ABSTRACT

DITTMAR, PETER JAMES. Effect of Drip Applied Herbicides on Yellow Nutsedge and Solanaceous Crops. (Under the direction of Dr. David W. Monks).

Plasticulture systems utilizing polyethylene mulch and drip irrigation provide many advantages for tomato and pepper production. However, yellow nutsedge can pierce the polyethylene mulch and compete with the crops for nutrients, water, and sunlight. Greenhouse and field studies were conducted to determine the effect of drip-applied halosulfuron, imazosulfuron, and trifloxysulfuron on yellow nutsedge and solanaceous crops (tomato and pepper). In greenhouse studies, tomato treated with soil applied halosulfuron, imazosulfuron, and trifloxysulfuron had lower visual injury (5, 5, and 14%, respectively) than the POST applied (23, 26, and 54% visual injury, respectively) treatments. Pepper treated in the greenhouse with soil applied halosulfuron, imazosulfuron, and trifloxysulfuron had lower visual injury (8, 6, and 6%, respectively) than POST applied (21, 35, and 26%, respectively) treatments. For both tomato and pepper, injury followed a linear relationship with increasing injury as herbicide rate increased. In field studies, tomato yield (62,722 to 80,328 kg/ha), and height (73 to 77 and 79 to 84 cm at 14 and 21 d after treatment (DAT) was not different among drip applied or POST herbicide treatments. Likewise, pepper fancy grade yield (21,128 to 27974 kg/ha), number one fruit yield (7,825 and 14,672 kg/ha) and pepper height (32 to 37 cm at 14 DAT) were not different among herbicide treatments. In greenhouse studies, photosynthetic rate and stomatal conductance rate of tomato and yellow nutsedge was reduced by soil or POST applied herbicides. Yellow nutsedge control in greenhouse studies by soil applied halosulfuron (78 to 87%), imazosulfuron (69 to 82%), and trifloxysulfuron (85 to 91%) was greater than the nontreated (0%). In field studies, drip applied

halosulfuron (72%), imazosulfuron (95%), and trifloxysulfuron (110%) in plasticulture systems had less nutsedge emergence during the experiment than the nontreated (876%). Tomato and pepper have excellent tolerance to halosulfuron, imazosulfuron, and trifloxysulfuron applied through drip irrigation systems. Based on greenhouse and field studies, drip applied herbicides would likely fit into pepper and tomato plasticulture systems and would provide suppression of yellow nutsedge in this system.

Tomato and Pepper Crop Tolerance and Yellow Nutsedge (*Cyperus esculentus*) Control to Drip Applied Herbicides

by
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DEDICATION

To James and Karen Dittmar,

whose support has allowed me to do everything in horticulture.

BIOGRAPHY

Peter James Dittmar grew up on his family's farm outside of Elizabeth, Illinois. Peter's family raised beef, hogs, sheep, and grain crops. Peter's interest in horticulture began in the family's large garden. Peter was active in 4-H, FFA, and his church. Peter graduated from River Ridge High School in May 2000. In 2002, Peter received his Associate of Applied Science-Ornamental Horticulture degree from Kishwaukee College, Malta, Illinois. Peter continued his education at Southern Illinois University-Carbondale and received his Bachelor of Science Degree-Plant & Soil Science in 2004. At SIU, Peter had an undergraduate assistantship with Drs. Alan Walters and Bradley Taylor. They played an integral role in introducing Peter to fruit and vegetable research. Peter completed his undergraduate research on sweetpotato plant spacing and planting date on clay soils for southern Illinois. Peter's Masters research was on seedless watermelon pollination and halosulfuron POST to watermelon. Peter's doctoral research studied the effect of herbicide drip applied in tomato and pepper plasticulture production.

ACKNOWLEDGEMENTS

I have many people to thank for helping me through my degree program. I want to start by thanking David Monks, he has taught me how address the growers' needs, develop a research program, and ask a better research question. I want to thank Katie Jennings for her assistance with the day-to-day activities and her patience while answer the thousands of questions that I had. Jonathan Schultheis started as advisor during my masters degree and has become a great friend and mentor during my PhD program. Garry Grabow was very patient with answering questions about irrigation and coming to the many meetings. Rachel McClaughlin was instrumental navigating me through all the paperwork involved with a university and has been an amazing friend who was always willing to listen. I was very fortunate to work with amazing fellow graduate students. Ryan Pekarek, Steve Meyers, and Bradley Cole provided the greatest help in the field and amazing friendship over the thousands of miles that we drove. My research plots were at stations across the state, but my plots were always taken care of by the best crews. I want to thank the crews at the Cunningham Research Station, Mountain Horticulture Research Station, and Horticultural Crops Research Station. Finally, my parents have always supported everything that I have done in horticulture starting with a garden at age 6 and continuing through a move 20 hrs away from home for a job at University of Florida. When I was young and going to a conference my parents would say, "Good luck and have fun". The luck was very helpful in everything I have done and I have had a lot of fun.

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Chapter 1

Tolerance of Tomato to Herbicides Applied Through Drip Irrigation

(In the format appropriate for submission to Weed Technology)

Tolerance of Tomato to Herbicides Applied Through Drip Irrigation

Peter J. Dittmar, David W. Monks, and Katherine M. Jennings[*]

Greenhouse and field studies were conducted to determine tolerance of plasticulture tomatoes to halosulfuron, imazosulfuron, and trifloxysulfuron applied through drip irrigation. In greenhouse studies, trifloxysulfuron POST and soil applied (54 and 14% injury, respectively) caused greater tomato injury than POST and soil applied halosulfuron (26 and 5% injury, respectively) or imazosulfuron (23 and 5% injury, respectively). All herbicide treatments in the greenhouse studies caused greater injury to tomato than the nontreated. Greater tomato injury was observed in the greenhouse from herbicides applied POST than when soil applied. Tomato injury from POST applied halosulfuron, imazosulfuron, and trifloxysulfuron followed a linear relationship with tomato injury increasing with increasing herbicide rate. In 2008 and 2009 field studies, no tomato injury was observed. Herbicide, herbicide application method, and herbicide rate had no effect on tomato height (73 to 77 cm 14 DAT, 79 to 84 cm 21DAT) and total fruit yield (62,722 to 80,328 kg/ha).

Nomenclature: Halosulfuron; imazosulfuron; trifloxysulfuron; tomato, *Solanum lycopersicum* L.

Key words: Sulfonylurea, application method, methyl bromide alternatives, drip applied.

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Tomato was grown on 49,645 ha in the U.S. and 1486 ha in North Carolina in 2007 (USDA-NASS 2009). Fresh market tomato is commonly grown using plasticulture in the U.S. Plasticulture is a system that is not only used for single crops, but also can be used to produce multiple crops per season (Gordon et al. 2008; Lamont et al. 2002; Morales-Garcia 2010; Poling 1993). Tomato fruit develop earlier (Bhella 1988; Schalk and Robbins 1987) and yield is increased (Jones et al. 1977; Wien and Minotti 1987) and in plasticulture production compared to tomato produced in systems not utilizing polyethylene mulch.

Polyethylene mulch provides excellent broadleaf and grass weed control, however, yellow (*Cyperus esculentus* L.) and purple (*C. rotundus* L.) nutsedge can pierce through polyethylene mulches (Adcock et al. 2008; Henson and Little 1969; Johnson and Mullinix 2008; Webster 2005). Yellow and purple nutsedge are troublesome weeds in tomato and pepper (Webster 2006). In greenhouse studies, Morales-Payan et al. (1997) reported that purple nutsedge interference in tomato caused a linear relationship in shoot dry weight loss and yield loss with increasing purple nutsedge density and at 200 plants m^2 yield loss was 44%. In subsequent greenhouse studies Morales et al. (2003) found that purple nutsedge interference with tomato was greater below-ground than above-ground and yellow nutsedge interference was both above- and below-ground.

Tomato is tolerant to halosulfuron POST at 26 to 53 g ai/ha (Adcock et al. 2008; Jennings 2010). Yellow or purple nutsedge control is greater from halosulfuron POST than from halosulfuron PRE (Adcock et al. 2008). However, in greenhouse studies dry weight of purple and yellow nutsedge shoots and roots did not differ between halosulfuron applied solely to foliage or solely to soil (Vencill et al. 1995). Halosulfuron POST also controls other broadleaf weeds found in vegetable fields including pigweed (*Amaranthus palmeri* S. Wats. and

Amaranthus albus L.), eclipta (*Eclipta prostrata* L.), and cutleaf groundcherry (*Physalis angulata* L.) (Shrefler et al. 2007).

Imazosulfuron is an experimental sulfonylurea herbicide being developed in the U.S. by Valent USA Corporation. Excellent tomato safety to POST-DIR imazosulfuron at 0.11, 0.22, and 0.33 kg ai/ha was reported by Jennings (2010). Imazosulfuron applied POST sequentially provided yellow nutsedge control greater than 92% at 21 d after POST treatment (Felix and Boydston 2010). Pekarek (2008) found that imazosulfuron POST at 0.11 and 0.22 kg ai/ha controlled yellow nutsedge and hairy galinsoga.

Tomato tolerance to POST-DIR trifloxysulfuron at 5.6 to 33.4 g/ha has been observed (Buckelew et al. 2007; Jennings 2010). Santos et al. (2006) reported tomato tolerance to POST trifloxysulfuron at 5.3 g/ha as part of a pest management program with metolachlor preplant incorporated and 1,3-D + chloropicrin injected. Trifloxysulfuron at 11.2, 16.8, and 33.4 g/ha provided 75 to 100% control of redroot pigweed, ivyleaf and pitted morningglories, sicklepod, and velvetleaf (Buckelew et al. 2007). Trifloxysulfuron applied to the soil decreased shoot number, shoot weight, and root weight of purple and yellow nutsedge more than a foliar application in greenhouse studies (McElroy et al. 2003).

Eggplant height, fruit number, and fruit yield followed an inverse relationship to halosulfuron at 0, 26, 39, and 52 g ai/ha applied pretransplant through the drip irrigation (Webster and Culpepper 2005). Total fruit yield of eggplant treated with drip-applied halosulfuron at 39 g ai/ha or less was ≤ 4% of the nontreated check. Drip-applied halosulfuron at 26 g ai/ha applied 1 and 3 wk after transplant reduced initial harvests biomass ≥ 33% and ≤ 7% of the nontreated check. Total fruit yield of eggplant treated 1, 2, and 3 wk after transplant with halosulfuron was similar to the nontreated check.

1,3-dichloropropene + chloropicrin and methyl isothiocyanate applied through drip irrigation system controlled *Phytophthora capsici, Rhizoctonia solani,* and yellow nutsedge 10 cm vertically below the emitter, however, no control was observed 20 cm horizontally below the drip irrigation tape emitter (Candole et al. 2007a). *Rhizoctonia solani* and yellow nutsedge mortality was similar at 10 and 20 cm below the drip irrigation tape emitter (Candole et al. 2007b). *Fusarium oxysporum* wilt incidence and *Tylenchorhynchus* was controlled with drip-applied metam sodium and with shank applied chloropicrin and PPI pebulate followed by shank applied chloropicrin and drip applied fosthiazate (Santos et al. 2006). Below the drip irrigation emitter there was greater *Rhizoctonia solani* and yellow nutsedge mortality was observed compared to 20 and 30 cm away from the emitter (Candole et al. 2007b). Concentrations of methyl isothiocyanate 20 and 30 cm away from the emitter increased over time (Candole et al. 2007b).

Halosulfuron, imazosulfuron, and trifloxysulfuron provide control of yellow and purple nutsedge in many cropping systems. The phaseout of methyl bromide requires new methods of weed control in plasticulture. Application of herbicides through the drip irrigation system is a possible alternative. The objective of this research was to determine the tolerance of plasticulture tomato to halosulfuron, imazosulfuron, and trifloxysulfuron herbicides applied through the drip irrigation system.

Materials and Methods

Greenhouse. Studies were conducted at the Mary Anne Fox Greenhouse at N.C. State

University, Raleigh, NC. Greenhouse temperature ranged from 17 to 27°C. ‘Amelia’ tomato[1] was transplanted on March 3, 2007, into 20 cm wide and 15 cm deep polyethylene pots[2] containing Orangeburg loamy sand (fine-loamy, kaolinitic, thermic typic Kandiudults having pH 5.7 and 0.7% humic matter) from the Horticulture Crops Research Station near Clinton, NC (35°17’N, 77°34’W). Herbicide treatments were applied 12 d after transplanting (March 15) when tomato was 15 to 20 cm tall with 8 true leaves and 1 to 2 open flowers. Treatments included soil-applied halosulfuron at 13, 26, 53, and 80 g/ha, imazosulfuron at 112, 224, 336, and 504 g/ha, and trifloxysulfuron at 5, 11, 16, and 24 g/ha. Soil applied herbicide treatment was an attempt to determine response of tomato to herbicides reaching the root systems as in the case with drip applied herbicides. Soil treatments were applied based on amount of active ingredient per hectare and the surface area of the pot and were poured equally over the soil surface. POST treatments were halosulfuron at 26 and 53 g/ha, imazosulfuron at 224 and 336 g/ha, and trifloxysulfuron at 11 and 16 g/ha. All POST treatments included nonionic surfactant[3] at 0.25% (v/v). POST herbicide treatments were applied in a spray chamber equipped with an 8002EVS nozzle[4] calibrated to deliver 167 L/ha. Nontreated plants were included in each replication for comparison. Treatments were applied to 3 plants per plot in a randomized complete block design with 4 replications. Tomato was evaluated for injury (0% = no injury, 100% = tomato death) 7 and 14 d after treatment (DAT). Data were analyzed using analysis of variance and means were separated with Fisher’s Protected LSD’s ($P \leq 0.05$). Dependant variables and herbicide rates were fit to regression models.

Field. Studies were conducted at the Mountain Horticultural Crops Research Station, Mills River, NC (35°23’N, 82°33’W) in 2008 and 2009. ‘Amelia’ tomato was planted in plasticulture on raised beds 91 cm wide and 13 cm tall; between bed spacing was 1.5 m on row center. Plasticulture including fertility and pest management was according to grower standards (Kemble 2010). Soil type in the fields was Codorus loam (Fine-loamy, mixed, mesic Fluvaquentic Dystrochrepts with pH 5.9 and 1.1% humic matter). Two drip tapes[5] were in the center of the bed 2.5 to 5 cm deep and spaced 31 cm apart. Similar to some eastern North Carolina growers who are utilizing two drip tapes in plasticulture fields having high percentage of sand (Alan Thornton personal communication). The drip tapes had emitters spaced 30.5 cm apart and delivered 374 L/ha/hr. Experimental design was a randomized complete block with 4 replications. Herbicides were applied 3 and 4 wk after transplanting in 2008 and 2009, respectively; tomato was 25 to 31 cm tall. Based on the greenhouse data, the highest herbicide rate of the soil applied treatment was not used in the field. Herbicides applied through the drip tape were halosulfuron at 13, 26, and 53 g/ha; imazosulfuron at 112, 224, and 336 g/ha; and trifloxysulfuron at 5, 11, and 16 g/ha. The quantity of herbicide applied through the drip irrigation was based on the area of the plot (6.1 m long and 0.9 m wide). The drip applied herbicide treatments were applied with layflat tubing (A), backflow valve (B), fertilizer injectors[6] (C), clear tubing (D), and drip tape (E) (Figure 1). Layflat tubing was laid across the front of each plot for delivering water to each plot from the pump at water pressure 82 kPa. The water flows through a backflow valve to prevent herbicide from entering the water source. Water then enters the tank filled with the herbicide treatment and spray dye[7]. The treated solution leaves the tank by displacement by water entering the tank. The clear tube is dark in color from spray dye until the herbicide treatment is displaced and the tube is clear (~45 to 55 min). The tank was then disconnected and moved to the next plot. The clear tubing connects to the drip irrigation tapes in the planting bed. Herbicides POST-DIR were halosulfuron at 25 and 53 g/ha; imazosulfuron at 224 and 336 g/ha; and trifloxysulfuron at 11 and 16 g/ha. POST-DIR herbicide treatments included a nonionic surfactant[3] at 0.25% (v/v) and were applied to the lower 15 cm of one side of the tomato plant using a CO_2 backpack sprayer equipped with an 8002EVS single nozzle[4] calibrated to deliver 167 L/ha of spray solution. Plots were maintained weed-free by hand weeding as needed.

Tomato stand, height, and visual injury (0% = no injury, 100% = tomato death) (Camper 1986). Plant height (soil surface on bed to top of growing point) was measured 14 and 21 DAT. Tomato fruit was harvested six times when fruit were 5 cm or larger in diameter and in breaker to red stage. Fruit was harvested by hand and graded according to USDA grade standards (United States Department of Agriculture-Agricultural Marketing Service, 1997) with a mechanical grader[8]. Marketable fruit consisted of large, extra-large, and jumbo fruit grades. Total fruit consisted of the same fruit grades plus medium grade. Data were analyzed using analysis of variance and means were separated using Fisher's Protected LSD ($P \leq 0.05\%$).

Results and Discussion

Greenhouse. Tomato injury was chlorosis and stunting. All herbicide POST treatments resulted in greater injury to tomato than the nontreated check (Table 1). At 14 and 21 DAT, halosulfuron POST (26 and 17%) and imazosulfuron POST (23 and 12%) caused less tomato injury than trifloxysulfuron POST (54 and 42%). For soil application treatments, halosulfuron (5%) and imazosulfuron (5%) were similar to the nontreated (0%). Trifloxysulfuron applied to the soil surface (14%) caused greater injury to tomato than the nontreated (0%), however, injury to tomato from trifloxysulfuron was similar to injury caused by soil applied halosulfuron (5%) and imazosulfuron (5%). Each herbicide in the greenhouse study caused greater injury when applied POST than when applied to the soil (Table 2).

