Weed Technology 2013 27:741–746

Bell Pepper (*Capsicum annuum*) Tolerance to Imazosulfuron and Thifensulfuron-Methyl

Ryan A. Pekarek, David W. Monks, Katherine M. Jennings, and Greg D. Hoyt*

Greenhouse and field studies were conducted to evaluate bell pepper tolerance to the sulfonylurea herbicides imazosulfuron and thifensulfuron-methyl. Imazosulfuron was applied at 56, 112, 224, 336, or 448 g ai ha^{-1}. Thifensulfuron-methyl was applied at 2.6, 5.3, 10.5, 21.0, or 31.6 g ai ha^{-1}. In the greenhouse over 2 yr, bell pepper injury due to imazosulfuron POST ranged from 12 to 27%. Reductions in plant height and numbers of nodes, buds, flowers, and fruits were generally minor or not observed. Injury from thifensulfuron-methyl POST ranged from 40 to 60% in the greenhouse. Similar trends were observed for leaf chlorosis and distortion. Thifensulfuron-methyl tended to decrease numbers of buds, flowers, and fruits in the greenhouse. In the field at three sites, bell pepper injury due to imazosulfuron applied POST-directed (POST-DIR) was less than 10% at all rating times, and height and yield were not affected. Total and marketable yield averaged 40,300 and 35,810 kg ha^{-1}, respectively, across environments and years. Bell pepper injury from thifensulfuron-methyl applied POST-DIR in the field was less than 20% with all rates and less than 10% when rates less than 10.6 g ai ha^{-1} thifensulfuron-methyl were applied. Bell pepper stand (plants ha^{-1}) or height was not affected by thifensulfuron-methyl. Thifensulfuron-methyl did not affect total bell pepper yield (39,310 kg ha^{-1} averaged across environments); however, reductions in Fancy grade yield were observed. No. 1 and cull yield grades tended to increase with increasing thifensulfuron-methyl rate, apparently compensating for lost Fancy yield.

Nomenclature: Imazosulfuron; thifensulfuron-methyl; bell pepper, *Capsicum annuum* L. 'Heritage'.
Key words: ALS inhibitor herbicide, crop tolerance, herbicide, integrated weed management, sulfonylurea.

Se realizaron estudios de invernadero y de campo para evaluar la tolerancia del pimentón a los herbicidas sulfonylurea imazosulfuron y thifensulfuron-methyl. Se aplicó imazosulfuron a 56, 112, 224, 336, ó 448 g ai ha^{-1}. Thifensulfuron-methyl fue aplicado a 2.6, 5.3, 10.5, 21.0, ó 31.6 g ai ha^{-1}. En el invernadero y durante 2 años, el daño en el pimentón causado por imazosulfuron POST varió de 12 a 27%. Las reducciones en altura de planta, número de nudos, yemas, flores, y frutos fue generalmente menor o no se observó del todo. El daño debido a thifensulfuron-methyl tendió a reducir el número de yemas, flores, y frutos en el invernadero. En el campo en tres localidades, el daño en el pimentón causado por imazosulfuron aplicado POST-dirigido (POST-DIR) fue menor a 10% en todos los momentos de evaluación, y ni la altura ni el rendimiento fueron afectados. El rendimiento total y comercializable promedió 40,300 y 35,810 kg ha^{-1}, respectivamente, al promediarse ambientes y años. El daño del pimentón debido a thifensulfuron-methyl aplicado POST-DIR en campo, fue menos de 20% con cualquiera de las dosis y menor a 10% cuando las dosis aplicadas fueron inferiores a 10.6 g ai ha^{-1} de thifensulfuron-methyl. El establecimiento (plantas ha^{-1}) o la altura del planta del pimentón no fueron afectados por thifensulfuron-methyl. Thifensulfuron-methyl no afectó el rendimiento total del pimentón (39,310 kg ha^{-1} promediado para los diferentes ambientes). Sin embargo, se observaron reducciones en el rendimiento del grado 'Fancy'. Los grados No. 1 y 'cull' tendieron a incrementar con la dosis de thifensulfuron-methyl, aparentemente compensando por las pérdidas de rendimiento 'Fancy'.

Few herbicides are registered to control emerged weeds in bell pepper grown in a plasticulture production system. Only sethoxydim and clethodim are registered for POST applications in bell pepper in North Carolina (Kemble 2012), but these herbicides only control grasses. In the past, fumigation with methyl bromide provided excellent weed control in plasticulture bell pepper (Noling and Gilreath 2002a). However, with the loss of methyl bromide (Noling and Gilreath 2002b), new herbicides are needed to control troublesome weeds such as yellow nutsedge (*Cyperus esculentus* L.), pink and common purslane (*Portulaca pilosa* L. and *Portulaca oleracea* L., respectively), and pigweed species (*Amaranthus* spp.).

Identification of herbicides that are safe to bell pepper yet effectively control yellow nutsedge is a key obstacle to successful bell pepper production across the southeastern United States (Motis et al. 2003). The addition of POST herbicides effective on broadleaf weeds, nutsedge, or both to the currently registered herbicides for bell pepper would benefit bell pepper growers by increasing herbicide options beyond fumigation and PRE herbicides (bensulide, clomazone, napropamide, trifluralin, oxyfluorfen, DCPA) registered in North Carolina (Kemble 2012). Additional herbicide registrations could also reduce the amount of hand-weeding. POST herbicides may minimize or prevent late-season interference due to weeds emerging after the residual period of activity of a PRE herbicide. POST herbicides fit well into integrated weed management programs since herbicide choices, rates, and timings can be tailored to the weeds present. An ideal herbicide would control a broad spectrum of

DOI: 10.1614/WT-D-12-00101.1

* First, second, and third authors: Graduate Student, Professor, and Research Assistant Professor, respectively, Department of Horticultural Science, North Carolina State University, Raleigh, NC 27695; fourth author: Professor, Department of Soil Science, North Carolina State University, Mountain Horticultural Crops Research and Extension Center, 455 Research Drive, Mills River, NC 28732. Corresponding author's E-mail: david_monks@ncsu.edu

weeds during the critical weed-free period and would be safe to the crop (VanGessel et al. 2000).

