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Tolerance of Tomato to Herbicides Applied through Drip Irrigation

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Greenhouse and field studies were conducted to determine tolerance of tomato to halosulfuron, imazosulfuron, and trifloxysulfuron herbicides applied through drip irrigation. In greenhouse studies, PRE- and POST-applied trifloxysulfuron caused greater tomato injury (14 and 54% injury, respectively) than PRE- and POST-applied halosulfuron (5 and 26% injury, respectively) or imazosulfuron (5 and 23% 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, or trifloxysulfuron followed a linear relationship, with tomato injury increasing with increasing herbicide rate. Tomato photosynthetic rate did not differ among the herbicide treatments (32.7 to 55.0 μmol m^{-2} s^{-1}) and the nontreated (38.0 to 55.0 μmol m^{-2} s^{-1}). At 5 to 16 days after treatment (DAT), tomato treated with imazosulfuron POST (0.26 to 0.46 cm s^{-1}) or trifloxysulfuron POST (0.27 to 0.51 cm s^{-1}) had lower stomatal conductance compared to the stomatal conductance of the nontreated tomato (0.65 to 0.76 cm s^{-1}). Chlorophyll content did not differ among treatments at 0 to 6 DAT. At 7 to 12 DAT, tomato treated with imazosulfuron POST (34.0 to 40.1 SPAD) and trifloxysulfuron POST (35.0 to 41.6 SPAD) had lower chlorophyll content compared to the nontreated (39.1 to 48.1 SPAD). 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 21 DAT) and total fruit yield (62,722 to 80,328 kg ha^{-1}).

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

Key words: Application method, drip applied, methyl bromide alternatives, sulfonylurea.

Se realizaron estudios de invernadero y de campo para determinar la tolerancia del tomate a halosulfuron, imazosulfuron y trifloxysulfuron aplicados a travõs de un sistema de riego por goteo. En los estudios de invernadero, trifloxysulfuron aplicado PRE y POST causõ más daño al tomate (14 y 54%, respectivamente) que halosulfuron aplicado PRE y POST (5 y 26%, respectivamente) o imazosulfuron (5 y 23%, respectivamente). En los estudios de invernadero, todos los tratamientos de herbicidas causaron mayor daño al tomate que el testigo no-tratado. En el invernadero cuando se aplicaron los herbicidas POST, se observõ un mayor daþo que cuando se aplicaron al suelo. El daño al tomate causado por halosulfuron, imazosulfuron o trifloxysulfuron aplicados POST siguiõ una relaciõn lineal, incrementándose el daño al tomate conforme incrementõ la dosis del herbicida. La tasa fotosintõtica del tomate no difiriõ entre los tratamientos de herbicidas (32.7 a 55.0 mol m^{-2} s^{-1}) y el testigo no-tratado (38.0 a 55.0 mol m^{-2} s^{-1}). De 5 a 16 dúas despuõs del tratamiento (DAT), el tomate tratado con imazosulfuron POST (0.26 a 0.46 cm s^{-1}) o trifloxysulfuron (0.27 a 0.52 cm s^{-1}) tuvo una menor conductancia estomática comparado con el tomate no-tratado (0.65 a 0.76 cm s^{-1}). El contenido de clorofila no difiriõ entre tratamientos de 0 a 6 DAT. De 7 a 12 DAT, el tomate tratado con imazosulfuron POST (34.0 a 40.1 SPAD) and trifloxysulfuron (35.0 a 41.6 SPAD) tuvo un menor contenido de clorofila comparado con el testigo no-tratado (39.1 a 48.1 SPAD). En los estudios de campo en 2008 y 2009, no se observõ ningún daño al tomate. El herbicida, el mõtodo de aplicaciõn del herbicida y la dosis del herbicida no tuvieron efecto sobre la altura del tomate (73 a 77 cm 14 DAT, 79 a 84 cm 21 DAT) y el rendimiento total de fruto (62,722 a 80,328 kg ha^{-1}).

Tomato was grown on 49,645 ha in the United States and 1,486 ha in North Carolina in 2007 (U.S. Department of Agriculture [USDA-NASS] 2009). Fresh market tomato is commonly grown by plasticulture in the United States. 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) 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 in the southeastern United States (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. At 200 plants m^2 they reported a yield loss of 44%. In subsequent greenhouse studies, Morales-Payan et al. (2003) found that purple nutsedge interference with tomato was greater belowground

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than aboveground and yellow nutsedge interference was equal both above- and belowground.