Tomato injury increased in a linear relationship to increasing rate of halosulfuron POST (Figure 2). At 14 DAT, injury from halosulfuron POST ranged between 26 to 37% and 13 to 28% at 21 DAT. Injury from soil-applied halosulfuron was not greater than 6%. Tomato injury was a linear relationship to imazosulfuron POST rate with increased injury as rate of imazosulfuron increased (Figure 3). The soil application of imazosulfuron caused less than 6% injury, but followed a linear relationship. At 21 DAT, injury from all rates of imazosulfuron were similar to the nontreated. Tomato injury increased as a linear relationship to increasing trifloxysulfuron rate applied both POST and soil applied (Figure 4). At 14 DAT, injury to tomato treated with trifloxysulfuron POST was 34 to 74% and soil applied trifloxysulfuron was 7 to 27%. Injury from trifloxysulfuron at 5 and 11 g/ha was similar to the nontreated (data not shown).

Field. Years were not significantly different for crop injury and yield so years were combined. Herbicide treatments did not affect tomato stand and injury in the field studies (data not shown). Tomato height and yield did not differ between herbicide, placement, or rate. Tomato height was 75 to 77 cm at 14 DAT and 79 to 84 cm at 21 DAT (Table 3). Each tomato grade, marketable yield, and total yield did not differ (data not shown). Tomato total yield ranged from 64922 to 80328 kg/ha (Table 3). Adcock et al. (2008), Buckelew et al. (2007), and Jennings (2010) also reported no effects of halosulfuron, imazosulfuron, and trifloxysulfuron on tomato injury and yield.

The tomato studies in the greenhouse had more tomato injury from herbcides than the field experiments. This increased injury from POST herbicide treatments may have been due to the POST treatment being applied over-the-top (greenhouse) instead of directed (field), plants were more succulent in the greenhouse, or smaller tomato plants in greenhouse study at time of treatment. Although injury was greater in greenhouse experiments, the greenhouse studies were important in showing tomato tolerance increased with herbicides applied only to soil compared to when applied POST. Halosulfuron (Anonymous 2007) and trifloxysulfuron (Anonymous 2006) POST-DIR were applied at registered rates and imazosulfuron POST-DIR applied at rates that have been reported to be safe to tomato (Jennings 2010). Delayed drip application (3 to 4 wk after transplanting of these herbicides) likely increased the tomato tolerance similar to increased eggplant tolerance when halosulfuron applied through drip irrigation was delayed until 3 wk after transplanting (Webster and Culpepper 2005). Sulfonylurea herbicides break down quicker in more acidic soils, however, in our greenhouse and field studies soil pH was similar and would not be a major factor in observed differences between greenhouse and field trials (Brown 1990).

The application of pesticides through drip irrigation has shown to control the pest in raised bed plasticulture systems (Fennimore 2003; Candole et al. 2007a, 2007b; Santos 2006). However, control of pest further away from the drip irrigation emitters is lower than control closer to the drip irrigation emitter. The mean width (cm) of the wetting front in Lakeland fine sand follows a linear response to increasing depth (cm) (W_{mean}= -0.65 D + 79) in the raised bed (Farneselli et al. 2008). In our studies, 2 drip tapes were used in the planting bed to insure application of herbicide across the bed.

Tomato demonstrated excellent tolerance to halosulfuron, imazosulfuron, and trifloxysulfuron applied through drip irrigation at 3 to 4 wk after transplanting. Applying halosulfuron, imazosulfuron, and trifloxysulfuron through drip irrigation provides growers a method for POST and PRE control in plasticulture after the tomato crop has been planted. Applying herbicides through drip irrigation would be important for multicropping plasticulture systems when polyethylene mulch is not removed for subsequent crops. Further studies are needed to determine to know the effect of halosulfuron, imazosulfuron, and trifloxysulfuron applied through the drip irrigation on suppression or control of weeds.

Sources of Materials

[1] 'Amelia' tomato. Harris Moran, P.O. Box 4938, Modesto, CA 95352.

[2] 15-cm azalea polyethylene pots. ITML Horticultural Products, 75 Plant Farm Blvd, Brantford, ON N35 7W2, Canada.

[3] X-77®, alkylphenol ethoxylate, alcohol ethoxylate, tall oil fatty acid, 2,2' dihydroxydiethyl ether and dimethylpolysiloxane. Loveland Products Inc., PO Box 1286, Greeley, CO 80632-1286.

[4] 8002EVS TeeJet drift even flat spray tip. TeeJet Technologies. P.O. Box 7900. Wheaton, IL, 61087.

[5] Drip tape. Jain Irrigation Inc. P.O. Box 3546. 3857 W. Lake Hamilton Dr. Winter Haven, FL 33881.

[6] EZ-FLO hose and drip system 2.8 L tank. EZ-FLO Fertilizing Systems, 3640 Cincinnati Ave., Buildings C&D, Rocklin, CA 95765.

[7] Highlight spray indicator. Becker Underwood, Inc. 801 Dayton Ave., Ames, IA 50010.

[8] Greefa Type A3. Greefa, Langstraat 12, 4196 JB Tricht, Netherlands.

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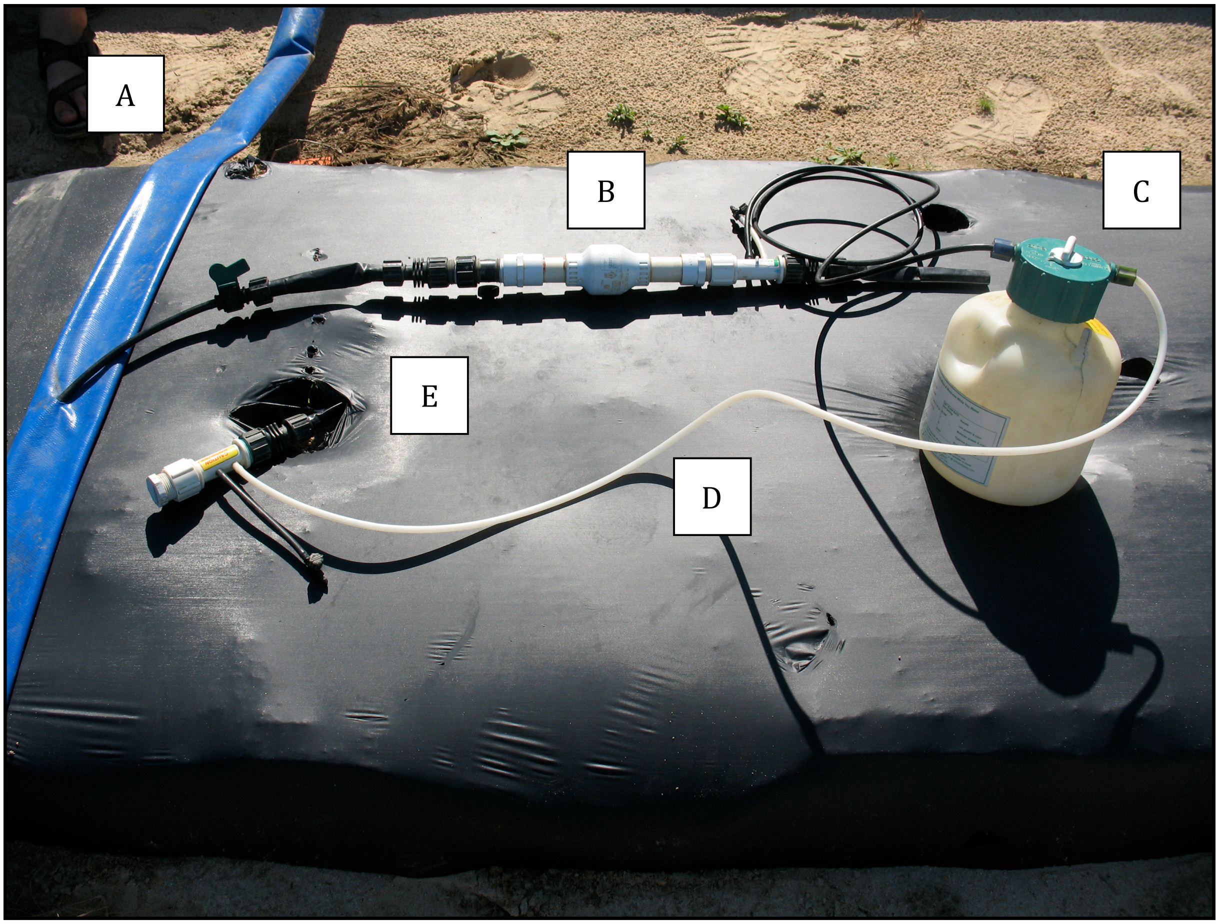

Figure 1. Equipment setup for application of drip applied herbicide treatments in tomato field studies. The equipment is layflat (A), backflow valve (B), injector tank (C), clear tubing (D), and drip tape (E).

Table 1. Effect of halosulfuron, imazosulfuron, and trifloxysulfuron (averaged over rates) POST or soil applied on tomato injury[z] grown in Orangeburg loamy sand in greenhouse studies.

		Injury	
Treatment		14 DAT[y]	21 DAT
		%	
POST	Halosulfuron	26	17
	Imazosulfuron	23	12
	Trifloxysulfuron	54	42
	Nontreated	0	0
	LSD (P≤0.05)	17	10
Soil	Halosulfuron	5	2
	Imazosulfuron	5	2
	Trifloxysulfuron	14	8
	Nontreated	0	0
	LSD (P≤0.05)	11	8

[z] 0% = no injury, 100% = plant death.

[y] DAT = d after treatment.

Table 2. Effect of POST or soil applied halosulfuron, imazosulfuron, and trifloxysulfuron (averaged over rates) on tomato injury[z] grown in Orangeburg loamy sand in greenhouse studies.

	Injury	
Treatment	14 DAT	21 DAT
	%	
Halosulfuron		
POST	23	12
Soil	5	2
LSD ($P \leq 0.05$)	3	3
Imazosulfuron		
POST	26	17
Soil	5	2
LSD ($P \leq 0.05$)	7	7
Trifloxysulfuron		
POST	54	42
Soil	14	8
LSD ($P \leq 0.05$)	10	9

[z] 0% = no injury, 100% = plant death.

[y] DAT = d after treatment.

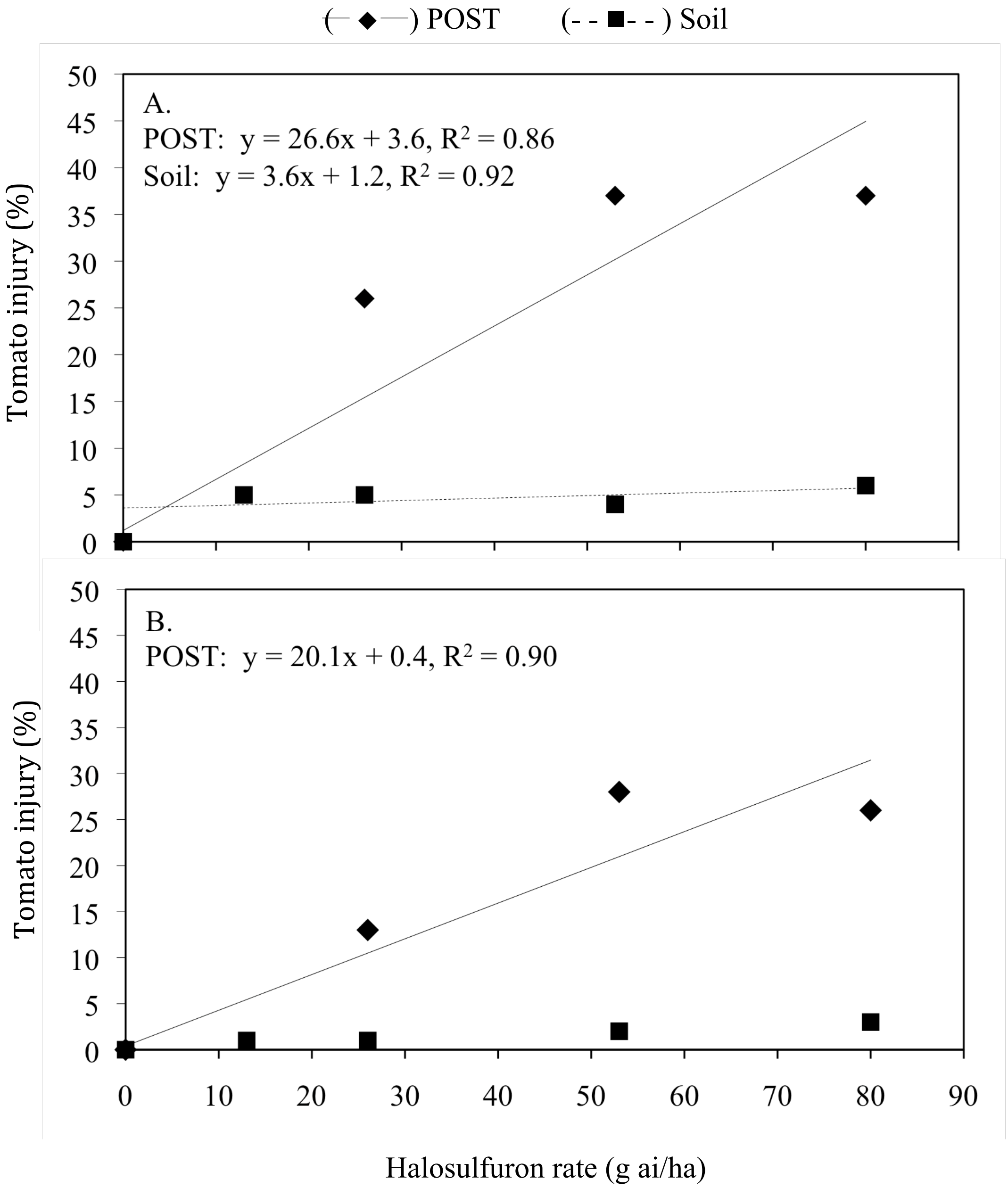

Figure 2. Effect of halosulfuron soil or POST applied on visual tomato injury (0% = no injury, 100% = plant death) 14 (A.) and 21 (B.) d after treatment in greenhouse studies.

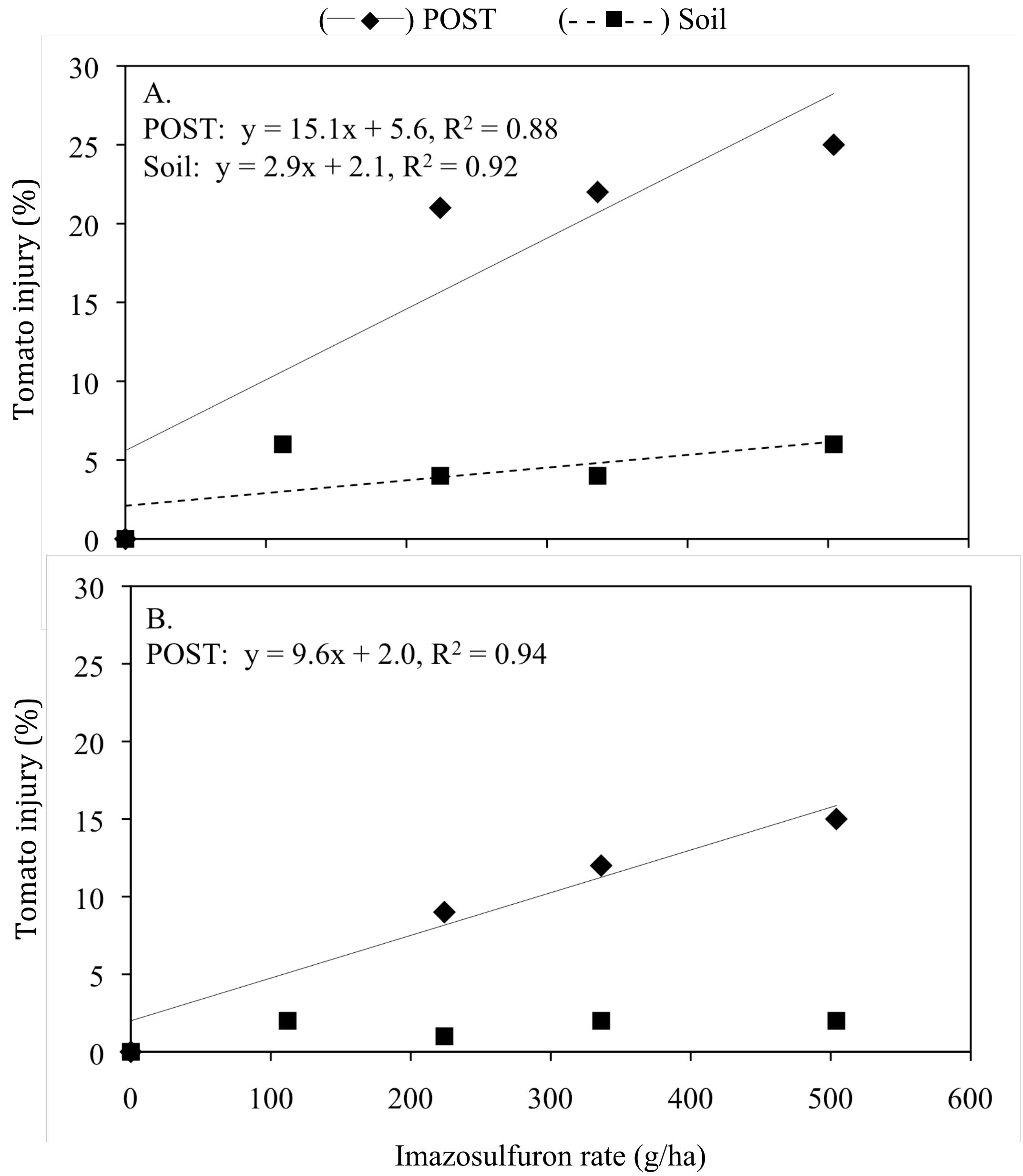

Figure 3. Effect of imazosulfuron soil or POST applied on visual tomato injury (0% = no injury, 100% = plant death) 14 (A.) and 21 (B.) d after treatment in greenhouse studies.

