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Weed Management–Other Crops/Areas

Tomato Root Uptake of Carfentrazone

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Fresh market tomato is an important and valuable crop in Florida, accounting for 630 million dollars farm-gate value, which was 45% of the total value of the U.S. crop in 2010. In order to maintain or increase its productivity, labeled herbicide alternatives to methyl bromide are important to limiting seed production of weeds emerging between the raised plasticulture beds. A study was conducted inside a greenhouse where carfentrazone was applied as a drench at 0.03125×, 0.0625×, 0.125×, 0.25×, 0.5×, 1×, 2×, 4×, and 8× and as a subsurface irrigation at 0.0625×, 0.125×, 0.25×, 0.5×, 1×, 2×, 4×, 8×, and 16× rates. The 1× rate equaled the maximum labeled rate of carfentrazone (35.1 g ai ha^{-1}) that would be applied to an area of 0.360 m^2. Both the drench and subsurface trials showed an increase in plant injury and reduced growth as the rate of carfentrazone increased. The drench trial, however, was observed to have higher visible injury and greater growth reduction (based on plant measurement) than the subsurface trial, when comparing similar rates. For the 1× rate of carfentrazone in the drench trial vs. the subsurface trial, injury was 66 and 24.5%, respectively. For the 1× rate the tomato plants had estimated growth, based on the curves fit for the data, of 4.8% vs. 39.9% for the drench and subsurface trials, respectively. The subsurface trial better represents what happens in the field when carfentrazone root uptake injury is observed since it is normally observed to be around 10% or less. This still leaves a level of concern; once a 10% injury level in the subsurface trial was estimated to have reduced tomato growth, fruit weight, and total shoot dry weight by 33, 15, and 9.5%, respectively.
Nomenclature: Carfentrazone; methyl bromide; tomato, *Lycopersicon esculentum* L.
Key words: Crop injury, growth, vegetable.

El tomate fresco es un cultivo importante y valioso en Florida, representando 630 millones de dólares de valor a las puertas de las fincas, lo cual a su vez representó 45% del total del valor del cultivo en Estados Unidos en 2010. Con el fin de mantener o incrementar su productividad, los herbicidas registrados para este cultivo como alternativas a methyl bromide son importantes para limitar la producción de semillas de malezas que emergen entre las camas con cobertura plástica. Se realizó un estudio dentro de un invernadero donde se aplicó carfentrazone como "drench" a dosis de 0.03125×, 0.0625×, 0.125×, 0.25×, 0.5×, 1×, 2×, 4× y 8× y mediante irrigación subterránea a dosis de 0.0625×, 0.125×, 0.25×, 0.5×, 1×, 2×, 4×, 8× y 16×. La dosis 1× fue igual a la dosis máxima en la etiqueta de carfentrazone (35.1 g ai ha^{-1}) que sería aplicada a un área de 0.360 m^2. Ambas formas de aplicación, drench y subterránea, mostraron un incremento en el daño de la planta y redujeron el crecimiento conforme se aumentó la dosis de carfentrazone. Sin embargo, en el estudio con drench, se observó un mayor daño visible y una mayor reducción en el crecimiento (basándose en medidas de plantas) que en el estudio con aplicación subterránea, cuando se compararon dosis similares. Para la dosis 1× de carfentrazone en el estudio con drench vs. el estudio con aplicación subterránea, el daño fue 66 y 24.5%, respectivamente. Basándose en curvas de mejor ajuste de los datos, para la dosis 1×, las plantas de tomate tuvieron un crecimiento estimado de 4.8% vs. 39.9% para aplicaciones drench y subterráneas, respectivamente. El estudio con aplicación subterránea representa mejor lo que pasa en el campo cuando se observa un daño causado por la absorción de carfentrazone por las raíces, el cual es normalmente 10% o menor. Esto aún es preocupante, ya que se estimó que un nivel de daño de 10% en el estudio de aplicación subterránea redujo el crecimiento del tomate, el peso del fruto y el peso seco total de la parte aérea en 33, 15 y 9.5%, respectivamente.