Tomato is tolerant to POST-applied halosulfuron at 26 to 53 g ai ha^{-1} (Adcock et al. 2008; Jennings 2010). Yellow or purple nutsedge control is greater from POST-applied halosulfuron than from PRE-applied halosulfuron (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 applied POST also provides control of 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 a sulfonylurea herbicide being developed in the United States by Valent USA Corporation. Excellent tomato safety to POST-DIR imazosulfuron at 0.11, 0.22, and 0.33 kg ai ha^{-1} was reported by Jennings (2010). Imazosulfuron applied POST sequentially provided yellow nutsedge control greater than 92% at 21 d after treatment (Felix and Boydston 2010). Pekarek (2008) found that POST-applied imazosulfuron at 0.11 and 0.22 kg ai ha^{-1} controlled yellow nutsedge and hairy galinsoga (*Galinsoga quadriradiata* Cav.).

Tomato tolerance to POST-DIR trifloxysulfuron at 5.6 to 33.4 g ha^{-1} has been observed (Buckelew et al. 2007; Jennings 2010). Santos et al. (2006) reported tomato tolerance to POST-applied trifloxysulfuron at 5.3 g ai ha^{-1} 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^{-1} provided 75 to 100% control of redroot pigweed, ivyleaf (*Ipomoea hederacea* Jacq.) and pitted morningglory (*Ipomoea lacunosa* L.), sicklepod (*Sienna obtusafolia* L.), and velvetleaf (*Abutilon theophrasti* Medik.) (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^{-1} applied pretransplant through the drip irrigation (Webster and Culpepper 2005). Drip-applied halosulfuron at 26 g ai ha^{-1} applied 1 and 3 wk after transplant reduced initial harvests biomass $>$ 33% and $<$ 7% of the nontreated check. However, total fruit biomass 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 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 emitters 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).

Stress to tomato can not only cause visually observable 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^{-1} compared to the net photosynthesis of 28.6 CO_2 dm^{-2} h^{-1} for the nonchilled plants (Martin et al. 1981). Tomato may be subject to other stresses, such as high temperature, flooding, and pests, and herbicide injury in a plasticulture system.

Halosulfuron, imazosulfuron, and trifloxysulfuron provide control of yellow and purple nutsedge in many cropping systems (Adcock et al. 2008; Felix and Boydston 2010; McElroy et al. 2003). The phaseout of methyl bromide requires new methods of weed control in crops grown 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 tomato grown in plasticulture to halosulfuron, imazosulfuron, and trifloxysulfuron herbicides applied through the drip irrigation system.

Materials and Methods

Greenhouse Studies. Studies were conducted at the Mary Anne Fox Greenhouse at North Carolina State University, Raleigh, NC to determine the effect of PRE- and POST-applied halosulfuron, imazosulfuron and trifloxysulfuron to tomato. Greenhouse temperature ranged from 17 to 27 C. 'Amelia' tomato ('Amelia' tomato, Harris Moran, P.O. Box 4938, Modesto, CA 95352) was transplanted on March 3, 2007 and February 25, 2008 into 20-cm-wide and 15-cm-deep polyethylene pots (15-cm azalea polyethylene pots. ITML Horticultural Products, 75 Plant Farm Blvd., Brantford, ON N35 7W2, Canada.) 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 when tomato was 15 to 20 cm tall with eight true leaves and one to two open flowers. Treatments included soil-applied halosulfuron at 13, 26, 53, and 80 g ha^{-1}; imazosulfuron at 112, 224, 336, and 504 g ha^{-1}; and trifloxysulfuron at 5, 11, 16, and 24 g ha^{-1}. 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. The solution was poured with uniform distribution over the soil surface. POST treatments were halosulfuron at 26 and 53 g ha^{-1}, imazosulfuron at 224 and 336 g ha^{-1}, and trifloxysulfuron at 11 and 16 g ha^{-1}. All POST treatments included nonionic surfactant (X-77®, alkylphenol ethoxylate, alcohol ethoxylate, tall oil fatty acid,

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

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

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

[b] DAT = days after treatment.