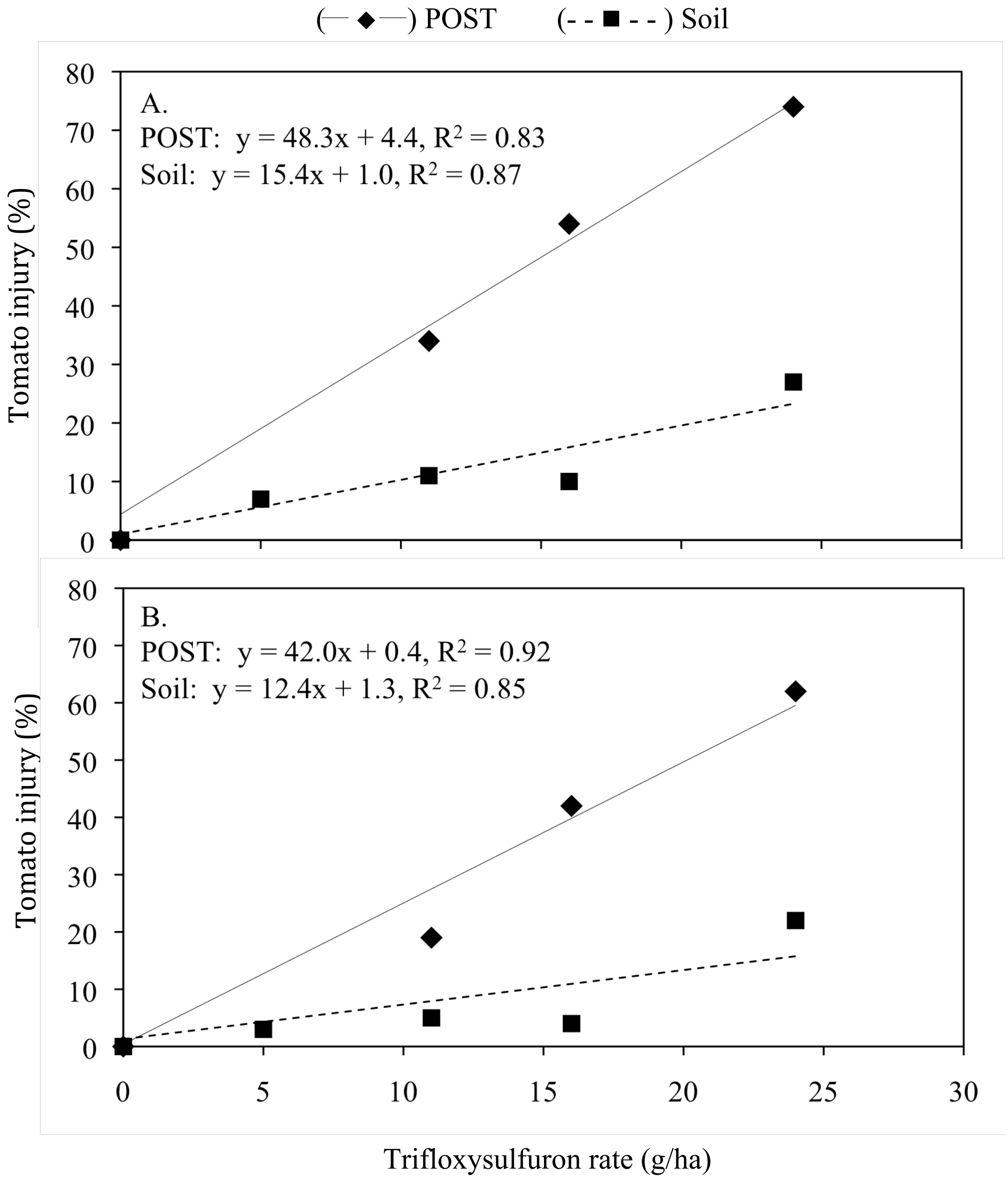

Figure 4. Effect of trifloxysulfuron soil or POST applied on visual tomato injury (0% = no injury, 100% = plant death) 14 (A.) and 21 (B.) d after treatment in greenhouse studies.

Table 3. Effect of herbicide applied POST or through the drip irrigation on tomato height (20 and 34 d after treatment) and yield.

Herbicide	Rate	Method	Height 14 DAT	Height 21 DAT	Yield
	g/ha		cm	cm	kg/ha
Halosulfuron	13	Drip	77	84	70424
Halosulfuron	26	Drip	75	84	68224
Halosulfuron	53	Drip	76	83	63822
Halosulfuron	26	POST	76	83	70424
Halosulfuron	53	POST	73	79	68224
Imazosulfuron	112	Drip	75	82	69324
Imazosulfuron	224	Drip	76	82	62722
Imazosulfuron	336	Drip	76	84	66023
Imazosulfuron	224	POST	77	84	68224
Imazosulfuron	336	POST	77	82	80328
Trifloxysulfuron	5	Drip	76	83	69324
Trifloxysulfuron	11	Drip	75	81	64922
Trifloxysulfuron	16	Drip	75	82	67123
Trifloxysulfuron	11	POST	75	83	71525
Trifloxysulfuron	16	POST	75	82	70424
Nontreated			75	81	66024
LSD ($P \leq 0.05$)			NS	NS	NS

(Table 3, continued)

Drip vs nontreated contrast	NS	NS	NS
POST-DIR vs nontreated contrast	NS	NS	NS
Drip vs POST-DIR contrast	NS	NS	NS

[z]DAT = d after treatment.

Chapter 2

Tolerance of Bell Pepper to Herbicides Applied Through a Drip Irrigation System

(In the format appropriate for submission to Weed Technology)

Tolerance of Bell Pepper to Herbicides Applied Through a Drip Irrigation System

Peter J. Dittmar, David W. Monks, and Katherine M. Jennings*

Greenhouse and field studies were conducted to determine bell pepper tolerance to halosulfuron, imazosulfuron, and trifloxysulfuron applied through drip irrigation. In greenhouse studies, pepper injury at 14 and 21 DAT from halosulfuron, imazosulfuron, and trifloxysulfuron POST was similar (21 to 35% and 54 to 60%, respectively). Halosulfuron, imazosulfuron, and trifloxysulfuron soil applied in greenhouse studies caused 6 to 8% and 13 to 20% injury to pepper at 14 and 21 DAT, respectively. Pepper injury in greenhouse studies increased in a linear relationship to increasing rate of halosulfuron, imazosulfuron, and trifloxysulfuron regardless of method of application (soil or POST applied). Fresh and dry pepper weight at 28 DAT followed an inverse linear relationship to increasing rate of halosulfuron, imazosulfuron, and trifloxysulfuron. In field studies, bell pepper was tolerant to all herbicide treatments. Pepper height among herbicide treatments ranged from 32 to 37 cm at 14 DAT and were not different than the nontreated check (36 cm). Yield of number one grade (7825 to 14672 kg/ha) and fancy grade (21128 to 27974 kg/ha) pepper fruit was not different in herbicide treated pepper compared to the pepper in the nontreated check (9977 to 26605 kg/ha, respectively).

Nomenclature: Halosulfuron; imazosulfuron; trifloxysulfuron; bell pepper, *Capsicum annuum* L.

Key words: Sulfonylurea, application method, methyl bromide alternatives.

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Bell pepper was grown on 22105 ha in the U.S and N.C. ranked 3rd in pepper production producing 1943 ha of bell pepper in 2006 (USDA-NASS 2008). Bell pepper grown in a plasticulture system has greater water use efficiency and higher marketable yields than pepper produced in a production system not utilizing polyethylene mulch (Morales-Garcia et al. 2010). The use of plasticulture increased early harvest and total yield of bell pepper compared to bareground (Bowen and Frey 2002; VanDerken and Wilcox-Lee 1988).

Most grass and broadleaf weeds are controlled with polyethylene mulches in plasticulture. However, weeds can emerge in the holes where the crop transplants are inserted through the mulch. Yellow (*Cyperus esculentus* L.) and purple nutsedge (*Cyperus rotundus* L.) can also pierce through mulch in plasticulture (Adcock et al. 2008; Henson and Little 1969; Johnson and Mullinix 2008; Webster 2005). To prevent a 10% or greater yield reduction, bell pepper requires a yellow nutsedge weedfree period between 3 to 5 wk after transplanting for a spring crop and 1 to 7 wk after transplanting for a fall crop (Motis et al. 2004). Season-long yellow nutsedge interference at a density < 5 tuber/m^2 decreased bell pepper yield by 10% (Motis et al. 2003). American black nightshade (*Solanum americanum* P. Mill.) at 1 and 4 plants/m^2 decreased bell pepper yield 20 and 50% respectively (Roos 1999). Roos (1999) also reported the critical weedfree period from 3.6 to 4.8 wk after transplanting for American black nightshade in bell pepper based on a 10% total yield loss. Palmer amaranth established as early as 6 wk after planting in the bell pepper planting hole reduced fruit number, whereas, large crabgrass had no effect on fruit number in a study by Norsworthy et al. (2008).

Several herbicides have been evaluated for bell pepper production to control weeds. In a greenhouse study, halosulfuron at 27 and 54 g/ha POST-OTT to bell pepper caused less injury than halosulfuron at 134 g/ha and all three rates of halosulfuron caused greater injury than the nontreated (Armel et al. 2009). Halosulfuron at 13 and 27 g/ha POST-DIR caused minimal injury (≤2%) to bell pepper (Bangarwa et al. 2009). Chile pepper injury was minimal (<10%) when halosulfuron was applied POST-directed at 36 and 43 g/ha (Norsworthy et al. 2007). Halosulfuron PRE at 26, 39, and 52 g/ha gave greater control of carpetweed (*Mollugo verticillata* L.), Palmer amaranth (*Amaranthus palmeri* S. Wats.), and smooth pigweed (*Amaranthus hybridus* L.) in watermelon than halosulfuron POST at 26, 39, and 52 g/ha (MacRae et al. 2008). However, halosulfuron POST provided better yellow nutsedge control than PRE. Shrefler et. al (2007) reported that halosulfuron at 27 g/ha must be applied at 1 wk after watermelon crop emergence to control pigweeds, eclipta (*Eclipta prostrata* L.), and cutleaf groundcherry (*Physalis angulata* L.). Halosulfuron at 53 g/ha applied to the soil or foliage reduced purple nutsedge dry weight by 70 and 71%, respectively, and yellow nutsedge dry weight by 54% for both foliar and soil application (Vencill et al. 1995).

Imazosulfuron PRE applied to sweetpotato controlled cutleaf groundcherry (99 to 100%), entireleaf morningglory (*Ipomoea hederacea* (L.) Jacq. var. *integriuscula* Gray) (96 to 100%), yellow nutsedge (93 to 96%), and purple nutsedge (93 to 96%) at 14 DAT (Miller et al. 2009). *S*-metolachlor at 0.8 kg ai/ha followed by imazosulfuron at 0.112 and 0.224 kg/ha POST-DIR in bell pepper controlled nutsedge 65 to 71% and hairy galinsoga 67 to 100% (Pekarek 2009). Tomato has excellent tolerance to imazosulfuron POST-DIR at 0.11 to 0.33 kg/ha (Jennings 2010). Diploid watermelon yield followed a linear relationship to imazosulfuron rate between 0.1 and 0.4 kg/ha (Dittmar et al. 2010a). Summer squash total yield was not lowered by imazosulfuron at 0.1 to 0.4 kg/ha compared to the nontreated check (Dittmar et al. 2010b).

Trifloxysulfuron at 3.9 and 7.8 g/ha POST-DIR to bell pepper resulted in minimal injury (≤2%) (Bangarwa et al. 2009). Trifloxysulfuron at 11.2 to 33.4 g/ha applied POST-DIR to tomato provided 75 to 100% control of redroot pigweed, ivyleaf and pitted morningglory, sicklepod, and velvetleaf (Buckelew et al. 2007). Soil application of trifloxysulfuron reduced shoot number, shoot weight, and root weight of purple and yellow nutsedge more than a foliar application (McElroy et al. 2003). Culpepper and Stall (2003) also reported trifloxysulfuron at 52 g/ha applied to 5.08 or 12.7 cm yellow nutsedge (80%), smallflower morningglory (94%), and tropic croton (73%).

Although various herbicides have been evaluated in vegetable crops and specifically in pepper and related crops like tomato, few herbicides have been evaluated for application through a drip irrigation system. Herbicide application through drip irrigation may increase herbicide efficacy, increase worker safety, lower rates, and lower cost. Thus, these studies were conducted to determine tolerance of bell pepper to halosulfuron, imazosulfuron, or trifloxysulfuron applied through the drip irrigation.

Materials and Method

Greenhouse. Greenhouse studies were conducted at the Mary Anne Fox Greenhouses, Raleigh, NC. 'Heritage' bell pepper[1] was transplanted into 20 cm wide and 15 cm deep polyethylene pots[2] containing Orangeburg loamy sand (fine-loamy, kaolinitic, thermic typic Kandiudults having pH 5.7 and 0.7% humic matter) from the Horticultural Crops Research Station near Clinton, NC (35°17'N, 77°34'W). Temperature during the studies ranged from 17 to 27°C and pepper received natural light. Pepper was fertilized twice with 20-20-20 fertilizer.

Soil applied treatments in the greenhouse were included to represent drip applied treatments in the field experiments. Soil applied treatments were halosulfuron at 13, 26, 53, and 80 g/ha, imazosulfuron at 112, 224, 336, and 504 g/ha, and trifloxysulfuron at 5, 11, 16, and 24 g/ha. For soil applied treatments, amount of herbicide mixed with water was calculated using the soil surface area in the pot and was applied by pouring the herbicide solution evenly across the soil surface. POST treatments were halosulfuron at 26 and 53 g/ha, imazosulfuron at 224 and 336 g/ha, and trifloxysulfuron at 11 and 16 g/ha. POST treatments included a nonionic surfactant[3] at 0.25% (v/v) and were applied in a spray chamber with an 8002EVS nozzle[4] calibrated to deliver 167 L/ha. The experimental design was randomized complete block design having 3 plants per treatment and each treatment replicated 4 times.

Field. Field studies with plasticulture pepper were conducted in 2008 and 2009 at the Mountain Horticultural Crops Research Station, Mills River, NC (35°23'N, 82°33'W). Production practices for pepper in study were according to N.C. recommendations (Kemble 2010). 'Heritage' bell pepper was planted in plasticulture on raised beds 91 cm wide and 13 cm tall; between bed spacing was 1.5 m on row center. Soil was Codorus loam (fine-loamy, mixed, mesic fluvaquentic Dystrochrepts with pH 6.7 and 1.43% humic matter). Two drip tapes[5] were placed in the center of the bed 2.5 to 5 cm deep and spaced 31 cm apart. Herbicides were applied 3 and 4 wk after transplanting in 2008 and 2009, respectively, when pepper was 20 to 30 cm tall. Herbicide treatments applied through the drip irrigation tape were halosulfuron at 13, 25, and 53 g/ha; imazosulfuron at 112, 224, 336 g/ha; and trifloxysulfuron at 5, 11, and 16 g/ha. Herbicides applied through drip application were injected using a fertilizer injector[6] at 82 kPa (Figure 1). Layflat (A.) was across the experiment in front of each plot to supply water to each plot.

Connected to the layflat was a backflow valve to prevent the herbicide solution from entering the water source. In the injector tank (C.), water mixed with the herbicide solution and spray dye[7]. The clear tubing (D.) is dark in color from the spray dye and as water from the layflat displaced the herbicide solution and spray dye it becomes clear (~45 to 55 min). Finally, the herbicide enters the drip tape (E.) in the raised bed. POST herbicide treatments were halosulfuron at 25 and 53 g/ha, imazosulfuron at 224 and 336 g/ha, and trifloxysulfuron at 11 and 16 g/ha. POST treatments included a nonionic surfactant[3] at 0.25% (v/v) and were directed to the lower 10 cm of the pepper plant using a CO_2 backpack sprayer equipped with an 8002EVS single nozzle[4] calibrated to deliver 167 L/ha of spray solution. Experimental design was a randomized complete block with 4 replications. The studies were maintained weed free by hand removal of weeds from the planting holes at the cotelydon stage of weed growth.

Data collected included pepper height (measured from the soil surface in the hole to the last fully expanded pepper leaf) and visual injury (0% = no injury, 100% = crop death) (Camper 1986) determined at 14 and 21 DAT. Pepper fruit were graded into USDA grades cull, number 1, and fancy grade yields using a mechanical grader[8] (USDA-Agricultural Marketing Service 2005). Marketable fruit consisted of number 1 and fancy grade fruit.

All studies. Data were analyzed using analysis of variance and means were separated using Fisher's Protected LSD ($P \leq 0.05$). Pepper injury, height, weight, and yield where appropriate were fit to regression models with herbicide rate. Years were pooled for injury, plant height, and yield because year variable was not significant.