Fresh market tomato is an important crop in Florida. In 2010, more than 11,000 ha were harvested at a value of 630 million dollars. This farm-gate value accounted for 45% of the total value of the U.S. crop (USDA 2011).

Methyl bromide (MB) is an effective broad-spectrum fumigant that has been used prior to planting by vegetable growers for many years (Noling and Becker, 1994). Since 1991 more than 20 million kg of MB has been applied to more than 100 crops (Culpepper et al. 2009). It provides a high level of efficacy in combatting soil disease, pests, and weeds (Noling and Becker 1994). It was classified as a Class I ozone-depleting substance by the U.S. Environmental Protection Agency in 1993, with the intent of being removed from the market in 2005. The critical use exemption program has allowed limited use of MB, but the supplies available are critically low. With most vegetable crops being considered to be minor crops and the high cost related to the chemical registration process, there are few weed control products registered for use, leaving producers in desperate need for effective alternatives (Gilreath et al. 2004; Webster et al. 2001).

Carfentrazone is a contact, POST-applied, low-use-rate aryl triazolinone herbicide with little or no residual activity. Within a few hours following application, the foliage of

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susceptible weeds show signs of desiccation resulting in necrosis and death (Anonymous 2008). It is absorbed by foliage and acts by inhibiting protoporphyrinogen oxidase, which results in accumulated reactive oxygen species and membrane disruption (Dayan et al. 1997).

Carfentrazone can be used as a burn-down prior to planting, as a harvest aid, to defoliate or desiccate labeled crops, and, in the row middles, to control broadleaved weeds, mainly species such as morningglory (*Ipomoea* spp.), nightshade (*Solanum* spp.), pigweed (*Amaranthus* spp.), and lambsquarters (*Chenopodium* spp.) (Anonymous 2008). Limiting seed production of weeds emerging between the raised plasticulture beds is important for MB alternatives' sustainability.

Studies have shown the efficacy of carfentrazone on broadleaf weed species. Durgan et al. (1997) observed 90% or greater control of common lambsquarters (*Chenopodium album* L.) with carfentrazone at 26 g ai ha^{-1} applied in red spring wheat. Carfentrazone at 56 g ha^{-1} provided 93% or greater control of hairy nightshade (*Solanum physalifolium* Rusby) in potato (*Solanum tuberosum* L.) (Hutchinson et al. 2006). In Brazil a study was conducted in a sugar-cane (*Saccharum officinarum* L.) crop with multiple rates of carfentrazone. Carfentrazone at 10 g ha^{-1} provided 80% or greater control of Japanese morningglory [*Ipomoea nil* (L.) Roth.] and cypressvine morningglory (*Ipomoea quamoclit* L.). Complete control of the *Ipomoea* species was obtained with the 50 g ha^{-1} rate. Balsam apple (*Momordica charantia* L.) and Benghal dayflower (*Commelina benghalensis* L.) weeds require 30 and 10 g ha^{-1} as minimum rates, respectively, for 80% control. This study also concluded decreasing susceptibility of *Ipomoea* species to carfentrazone was as follows: ivyleaf red morningglory (*Ipomea hederifolia* L.) $\geq$ cypressvine morningglory $>$ Japanese morningglory (Christoffoleti et al. 2006).

Research has been conducted to determine the effect of environmental conditions on carfentrazone injury in wheat (*Triticum aestivum* L.), corn (*Zea mays* L.) and soybean (*Glycine max* L. Merr.) fields. The results showed soil moisture conditions impacted crop injury. In the wet year, wheat had greater injury (20%) than in the dry year (5%). Corn had 15% greater injury and soybean 30% greater injury in the wet year than in the dry year (Thompson and Nissen 2002). Carfentrazone-ethyl (compound I) is hydrolyzed at the soil to chloropropionic acid (compound II), which may act as a protoporphyrinogen oxidase inhibitor through root uptake (Anonymous 2008). It is reported to be retained less strongly on soil than compound I (K_{OC} 15 to 35 vs. 750 $\pm$ 60 at 25 C), allowing lateral movement via soil interstitial water, which may lead to injury on nontarget plants (Ngim and Crosby 2001).

