 107	Syngenta
Napropamide + oxyfluorfen	Devrinol DF-XT + Goal 2XL	448 + 56	United Phosphorus Inc., King of Prussia, PA (http://www.upi-usa.com), and Dow AgroScience Indianapolis, IN (http://www.dowagro.com/)
Napropamide + *S*-metolachlor	Devrinol DF-XT + Dual Magnum	448 + 107	United Phosphorus Inc. and Syngenta

to PRE herbicides injected through the drip tape 1, 7, 15, and 30 d prior to transplant.

Materials and Methods

Experiments were conducted in 2012 to 2013 (year 1) and 2013 to 2014 (year 2) at the Gulf Coast Research and Education Center (27°N, 82°W) in Wimauma, FL, to evaluate strawberry tolerance to multiple PRE herbicides applied on the bed top or injected through the drip tape. The herbicide list is shown in Table 1. Soil type at the research center is a Myakka fine sand (sandy, siliceous, hyperthermic Oxyaquic Alorthod) with a pH of 7.6 and 0.8% organic matter. Raised beds were formed with bed-pressing equipment (Kennco Manufacturing, Ruskin, FL) on 1.2-m centers, a height of 30.5 cm, and a bed-top width of 66 cm. The soil was fumigated with 336 kg ha^{-1} of 63.4% 1,3-dichloropropene + 34.7% chloropicrin (Telone C-35, Dow AgroSciences LLC, Indianapolis, IN) on August 28, 2012, and August 19, 2013. Fumigants were injected with a two-shank fumigation rig (Kennco) at a 20-cm depth. A single drip tape with emitters every 30 cm and a flow rate of 0.95 L min^{-1} per 30.5 m (Jain Irrigation Inc., Haines City, FL) was installed in the center of the bed and the beds covered with virtually impermeable film plastic mulch (Berry Plastics Corp, Evansville, IN). All plots were irrigated and fertilized throughout the season as per industry standards (Vallad et al. 2014).

Bed-Top Herbicide Experiment. Experiments were arranged as a randomized complete block design in four blocks. Each plot was 4.5 m long with a 1.5-m buffer between plots. Herbicides were applied after shaping and fumigating the bed and immediately prior to laying the plastic in both years. All herbicides were applied in 187 L ha^{-1} of water with a backpack sprayer (Bellspray Inc., Opelousa, LA) equipped with a single 8002VS nozzle (Teejet Technologies, Wheaton, IL) and a pressure of 0.24 MPa. Two rows of strawberry transplants were planted per bed with 38-cm spacing between plants on October 22, 2013, and October 10, 2014. The experiment was conducted in two strawberry cultivars ('Strawberry Festival' and 'WinterStar'™) in each year.

Drip-Applied Experiment. Experiments were arranged as a split-plot design in four blocks. Each main plot was one bed 30 m long and the subplots were 4.5 m long with a 1.5-m buffer. The main plot was the injected herbicide and the subplot was number of days between herbicide injection and

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strawberry transplanting. Herbicide treatments included fomesafen at 42 and 84 g ha^{-1}, EPTC at 229 and 458 g ha^{-1}, and oxyfluorfen + napropamide at 56 and 448 g ha^{-1}, respectively (Table 1). Herbicides were injected in 3.786 L $plot^{-1}$ of water using CO_2-pressurized cannisters on October 14, 2013, and October 8, 2014. Prior to injection, the drip tape was cut and the ends sealed between main plots to enable application to individual plots. The drip tape was flushed with water following each injection to remove all herbicide residue from the tape. At the end of the herbicide application, the drip tape was reconnected. Two rows of strawberry transplants (Strawberry Festival) were planted per bed with 38-cm spacing between plants 1, 7, 15, and 30 d following the herbicide application.

Data Collection. Crop injury where 0 is no injury and 100 represents complete shoot death was evaluated 14, 28, and 56 d after transplanting in all experiments. Nutsedge shoots were counted over the entire plot (4.5 by 0.66 m) on December 9 and January 28 in year 1 and on December 11 and February 26 in year 2 of the bed-top experiment. Nutsedge was counted in the injection experiment but the data are not included due to the lack of weeds present. A relatively weed-free site was selected so that the experiments could focus on crop tolerance. Berries were harvested twice per week from late December through early March with harvest initiated when berries begin to ripen and terminated when commercial growers in the region stopped harvesting their fields.

Data were analyzed in SAS (version 9.2, SAS Institute Inc., Cary, NC) using the mixed procedure with block as the random factor for the bed-top experiment. In the drip-applied experiment the data were analyzed using the mixed procedure with block and block by main plot as the random factors. Data were checked for normality and constant variance prior to analysis. Years and cultivars were analyzed separately as they were conducted as separate experiments. Means were compared using the least squares means statement in SAS with the Tukey adjustment at $P = 0.05$. Data collected on multiple dates, such as nutsedge counts and berry yields, were analyzed using the repeated statement.