Results and Discussion

Greenhouse. Injury occurred on pepper as chlorosis and stunting of new growth. Injury to pepper was observed at 14 and 21 DAT, with POST halosulfuron (21 and 60%, respectively), imazosulfuron (35 and 54%, respectively), and trifloxysulfuron (26 and 54%, respectively) (Table 1). Herbicides applied to the soil surface (6 to 20%) caused greater pepper injury than the nontreated (0%). Greater pepper injury was caused by POST halosulfuron (21 and 60%, respectively) than from halosulfuron soil applied (8 and 20%, respectively) (Table 2). Imazosulfuron and trifloxysulfuron followed similar trends. Pepper injury increased in a linear relationship with increasing halosulfuron rate (Figure 2). Halosulfuron POST caused pepper injury between 18 and 24% and soil applied halosulfuron cause pepper injury 6 to 9% at 14 DAT. At 21 DAT, foliar applied halosulfuron injury to pepper was 19 to 24% and soil applied halosulfuron was 9 to 29%. Imazosulfuron POST caused 34 to 36% pepper injury at 14 DAT and 49 to 55% pepper injury at 21 DAT (Figure 3). Imazosulfuron soil application caused pepper injury 5 to 7% at 14 DAT and 4 to 21% at 21 DAT. Pepper injury was 22 to 27% at 14 DAT with increasing rates of trifloxysulfuron POST and 5 to 9% with trifloxysulfuron soil applied (Figure 4). At 21 DAT, pepper injury was 42 to 69% with trifloxysulfuron POST and 4 to 19% with trifloxysulfuron soil applied.

Pepper fresh and dry weight followed an inverse linear relationship to increasing rates of halosulfuron, imazosulfuron, and trifloxysulfuron rate. The nontreated fresh weight was 36 g and fresh weight of foliar applied halosulfuron was 4 to 13 g (Figure 5). Dry weight of the nontreated pepper was 5 g and halosulfuron at 80 g/ha had a dry weight of 1 g. Pepper in POST and soil applied imazosulfuron (Figure 6) and trifloxysulfuron (Figure 7) followed the same trend.

Field. No pepper injury was observed from any herbicide treatment (data not shown). Bell pepper height at 14 or 21 DAT did not differ among herbicide treatments (32 to 37 cm and 39 to 47 cm, respectively) and were similar to pepper in the nontreated treatment (36 and 42 cm, respectively) (Table 3). Pepper in the herbicide treatments produced similar number 1 grade yield (7825 to 14672 kg/ha) compared to the nontreated. Pepper yield over herbicide, herbicide rate, and method of application was not different from the nontreated. Treatments were not different for fancy or total yield.

All studies. Pepper appeared more sensitive to herbicides in greenhouse studies relative to the field studies. In addition, POST herbicide treatments in the greenhouse were applied over-the-top while in the field studies the POST treatments were directed. Bangarwa (2009) reported that pepper tolerance to some sulfonylurea herbicides is improved when POST-directed compared to POST. Candole et al. (2007) showed that one complication with drip applied herbicides is distribution across the raised bed. These field studies included 2 drip tapes in the planting bed to increase application of herbicide treatment across the raised bed.

Soil applied halosulfuron and trifloxysulfuron controlled yellow nutsedge in greenhouse studies (Vencill et al. 1995; McElroy 2003). Additional studies need to be conducted to study the effects of drip applied halosulfuron, imazosulfuron, and trifloxysulfuron on PRE and POST suppression or control of weeds.

Previous research has shown halosulfuron and imazosulfuron applied POST-DIR causes no to minimal pepper injury (Bangarwa et al. 2009; Pekarek 2009). Applying halosulfuron, imazosulfuron, and trifloxysulfuron through the drip irrigation did not cause injury to pepper. An application through drip irrigation would offer a method of application of PRE herbicides under polyethylene mulch in a multicropping plasticulture system and would likely have a minimal effect of the current bell pepper crop.

Sources of Materials

[1] 'Heritage' pepper. Harris Moran, P.O. Box 4938, Modesto, CA 95352.

[2] 15 cm azalea polyethylene pots. ITML Horticultural Products, 75 Plant Farm Blvd, Brantford, ON N35 7W2, Canada.

[3] X-77®, alkylphenol ethoxylate, alcohol ethoxylate, tall oil fatty acid, 2,2' dihydroxydiethyl ether and dimethylpolysiloxane. Loveland Products Inc., PO Box 1286, Greeley, CO 80632-1286.

[4] 8002EVS TeeJet even flat spray tip. TeeJet Technologies. P.O. Box 7900. Wheaton, IL, 61087.

[5] Drip irrigation. Jain Irrigation Inc. P.O. Box 3546. 3857 W. Lake Hamilton Dr. Winter Haven, FL 33881.

[6] EZ-FLO hose and drip system 2.8 L tank. EZ-FLO fertilizing systems, 3640 Cincinnati Ave., Buildings C&D, Rocklin, CA 95765.

[7] Highlight Spray Indicator. Becker Underwood, Inc. 801 Dayton Ave., Ames, IA 50010.

[8] Kerian Speed Sizer Model M30. Kerian Machines Inc. 1709 Hwy 81 S, Grafton, ND 58237.

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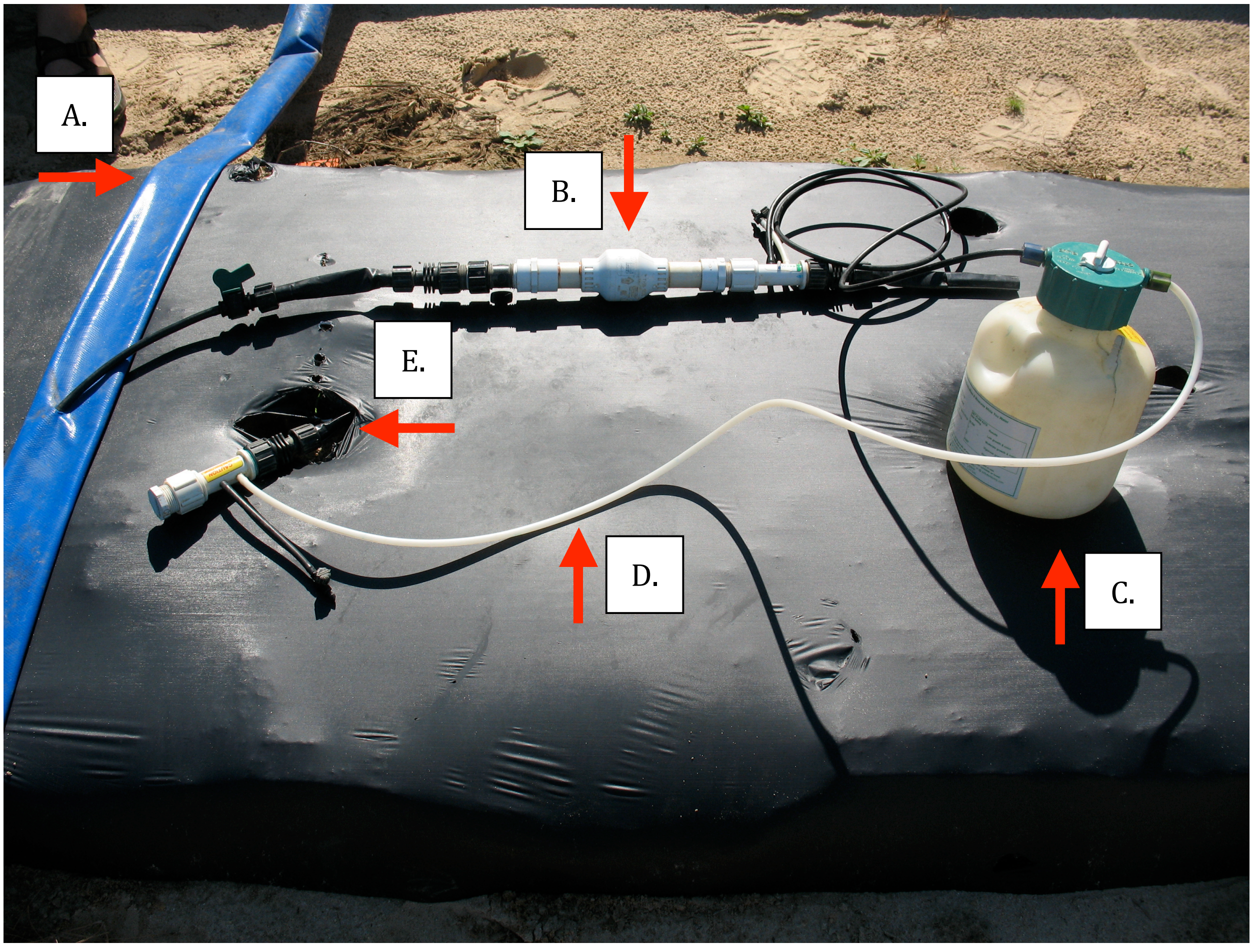

Figure 1. Equipment setup for drip applied herbicide treatments in field studies. Parts are layflat (A.), backflow valve (B.), fertilizer injector tanks (C.), clear tubing (D.), and drip tape irrigation (E.).

Table 1. Effect of halosulfuron, imazosulfuron, and trifloxysulfuron applied postemergence (POST) or to soil on pepper injury[z] in greenhouse studies, Raleigh, NC.

Treatment		Injury	
		14 DAT[y]	21 DAT
		%	
POST	Halosulfuron	21	60
	Imazosulfuron	35	54
	Trifloxysulfuron	26	54
	Nontreated	0	0
	LSD ($P \leq 0.05$)	18	53
Soil	Halosulfuron	8	20
	Imazosulfuron	6	13
	Trifloxysulfuron	6	13
	Nontreated	0	0
	LSD ($P \leq 0.05$)	5	12

[z]0% = no injury, 100% = plant death.

[y]DAT = after treatment (DAT).

Table 2. Effect of halosulfuron, imazosulfuron, or trifloxysulfuron (over rates) applied postemergence (POST) or to soil on pepper injury[z] in greenhouse studies, Raleigh, NC.

	Injury	
Treatment	14 DAT[y]	21 DAT
	%	
Halosulfuron		
POST	21	60
Soil	8	20
LSD ($P \leq 0.05$)	12	32
Imazosulfuron		
POST	35	54
Soil	6	13
LSD ($P \leq 0.05$)	21	39
Trifloxysulfuron		
POST	26	54
Soil	6	13
LSD ($P \leq 0.05$)	18	37

[z]0% = no injury, 100% = plant death.

[y]DAT = d after treatment

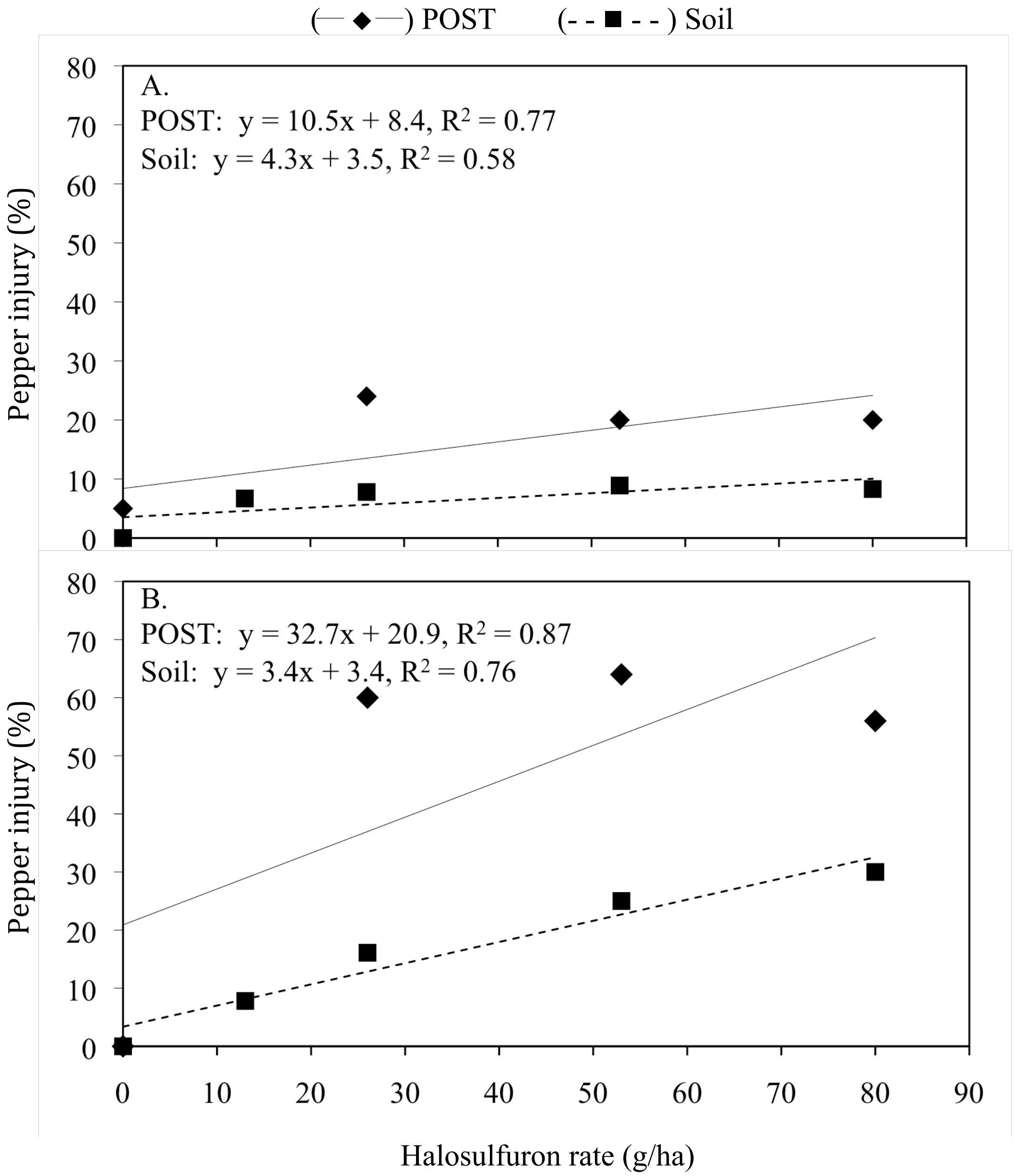

Figure 2. Effect of halosulfuron applied to the soil or POST on visual pepper injury (0% = no injury, 100% = plant death) 14 (A.) and 21 (B.) d after treatment in greenhouse studies, Raleigh, NC.

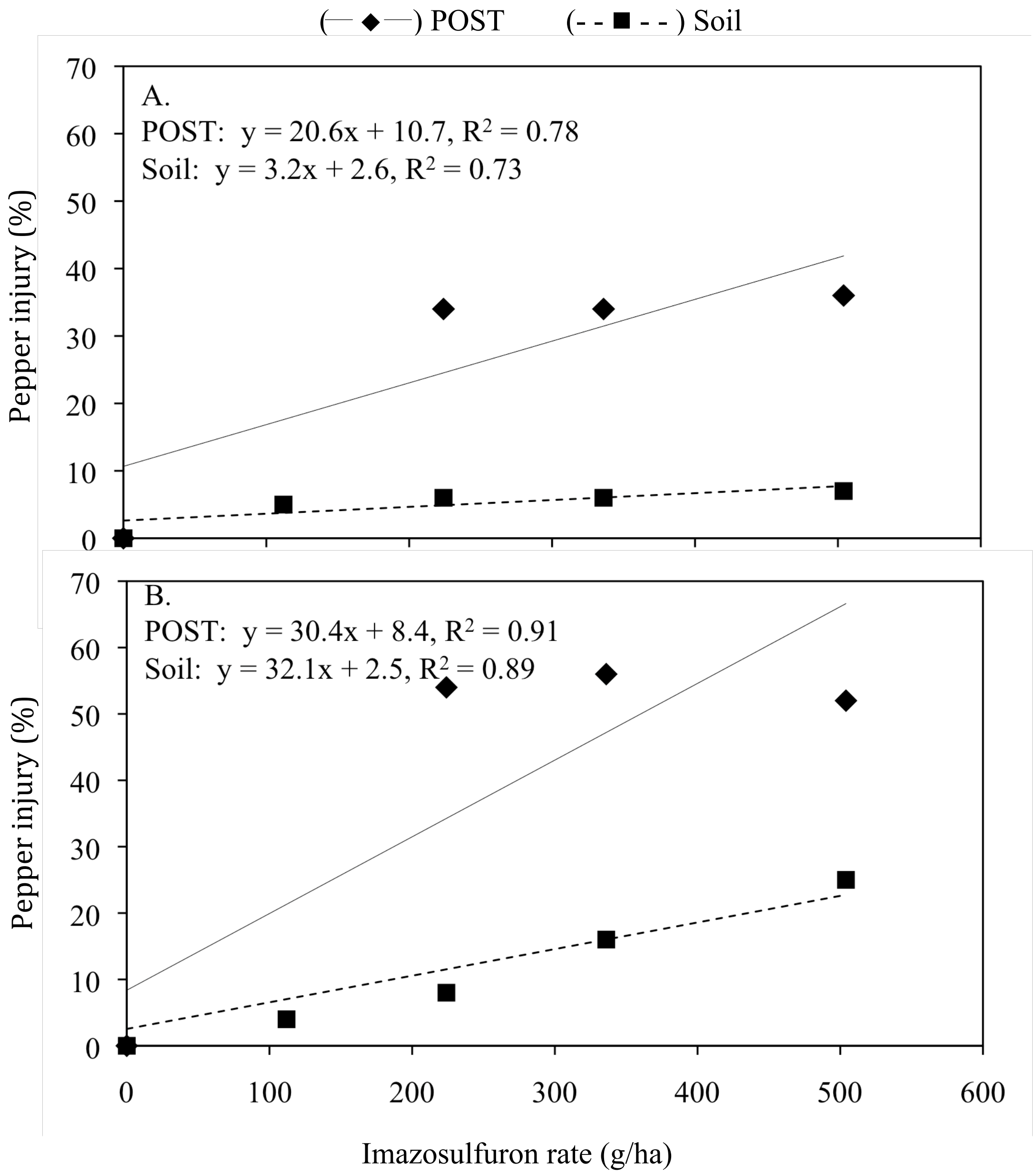

Figure 3. Effect of imazosulfuron applied to the soil or POST on visual pepper injury (0% = no injury, 100% = plant death) 14 (A.) and 21 (B.) d after treatment in greenhouse studies, Raleigh, NC.