Weed control during the critical weed-free period provides a competitive advantage to a crop (Amador-Ramirez 2002). Weeds not only reduce yield of bell pepper by competing for light, water, and nutrients (Gonzalez Ponce and Santin 2004), but can also cause crop loss due to reduced harvesting efficiency (Lanini and Le Strange 1994). Amador-Ramirez (2002) reported critical weed-free periods of 1 wk to approximately 14 wk after transplanting of chili pepper when competing with *Simsia amplexicaulis* (Cav.) Pers., Palmer amaranth [*Amaranthus palmeri* (S.) Wats.] and prairie sunflower (*Helianthus petiolaris* Nutt.). Motis et al. (2004) reported critical yellow nutsedge–free periods of 3 to 5 wk after transplanting for spring-grown bell pepper and 1 to 7 wk after transplanting for fall-grown pepper. Planting as few as 5 yellow nutsedge tubers m^{-2} into bell pepper caused a 10% reduction in bell pepper yield (Motis et al. 2003). Fu and Ashley (2006) reported bell pepper yield loss up to 70% due to hairy galinsoga [*Galinsoga ciliate* (Raf.) Blake] and greater than 90% due to redroot pigweed (*Amaranthus retroflexus* L.). The authors also report near 100% yield loss due to large crabgrass [*Digitaria sanguinalis* (L.) Scop.] competition (Fu and Ashley 2006). Norsworthy et al. (2008) reported decreased bell pepper fruit number due to competition with Palmer amaranth and large crabgrass. Competition between bell pepper and jimsonweed (*Datura stramonium* L.) or barnyardgrass [*Echinochloa crus-galli* (L.) Beauv.] reduced shoot dry weight, fresh fruit yield, number of fruits, average fruit weight, and nitrogen uptake of bell pepper (Gonzalez Ponce and Santin 2004).

Many factors affect bell pepper tolerance to herbicides, including chemistry, application technique, and cultivar. Certain lines of bell pepper are tolerant to bentazon, but this tolerance is not widespread in commercial bell pepper cultivars (Harrison and Fery 1998; Wolff et al. 1992). Adigun et al. (1991) applied several PRE herbicide tank mixes to bell pepper and documented reduced vigor and yield, indicating bell pepper was not tolerant to all of the herbicides applied. Herbicides that reduced vigor and yield included metolachlor plus metobromuron, diphenamid plus linuron, diphenamid plus metribuzin, and alachlor plus linuron. Oxyfluorfen, a PPO inhibitor, was safe when applied POST-DIR in chili pepper but did not always provide satisfactory control of certain pigweed species to prevent yield loss from weed competition (Schroeder 1992).

Several sulfonylurea (SU) herbicides control yellow nutsedge and have been evaluated in tomato (*Solanum lycopersicum* L.), another solanaceous crop, for crop tolerance. However, bell pepper tolerance is not always sufficient to permit registration. Additionally, tolerance of tomato to a SU herbicide does not imply that bell pepper will also have tolerance (Buker et al. 2004). For example, bell pepper tolerance to rimsulfuron POST was not satisfactory in field and greenhouse studies (Ackley et al. 1998), and different cultivars may exhibit different tolerance levels to rimsulfuron (Scarponi et al. 2001). Tomato is tolerant of imazosulfuron applied POST-DIR (Jennings, 2010) and trifloxysulfuron-sodium and thifensulfuron-methyl applied POST-DIR (Buckelew et al. 2007). Imazosulfuron is a herbicide registered in rice for the POST control of many weeds such as dayflower (*Commelina communis* L.), eclipta [*Eclipta prostrata* (L.) L.], pitted morningglory (*Ipomoea lacunosa* L.), yellow nutsedge, and pigweed (Anonymous 2011). Trifloxysulfuron is herbicide-registered in cotton (*Gossypium hirsutum* L.), sugarcane (*Saccharum* spp. hybrids L.), and transplanted tomato for POST control of many weeds, including yellow nutsedge, entireleaf morningglory (*Ipomoea hederacea* Jacq.), ivyleaf morningglory (*Ipomoea hederacea* var. *integriuscula* Gray), tall morningglory (*Ipomoea purpurea* L.), pitted morningglory, common lambsquarters (*Chenopodium album* L.), and common cocklebur (*Xanthium strumarium* L.) (Anonymous 2012). Imazosulfuron and trifloxysulfuron are in the SU herbicide family, but little is known about bell pepper tolerance to these herbicides. Thus, greenhouse and field studies were conducted to determine bell pepper tolerance to imazosulfuron and thifensulfuron-methyl.