Results and Discussion

Bed-Top Experiment. None of the PRE herbicides injured either strawberry cultivar in either year (data not shown). The harvest date by herbicide interaction was never significant and as a result only total berry yields and counts are presented (Table 2). Total berry yield was only affected by herbicide treatment in the WinterStar cultivar in year 2 where plots treated with 214 g ha^{-1} *S*-metolachlor had significantly lower yields than the nontreated control. This trend was observed for the berry number as well indicating that the yield difference can be attributed to a reduction in berry number, not berry size. No other significant yield differences were observed in either year in either cultivar. Overall we conclude that the evaluated herbicides and herbicide tank mixes were safe for annual strawberry production in Florida with the exception of *S*-metolachlor at 214 g ha^{-1}.

Purple nutsedge shoot densities were relatively low in both years and therefore the results must be interpreted with caution. Nutsedge was counted on two dates in each cultivar in each year giving a total of four site-years. The treatment by time interaction was not significant in any site-year and as a result the nutsedge densities are presented as an average of both counts (Table 3). Herbicides had a significant effect on nutsedge density in year 1 but not year 2. In year 1 in the Strawberry Festival cultivar, applications of EPTC at 229 g ha^{-1}, halosulfuron at 5 g ai ha^{-1}, halosulfuron at 10 g ha^{-1}, *S*-metolachlor at 214 g ha^{-1}, EPTC 229 g ha^{-1} + *S*-metolachlor at 107 g ha^{-1}, and napropamide 448 g ai ha^{-1} + oxyfluorfen 56 g ai ha^{-1} resulted in a 70 to 90% reduction in purple nutsedge densities compared to the nontreated control. In the WinterStar cultivar, EPTC at 229 g ha^{-1} and the EPTC + *S*-metolachlor tank mix reduced purple nutsedge density by 86 and 71%, respectively. The apparent efficacy of the oxyfluorfen + *S*-metolachlor tank mix on yellow nutsedge in year 1 cannot adequately be explained by the authors. The lack of efficacy of this tank mix in year 2 is what would be expected given that this tank mix is widely used by commercial growers for broadleaf and grass weed control and is known to have limited to no activity on nutsedge (Daugovish et al. 2008; Vallad et al. 2014).

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Table 2. Season total berry counts and yield in 2012 to 2013 (year 1) and 2013 to 2014 (year 2) in two strawberry cultivars following PRE herbicide applications under plastic mulch at the Gulf Coast Research and Education Center in Wimauma, FL.

		Strawberry Festival				WinterStar			
		Yield[a]		Count		Yield		Count	
Herbicide	Rate	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2
	g ai ha^{-1}	kg ha^{-1}		no. 10 plants^{-1}		kg ha^{-1}		no. 10 plants^{-1}	
Nontreated control	—	11,356	13,387	143	140	12,000	14,014 ab[b]	156	187 abc
EPTC	229	11,089	10,409	162	111	12,625	13,783 ab	161	178 abcd
EPTC	458	10,564	15,020	155	149	10,456	15,348 a	134	189 abc
Fomesafen	42	11,752	13,889	170	140	10,996	12,656 bc	145	170 bcd
Fomesafen	84	9,434	12,706	135	131	12,203	14,134 ab	154	194 ab
Halosulfuron	5	12,214	13,372	172	134	10,829	12,524 bc	136	165 cd
Halosulfuron	10	11,404	12,100	158	125	10,027	13,581 ab	130	180 abcd
S-metolachlor	107	10,901	12,842	156	128	10,684	14,896 a	142	203 a
S-metolachlor	214	11,966	11,178	173	115	12,392	11,289 c	164	155 d
EPTC + *S*-metolachlor	229 + 107	12,871	13,883	184	145	13,552	13,570 ab	176	180 abcd
Fomesafen + *S*-metolachlor	42 + 107	11,744	9,895	169	101	10,425	13,365 ab	128	178 abcd
Napropamide + oxyfluorfen	448 + 56	11,538	13,740	184	137	7,710	13,585 ab	103	185 abc
P value		0.2336	0.1939	0.2503	0.2722	0.2963	0.0325	0.2118	0.0528

[a] Yield calculations were based on berries harvested from 6.1 m of a single bed with two rows of plants with 38-cm spacing between plants.

[b] Least-squares means within columns followed by different letters are significantly different at $P < 0.05$.

Drip-Applied Experiment. The herbicide by time interaction was not significant in year 1 ($P = 0.0764$) or year 2 ($P = 0.3025$) and as a result strawberry injury ratings are presented as an average of all ratings (Table 4). Injury ratings did differ with planting date in year 1 ($P < 0.0001$) and year 2 ($P = 0.0430$), with yields tending to be lower with later planting dates. However, given that no herbicide

Table 3. Number of purple nutsedge shoots in two strawberry cultivar experiments averaged across counting dates December 9, 2012, and January 28, 2013 (year 1) and December 11, 2013, and February 26, 2014 (year 2) following PRE herbicide applications under plastic mulch at the Gulf Coast Research and Education Center in Wimauma, FL.