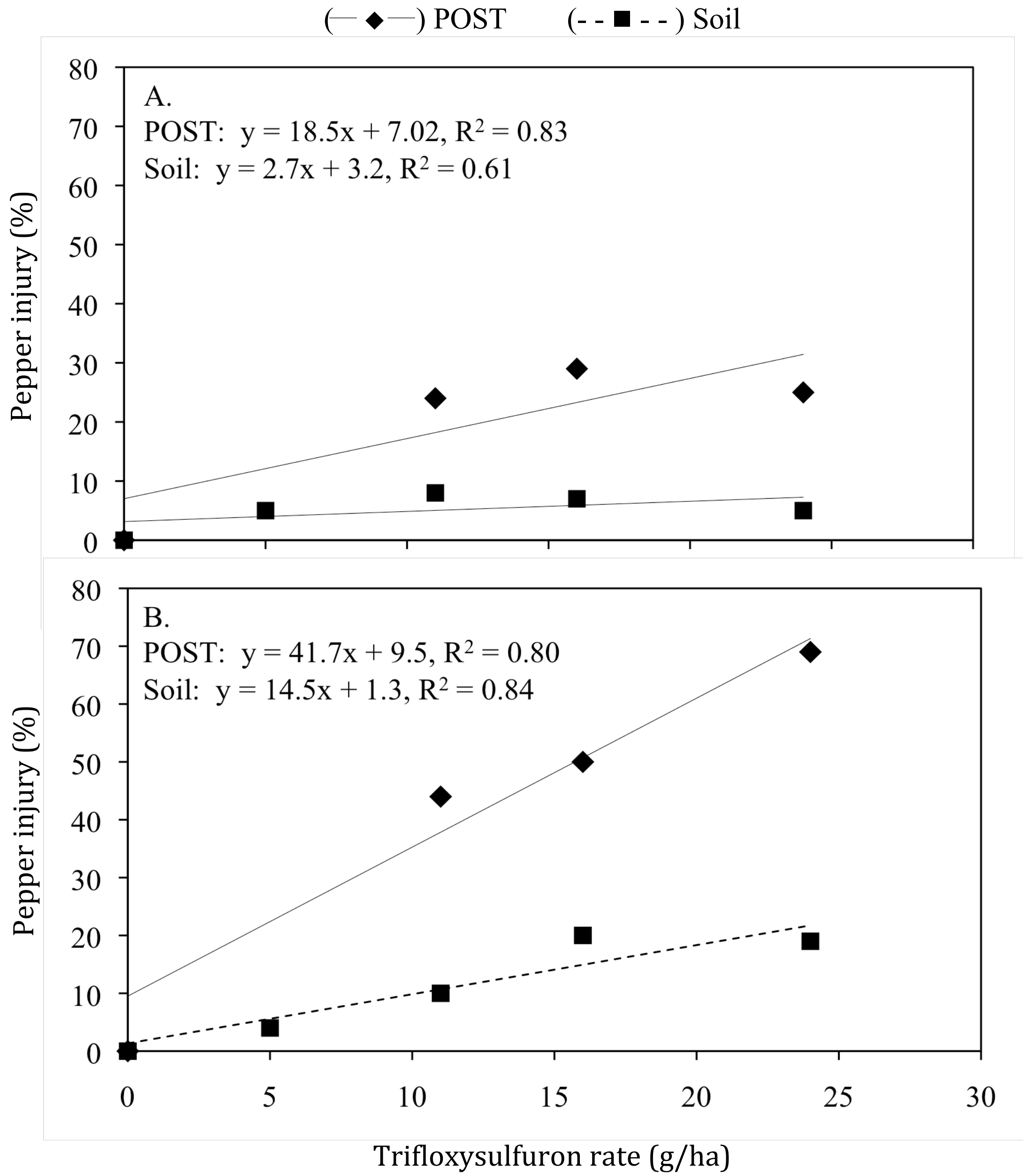

Figure 4. Effect of trifloxysulfuron applied to the soil or POST on visual pepper injury (0% = no injury, 100% = plant death) 14 (A.) and 21 (B.) d after treatment in greenhouse studies, Raleigh, NC.

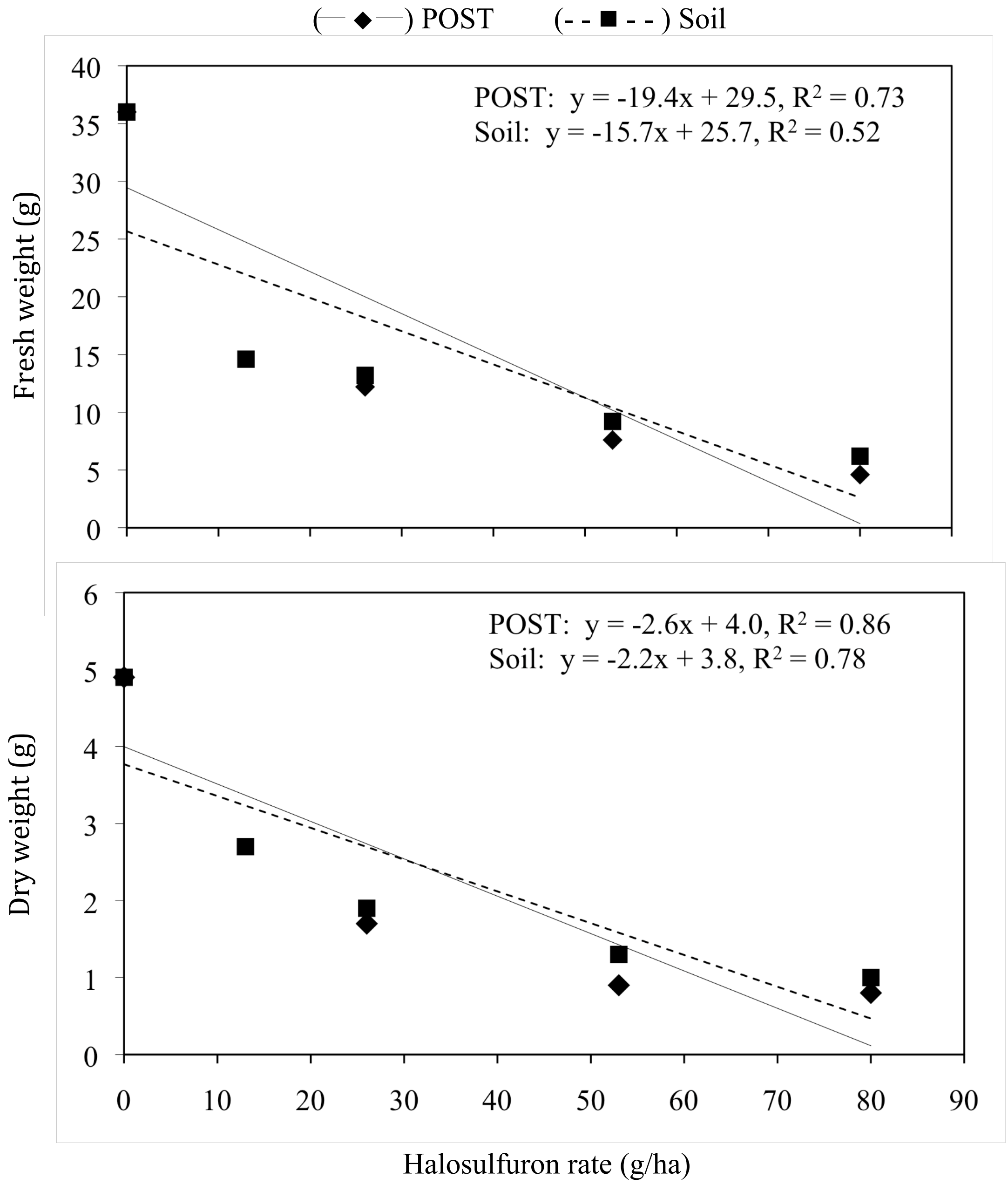

Figure 5. Effect of halosulfuron applied to the soil or POST on pepper fresh and dry weight in greenhouse studies, Raleigh, NC.

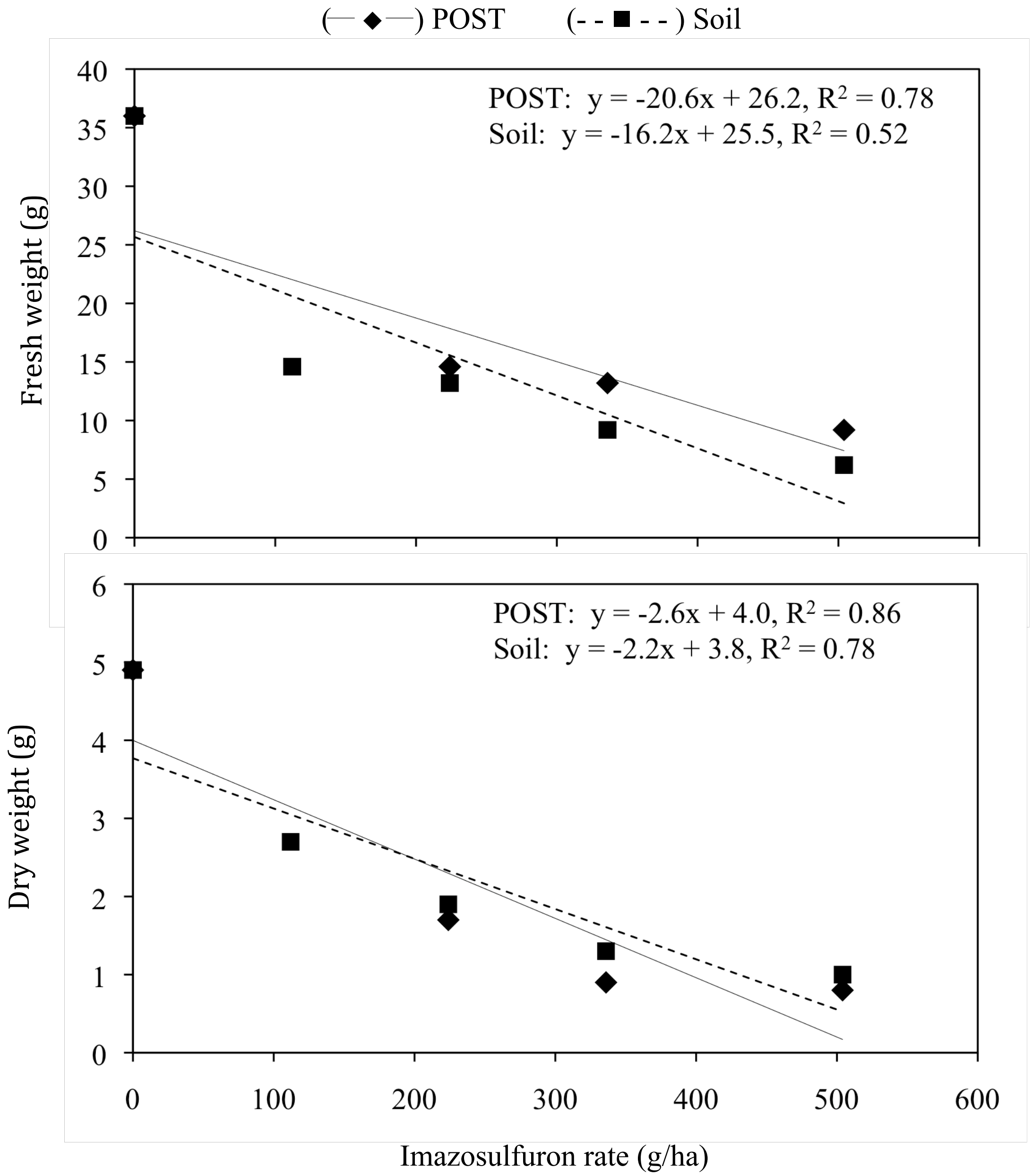

Figure 6. Effect of imazosulfuron applied to the soil or POST on pepper fresh and dry weight in greenhouse studies, Raleigh, NC.

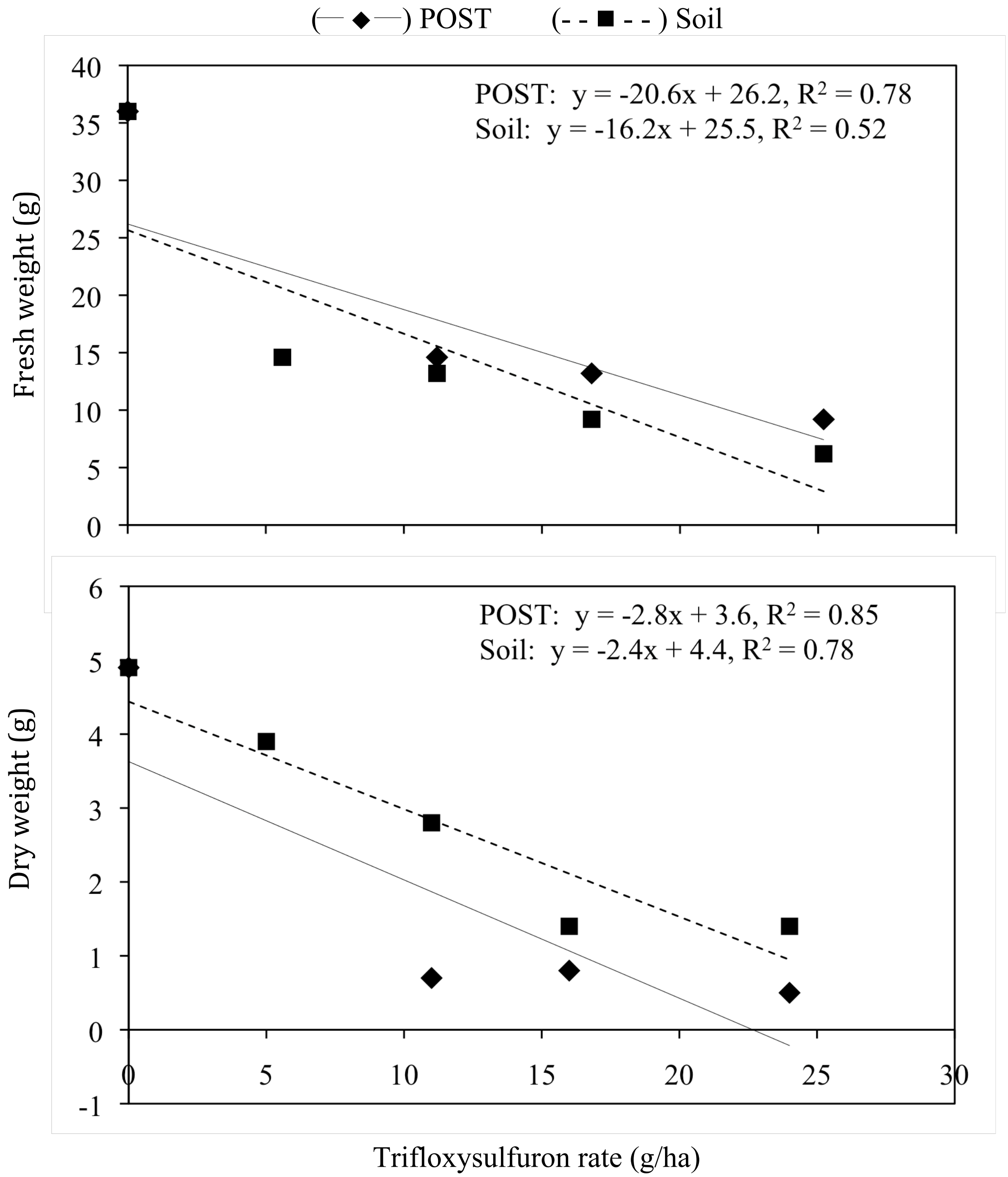

Figure 7. Effect of trifloxysulfuron applied to the soil or POST on pepper fresh and dry weight in greenhouse studies, Raleigh, NC.

Table 3. Effect of herbicide POST-DIR or applied through the drip irrigation on pepper height (20 and 34 d after treatment) and yield, Mills River, NC.

			Height		Yield		
Herbicide	Rate	Method	14 DAT	21 DAT	No. 1	Fancy	Total
	g/ha		cm		kg/ha		
Halosulfuron	13	Drip	37	43	11542	23083	34625
Halosulfuron	26	Drip	36	41	11542	21910	33452
Halosulfuron	53	Drip	35	39	8608	22693	31301
Halosulfuron	26	POST-DIR	36	41	8999	26213	35407
Halosulfuron	53	POST-DIR	34	41	10368	22497	32864
Imazosulfuron	112	Drip	36	43	13889	26801	40690
Imazosulfuron	224	Drip	34	41	11151	25431	36582
Imazosulfuron	336	Drip	35	42	11542	25040	36582
Imazosulfuron	224	POST-DIR	36	44	7825	27974	35604
Imazosulfuron	336	POST-DIR	37	46	14672	22105	35212
Trifloxysulfuron	5	Drip	37	47	13694	21128	35017
Trifloxysulfuron	11	Drip	36	42	10368	25626	35995
Trifloxysulfuron	16	Drip	34	39	12716	22497	35408
Trifloxysulfuron	11	POST-DIR	36	42	11151	24648	35995
Trifloxysulfuron	16	POST-DIR	32	40	11737	23866	35604
Nontreated			36	42	9977	26605	36582
LSD ($P \leq 0.05$)			NS	NS	NS	NS	NS

(Table 3, continued)

Drip vs POST-DIR contrast	NS	NS	NS	NS	NS
POST-DIR vs nontreated contrast	NS	NS	NS	NS	NS
Drip vs nontreated contrast	NS	NS	NS	NS	NS

[z]DAT=d after treatment.