Materials and Methods

Greenhouse Experiments. Greenhouse studies were conducted in 2007 and 2008 in Raleigh, NC, to determine effects of imazosulfuron and thifensulfuron-methyl POST on bell pepper. Bell pepper 'Heritage' (Harris Moran, Modesto, CA 95357) transplants were grown in 98-cell (2007) or 72-cell (2008) trays (Wyatt Quarles, Garner, NC 27529) and transplanted into individual 15-cm (diam) pots (Wyatt Quarles) containing soilless medium (Fafard 4P soil, Conrad Fafard, Inc., Agawam, MA 01001) when seedlings were approximately 12 cm tall. Plants were fertilized weekly with a 20–10–20 fertilizer at 100 ppm N. Fresh water was applied at all other waterings. In 2007 the greenhouse temperatures ranged from 23 to 25 C (day) and 17 to 19 C (night), and in 2008 the greenhouse temperature ranged from 21 to 24 C (day) and 18 to 21 C (night).

Treatments included imazosulfuron (Valent U.S.A. Corportation, Walnut Creek, CA 94596) at 56, 112, 224, 336, or 448 g ai ha^{-1} and thifensulfuron-methyl (Dupont Crop Protection Co. Inc., Wilmington, DE 19898) at 2.6, 5.3, 10.5, 21.0, or 31.6 g ai ha^{-1} applied 12 and 16 wk after seeding in 2007 and 2008, respectively. X-77 surfactant (Valent U.S.A.) was included in all treatments at 0.25% (v/v). Bell pepper plant heights were 22 $\pm$ 3.9 cm and 32 $\pm$ 2.8 cm (mean $\pm$ SD) in 2007 and 2008 at treatment initiation, respectively. A randomized complete block design was used both years with five replications and one plant per treatment in 2007 and three plants per treatment in 2008. A nontreated check plant (or plants) were included in each replication for comparison. Treatments were applied with a spray chamber equipped with a TeeJet 8002 even flat spray nozzle (TeeJet nozzles, Spraying Systems, Inc., Wheaton, IL 60189) producing a 50-cm-wide spray band at the canopy of the pepper plant and calibrated to deliver 187 L ha^{-1} at 193 or 207 kPa and 3.5 or 3.4 km h^{-1} in 2007 and 2008, respectively.

Number of bell pepper nodes, buds, flowers, and fruits, and plant height and visible injury were recorded 2 and 4 wk after treatment (WAT). Injury was rated by assessing the total symptomology of treated plants including (but not limited to) height reductions, chlorosis, mottling, necrosis of leaves and reproductive structures, and malformed fruit. Plants treated with imazosulfuron were also rated for leaf mottling (yellow-green coloration) and leaf distortion. Thifensulfuron-methyl treated plants were rated for leaf chlorosis (yellowing) and leaf distortion. Mottling, distortion, and chlorosis were rated only on leaf tissues. Differences in rating parameters were due to differences in the symptomology of the two SU herbicides evaluated. Bell pepper plants were cut at the soil surface 5 and 6 WAT in 2007 and 2008, respectively, and weighed and then dried in an oven at 107 C for 1 wk to determine fresh and dry foliage and fruit weights.

Field Experiments. Field studies were conducted at the Mountain Horticultural Crops Research Station (35.43°N, 82.56°W), Mills River, NC, in 2007 and 2008 (MHCRS 2007 and 2008), and the Cunningham Research Station (35.30°N, 77.57°W), Kinston, NC, in 2008 (CRS 2008). Soils at the three sites were a Codorus loam (Fine-loamy, mixed, mesic Fluvaquentic Dystrochrepts, MHCRS 2007 and 2008) and a Norfolk loamy-sand (Fine-loamy, kaolinitic, thermic Typic Kandiudults, CRS 2008). Soil pH was 5.5, 5.9, and 6.3 at MHCRS 2007, MHCRS 2008, and CRS 2008, respectively. The design of the studies at all locations was a randomized complete block design with four replications. Plots were one 6.1-m-long bed on 1.5-m centers containing 30 plants.

Heritage (Harris Moran) bell pepper plants were manually transplanted to a double row with 30-cm in-row and between-row spacings on a raised bed covered with black polyethylene mulch. A single drip tape was laid between pepper rows in each bed approximately 8 cm below the soil surface. Appropriate production practices for plasticulture bell pepper were utilized (Kemble 2012). Plots were maintained weed-free by hand weeding.

Treatments were applied 4 and 5 wk after transplanting (WATP) at MHCRS in 2007 and 2008, respectively, and 6 WATP at CRS 2008. At the time of application bell pepper was 30 cm tall and blooming, and fruit was beginning to develop. Treatments were applied with a CO_2-pressurized backpack spraying 187 L ha^{-1} at 4.8 km h^{-1} and 221 kPa (MHCRS 2007 and 2008) or 269 kPa (CRS 2008) equipped with a TeeJet 8002 EVS nozzle (Spraying Systems, Inc.). A single nozzle boom was passed down each bed shoulder to treat one-half of each bed and one row of pepper in each pass. The spray pattern was directed under the canopy of the bell pepper crop and directed at the transplant hole.

Treatments included imazosulfuron POST-DIR at 56, 112, 224, 336, or 448 g ai ha^{-1} and thifensulfuron-methyl POST-DIR at 2.6, 5.3, 10.5, 21.0, or 31.6 g ai ha^{-1}. X-77 (Valent U.S.A.) surfactant was included in all treatments at 0.25% (v/v). A nontreated check plot was included in each replication for comparison.