2,2′ dihydroxydiethyl ether and dimethylpolysiloxane, Loveland Products Inc., P.O. Box 1286, Greeley, CO 80632-1286) at 0.25% (v/v). POST herbicide treatments were applied in a spray chamber equipped with an 8002EVS nozzle (8002EVS TeeJet drift even flat spray tip, TeeJet Technologies, P.O. Box 7900, Wheaton, IL 61087) calibrated to deliver 167 L ha^{-1}. Also included was a nontreated check. Treatments were applied to three plants per plot in a randomized complete block design with four replications. Tomato was evaluated for injury (0% = no injury, 100% = tomato death) 7 and 14 d after treatment (DAT). Data were analyzed with the use of analysis of variance, and means were separated with Fisher's protected LSD ($P \leq 0.05$). Dependent variables and herbicide rates were fit to regression models.

In separate tomato studies at the Mary Anne Fox Greenhouses at North Carolina State University, 'Mountain Fresh Plus' tomato ('Mountain Fresh Plus' tomato, Harris Moran, P.O. Box 4938, Modesto, CA 95352) transplants (23 cm tall) were planted into 20-cm-wide and 15-cm-deep polyethylene pots (15-cm azalea polyethylene pots. ITML Horticultural Products, 75 Plant Farm Blvd., Brantford, ON N35 7W2, Canada) 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, NC. Tomato transplants were planted July 28, September 8, and October 28, 2010. Plants were watered when the soil was dry and fertilized with 20-20-20 ($N–P_2O_2–K_2O$) fertilizer at 238 ppm. Greenhouse had temperatures ranging from 24 to 28 C and natural light during August through November. Herbicide treatments were applied to tomato 20 to 24 cm tall (first and third experiment) and 32 to 37 cm tall (second experiment). Herbicide treatments included soil or POST applied halosulfuron at 53 g ha^{-1}, imazosulfuron at 336 g ha^{-1}, trifloxysulfuron at 16 g ha^{-1} and a nontreated check. Herbicide treatments were applied in a similar manner to the previous greenhouse experiment.

Photosynthetic rate and stomatal conductance were measured with a Licor 6400 Portable Photosynthesis System (LI-6400XT portable photosynthesis system, Licor Biosciences, 4647 Superior St., P.O. Box 4425, Lincoln, NE 68504-0425.). The light source was set at 1500 µmol m^{-2} s^1 and the reference CO_2 was set to 350 µmol. Photosynthetic rate, stomatal conductance, and chlorophyll content were measured on tomato at 0, 3, 5, 7, and 16 d after treatment (DAT). Photosynthetic rate and stomatal conductance were 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 ($P \leq 0.10$).

Field Studies. 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, 13 cm tall, and 6.1 m long; between-bed spacing was 1.5 m on row center. Plasticulture, including fertility and pest management, followed commercial growing standards (Kemble 2010). Field soil was Codorus loam (fine–loamy, mixed, mesic Fluvaquentic Dystrochrepts with pH 5.9 and 1.1% humic matter). Two drip tapes (drip tape, Jain Irrigation, Inc., P.O. Box 3546, 3857 W. Lake Hamilton Dr., Winter Haven, FL 33881) were in the center of the bed 2.5 to 5 cm deep and spaced 31 cm apart. This placement is similar to some eastern North Carolina growers who are utilizing two drip tapes in plasticulture fields having a high percentage of sand. The drip tapes had emitters spaced 30.5 cm apart and delivered 374 L ha^{-1} h^{-1}. Experimental design was a randomized complete block with four replications. Herbicides were applied 3 and 4 wk after transplanting in 2008 and 2009, respectively; tomato was 25 to 31 cm tall. Herbicide rates in the field studies were based on the greenhouse data; thus the highest herbicide rate of the soil-applied treatment was not used in the field studies. Herbicides applied through the drip tape were halosulfuron at 13, 26, and 53 g ha^{-1}; imazosulfuron at 112, 224, and 336 g ha^{-1}; and trifloxysulfuron at 5, 11, and 16 g ha^{-1}. 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 made by the method described in Dittmar et al. (2012). POST-DIR herbicides were halosulfuron at 25 and 53 g ha^{-1}; imazosulfuron at 224 and 336 g ha^{-1}; and trifloxysulfuron at 11 and 16 g ha^{-1}. POST-DIR herbicide treatments included a nonionic surfactant (X-77®, alkylphenol ethoxylate, alcohol ethoxylate, tall oil fatty acid, 2,2′ dihydroxydiethyl ether and dimethylpolysiloxane, Loveland Products) at 0.25% (v/v) and were applied to the lower 15 cm of one side of the tomato plant with the use of a CO_2 backpack sprayer equipped with an 8002EVS single nozzle (8002EVS TeeJet drift even flat spray tip, TeeJet Technologies) calibrated to deliver 167 L ha^{-1} 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