Chapter 3

Effect of Drip-Applied Herbicides on Yellow Nutsedge (*Cyperus esculentus*) in Plasticulture

(In the format appropriate for submission to Weed Technology)

Effect of Drip-Applied Herbicides on Yellow Nutsedge (*Cyperus esculentus*) in Plasticulture

Peter J. Dittmar, Katherine M. Jennings, and David W. Monks[*]

Greenhouse and field studies were conducted to determine the effect of halosulfuron, imazosulfuron, and trifloxysulfuron applied through drip irrigation on yellow nutsedge. In greenhouse studies, no differences in yellow nutsedge control were observed between halosulfuron, imazosulfuron, and trifloxysulfuron and control ranged from 69 to 91%. Yellow nutsedge control by halosulfuron, imazosulfuron, and trifloxysulfuron was greater than the nontreated. In field studies at Clinton, yellow nutsedge density increased from treatment (day 0) to 56 d after treatment. Increase in yellow nutsedge density was 72 and 95% in drip applied halosulfuron and imazosulfuron treatments compared to yellow nutsedge density increases of 876% for the same time period in the nontreated. Yellow nutsedge density increased 69 and 57% at Clinton and Kinston, respectively, in the drip applied 15 g/ha trifloxysulfuron treatment compared to 876% in the nontreated. In field studies at Clinton and Kinston, suppression of yellow nutsedge emergence in POST and drip applied herbicide treatments was similar. Emergence of yellow nutsedge was similar in the imazosulfuron POST and the nontreated. Based on these studies, drip applied herbicides may be beneficial in yellow nutsedge control programs, and when included with POST herbicides likely may result in both PRE and POST control of yellow nutsedge. Drip applied herbicides also may give growers an option for application of herbicides after drip irrigation tape and polyethylene mulch has been installed in

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vegetable crops and in a plasticulture system that reuses the mulch such as in multicropping systems.

Nomenclature: Halosulfuron; imazosulfuron; trifloxysulfuron; yellow nutsedge, *Cyperus esculentus* L.

Key words: Sulfonylurea, herbicide application method, methyl bromide alternatives, drip irrigation.

Vegetable crop production utilizing polyethylene mulch and fertigation increases crop yield of vegetables, reduces nutrient leaching, produces a cleaner harvested product, and allows multi-cropping compared to bareground vegetable production (Lamont 1993). Polyethylene mulches provide excellent control of grass and broadleaf weeds; however, weeds commonly emerge through the hole in the mulch where the crop is established. The most troublesome weeds in plasticulture vegetable crops are yellow (*Cyperus esculentus* L.) and purple nutsedge (*Cyperus rotundus* L.), which not only emerge from the hole in the mulch where the crop is transplanted, but can also penetrate through polyethylene mulch (Adcock et al. 2008; Henson and Little 1969; Johnson and Mullinix 2008; Webster 2005).

Plasticulture systems utilize drip irrigation to deliver water and fertilizer to the root zone of vegetables (Kemble 2010). The wetting front from drip irrigation is u-shaped, with vertical water movement predominating over lateral water movement (Csinos et al. 2002). Various fumigants and other pesticides including insecticides and herbicides have been applied via drip irrigation in plasticulture and then evaluated for their effectiveness in providing control of pests. 1,3-dichloropropene plus chloropicrin applied through dip irrigation gave greater control of *Phytophthora capsici* and *Rhizoctonia solani* 10 cm below the emitter than 20 cm away from the emitter (10 cm deep) (Candole et al. 2007). Chloropicrin EC at 200 L/ha and 1,3-dichloropropene + chloropicrin at 236 to 393 L/ha applied through drip irrigation provided weed control similar to shank applied methyl bromide:chloropicrin mixture (67:33) (Fennimore et al. 2003). 1,3-dichloropropene plus chloropicrin and chloropicrin EC applied through drip irrigation in strawberry on bedded rows provided greater control of little mallow (*Malva parviflora* L.) and prostrate knotweed (*Polygonum aviculare* L.) in the center of the bed than at the edges

(Fennimore et al. 2003). Thus drip applied pesticides have great potential for controlling pests in vegetables grown in plasticulture.

Various herbicides have given effective control of yellow or purple nutsedge in crop systems. Sulfonylurea herbicides are a family of herbicides that includes halosulfuron, imazosulfuron, and trifloxysulfuron, all which give varying levels of suppression or control of nutsedge species. Control of purple and yellow nutsedge is greater when halosulfuron is applied POST than when halosulfuron is applied PRE (Adcock et al. 2008). However, Vencill et al. (1995) reported dry weight of purple and yellow nutsedge shoots and roots did not differ between halosulfuron applied solely to foliage or to soil. Halosulfuron also controlled other broadleaf weeds including pigweed (*Amaranthus palmeri* S. Wats. and *Amaranthus albus* L.), eclipta (*Eclipta prostrata* L.), and cutleaf groundcherry (*Physalis angulata* L.) in watermelon (Shrefler et al. 2007). Eggplant height, fruit number, and fruit yield followed an inverse linear relationship to halosulfuron at 0, 26, 39, and 52 g ai/ha applied pretransplant through the drip irrigation (Webster and Culpepper 2005). Total fruit yield of eggplant treated with drip-applied halosulfuron at 39 g ai/ha or less was ≤4% of the nontreated check. Drip-applied halosulfuron at 26 g ai/ha applied 1 and 3 wk after transplant reduced first and second harvests biomass ≥33% and ≤7% of the nontreated check. Total fruit yield from the 1, 2, and 3 wk after transplant applications of halosulfuron were similar to the nontreated check (Webster and Culpepper 2005). Triploid watermelon treated with halosulfuron POST at 39 g/ha lowered marketable and average individual fruit weight, and vine length compared to the nontreated check (Dittmar et al. 2008).

Imazosulfuron is an experimental herbicide being developed in the U.S. by Valent USA Corporation for tomato, pepper, potato, and row crops. Imazosulfuron POST-DIR at 0.11 and

0.22 kg ai/ha controlled yellow nutsedge and hairy galinsoga (Pekarek 2008). Imazosulfuron applied sequentially at 0.34, 0.45, and 0.56 kg ai/ha provided yellow nutsedge control ranging from 79 to 98% (Boydston & Felix 2008). Imazosulfuron at 0.1 and 0.2 kg/ha caused less injury to diploid watermelon when applied at the 30.5 cm vining stage compared to the 2- to 4- lf stage (Dittmar et al. 2010).

Trifloxysulfuron is a sulfonylurea herbicide registered for cotton, tomato, and sugarcane and controls redroot pigweed, smooth pigweed, yellow nutsedge, and morningglory and provides suppression of purple nutsedge (Anonymous 2009). Trifloxysulfuron at 11.2, 16.8, and 33.4 g/ha provided 75 to 100% control of redroot pigweed, ivyleaf, and pitted morningglories, sicklepod, and velvetleaf (Buckelew et al. 2007). Soil application of trifloxysulfuron decreased shoot number, shoot weight, and root weight of purple and yellow nutsedge more than a foliar application (McElroy et al. 2003). Trifloxysulfuron at 21 to 63 g/ha with 0.25% (v/v) nonionic sufactant applied at the six leaf stage of yellow nutsedge growth reduced fresh weight 91 to 93% of the control (Singh and Singh 2004).

Although halosulfuron, imazosulfuron and trifloxysulfuron have been evaluated PRE and POST for nutsedge control, few studies have evaluated drip applied sulfonylurea herbicides in plasticulture. The objective of this study was to determine yellow nutsedge control with drip applied halosulfuron, imazosulfuron, and trifloxysulfuron.

Materials and Methods

Greenhouse. Studies were conducted at the Mary Anne Fox Greenhouses at N.C. State University, Raleigh, NC. Yellow nutsedge tubers were planted five per pot into Orangeburg loamy sand (fine-loamy, kaolinitic, thermic typic Kandiudults having pH 5.7 and 0.27% humic matter) from the Horticultural Crops Research Station, Clinton, NC, in 20 cm wide by 15 cm deep polyethylene pots[1]. Plants were fertilized twice with a 20-20-20 fertilizer at 238 ppm nitrogen. Greenhouse temperatures were 24 to 28°C and plants were given natural sunlight with no artificial lighting. Herbicide treatments were soil applied halosulfuron at 13, 26, 53, and 80 g/ha, imazosulfuron at 112, 224, 336, and 504 g/ha, and trifloxysulfuron at 5,11, 16, and 24 g/ha. The soil applied treatments were included to determine the effect of herbicides on yellow nutsedge when applied to the root system as occurs with a drip applied herbicide treatment in the field. Quantity of herbicide was based on the area of soil surface and was applied with 3 ml of water equally across the soil surface. POST treatments of halosulfuron at 26 and 53 g/ha, imazosulfuron at 224 and 336 g/ha, and trifloxysulfuron at 11 and 16 g/ha were also included. The POST applied treatments are similar to current growers' practices. A nonionic surfactant[2] at 0.25% (v/v) was added to all herbicide spray solutions applied POST. Nontreated check plants were included for comparison. All herbicide treatments were applied when yellow nutsedge was 20 to 25 cm tall. Soil applied herbicide treatment rates were calculated based on the area of the soil surface and were poured over the soil surface. POST treatments were applied in a spray chamber equipped with an 8002EVS[3] nozzle calibrated to deliver 167 L/ha at 276 kPa and 4.8 km/h.

Treatments were arranged in a randomized complete block design with 4 replications and 3 pots per replication. Yellow nutsedge control was visually rated (0% = no control and 100% = complete control) (Camper 1986) at 14 and 21 d after treatment (DAT). Plant height was measured at 14 DAT.

Field. Studies were conducted in 2010 at the Cunningham Research Station, Kinston, NC (35°1'N, 78°15'W), and Horticultural Crops Research Station, Clinton, NC (35°17'N, 77°34'W) in fields having a history of yellow nutsedge and in a raised bed plasticulture system with beds 13 cm tall and 91 cm wide. Soil was a Norfolk sandy loam (fine loamy, siliceous, thermic, typic Kandiudults having pH 5.9 and 0.27% humic matter) at Kinston and an Orangeburg loamy sand (fine-loamy, kaolinitic, thermic typic Kandiudults having pH 5.9 and 0.13% humic matter) at Clinton. Treatments were a factorial arrangement of 2 drip tape treatments (one drip tape or two drip tapes) by 12 herbicide treatments and a nontreated check. The treatment with two drip tapes included two drip tapes positioned 30 cm apart in the center of the bed. The treatment with one drip tape was in the center of the bed. Fewer herbicide treatments were used in the field experiments because of field space and amount of time for applications. Selected herbicide treatments were based on greenhouse experiment conclusions. Soil applied herbicides were injected and consisted of halosulfuron at 13, 25, and 53 g/ha; imazosulfuron at 112, 224, and 336 g/ha; and trifloxysulfuron at 5, 11, and 16 g/ha. The POST herbicide treatments were applied over the top of yellow nutsedge and included halosulfuron at 24 g/ha, imazosulfuron at 224 g/ha, and trifloxysulfuron at 11 g/ha. All POST treatments included a nonionic surfactant at 0.25% (v/v). POST treatments were applied with a backpack sprayer equipped with DG8002VS nozzles[4] calibrated to deliver 167 L/ha. Injected herbicides were applied with a tank[5] pressurized to 82 kPa. Drip tape was cut at the beginning and end of each plot and closed at the end of the plot. Across the front of each plot was layflat (A.) to bring water to each plot (Figure 1). Attached to the layflat was a backflow valve (B.) to prevent the herbicide from entering the water source. Water displaced the herbicide solution and spray dye[6] in the injection tanks. The clear tubing (D.) was dark in color and became lighter in color over time. The clear tubing was connected to the drip tape (E.). When the solution in the clear tubing was clear (~45 to 55 min) then the tank was disconnected and moved to the next plot. At application of all herbicides, yellow nutsedge was 8 to 20 cm tall. Yellow nutsedge control was visually rated (0% = no control and 100% = complete control) at 7, 14, 21, and 56 d DAT and yellow nutsedge plants were counted at 0 and 56 DAT. Percent increase in yellow nutsedge density was calculated [(final count-initial count)/initial count]. Data was analyzed using analysis of variance and means were separated with Duncan's multiple range test ($P \leq 0.05$).

Results and Discussion

Greenhouse. Yellow nutsedge was controlled 78 to 87%, 69 to 82%, and 85 to 91% by the soil and POST applied halosulfuron, imazosulfuron, and trifloxysulfuron, respectively (Table 1). Yellow nutsedge control did not differ between herbicide placement (soil or POST) at 21 DAT (Table 2). With one exception, similar results were observed 14 DAT. No differences in yellow nutsedge visual control were observed for rate within each herbicide during the study (data not shown).

Field. No differences were observed between 1 and 2 drip tapes in the planting bed, thus means are combined. Yellow nutsedge emergence and the resulting yellow nutsedge density differed between locations and thus are presented separately. At Clinton, increases in yellow nutsedge density was less in the drip applied halosulfuron (72%) and imazosulfuron (95%) treatments compared to the nontreated (270%) (Table 3). Likewise, Kinston, increases in yellow nutsedge were lower with halosulfuron (267%) and imazosulfuron (354%) compared to the nontreated (876%). At both locations, increase in yellow nutsedge density (110 and 606%) in the trifloxysulfuron treatment was similar to the nontreated (270 and 876%). At Clinton, plots treated with halosulfuron, imazosulfuron and trifloxysulfuron drip or POST applied had lower yellow nutsedge increases than the nontreated check (Table 4). At Kinston, halosulfuron drip (267%) and POST (108%) applied suppressed the emergence of yellow nutsedge. Imazosulfuron POST (981%) treatment had similar emergence of yellow nutsedge as the nontreated check (876%).

Drip applied halosulfuron at all rates had less nutsedge emergence (68 to 69% at Clinton and 248 to 297% at Kinston) than the nontreated check (270% and 876%) (Table 5). Drip applied imazosulfuron at the highest two rates suppressed yellow nutsedge emergence compared to the nontreated and imazosulfuron at 112 g/ha. Drip applied trifloxysulfuron at 15 g/ha (69 and 57% at Clinton and Kinston, respectively) had lower yellow nutsedge emergence than trifloxysulfuron 5 g/ha (130 and 1237%, respectively), trifloxysulfuron 11 g/ha (133 and 527%, respectively), and nontreated (270 and 876%, respectively). At both locations, trifloxysulfuron POST was similar to the drip treatment (Table 6).

In the greenhouse, the application of herbicides regardless of placement (POST or soil applied) provided 74% yellow nutsedge control. Applying halosulfuron, imazosulfuron, and trifloxysulfuron through drip irrigation reduced the emergence of yellow nutsedge. However, at Kinston, yellow nutsedge emergence was higher in the trifloxysulfuron treatment compared to halosulfuron and imazosulfuron treatments. Halosulfuron at registered and lower rates provided 72% yellow nutsedge control.

No differences were observed between one or two drip tapes. Fennimore (2003) and Candole

(2007) reported lowered weed control at distance further from the drip irrigation emitters, however, these studies used fumigants that stay in the soil for a shorter period of time. In this study, some yellow nutsedge had emerged and weed counts were over a longer period of time than in the study by Fennimore (2003) or Candole (2007). This extended period of time allowed observation of POST and PRE control of the yellow nutsedge. The application of these herbicides through drip irrigation provides control or suppression to the subterranean parts of the yellow nutsedge, which have been identified by Morale-Payan et al. (1997) is most important in weed/tomato competition.

While drip applied herbicides gives some reduction in the emergence of yellow nutsedge, other methods must be included in the weed management system for effective yellow nutsedge control. POST application of halosulfuron or trifloxysulfuron applied over the polyethylene mulch is likely needed for acceptable control of yellow nutsedge. An application of herbicides through drip irrigation would be extremely valuable in a plasticulture system that reuses the mulch such as in multicropping systems.

Sources of Materials

[1]15 cm azalea polyethylene pots. ITML Horticultural Products, 75 Plant Farm Blvd, Brantford, ON N35 7W2, Canada.

[2] X-77®, alkylphenol ethoxylate, alcohol ethoxylate, tall oil fatty acid, 2,2’ dihydroxydiethyl ether and dimethylpolysiloxane. Loveland Products Inc., PO Box 1286, Greeley, CO 80632-1286.

[3] 8002EVS TeeJet even flat spray tip. TeeJet Technologies. P.O. Box 7900. Wheaton, IL,

61087.

[4] DG8002 TeeJet drift guard flat spray tip. TeeJet Technologies. P.O. Box 7900. Wheaton, IL, 61087.

[5] EZ-FLO hose and drip system 2.8 L tank. EZ-FLO Fertilizing Systems, 3640 Cincinnati Ave., Buildings C&D, Rocklin, CA 95765.

[6] Highlight spray indicator. Becker Underwood, Inc. 801 Dayton Ave., Ames, IA 50010.