Evaluations included crop stand (plants ha^{-1}), plant height, and visual bell pepper injury. Stand was evaluated 3 (MHCRS 2007) and 2 (MHCRS 2008 and CRS 2008) WAT. Pepper injury was rated 1 and 3 (MHCRS 2007) WAT, 2 and 4 (MHCRS 2008) WAT, and 2 and 5 (CRS 2008) WAT on a 0% (no injury) to 100% (bell pepper death) scale. Plant

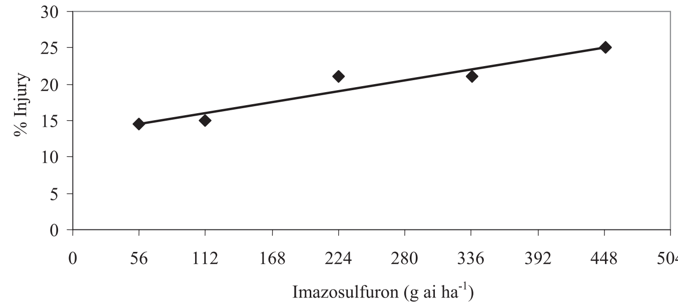

Figure 1. Effect of imazosulfuron applied POST to bell pepper on injury (%) 2 wk after treatment (WAT) in the greenhouse. Injury was rated on a 0 (no injury) to 100% (bell pepper death) scale. Means were averaged across 2007 and 2008 due to lack of interaction between year and imazosulfuron rate. Injury = 0.027x + 12.9, where x = imazosulfuron rate (g ai ha^{-1}); R^2 = 0.79.

height was measured at the same timings as injury ratings, except that height was only measured 2 WAT at CRS 2008. To determine yield, bell pepper was hand-harvested and manually graded at MHCRS 2007 or mechanically graded (Kerian Speed Sizer, Kerian Machines, Inc., Grafton, ND 58237) at MHCRS 2008 and CRS 2008. Grading was conducted according to U.S. Department of Agriculture–Agricultural Marketing Service grade standards for fresh market bell pepper (USDA-AMS 2008).

Data analysis for both greenhouse and field experiments was conducted using PROC GLM of SAS (SAS Version 9.1, SAS Institute, Inc., Cary, NC 27513) at the P < 0.05 level. Visual analysis of residual plots was conducted to determine validity of statistical assumptions and if transformation of raw data was necessary. Where transformation was necessary, analysis was conducted on transformed data, but non-transformed means are presented. When ANOVA indicated a significant effect of rate, further analysis was conducted to determine a rate response on each dependent variable. Rate responses were determined without the inclusion of the nontreated check. For the greenhouse study conducted in 2008, data recorded from the three plants receiving a common treatment within a replication were averaged to obtain one value for analysis. For the field study, year and location were combined into an "environment" factor.

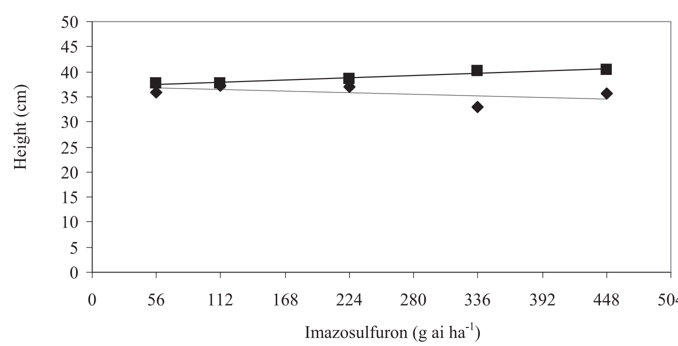

Figure 2. Effect of year and imazosulfuron rate on bell pepper height 4 wk after treatment (WAT) in the greenhouse. 2007 (◆, dashed line): Height = –0.0054x + 37.0; 2008 (■, solid line): Height = 0.0080x + 37.0; where x = imazosulfuron rate (g ai ha^{-1}); R^2 = 0.79.

https://doi.org/10.1614/WT-D-12-00101.1 Published online by Cambridge University Press

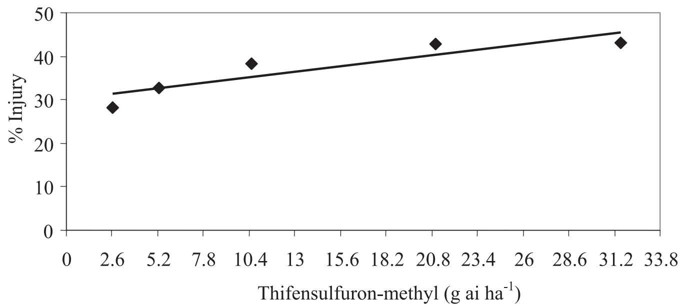

Figure 3. Effect of thifensulfuron-methyl applied POST to bell pepper on injury (%) 2 wk after treatment (WAT) in the greenhouse. Injury was rated on a 0 (no injury) to 100% (bell pepper death) scale. Means were averaged over 2007 and 2008 due to lack of interaction of year by thifensulfuron-methyl rate. Injury = 0.49x + 30.0, where x = thifensulfuron-methyl rate (g ai ha^{-1}); R^2 = 0.52.

Results and Discussion

Results for both imazosulfuron and thifensulfuron-methyl were generally similar for ratings at 2 and 4 WAT whether in the greenhouse or field studies. Therefore, discussion of results will focus on 2 WAT ratings in the greenhouse and 4 WAT in the field. Where differences in ratings between 2 and 4 WAT occurred, the 2 WAT ratings were generally less than those at 4 WAT.

Greenhouse Experiments. *Imazosulfuron.* Bell pepper injury (rated on the whole plant) 2 WAT increased as imazosulfuron rate increased (Figure 1). Injury 2 WAT from imazosulfuron ranged from 15 to 25% averaged over 2007 and 2008. Likewise, leaf mottling and leaf distortion followed a similar trend as injury (data not shown).

In 2007 bell pepper height decreased with increasing imazosulfuron rate; however, in 2008 bell pepper height increased slightly with increasing imazosulfuron rate (Figure 2). The slope values for the height curves indicate that bell pepper height was only slightly affected by imazosulfuron.