In Florida, we have observed carfentrazone injury in tomato via root uptake, most likely related to high soil moisture levels. The crops are grown using a plasticulture system, which generally consists of raised beds of soil covered with polyethylene mulch. An application of carfentrazone applied to dry soil that is followed by a rainfall of at least 2.5 cm can result in foliar symptoms of carfentrazone. It is surmised that the roots of the tomato that have grown to the edge of the plastic are picking up the carfentrazone (or the metabolite) and translocating the product to the growing points, causing the injury.

The purpose of this research was to study if tomato root uptake of carfentrazone in soil is possible, and at what rate the carfentrazone affects plant growth.

Material and Methods

Two trials were conducted inside a greenhouse in order to determine at what rate carfentrazone reduces plant growth and causes injury in tomato.

Trial 1. Two studies were conducted over time and consisted of carfentrazone (Aim EC®, FMC Corporation, Philadelphia, PA) treatments being applied as a drench to field-gathered Myakka fine sand soil (sandy, siliceous, hyperthermic Aeric Alaquods) with a pH of 6.2 and organic matter content of 0.7%. The trial was a completely randomized design with 20 'Florida 47' tomato plants per treatment. The field soil was sterilized in a wagon steamer for 2 h prior to potting the tomato plants. The tomato seedlings were placed in 3.8-L pots that contained the field soil and fertilized throughout the trial as needed. Carfentrazone was applied at nine rates plus a nontreated control. The rates studied were 0.03125×, 0.0625×, 0.125×, 0.25×, 0.5×, 1×, 2×, 4×, and 8×. The 1× rate equaled the maximum labeled rate of carfentrazone (35.1 g ha^{-1}). This would be the maximum amount of carfentrazone that could be absorbed by the tomato roots from the row middles of a production field in Florida. This would equal tomato plants being placed 60 cm apart in the raised bed with 30 cm of soil on each side of the bed. Each pot was drenched with 400 m. of solution that contained the carfentrazone that would be applied in a 0.360-m^2 area of soil, which for the 1× rate equaled 0.0013 g of carfentrazone per plant (35.1 g ha^{-1}). This bottle volume was determined after prior testing in a tomato plant pot, which proved this volume would not be lost by basal dripping. During the trial additional water was added but only as needed for tomato growth so as not to result in leaching of the carfentrazone out the bottom of the pot.

Trial 2. Two studies were conducted over time and consisted of carfentrazone treatments being applied as a subsurface irrigation to the tomato plants. This was meant to mimic a flood situation in the field, the most common event resulting in tomato injury from carfentrazone. The trial was a completely randomized design with 20 Florida 47 tomato plants per treatment. The study was conducted in the greenhouse using the same field soil and preparation procedures mentioned in the previous trial. The tomato seedlings were placed in 3.8-L pots that contained the field soil and fertilized throughout the trial as needed. Carfentrazone was applied at nine rates plus a nontreated control. The rates studied were 0.0625×, 0.125×, 0.25×, 0.5×, 1×, 2×, 4×, 8×, and 16×. The 1× rate equaled the maximum labeled rate of carfentrazone (35.1 g ai ha^{-1}). Each pot was placed in a plastic tub in which 2 L of solution containing the carfentrazone was placed, which for the 1× rate equaled 0.0013 g ai of carfentrazone per plant.