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

Treatment	Injury	
	14 DAT[y]	21 DAT
	%	
Halosulfuron		
POST	26	17
Soil	5	2
LSD (P<0.05)	3	3
Imazosulfuron		
POST	26	17
Soil	5	2
LSD (P<0.05)	7	7
Trifloxysulfuron		
POST	54	42
Soil	14	8
LSD (P<0.05)	10	9

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

[y] DAT = days after treatment.

were 5 cm or larger in diameter and in breaker to red stage. Fruit was harvested by hand and graded according to U.S. Department of Agriculture (USDA) grade standards (USDA-Agricultural Marketing Service, 1997) with a mechanical grader (Greefa Type A3, Greefa, Langstraat 12, 4196 JB Tricht, Netherlands.). 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 with the use of analysis of variance and means were separated with the use of Fisher's protected LSD ($\alpha \leq 0.05$).

Results and Discussion

Greenhouse Studies. The experiment was conducted twice and timing was not different, so greenhouse studies were combined. Application method was significantly different and analyzed separately. Tomato injury included chlorosis and stunting. All POST-applied herbicide treatments resulted in greater injury to tomato than the nontreated check (Table 1). At 14 and 21 DAT, POST-applied halosulfuron (26 and 17%) and imazosulfuron (23 and 12%) caused less tomato injury than POST-applied trifloxysulfuron (54 and 42%). For soil-applied treatments, halosulfuron (5%) and imazosulfuron (5%) were similar to the nontreated (0%). Trifloxysulfuron applied to the soil surface (14% injury) 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 1). At 14 DAT, injury from POST-applied halosulfuron 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 POST-applied imazosulfuron rate with increased injury as imazosulfuron rate increased. The soil-applied imazosulfuron caused less than 6% injury, but followed a linear relationship.