Foliage, fruit, and total plant weights (fresh and dried) were not affected by imazosulfuron, although differences in study years were significant (data not shown).

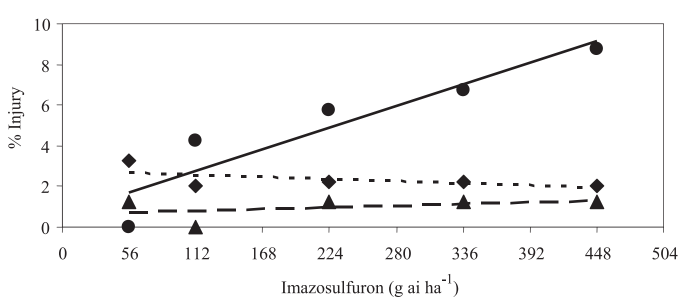

Figure 4. Effect of environment imazosulfuron applied POST-DIR on bell pepper injury (%) in the field at the early rating times at MHCRS 2007, MHCRS 2008, and CRS 2008. Injury was rated on a 0 (no injury) to 100% (bell pepper death) scale. Rating times were 1, 2, and 2 wk after treatment (WAT) at MHCRS 2007, MHCRS 2008, and CRS 2008, respectively. Three distinct curves were fit simultaneously due to interaction of environment by imazosulfuron rate. MHCRS 2008 (●, solid line): Injury = 0.019x + 0.63; MHCRS 2007 (◆, short dashed line): Injury = –0.0020x + 2.8; CRS 2008 (▲, long dashed line): Injury = 0.0015x + 0.65; where x = imazosulfuron rate (g ai ha^{-1}); R^2 = 0.91.

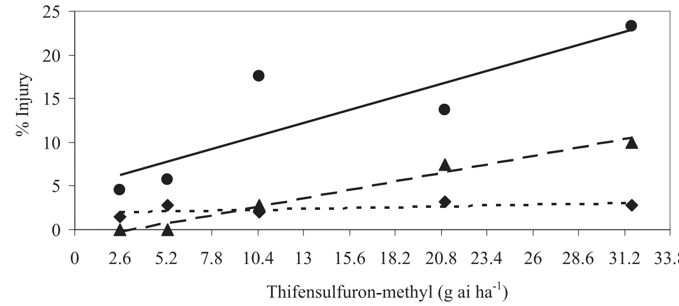

Figure 5. Effect of environment and thifensulfuron-methyl applied POST-DIR on bell pepper injury (%) at the early rating time at MHCRS 2007, MHCRS 2008, and CRS 2008. Injury was rated on a 0 (no injury) to 100% (bell pepper death) scale. Rating times were 1, 2, and 2 WAT at MHCRS 2007, MHCRS 2008, and CRS 2008, respectively. The interaction of environment by thifensulfuron-methyl rate was significant, so three curves were fit simultaneously. MHCRS 2007 (◆, short dashed line): Injury = 0.036x + 1.9; MHCRS 2008 (●, solid line): Injury = 0.57x + 4.8; CRS 2008 (▲, long dashed line): Injury = 0.37x – 1.2; where x = thifensulfuron-methyl rate (g ai ha^{-1}); R^2 = 0.90.

Thifensulfuron-Methyl. Thifensulfuron-methyl affected all measured parameters 4 WAT, except number of buds and flowers (data not shown). However, rate-dependent responses were not always significant for all parameters.

Injury (rated on the whole plant) 2 WAT was affected by thifensulfuron-methyl rate and had significant rate-dependent responses with injury increasing as thifensulfuron-methyl rate increased (Figure 3). Injury 2 WAT increased from 28 to 42% at thifensulfuron-methyl rates of 2.6 to 31.6 g ai ha^{-1}. Chlorosis (rated on the leaf tissue only) exhibited a rate-dependent trend 4 WAT and increased from 24 to 41% at thifensulfuron-methyl rates of 2.6 to 31.6 g ai ha^{-1} (data not shown). Leaf distortion 4 WAT increased with increasing rate of thifensulfuron-methyl and ranged from 41 to 53% (data not shown). Trends for chlorosis and leaf distortion were similar to trends for injury 2 and 4 WAT.

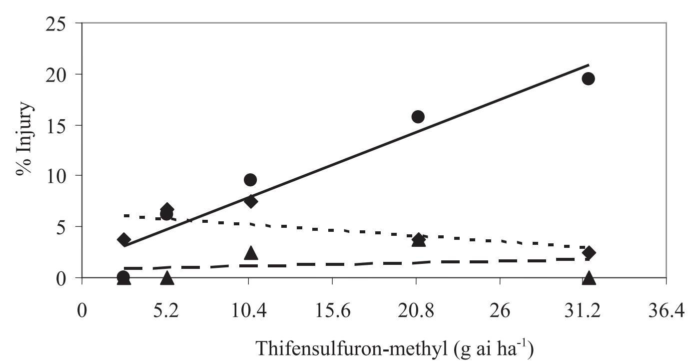

Figure 6. Effect of environment and thifensulfuron-methyl applied POST-DIR on bell pepper injury (%) at the late rating times in the field at MHCRS 2007, MHCRS 2008, and CRS 2008. Injury was rated on a 0 (no injury) to 100% (bell pepper death) scale. Rating times were 3, 4, and 5 WAT at MHCRS 2007, MHCRS 2008, and CRS 2008, respectively. Three distinct curves were fit simultaneously due to the significant interaction of environment by thifensulfuron-methyl rate. MHCRS 2008 (●, solid line): Injury = 0.62x + 1.4; MHCRS 2007 (◆, short dashed line): Injury = –0.11x + 6.4; CRS 2008 (▲, long dashed line): Injury = 0.028x + 0.85; where x = thifensulfuron-methyl rate (g ai ha^{-1}); R^2 = 0.91.