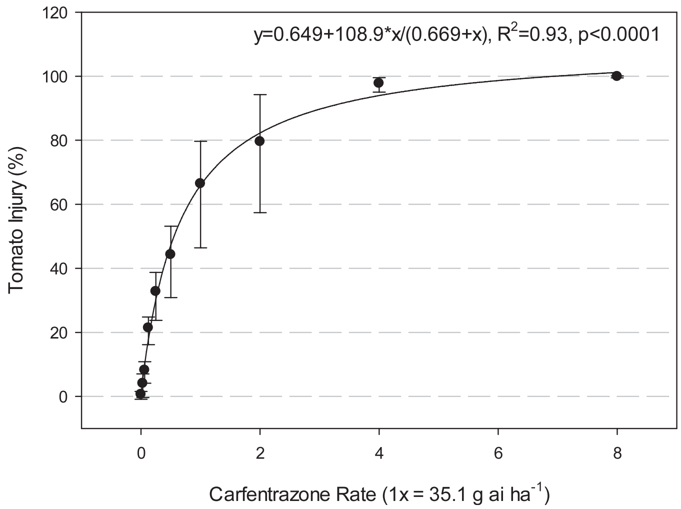

Figure 1. Tomato injury with drench applications of carfentrazone. Tomato injury is a visual estimate 4 wk after treatment. The x-axis is the multiple of carfentrazone rate where 2 = 2×, twice the maximum field application rate.

Data collected for both trials consisted of plant injury assessments on a scale of 0 (no injury) to 100 (complete plant death), plant heights, and aboveground shoot biomass. Visible injury ratings were conducted 4 wk after treatment (WAT). The tomato plants were measured the day prior to treatment and at 4 WAT with the difference between the measurements being converted to percentage of growth compared to the nontreated control. Aboveground shoot biomass was collected 4 WAT, placed in paper bags, and dried at 43 C for 5 d prior to weighing and hereafter will be referred to as shoot dry weight. Shoot dry weight was converted to percentage of the nontreated control. Data were analyzed for normality and interactions between treatment and study (two studies per trial completed over time) using SAS (Version 9.2, SAS Institute, Cary, NC). Without interactions among study and treatment, data were pooled over study for each trial. Data were regressed with SigmaPlot 11 (Systat Software, San Jose, CA), and either a hyperbolic decay (two or three parameters) or a single rectangular hyperbola curve was plotted.

Results and Discussion

Trial 1. In the drench trial, there was a relationship of increased injury as the rate of carfentrazone increased (Figure 1). The relationship was a rectangular hyperbola and using curve-fitting the estimated levels of 10, 20, and 50% visible injury to the tomato would be observed with 0.89, 2.1, and 7.9 g ha^{-1} of carfentrazone. In a soil drench situation, tomato injury of 14.8% would be observed with an application of carfentrazone at 10% of the maximum field application rate. The full field rate of carfentrazone applied as a drench would result in 66% injury to the tomato.

The injury observed resulted in a reduction in tomato growth and shoot dry weight. The data were plotted and a hyperbolic decay curve was fit for each variable. The estimated levels of 90, 80, and 50% of the nontreated control were selected to simulate 10, 20, and 50% reduction in growth and

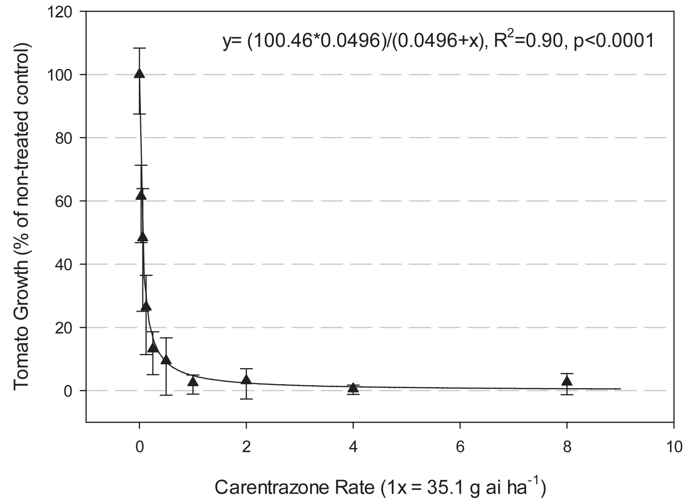

Figure 2. Tomato growth with drench applications of carfentrazone. Tomato growth was determined from the difference in plant height from treatment application to 4 wk after treatment and converted to percentage of the nontreated control. The x-axis is the multiple of carfentrazone rate where 2 = 2×, twice the maximum field application rate.

shoot dry weight. The growth rate of the tomato was estimated to be reduced 10, 20, and 50% with rates of carfentrazone at 0.082, 0.180, and 0.71 g ha^{-1}, respectively (Figure 2). With the maximum recommended field rate of carfentrazone applied (35.1 g ha^{-1}) the plants grew only 4.75% from the time of application. Shoot dry weight was estimated to be reduced by 10, 20, and 50%, compared to the nontreated control, with carfentrazone applied at 0.47, 1.06, and 4.53 g ha^{-1}, respectively (Figure 3). The maximum field use rate of carfentrazone (1×) was estimated to reduce shoot dry weight by 73.5%.