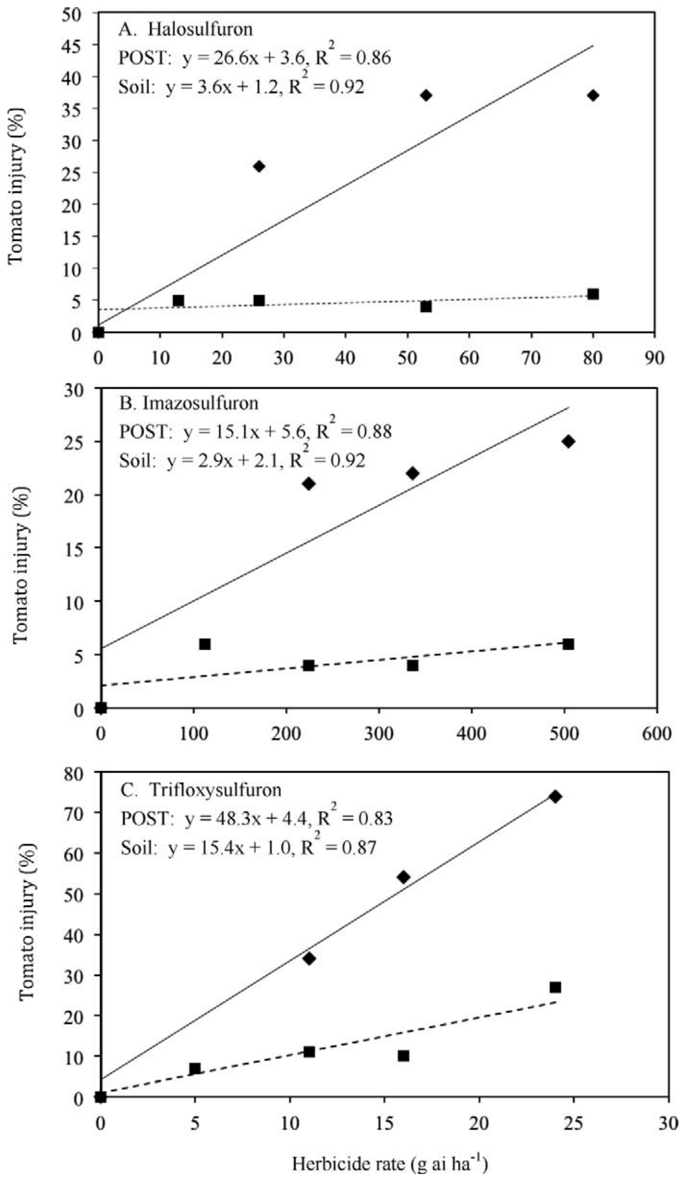

Figure 1. Effect of halosulfuron (A), imazosulfuron (B), and trifloxysulfuron (C) soil (■) or POST (◆) applied on visual tomato injury nature of injury was chlorosis and stunting (0% = no injury, 100% = plant death) 14 d after treatment in greenhouse studies.

At 21 DAT, injury from all rates of imazosulfuron did not differ from to the nontreated. Tomato injury increased as a linear relationship to increasing trifloxysulfuron rate applied both POST and soil applied. At 14 DAT, injury to tomato treated with POST-applied trifloxysulfuron was 34 to 74% and for soil-applied trifloxysulfuron it was 7 to 27%. Injury from trifloxysulfuron at 5 and 11 g ha^{-1} was similar to the nontreated (data not shown).

Photosynthetic rate of tomato did not differ among herbicides and placement (data not shown). Photosynthetic rate of tomato treated with herbicide was 32.7 to 55.0 µmol m^{-2} s^{-1} and the nontreated tomato had a photosynthetic rate of 38.0 to 55.0 µmol m^{-2} s^{-1}. Stomatal conductance was similar among halosulfuron POST, halosulfuron soil applied,

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Table 3. Effect of halosulfuron at 53 g ha^{-1}, imazosulfuron at 336 g ha^{-1}, and trifloxysulfuron at 16 g ha^{-1} POST or soil applied on stomatal conductance of tomato in greenhouse studies.

Herbicide	Placement[z]	0	3	5	7	10	16
		d after treatment					
		cm s$-$1					
Halosulfuron	Soil	0.44 a[y]	0.77 a	0.77 a	0.59 a	0.55 a	0.57 a
	POST	0.30 a	0.65 a	0.59 a	0.53 a	0.74 a	0.52 a
	Nontreated	0.37 a	0.60 a	0.74 a	0.76 a	0.65 a	0.65 a
Imazosulfuron	Soil	0.51 a	0.62 a	0.57 a	0.45 b	0.46 b	0.48 ab
	POST	0.37 a	0.49 a	0.26 b	0.27 b	0.46 b	0.39 b
	Nontreated	0.37 a	0.60 a	0.74 a	0.76 a	0.65 a	0.65 a
Trifloxysulfuron	Soil	0.36 a	0.53 a	0.43 b	0.33 b	0.52 ab	0.33 b
	POST	0.33 a	0.62 a	0.51 b	0.38 b	0.27 b	0.36 b
	Nontreated	0.37 a	0.60 a	0.74 a	0.76 a	0.65 a	0.65 a

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

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

and the nontreated (Table 3). At 5 to 16 DAT, tomato treated with imazosulfuron POST (0.26 to 0.46 cm s^{-1}) had lower stomatal conductance than the nontreated (0.65 to 0.76 cm s^{-1}). Imazosulfuron soil-applied treatment was lower than the nontreated only at 7 and 10 DAT. Tomato treated with POST-applied trifloxysulfuron (0.27 to 0.51 cm s^{-1}) had lower stomatal conductance than the nontreated (0.65 to 0.76 cm s^{-1}). The trifloxysulfuron soil-applied treatment was different than the nontreated control at 5, 7, and 16 DAT.

Chlorophyll content was similar among all herbicide treatments and the nontreated at 0 to 6 DAT (data not shown). Tomato chlorophyll content was not different between halosulfuron POST, halosulfuron soil applied, and the nontreated for the duration of the experiment (Table 4). Chlorophyll content of tomato treated with imazosulfuron POST (34.0 to 40.1 SPAD reading) was lower than the nontreated (39.1 to 48.6 SPAD reading), except at 13 and 15 DAT. The imazosulfuron soil applied (39.9 to 50.2 SPAD reading) treatment was similar to the nontreated (29.1 to 49.4 SPAD reading) at 7 to 16 DAT. Trifloxysulfuron applied either POST (35.0 to 41.6 SPAD reading) or to the soil (35.1 to 39.6 SPAD reading) had lower chlorophyll content than the nontreated control (39.1 to 48.1 SPAD) at 7 and 9 to 11 DAT.