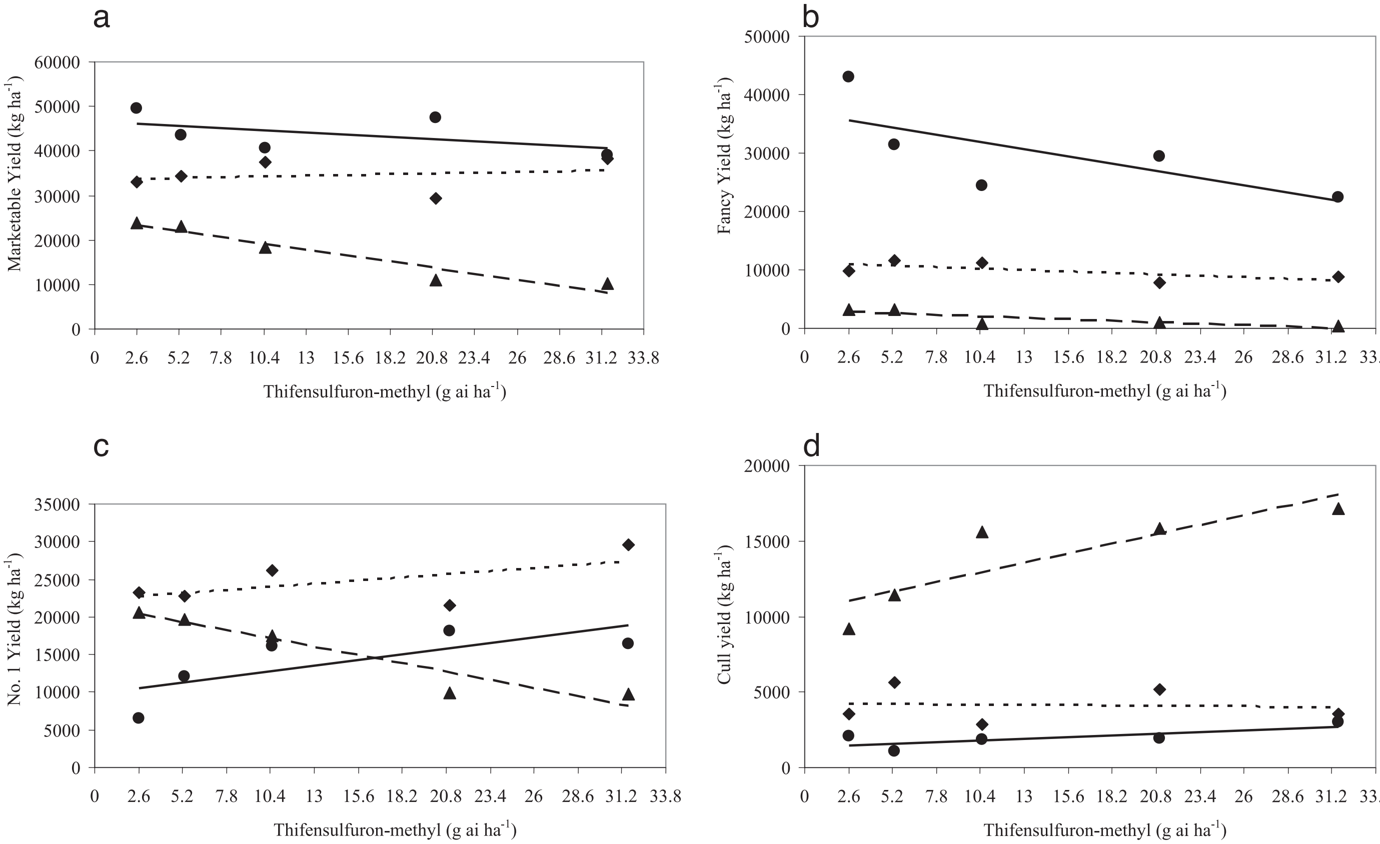

Figure 7. (a) Effect of environment and thifensulfuron-methyl applied POST-DIR on bell pepper marketable yield (sum of Fancy and No. 1 grades for all harvests) at MHCRS 2007, MHCRS 2008, and CRS 2008. Three distinct curves were fit simultaneously due to interaction of environment by thifensulfuron-methyl rate. MHCRS 2007 (◆, short dashed line): marketable yield = 68x + 33,500; MHCRS 2008 (●, solid line): marketable yield = –190x + 46,700; CRS 2008 (▲, long dashed line): marketable yield = –520x + 24,500; where x = thifensulfuron-methyl rate (g ai ha^{-1}); $R^2 = 0.94$. (b) Effect of environment and thifensulfuron-methyl applied POST-DIR on Fancy grade yield of bell pepper at MHCRS 2007, MHCRS 2008, and CRS 2008. Three distinct curves were fit simultaneously due to the significant interaction of environment by thifensulfuron-methyl rate. MHCRS 2007 (◆, short dashes): Fancy yield = –92x + 11,160; MHCRS 2008 (●, solid line): Fancy yield = –480x + 36,950; CRS 2008 (▲, long dashes): Fancy yield = –95x + 3,080; where x = thifensulfuron-methyl rate (g ai ha^{-1}); $R^2 = 0.94$. (c) Effect of environment and thifensulfuron-methyl applied POST-DIR on No. 1 grade yield of bell pepper at MHCRS 2007, MHCRS 2008, and CRS 2008. Three distinct curves were fit simultaneously due to the significant interaction of environment by thifensulfuron-methyl rate. MHCRS 2007 (◆, short dashed line): No. 1 yield = 160x + 22,370; MHCRS 2008 (●, solid line): No. 1 yield = 290x + 9,780; CRS 2008 (▲, long dashed line): No. 1 yield = –420x + 21,460; where x = thifensulfuron-methyl rate (g ai ha^{-1}); $R^2 = 0.87$. (d) Effect of environment and thifensulfuron-methyl applied POST-DIR on cull grade yield of bell pepper at MHCRS 2007, MHCRS 2008, and CRS 2008. Three distinct curves were fit simultaneously due to the significant interaction of environment by thifensulfuron-methyl rate. MHCRS 2007 (◆, short dashed line): cull yield = –7x + 4,270; MHCRS 2008 (●, solid line): cull yield = 40x + 1,390; CRS 2008 (▲, long dashed line): cull yield = 240x + 10,390; where x = thifensulfuron-methyl rate (g ai ha^{-1}); $R^2 = 0.96$.