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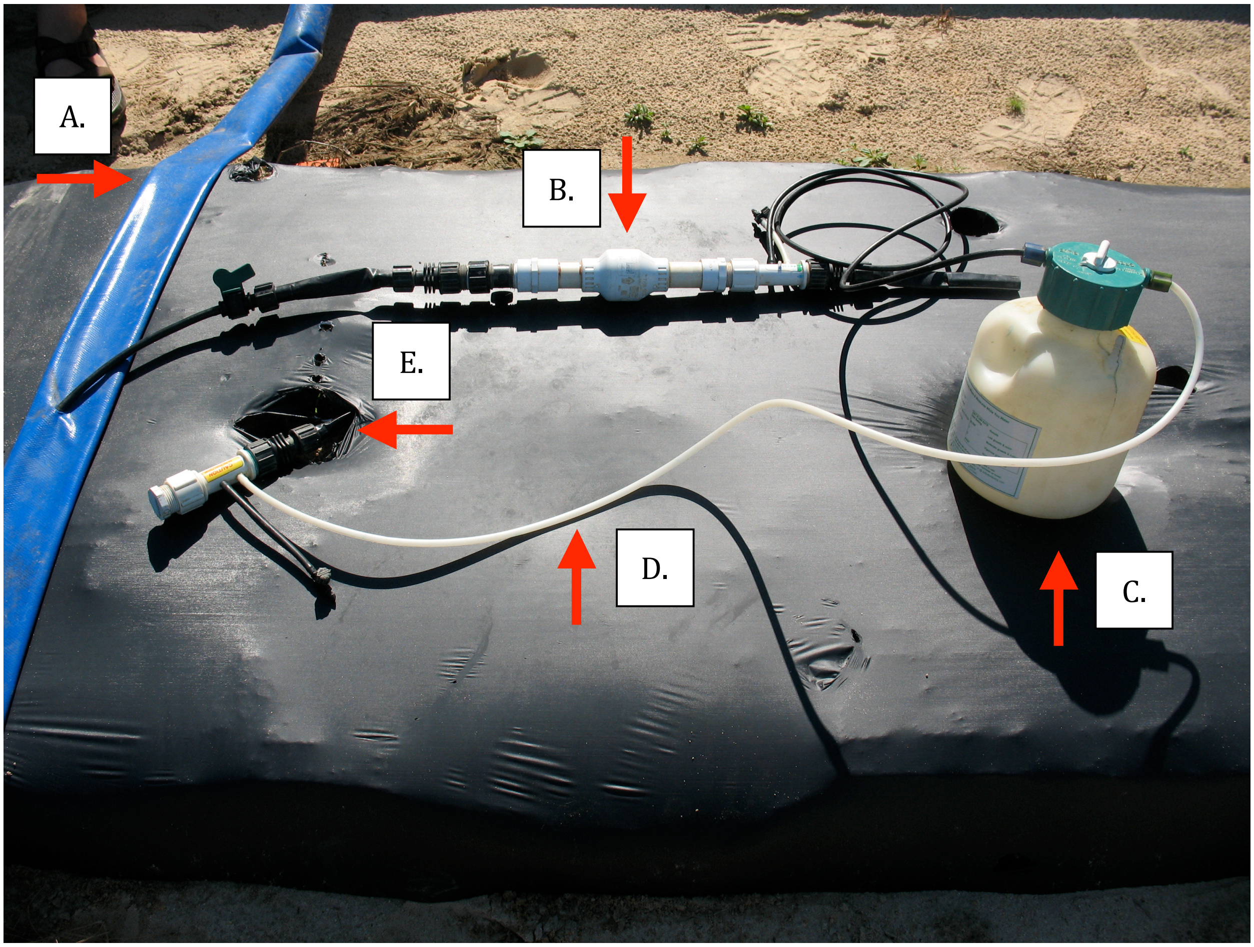

Figure 1. Equipment setup for drip applied herbicide treatments in field studies. Parts are layflat (A.), backflow valve (B.), fertilizer injector tanks (C.), clear tubing (D.), and drip tape irrigation (E.).

Table 1. Effect of POST and soil-applied halosulfuron, imazosulfuron, and trifloxysulfuron averaged over rates on yellow nutsedge control[z] in greenhouse studies, Raleigh, NC.

		Control	
Method	Herbicide	14 DAT[y]	21 DAT
		%	
POST	Halosulfuron	81 a[x]	87 a
	Imazosulfuron	74 a	82 a
	Trifloxysulfuron	87 a	91 a
	Nontreated	0 b	0 b
Soil	Halosulfuron	78 a	85 a
	Imazosulfuron	69 a	78 a
	Trifloxysulfuron	85 a	90 a
	Nontreated	0 b	0 b

[z] 0% = no control, 100% = plant death.

[y] DAT = d after treatment.

[x] Means within the column by method with the same letter are not statistically different at the $P \leq 0.05$ level using Fisher's Protected LSD.

Table 2. Effect of halosulfuron, imazosulfuron, and trifloxysulfuron averaged over rates POST and soil-applied on yellow nutsedge control[z] in greenhouse studies, Raleigh, NC.

Herbicide	Placement	Control 14 DAT[y]	Control 21 DAT
		%	
Halosulfuron	POST	81 a[x]	87 a
	Soil	78 a	85 a
Imazosulfuron	POST	74 a	82 a
	Soil	69 b	78 a
Trifloxysulfuron	POST	87 a	91 a
	Soil	85 a	90 a

[z] 0% = no control, 100% = plant death.

[y] DAT = d after treatment.

[x] Means within the column by method with the same letter are not statistically different at the $P \leq 0.05$ level using Fisher's Protected LSD.

Table 3. Effect of herbicide applied through drip irrigation on percent increase of yellow nutsedge density from 0 to 56 d after herbicide application [(final count-initial count)/initial count].

	Yellow nutsedge	
Treatment	Clinton	Kinston
	%	
Halosulfuron	72 b[z]	267 b
Imazosulfuron	95 b	354 b
Trifloxysulfuron	110 ab	606 ab
Nontreated	270 a	876 a

[z] Means within the column with the same letter are not statistically different at the $P \leq 0.05$ level using Fisher's Protected LSD.

Table 4. Effect of halosulfuron, imazosulfuron, and trifloxysulfuron (averaged over rates) applied through the drip tape irrigation on percent increase in yellow nutsedge density [(final count-initial count)/initial count] from 0 to 56 d after herbicide application.

		Yellow nutsedge	
Herbicide	Treatment	Clinton	Kinston
		%	
Halosulfuron	Drip	72 b[z]	267 b
	POST	62 b	108 b
	Nontreated	270 a	876 a
Imazosulfuron	Drip	95 b	354 b
	POST	90 b	981 a
	Nontreated	270 a	876 ab
Trifloxysulfuron	Drip	110 b	607 ab
	POST	115 b	259 b
	Nontreated	270 a	876 a

[z] Letters following numerical values are statistically different based on Duncan's Multiple Range Test ($P \leq 0.05$) within herbicide.

Table 5. Effect of halosulfuron, imazosulfuron, and trifloxysulfuron applied through the drip tape irrigation on percent increase in yellow nutsedge density [(final count-initial count)/initial count] from 0 to 56 d after herbicide application.

		Yellow nutsedge	
Herbicide	Method	Clinton	Kinston
		%	
Halosulfuron	13	78 b[z]	248 b
	26	68 b	297 b
	53	69 b	255 b
	0	270 a	876 a
Imazosulfuron	112	193 a	366 a
	224	45 b	381 a
	336	48 b	315 a
	0	270 a	876 a
Trifloxysulfuron	5	130 ab	1237 a
	11	133 ab	527 ab
	15	69 b	57 b
	0	270 a	876 a

[z] Letters following numerical values are statistically different based on Duncan's Multiple Range Test ($P \leq 0.05$) within herbicide.

Table 6. Effect of halosulfuron, imazosulfuron, and trifloxysulfuron applied through the drip tape irrigation or POST over-the-top on percent increase in yellow nutsedge density [(final count-initial count)/initial count] from 0 to 56 d after herbicide application.

			Yellow nutsedge	
Herbicide	Method	Rate	Clinton	Kinston
			%	
Halosulfuron	Drip	13	78 b[z]	248 b
		26	68 b	297 b
		53	69 b	255 b
	POST	26	62 b	108 b
		0	270 a	876 a
Imazosulfuron	Drip	112	193 ab	366 b
		224	45 b	381 b
		336	48 b	315 b
	POST	224	90 b	981 a
		0	270 a	876 ab
Trifloxysulfuron	Drip	5	130 ab	1237 a
		11	133 ab	527 bc
		15	69 b	57 c
	POST	11	115 b	259 bc
		0	270 a	876 ab

[z] Letters following numerical values are statistically different based on Duncan's Multiple Range Test ($P \leq 0.05$) within herbicide.

Chapter 4

Effect of Soil and POST applied Halosulfuron, Imazosulfuron, and Trifloxysulfuron on Photosynthetic Rate and Stomatal Conductance of Tomato and Yellow Nutsedge (*Cyperus esculentus*)

(In the format appropriate for submission to Weed Technology)

Effect of Soil and POST applied Halosulfuron, Imazosulfuron, and Trifloxysulfuron on Photosynthetic Rate and Stomatal Conductance of Tomato and Yellow Nutsedge (*Cyperus esculentus*)

Peter J. Dittmar, David W. Monks, and Katherine M. Jennings[*]

The effect of halosulfuron, imazosulfuron, and trifloxysulfuron on photosynthetic rate and stomatal conductance of tomato and yellow nutsedge was determined in greenhouse studies. Soil and POST applied treatments of halosulfuron at 53 g/ha, imazosulfuron at 336 g/ha, trifloxysulfuron at 16 g/ha, and a nontreated treatment were included in the studies. Tomato photosynthesis rate was reduced 5 d after treatment (DAT) by halosulfuron POST compared to nontreated tomato. Soil applied halosulfuron reduced photosynthesis rate of tomato in experiment 1. Stomatal conductance of tomato was not different among treatments except 7 DAT in experiment 1 when tomato treated with halosulfuron soil or POST applied was less than nontreated tomato. Yellow nutsedge treated with halosulfuron POST (0.6 to 22.6 $\mu mol/m^2/s$) had a lower photosynthetic rate at 4, 7, and 14 DAT than nontreated yellow nutsedge (3.3 to 26.2 $\mu mol/m^2/s$). Tomato treated with soil applied imazosulfuron had photosynthetic rate (7.1 to 17.1 and 42.0 to 64.1 $\mu mol/m^2/s$ in experiment 1 and 2, respectively) similar to the nontreated (8.9 to 29.7 and 39.1 to 68.4 $\mu mol/m^2/s$, respectively). Photosynthetic rate of tomato treated with trifloxysulfuron POST (28.6 to 39.0 $\mu mol/m^2/s$) was less than the tomato treated with

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trifloxysulfuron soil applied (44.1 to 49.2 μmol/m^2/s) or nontreated (45.6 to 47.3 μmol/m^2/s) in experiment 2. At 4 and 7 DAT, photosynthetic rate of yellow nutsedge was decreased with imazosulfuron soil applied (2.8 and 1.1 μmol/m^2/s, respectively) compared to nontreated tomato. Yellow nutsedge treated with trifloxysulfuron had lower photosynthetic rate and stomatal conductance than the nontreated. An application of halosulfuron, imazosulfuron, and trifloxysulfuron applied through the irrigation for a soil application would likely have minimal impact on photosynthetic rate and stomatal conductance of tomato. However, the same treatments would cause a decrease in photosynthetic rate and stomatal conductance of yellow nutsedge.

Nomenclature: Halosulfuron; imazosulfuron; trifloxysulfuron; tomato, *Lycopersicon esculentum* L.; yellow nutsedge, *Cyperus esculentus* L.

Key words: Sulfonylurea, application method, drip irrigation.

Southeastern fresh market tomato production is primarily produced in plasticulture in which the crop develops fruit earlier (Bhella, 1988; Schalk and Robins 1987) and has increased yield (Wien and Minotti 1987) compared to bareground tomato culture. Polyetheylene mulch provides control of broadleaf and grass weeds, but yellow and purple nutsedge can pierce through polyethylene mulch (Adcock et al. 2008; Henson and Little 1969; Johnson and Mullinix 2008; Webster 2005). Morales Payan et al. (203) found in greenhouse studies that yellow (*Cyperus esculentus* L.) and purple nutsedge (*C. rotundus*) have the ability to compete with tomato above- and below ground.

Various herbicides are registered for effective control of troublesome grass and broadleaf weeds in tomato (Kemble 2010). Additionally, several herbicides are being developed for solanaceous crops including tomato. In plasticulture, herbicides are applied PRE prior to laying polyethylene mulch or POST over the mulch (Anonymous 2007). Tomato is tolerant to halosulfuron POST at 26 to 53 g/ha (Adcock et al. 2008; Jennings 2010). Likewise, in a study by Bangarwa et al. (2009) halosulfuron at 13 to 27 g/ha POST-DIR caused only slight injury (≤2%) to bell pepper. In contrast, bell pepper was injured by 27, 54 and 134 g/ha halosulfuron POST in greenhouse studies (Armel et al. 2009). Yellow and purple nutsedge treated with halosulfuron applied to the soil or foliage did not differ in shoot (leaves plus stem) and root dry weight (Vencill et al. 1995). Halosulfuron POST gave greater control of yellow and purple nutsedge compared to halosulfuron PRE (Adcock et al. 2008).

Imazosulfuron is a sulfonylurea herbicide being developed by Valent U.S.A Corporation. Tomato exhibited tolerance (<3% injury) to imazosulfuron POST at 0.11, 0.22, and 0.33 kg ai/ha (Jennings 2010). Sequential application of imazosulfuron POST controlled yellow nutsedge

(>92%), common lambsquarters (*Chenopodium album* L.) (>98%), and pigweed species (100%) (Felix and Boydston 2010). Pekarek (2008) also reported that imazosulfuron POST at 0.11 and 0.22 kg ai/ha controlled yellow nutsedge and hairy galinsoga (*Galinsoga quadriradiata* Cav.).

Trifloxysulfuron is a registered herbicide for control of certain broadleaf weeds and nutsedge in transplanted tomato (Anonymous 2006). Tomato has demonstrated excellent tolerance to trifloxysulfuron POST-DIR at 5.6 to 33.4 g ai/ha (Buckelew et al. 2007; Jennings 2010). Tolerance of tomato is dependent on placement of trifloxysulfuron as tomato is more tolerant of POST-directed trifloxysulfuron than trifloxysulfuron applied POST over-the-top (Anonymous 2006). Trifloxysulfuron POST-DIR at 11.2, 16.8, and 33.4 g ai/ha provided 75 to 100% control of morningglory, redroot pigweed, sicklepod, and velvetleaf (Buckelew et al. 2007). Shoot number, shoot weight, and root weight of yellow and purple nutsedge was reduced by soil applied trifloxysulfuron (McElroy et al. 2003).

Some pesticides have been applied through drip irrigation with varying results. *Fusarium oxysporum* wilt incidence and *Tylenchorhynchus* was controlled with drip irrigation applied metam sodium plus shank applied chloropicrin and PPI pebulate followed by shank applied chloropicrin and drip applied fosthiazate (Santos et al. 2006). Application of 1,3-dichloropropene + chloropicrin through drip irrigation at 187 and 280.5 L/ha had similar yellow nutsedge mortality at 10 and 20 cm below the emitters (Candole et al. 2007). Greater *Rhizoctonia solani* and yellow nutsedge mortality was 10 cm below the drip irrigation emitter than 20 and 30 cm away from the emitter (Candole et al. 2007). Application of halosulfuron at 26 g/ha through the drip irrigation at 1 and 2 wk after transplanting decreased yield at initial harvests of eggplant, but did not affect total yield (Webster and Culpepper 2005). Thus drip application of herbicides warrants further evaluation.

Stress to tomato can not only causes injury to tomato, but can also affect plant processes such as photosynthesis rate, stomatal conductance, and yield. Leaf chlorosis in tomato from nitrogen stress caused photosynthesis and stomatal conductance to decrease over time compared to tomato with sufficient nitrogen (Chapin et al. 1988). Chilling of tomato plants reduced net photosynthesis rate of 13.9 mg $CO_2/dm^2/h$ compared to the net photosynthesis of 28.6 $CO_2/dm^2/h$ for the nonchilled plants (Martin et al. 1981). Although most research has determined control of yellow nutsedge and tolerance of tomato to halosulfuron, imazosulfuron, and trifloxysulfuron in field studies, these studies were conducted to determine the effect of these herbicides on photosynthesis and stomatal conductance of tomato and yellow nutsedge.

Materials and Methods

In separate tomato and yellow nutsedge studies at the Mary Anne Fox Greenhouses at N.C. State University, 'Mountain Fresh Plus' tomato[1] transplants (23 cm tall) and 5 yellow nutsedge tubers were planted into 20 cm wide and 15 cm deep polyethylene pots[2] filled with Orangeburg loamy sand (fine-loamy, kaolinitic, thermic typic Kandiudults having pH 5.7 and humic matter 0.7%) from the Horticultural Crops Research Station near Clinton, N.C. Plants were watered when the soil was dry and fertilized with 20-20-20 fertilizer at 238 ppm. Greenhouse temperatures ranged 24 to 28°C and natural light during August, September, and October. Herbicide treatments were applied to tomato 20 to 24 cm tall (first experiment) and 32 to 37 cm tall (second experiment) and to yellow nutsedge 15 to 25 cm tall. Herbicide treatments included soil or POST applied halosulfuron at 53 g/ha, imazosulfuron at 336 g/ha, trifloxysulfuron at 16 g/ha and a nontreated check. The quantity of herbicide applied was based on the area of the soil surface and was applied with 3 ml of water evenly across the surface. The POST herbicide treatments included in the studies included nonionic surfactant[3] at 0.25% (v/v) applied with a backpack CO_2 sprayer fitted with 8002EVS nozzles[4] calibrated to deliver 167 L/ha.