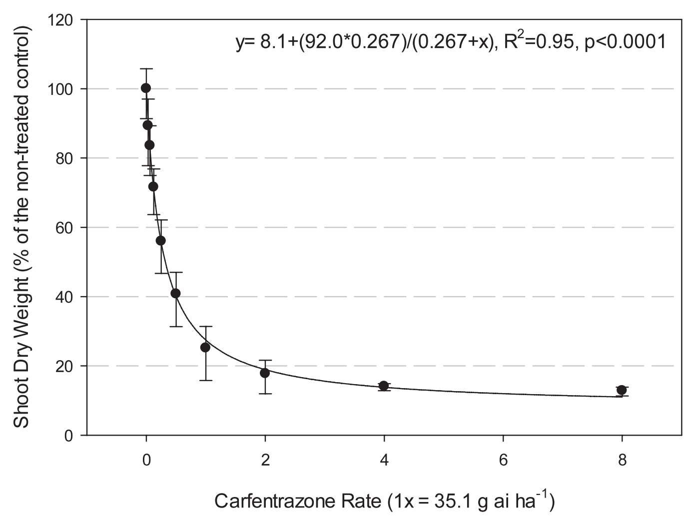

Figure 3. Tomato shoot dry weight with drench applications of carfentrazone. Shoot dry weight is the aboveground portion of the tomato plant collected 4 wk after treatment and converted to percentage of the nontreated control. The x-axis is the multiple of carfentrazone rate where 2 = 2×, twice the maximum field application rate.

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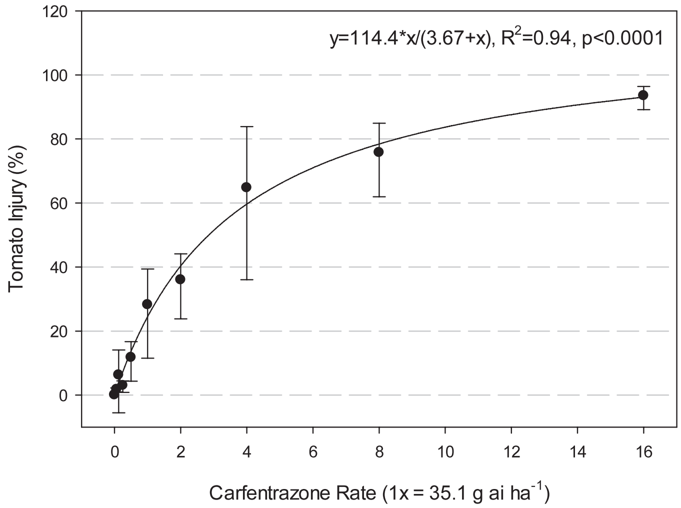

Figure 4. Tomato injury with subsurface applications of carfentrazone. Tomato injury is a visual estimate 4 wk after treatment. The x-axis is the multiple of carfentrazone rate where 2 = 2×, twice the maximum field application rate.