Bell pepper height was reduced 4 WAT (30.7 cm) compared to the nontreated check (40.6 cm), but differences among thifensulfuron-methyl rates were not significant (data not shown).

Fresh and dry bell pepper foliage weight was not affected by thifensulfuron-methyl rate, and no response curves were fit (data not shown).

Field Experiments. *Imazosulfuron.* Bell pepper was tolerant of imazosulfuron POST-DIR. Bell pepper injury exhibited a rate-dependent response at the early rating times with a significant environment by rate interaction (Figure 4). Although the overall response was different for each location, injury was always less than 10% at the early rating time. At the late injury ratings, no rate-dependent response was evident, and bell pepper injury was less than 5% at all environments (data not shown). Bell pepper height and yield (total, marketable, Fancy, No. 1, and cull) were not affected by imazosulfuron rate, although differences due to environment were evident (data not shown). Total (sum of Fancy, No. 1, and cull grades for all harvests) and marketable (Fancy and No. 1 grades for all harvests) yields were 40,300 and 35,810 kg ha^{-1}, respectively, averaged over environments and imazosulfuron rates.

Thifensulfuron-Methyl. Thifensulfuron-methyl POST-DIR in the field did not affect bell pepper stand (plants ha^{-1}) or height at any rating time (data not shown). Rate-dependent injury responses were evident in all environments and at both rating times due to thifensulfuron-methyl necessitating fitting of three separate curves for each rating time (early and late). Injury at the early rating increased at all locations but was greatest at MHCRS 2008 (Figure 5). Injury at the late rating was generally 10% or less at all locations except when > 21 g

https://doi.org/10.1614/WT-D-12-00101.1 Published online by Cambridge University Press

ai ha^{-1} thifensulfuron-methyl was applied at MHCRS 2008 (Figure 6).

Total yield (sum of all Fancy, No. 1, and cull grades for all harvests) of bell pepper was not affected by thifensulfuron-methyl, although variation among environments occurred (data not shown). Bell pepper total yield was 39,310 kg ha^{-1} averaged across environments. Marketable (sum of Fancy and No. 1 yields), Fancy, No. 1, and cull yield were affected by environment and thifensulfuron-methyl rate. Interaction of environment and thifensulfuron-methyl rate was significant for marketable, Fancy, No.1 and cull yields, but not for total yield. Rate-dependent responses were evident and three curves were fit for each yield parameter due to the environment by rate interaction.

Increasing thifensulfuron-methyl rate reduced marketable yield at MHCRS 2008 and CRS 2008, while little change in marketable yield was observed at MHCRS 2007 (Figure 7a). Fancy yield decreased with increasing rate of thifensulfuron-methyl at all environments (Figure 7b). Reduction in Fancy yield was most severe at MHCRS 2008. Yield of No. 1–grade pepper tended to increase with increasing rate of thifensulfuron-methyl at MHCRS 2007 and 2008 (Figure 7c). No. 1–grade pepper yield decreased at CRS 2008. Cull yield at MHCRS 2007 and 2008 remained roughly constant across thifensulfuron-methyl rates and increased at CRS 2008 (Figure 7d). These increases in No. 1 yield at MHCRS 2007 and 2008 and cull bell pepper yield at CRS 2008 help to explain why total yield was not affected by thifensulfuron-methyl but marketable yield was decreased. Generally, the more valuable grades of pepper (Fancy and No. 1) decreased with increasing thifensulfuron-methyl rate.

Bell pepper was tolerant (injury less than 10%) and yield reductions were insignificant when thifensulfuron-methyl was applied POST-DIR at rates less than 10.6 g ai ha^{-1}. If registered in the future for POST-DIR application to bell pepper, rates of thifensulfuron-methyl would need to be 10.6 g ai ha^{-1} or less to minimize injury and potential reduction in bell pepper grade.

This study identified two SU herbicides with acceptable bell pepper tolerance. In other studies, these herbicides have also been reported as effective for the control of weeds especially troublesome in North Carolina plasticulture bell pepper. Overall, bell pepper was tolerant to imazosulfuron in the greenhouse and in the field. This herbicide controls yellow and purple nutsedge (*Cyperus rotundus* L.) (Henry and Sladek 2008), which are very troublesome in plasticulture-grown bell pepper. Greater injury in the greenhouse due to imazosulfuron was likely due to application technique (POST vs. POST-DIR) and more succulent growth in the greenhouse compared to the field. Bell pepper was tolerant of thifensulfuron-methyl when less than 10.6 g ai ha^{-1} was applied in the field. Yield reductions were minor and no effect of height was observed. The results of this study showed that rates of thifensulfuron-methyl less than 10.6 g ai ha^{-1} may be applied safely to bell pepper. Buckelew et al. (2007) indicate that rates of thifensulfuron-methyl less than 10.6 g ai ha^{-1} can control pigweeds and purslanes that are not controlled by herbicides currently registered for application in bell pepper.