Field Studies. 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, herbicide placement, or herbicide rate. Tomato height was 75 to 77 cm at 14 DAT and 79 to 84 cm at 21 DAT. Each tomato grade, marketable yield, and total yield did not differ among treatment. Tomato total yield ranged from 64,922 to 80,328 kg ha^{-1}. Adcock et al. (2008), Buckelew et al. (2007), and Jennings (2010) also reported no effects of halosulfuron, imazosulfuron, and trifloxysulfuron POST on tomato injury and yield.

The tomato in greenhouse studies had more injury from herbicides than in the field experiments. This increased injury from POST-applied herbicide treatments may have been due to the treatment being applied over-the-top (greenhouse) instead of directed (field), plants being more succulent in the greenhouse, or smaller tomato plants in the greenhouse study at time of treatment. Although injury was greater in greenhouse experiments, the greenhouse experiments were important in showing differential tomato tolerance to increased herbicide rates applied to soil as compared to when applied POST. Halosulfuron (Anonymous 2007) and

Table 4. Effect of halosulfuron at 53 g ha^{-1}, imazosulfuron at 336 g ha^{-1}, and trifloxysulfuron at 16 g ha^{-1} POST or soil applied on chlorophyll content of tomato in greenhouse studies.

Herbicide	Placement[a]	7	8	9	10	11	12	13	14	15	16
		d after treatment									
		SPAD reading									
Halosulfuron	POST	39.0 a[b]	40.8 a	43.4 a	46.0 a	47.7 a	47.8 a	49.4 a	48.3 a	45.0 a	48.0 a
	Soil	42.8 a	43.8 a	45.1 a	47.1 a	48.5 a	48.8 a	49.8 a	46.5 a	46.8 a	49.6 a
	Nontreated	39.1 a	41.6 a	42.8 a	46.6 a	48.1 a	48.6 a	49.4 a	44.5 a	42.6 a	45.9 a
Imazosulfuron	POST	34.0 b	37.4 b	36.8 b	38.6 b	40.1 b	37.5 b	50.0 a	37.0 b	38.0 a	39.7 b
	Soil	39.9 a	41.2 a	41.6 a	45.2 a	47.3 a	47.8 a	46.4 a	48.1 a	45.2 a	50.2 a
	Nontreated	39.1 a	41.6 a	42.8 a	46.6 a	48.1 a	48.6 a	49.4 a	44.5 a	42.6 a	45.9 a
Trifloxysulfuron	POST	35.0 b	35.7 b	37.4 b	39.3 b	41.6 b	43.6 a	40.1 b	41.0 ab	40.4 a	43.7 a
	Soil	35.1 b	38.1 ab	37.8 b	39.4 b	39.6 b	35.3 b	46.5 a	36.1 b	36.0 a	40.6 a
	Nontreated	39.1 a	41.6 a	42.8 a	46.6 a	48.1 a	48.6 a	49.4 a	44.5 a	42.6 a	45.9 a

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

[b] Means within the column by herbicide with the same letter are not statistically different at the $P<0.1$ level using Duncan's multiple range test.

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trifloxysulfuron (Anonymous 2006) POST-DIR were applied at labeled rates and imazosulfuron POST-DIR applied at rates that have been reported to be safe to tomato (Jennings 2010). Delayed drip application of herbicide (3 to 4 wk after transplanting of these herbicides) likely increased 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). Riethmuller-Haage et al. (2006) and Bhatti et al. (1998) discussed sulfonylurea herbicides that cause increased chlorosis and decreased photosynthetic rate. This research shows trifloxysulfuron caused greater injury and lowered the photosynthetic rate compared to the nontreated. However, these results were not seen with the application of halosulfuron to tomato. The difference could be the result of difference in absorption or binding to the site of action and to an overall greater tolerance of tomato to halosulfuron compared to trifloxysulfuron.

The application of pesticides through drip irrigation has shown to control pests in raised-bed plasticulture systems (Candole et al. 2007a, 2007b; Fennimore et al. 2003; Santos et al. 2006). However, control of pests 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, two drip tapes were used in the planting bed to ensure 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 the effect of halosulfuron, imazosulfuron, and trifloxysulfuron applied through the drip irrigation on suppression or control of weeds.

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