		Strawberry Festival		WinterStar	
Herbicide	Rate	Year 1	Year 2	Year 1	Year 2
	g ai ha^{-1}	no. m^{-2}			
Nontreated control	—	10 a[a]	4	7 abc	2
EPTC	229	3 bcd	4	1 d	1
EPTC	458	5 abc	7	11 ab	2
Fomesafen	42	6 abc	3	20 a	1
Fomesafen	84	6 abc	8	13 ab	1
Halosulfuron	5	2 cde	10	6 abc	2
Halosulfuron	10	3 bcd	4	6 abc	2
S-metolachlor	107	5 abc	5	11 ab	2
S-metolachlor	214	1 de	1	4 bcd	1
EPTC + *S*-metolachlor	229 + 107	3 bcde	2	2 cd	2
Fomesafen + S-metolachlor	42 + 107	4 abcd	6	6 abc	2
Napropamide + oxyfluorfen	448 + 56	1 e	3	16 a	2
P value		0.0038	0.2519	0.0020	0.3387

[a] Least-squares means within columns followed by different letters are significantly different at $P < 0.05$.

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Table 4. Strawberry plant injury and cumulative berry yield in 2012 to 2013 (year 1) and 2013 to 2014 (year 2) following herbicide injection through the drip tape at 1,7, 15, and 30 d before transplant at the Gulf Coast Research and Education Center in Wimauma, FL.

Days before transplant	Herbicide	Rate	Year 1		Year 2	
			Strawberry injury	Berry yield[c]	Strawberry injury	Berry yield
		g ai ha^{-1}	%	kg ha^{-1}	%	kg ha^{-1}
1	Nontreated control	—	0[a]	6,725	0	10,510
	EPTC	229	0	6,583	6	10,024
	EPTC	458	0	6,725	6	10,113
	Fomesafen	42	0	5,933	4	10,140
	Fomesafen	84	2	6,301	11	10,367
	Napropamide + oxyfluorfen	448 + 56	0	6,156	4	10,427
	P value		—[b]	0.8907	0.5947	0.8800
7	nontreated control	—	0	5,672	0	10292
	EPTC	229	1	4,304	2	10408
	EPTC	458	0	6,094	5	10,466
	Fomesafen	42	1	5,049	2	10,412
	Fomesafen	84	1	6,024	11	10,322
	Napropamide + oxyfluorfen	448 + 56	3	5,679	0	10,405
	P value		0.2101	0.4084	0.0641	0.9955
15	Nontreated control	—	0	3,910	0	10,551
	EPTC	229	3	3,957	4	10,790
	EPTC	458	5	3,465	2	10,566
	Fomesafen	42	2	4,202	4	10,431
	Fomesafen	84	9	3,472	0	10,641
	Napropamide + oxyfluorfen	448 + 56	15	3,986	4	10,241
	P value		0.1473	0.8262	—	0.7217
30	Nontreated control	—	0	1,307	0	10,502
	EPTC	229	0	1,318	0	9,629
	EPTC	458	1	1,605	0	10,421
	Fomesafen	42	0	1,595	1	9,465
	Fomesafen	84	0	1,360	5	10,068
	Napropamide + oxyfluorfen	448 + 56	2	1,543	4	10,200
	P value		—	0.9122	—	0.4135

[a] Least-squares means within columns followed by different letters are significantly different at $P < 0.05$.

[b] P value was not calculated because model assumptions were not met.

[c] Yield calculations were based on berries harvested from 6.1 m of a single bed with two rows of plants with 38-cm spacing between plants.

damage was observed and the yields were lower in treatments planted later in the year, we conclude that differences in yield associated with planting date can be attributed longer storage periods for the transplants planted later in the season and changes in weather conditions associated with later planting rather than herbicide applications. Daugovish et al. (2008) also found that oxyfluorfen applications made 7, 15, and 30 d before transplanting did not injure strawberry. The current oxyfluorfen label requires a 30-d time frame between application and transplanting but our results indicate that drip applications as soon as 1 d prior to transplanting do not injure the crop. Total strawberry yield was not affected by herbicide application in year 1 ($P = 0.9396$) or year 2 ($P = 0.6457$).

We conclude that all of the herbicides evaluated except 214 g ha^{-1} of *S*-metolachlor are safe for use as PRE herbicides in strawberry plasticulture production systems. We also conclude that EPTC, fomesafen, and oxyfluorfen + *S*-metolachlor can be drip-applied 1, 7, 15, and 30 d prior to transplanting with no crop injury.

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