Literature Cited

Ackley, J. A., H. P. Wilson, and T. E. Hines. 1998. Weed management in transplanted bell pepper (*Capsicum frutescens*) with clomazone and rimsulfuron. Weed Technol. 12:458–462.

Adigun, J. A., S. T. Lagoke, and S. K. Karikari. 1991. Chemical weed control in irrigated sweet pepper (*Capsicum annuum* L.). Trop. Pest Manag. 37:155–158.

Amador-Ramirez, M. D. 2002. Critical period of weed control in transplanted chilli pepper. Weed Res. 42:203–209.

Anonymous. 2011. League herbicide product label. Valent U.S.A. Corporation Publication LEA 0001. Walnut Creek, CA: Valent U.S.A. 9 p.

Anonymous. 2012. Envoke herbicide product label. Syngenta Publication SCP 1132A-L1F 1210. Greensboro, NC: Syngenta. 44 p.

Buckelew, J. K., D. W. Monks, and K. M. Jennings. 2007. Response of transplanted plasticulture tomato to post-directed thifensulfuron and trifloxysulfuron. Proc. South. Weed Sci. Soc. 60:142.

Buker, R. S., III., B. Rathinasabapathi, W. M. Stall, G. MacDonald, and S. M. Olson. 2004. Physiological basis for differential tolerance of tomato and pepper to rimsulfuron and halosulfuron: site of action study. Weed Sci. 52:201–205.

Fu, R. and R. A. Ashley. 2006. Interference of large crabgrass (*Digitaria sanguinalis*), redroot pigweed (*Amaranthus retroflexus*), and hairy galinsoga (*Galinsoga ciliate*) with bell pepper. Weed Sci. 54:364–372.

Gonzalez Ponce, R. and I. Santin. 2004. Effects of early weed infestation on growth, yield, and nitrogen nutrition of pepper. J. Plant Nutr. 27:651–661.

Harrison, H. F. and R. L. Fery. 1998. Response of leading bell pepper varieties to bentazon herbicides. HortScience 33:318–320.

Henry, G. M. and B. S. Sladek. 2008. Control of yellow and purple nutsedge in bermudagrass turf with V-10142. Proc. South. Weed Sci. Soc. 61:125.

Jennings, K. M. 2010. Tolerance of fresh-market tomato to postemergence-directed imazosulfuron, halosulfuron, and trifloxysulfuron. Weed Technol. 24:117–120.

Kemble, J. M., ed. 2012. Southeastern U.S. Vegetable Crop Handbook. Lincolnshire, IL: Vance Publishing Corp, North Carolina Cooperative Extension Service. 260 p.

Lanini, W. T. and M. Le Strange. 1994. Weed control economics in bell pepper (*Capsicum annuum*) with napropamide and hand weeding. Weed Technol. 8:530–535.

Motis, T. N., S. J. Locascio, and J. P. Gilreath. 2004. Critical yellow nutsedge-free period for polyethylene-mulched bell pepper. HortScience 39:1045–1049.

Motis, T. N., S. J. Locascio, J. P. Gilreath, and W. M. Stall. 2003. Season-long interference of yellow nutsedge (*Cyperus esculentus*) with polyethylene-mulched bell pepper (*Capsicum annuum*). Weed Technol. 17:543–549.

Noling, J. W. and J. P. Gilreath. 2002a. Methyl Bromide: Progress and Problems Identifying Alternatives, Vol. I. University of Florida Extension. 16 p.

Noling, J. W. and J. P. Gilreath. 2002b. Methyl Bromide: Progress and Problems Identifying Alternatives, Vol. II. University of Florida Extension. 18 p.

Norsworthy, J. K., M. J. Oliveira, P. Jha, M. Malik, J. K. Buckelew, K. M. Jennings, and D. W. Monks. 2008. Palmer amaranth and large crabgrass growth with plasticulture-grown bell pepper. Weed Technol. 22:296–302.

Scarponi, L., A. Esposito, and C. Tomassini. 2001. Factors of tolerance to rimsulfuron in four pepper (*Capsicum annum* L.) lines. Agronomie 21:419–425.

Schroeder, J. 1992. Oxyfluorfen for directed postemergence weed control in chile peppers (*Capsicum annuum*). Weed Technol. 6:1010–1014.

[USDA-AMS] United States Department of Agriculture–Agricultural Marketing Service. 2005. United States Standards for Grades of Sweet Peppers. http://www.ams.usda.gov/AMSv1.0/getfile?dDocName=STELPRDC5050318. Accessed June 6, 2013.

VanGessel, M. J., A. O. Ayeni, and B. A. Majek. 2000. Optimum glyphosate timing with or without residual herbicides in glyphosate-resistant soybean (*Glycine max*) under full-season conventional tillage. Weed Technol. 14:140–149.

Wolff, D. W., W. W. Collins, and T. J. Monaco. 1992. Inheritance of tolerance to the herbicide bentazon in peppers (*Capsicum annuum* L.). J. Amer. Soc. Hort. Sci. 117:985–990.

Received July 12, 2012, and approved July 1, 2013.