Photosynthetic rate and stomatal conductance were measured with a Licor 6400 Portable Photosynthesis System[5]. The light source was set at 1500 μmol/m^2/s and the reference CO_2 was set to 350 μmol. Photosynthetic rate and stomatal conductance were measured on tomato at 0, 3, 5, 7, and 16 d after treatment and on yellow nutsedge at 1, 4, 7, 11, and 14 d after treatment. Photosynthetic rate and stomatal conductance was measured on the most recently expanded leaf that was over 1.77 cm^2. Data were analyzed with a general linear model and means were separated with Duncan's multiple range test ($P \leq 0.10$).

Results and Discussion

Halosulfuron. Yellow nutsedge photosynthetic rate at 7 and 14 DAT decreased with halosulfuron POST (0.6 to 22.6 μmol/m^2/s) or soil applied (1.7 and 23.4 μmol/m^2/s, respectively) compared to the nontreated (3.3 to 26.2 μmol/m^2/s, respectively) tomato (Table 1). A similar response of yellow nutsedge stomatal conductance to halosulfuron was observed at 7 DAT when tomato stomatal conductance in soil (0.03 cm/s) and POST (0.02 cm/s) treatments was less than the nontreated (0.05 cm/s) (Table 2). Stomatal conductance of yellow nutsedge did not differ among treatments at any other rating time.

Photosynthetic rate of tomato did not differ for herbicide treatment except at 5 DAT (Table 3). At 5 DAT, tomato treated with halosulfuron POST (6.7 and 41.1 μmol/m^2/s) had lower photosynthetic rate than the nontreated (8.9 and 47.3 μmol/m^2/s). Likewise, soil applied halosulfuron reduced photosynthetic rate of tomato in experiment 1. However, no effect on photosynthetic rate by soil applied halosulfuron occured in experiment 2. Stomatal conductance only differed among treatments at 7 DAT in experiment 1 (Table 4). In experiment 1, stomatal conductance of tomato treated with 53 g/ha halosulfuron soil applied (0.70 cm/s) or POST (0.61 cm/s) was less than nontreated tomato (0.89 cm/s). Stomatal conductance of tomato did not differ among treatments in experiment 2 (Table 4).

Imazosulfuron. At 4 and 7 DAT, yellow nutsedge photosynthetic rate was decreased by imazosulfuron soil (2.8 and 1.1 μmol/m^2/s, respectively) or POST (3.1 and 1.1 μmol/m^2/s, respectively) applied compared to the nontreated (7.4 and 3.3 μmol/m^2/s, respectively) (Table 5). At 11 and 14 DAT, photosynthetic rate of yellow nutsedge treated with imazosulfuron POST was similar to nontreated yellow nutsedge. Stomatal conductance of yellow nutsedge was not different among treatments except at 7 DAT (Table 6). At 7 DAT both soil and POST applied imazosulfuron reduced stomatal conductance of yellow nutsedge compared to the nontreated.

Photosynthetic rate of tomato treated with imazosulfuron POST (3.1 to 17.1 μmol/m^2/s) was less than the nontreated at 3, 5, 7, and 16 DAT (8.9 to 29.7 μmol/m^2/s) in experiment 1 (Table 7). Tomato treated with imazosulfuron soil applied had reduced photosynthetic rate (7.1 to 17.1 μmol/m^2/s) at 5 DAT, however, was similar to nontreated (8.9 to 29.7 μmol/m^2/s) tomato, at all other days. Photosynthetic rate of tomato did not differ among imazosulfuron treatments in experiment 2. Stomatal conductance of tomato treated with imazosulfuron soil applied (0.51 to 0.99 cm/s) and POST applied (0.07 to 0.19 cm/s) was less than the nontreated (0.74 to 1.23 cm/s) at 5, 7, and 16 DAT (Table 8). For the same period stomatal conductance was reduced more by imazosulfuron POST than by soil applied imazosulfuron. In the second experiment, the imazosulfuron soil applied (0.29 to 0.57 cm/s) to tomato caused stomatal conductance to be less than nontreated tomato (0.45 to 0.78 cm/s). Similar observations were observed with imazosulfuron POST at 3 or 5 DAT.

Trifloxysulfuron. Yellow nutsedge treated with trifloxysulfuron applied to the soil (1.2 to 23.0 $\mu mol/m^2/s$) or POST (1.6 to 22.4 $\mu mol/m^2/s$) reduced photosynthetic rate compared to the nontreated (3.3 to 26.2 $\mu mol/m^2/s$) at 7, 11, and 14 DAT (Table 9). Likewise, stomatal conductance of yellow nutsedge was decreased with trifloxysulfuron soil (0.3 to 0.08 cm/s) and POST (0.03 to 0.08 cm/s) applied compared to the nontreated (0.05 to 0.14 cm/s) (Table 10).

Trifloxysulfuron POST caused tomato photosynthetic rate to be less than the soil applied and nontreated (45.6 to 47.3 $\mu mol/m^2/s$) in experiment 1 (5 DAT) and experiment 2 (3, 5, and 7 DAT) (Table 11). Soil applied trifloxysulfuron (4.4 to 17.8 $\mu mol/m^2/s$) caused tomato photosynthetic rate to be less than the nontreated (8.9 to 29.7 $\mu mol/m^2/s$) in experiment 1 (Table 11). Tomato stomatal conductance was lowered with trifloxysulfuron soil applied (0.08 to 0.37 cm/s) compared to the nontreated (0.74 to 1.23 cm/s) (Table 12). POST applied trifloxysulfuron reduced stomatal conductance of tomato at 3, 5, 7 and 16 DAT in experiment 2, however, no effect was observed with this treatment in experiment 1.

Tolerance of plants to sulfonylurea herbicides is rate of metabolism of the herbicide (Brown 1990). Tomato plants in the second experiment were larger plants than the first experiment. The larger plants would likely be able to metabolize the herbicide quicker resulting in no differences in tomato photosynthetic rate and stomatal conductance being observed between treatments.

Halosulfuron, imazosulfuron, and trifloxysulfuron POST or soil applied reduced photosynthetic rate and stomatal conductance of yellow nutsedge. Although many researchers have reported tolerance of tomato to halosulfuron (Adcock et al. 2008; Jennings 2010), imazosulfuron (Jennings 2010), or trifloxysulfuron (Buckelew et al. 2007; Jennings 2010) POST, in our studies tomato photosynthetic rate and stomatal conductance was reduced in some cases by POST or soil applied treatments.

Sources of Materials

[1] 'Mountain Fresh Plus' tomato, Harris Moran, P.O. Box 4938, Modesto, CA 95352.

[2]Plastic pots (15 cm wide by 11.5 cm tall), Wyatt Quarles, 730 Hwy 70W, Garner, NC 27529.

[3] X-77®, alkylphenol ethoxylate, alcohol ethoxylate, tall oil fatty acid, 2,2' dihydroxydiethyl ether and dimethylpolysiloxane. Loveland Products Inc., PO Box 1286, Greeley, CO 80632-1286.

[4] 8002 TeeJet even flat spray tip. TeeJet Technologies. P.O. Box 7900. Wheaton, IL 61087.

[5] LI-6400XT portable photosynthesis system. Licor Biosciences. 4647 Superior St., P.O. Box 4425, Lincoln, NE 68504-0425.

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Table 1. Effect of halosulfuron POST or soil applied on photosynthetic rate of yellow nutsedge.

		d after treatment				
Treatment[z]	Rate	1	4	7	11	14
	g/ha	μmol/m²/s				
Soil	53	23.9 a	4.4 ab[y]	1.7 b	21.5 a	23.4 b
POST	53	23.8 a	3.9 b	0.6 b	21.6 a	22.6 b
Nontreated		28.8 a	7.4 a	3.3 a	21.1 a	26.2 a

[z] Soil = herbicide application to the soil surface with no contact to the foliage; POST= postemergence over-the-top of the foliage and soil.

[y] Means within the column with the same letter are not statistically different at the $P \leq 0.1$ level using Duncan's multiple range test.

Table 2. Effect of halosulfuron POST or soil applied on stomatal conductance of yellow nutsedge.

		d after treatment				
Treatment[z]	Rate	1	4	7	11	14
	g/ha			cm/s		
Soil	53	0.16 a	0.11 a	0.03 b[y]	0.09 a	0.06 a
POST	53	0.15 a	0.09 a	0.02 b	0.09 a	0.06 a
Nontreated		0.15 a	0.14 a	0.05 a	0.10 a	0.07 a

[z] Soil = herbicide application to the soil surface with no contact to the foliage; POST= postemergence over-the-top of the foliage and soil.

[y] Means within the column with the same letter are not statistically different at the $P \leq 0.1$ level using Duncan's multiple range test.

Table 3. Effect of halosulfuron POST or soil applied on photosynthetic rate of tomato.

		d after treatment				
Treatment[z]	Rate	0	3	5	7	16
Exp. 1	g/ha			μmol/m²/s		
Soil	53	16.4 a	18.3 a	6.1 b[y]	20.6 a	28.1 a
POST	53	15.8 a	18.3 a	6.7 b	16.4 a	29.0 a
Nontreated		11.3 a	17.8 a	8.9 a	21.6 a	29.7 a
Exp. 2						
Soil	53	39.6 a	42.8 a	52.9 a	44.6 a	65.6 a
POST	53	38.5 a	41.7 a	41.1 b	47.3 a	66.4 a
Nontreated		42.2 a	45.6 a	47.3 a	46.7 a	67.2 a

[z] Soil = herbicide application to the soil surface with no contact to the foliage; POST= postemergence over-the-top of the foliage and soil.

[y] Means within the column by experiment with the same letter are not statistically different at the $P \leq 0.1$ level using Duncan's multiple range test.

Table 4. Effect of halosulfuron POST or soil applied on stomatal conductance of tomato.

Treatment[z]	Rate	0	3	5	7	16
		d after treatment				
Exp. 1	g/ha			cm/s		
Soil	53	0.42 a	1.47 a	1.19 a	0.70 b[y]	0.49 a
POST	53	0.43 a	1.24 a	0.53 a	0.61 b	0.48 a
Nontreated		0.45 a	0.91 a	1.23 a	0.89 a	0.74 a
Exp. 2						
Soil	53	0.45 a	0.65 a	0.42 a	0.63 a	0.91 a
POST	53	0.38 a	0.61 a	0.35 a	0.59 a	0.68 a
Nontreated		0.54 a	0.74 a	0.54 a	0.67 a	0.78 a

[z] Soil = herbicide application to the soil surface with no contact to the foliage; POST= postemergence over-the-top of the foliage and soil.

[y] Means within the column by experiment with the same letter are not statistically different at the *P*≤0.1 level using Duncan's multiple range test.

Table 5. Effect of imazosulfuron POST or soil applied on photosynthetic rate of yellow nutsedge.

Treatment[z]	Rate	d after treatment 1	4	7	11	14
	g/ha	μmol/m²/s				
Soil	336	27.2 a	2.8 b[y]	1.1 b	21.0 a	22.5 b
POST	336	25.0 a	3.1 b	1.1 b	21.3 a	23.7 ab
Nontreated		23.8 a	7.4 a	3.3 a	21.1 a	26.2 a

[z] Soil = herbicide application to the soil surface with no contact to the foliage; POST= postemergence over-the-top of the foliage and soil.

[y] Means within the column with the same letter are not statistically different at the $P \leq 0.1$ level using Duncan's multiple range test.

Table 6. Effect of imazosulfuron POST or soil applied on stomatal conductance of yellow nutsedge.

		d after treatment				
Treatment[z]	Rate	1	4	7	11	14
	g/ha			cm/s		
Soil	336	0.15 a	0.16 a	0.02 b[y]	0.09 a	0.06 a
POST	336	0.15 a	0.05 a	0.02 b	0.11 a	0.09 a
Nontreated		0.15 a	0.14 a	0.05 a	0.10 a	0.07 a

[z] Soil = herbicide application to the soil surface with no contact to the foliage; POST= postemergence over-the-top of the foliage and soil.

[y] Means within the column with the same letter are not statistically different at the $P \leq 0.1$ level using Duncan's multiple range test.

Table 7. Effect of imazosulfuron POST or soil applied on photosynthetic rate of tomato.

		d after treatment				
Treatment[z]	Rate	0	3	5	7	16
Exp. 1	g/ha	μmol/m²/s				
Soil	336	12.9 a	16.1 a[y]	7.1 b	20.4 a	30.5 a
POST	336	16.7 a	13.0 b	3.1 c	7.1 b	17.1 b
Nontreated		11.3 a	15.8 a	8.9 a	21.6 a	29.7 a
Exp. 2						
Soil	336	42.7 a	42.0 a	42.3 a	46.9 a	64.1 a
POST	336	39.1 a	43.3 a	46.9 a	44.5 a	68.4 a
Nontreated		42.2 a	45.6 a	47.3 a	46.7 a	67.2 a

[z] Soil = herbicide application to the soil surface with no contact to the foliage; POST= postemergence over-the-top of the foliage and soil.

[y] Means within the column by experiment with the same letter are not statistically different at the $P \leq 0.1$ level using Duncan's multiple range test.

Table 8. Effect of imazosulfuron POST or soil applied on stomatal conductance of tomato.

		d after treatment				
Treatment[z]	Rate	0	3	5	7	16
Exp. 1	g/ha			cm/s		
Soil	336	0.21 a	1.14 a	0.99 b[y]	0.68 b	0.51 b
POST	336	0.46 a	0.76 a	0.19 c	0.07 c	0.07 c
Nontreated		0.25 a	0.91 a	1.23 a	0.89 a	0.74 a
Exp. 2						
Soil	336	0.69 a	0.52 b	0.29 c	0.31 b	0.57 b
POST	336	0.42 a	0.56 b	0.34 b	0.60 a	0.91 a
Nontreated		0.54 a	0.74 a	0.45 a	0.66 a	0.78 a

[z] Soil = herbicide application to the soil surface with no contact to the foliage; POST= postemergence over-the-top of the foliage and soil.

[y] Means within the column by experiment with the same letter are not statistically different at the $P \leq 0.1$ level using Duncan's multiple range test.

Table 9. Effect of trifloxysulfuron POST or soil applied on photosynthetic rate of yellow nutsedge.

		d after treatment				
Treatment[z]	Rate	1	4	7	11	14
	g/ha			μmol/m²/s		
Soil	16	21.8 a	4.2 b	1.2 b[y]	20.9 b	23.0 b
POST	16	25.6 a	5.0 ab	1.6 b	21.1 b	22.4 b
Nontreated		23.8 a	7.4 a	3.3 a	21.5 a	26.2 a

[z] Soil = herbicide application to the soil surface with no contact to the foliage; POST= postemergence over-the-top of the foliage and soil.

[y] Means within the column with the same letter are not statistically different at the $P \leq 0.1$ level using Duncan's multiple range test.

Table 10. Effect of trifloxysulfuron applied POST or soil to yellow nutsedge on stomatal conductance.

		d after treatment				
Treatment[z]	Rate	1	4	7	11	14
	g/ha	cm/s				
Soil	16	0.16 a	0.04 b[y]	0.03 b	0.08 b	0.11 a
POST	16	0.16 a	0.04 b	0.03 b	0.08 b	0.05 a
Nontreated		0.15 a	0.14 a	0.05 a	0.10 a	0.10 a

[z] Soil = herbicide application to the soil surface with no contact to the foliage; POST= postemergence over-the-top of the foliage and soil.

[y] Means within the column with the same letter are not statistically different at the $P \leq 0.1$ level using Duncan's multiple range test.

Table 11. Effect of trifloxysulfuron POST or soil applied on photosynthetic rate of tomato.

Treatment[z]	Rate	d after treatment 0	3	5	7	16
Exp. 1	g/ha	μmol/m²/s				
Soil	16	15.0 a	16.5 a	4.4 c[y]	8.2 b	17.8 b
POST	16	18.7 a	16.8 a	6.9 b	18.3 a	29.1 a
Nontreated		14.5 a	15.8 a	8.9 a	21.6 a	29.7 a
Exp. 2						
Soil	16	40.4 a	44.1 a	49.2 a	44.5 a	63.8 a
POST	16	37.2 a	38.8 b	39.0 b	28.6 b	63.8 a
Nontreated		42.2 a	45.6 a	47.3 a	46.7 a	67.2 a

[z] Soil = herbicide application to the soil surface with no contact to the foliage; POST= postemergence over-the-top of the foliage and soil.

[y] Means within the column by experiment with the same letter are not statistically different at the $P \leq 0.1$ level using Duncan's multiple range test.

Table 12. Effect of trifloxysulfuron applied POST or soil to tomato on stomatal conductance.

Treatment[z]	Rate	d after treatment				
		0	3	5	7	16
Exp. 1	g/ha	cm/s				
Soil	16	0.35 a	0.80 a	0.37 b[y]	0.08 b	0.11 b
POST	16	0.49 a	0.90 a	1.01 a	0.85 a	0.57 a
Nontreated		0.25 a	0.91 a	1.23 a	0.89 a	0.74 a
Exp. 2						
Soil	16	0.41 a	0.61 b	0.50 a	0.58 a	0.69 a
POST	16	0.30 a	0.36 c	0.17 b	0.12 b	0.38 b
Nontreated		0.54 a	0.74 a	0.54 a	0.67 a	0.71 a

[z] Soil = herbicide application to the soil surface with no contact to the foliage; POST =postemergence over-the-top of the foliage and soil.

[y] Means within the column by experiment with the same letter are not statistically different at the $P \leq 0.1$ level using Duncan's multiple range test.