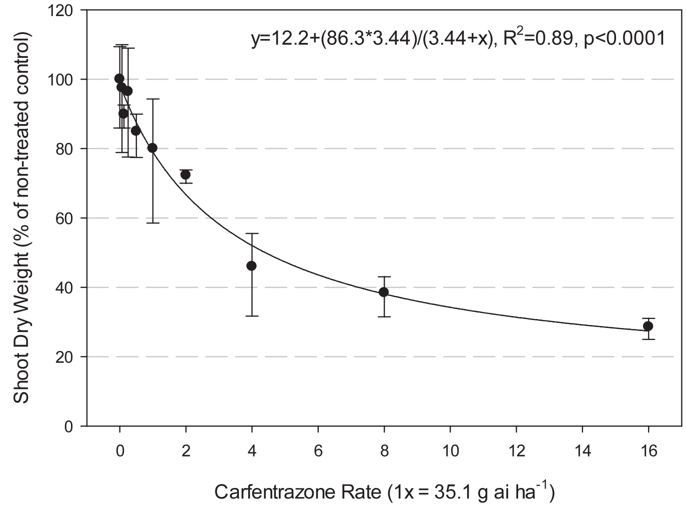

Figure 6. Tomato shoot dry weight with subsurface applications of carfentrazone. Shoot dry weight is the aboveground portion of the tomato plant collected 4 wk after treatment and converted to percentage of the nontreated control. The x-axis is the multiple of carfentrazone rate where 2 = 2×, twice the maximum field application rate.

Trial 2. In the subsurface irrigation trial, there was a relationship of increased injury as the rate of carfentrazone increased (Figure 4). The relationship was a rectangular hyperbola and using curve-fitting the estimated levels of 10, 20, and 50% visible injury to the tomato would be observed with 5.0, 11.1, and 40.5 g ha^{-1} of carfentrazone. In a subsurface irrigation situation, tomato injury of 3.0% would be observed with an application of carfentrazone at 10% of the maximum field application rate. The full field rate of carfentrazone applied as a subsurface application would result in 24.5% injury to the tomato.

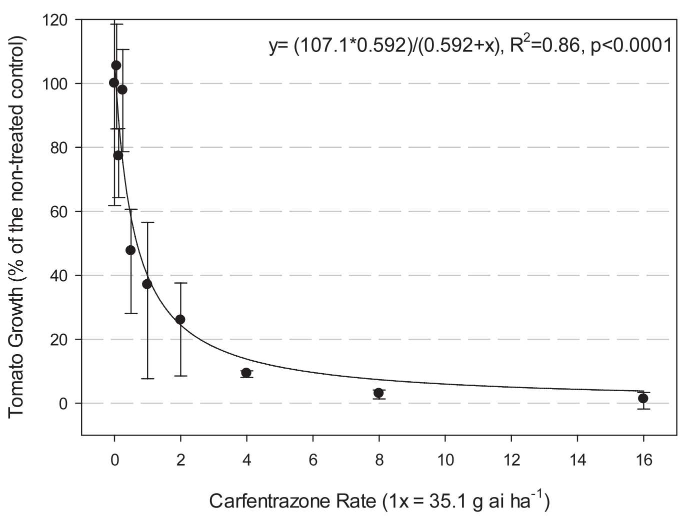

Figure 5. Tomato growth with subsurface applications of carfentrazone. Tomato growth was determined from the difference in plant height from treatment application to 4 wk after treatment and converted to percentage of the nontreated control. The x-axis is the multiple of carfentrazone rate where 2 = 2×, twice the maximum field application rate.

The injury observed resulted in a reduction in tomato growth and shoot dry weight. The data were plotted and a hyperbolic decay curve was fit for each variable. The estimated levels of 90, 80, and 50% of the nontreated control were selected to simulate 10, 20, and 50% reduction in growth and shoot dry weight. The growth rate of the tomato was reduced 10, 20, and 50% compared to the nontreated control with rates of carfentrazone at 1.6, 2.8, 9.6 g ha^{-1}, respectively (Figure 5). With the maximum recommended rate of carfentrazone applied (35.1 g ha^{-1}) the plants were estimated to grow 39.8% from the time of application. Shoot dry weight was estimated to be reduced by 10, 20, and 50% compared to the nontreated control with carfentrazone applied at 5.3, 13.3, and 62.5 g ha^{-1}, respectively (Figure 6). The maximum use rate of carfentrazone (1×) was estimated to reduce shoot dry weight by 20.9%.

Previous studies have determined injury to crops from foliar and postdirected rates of carfentrazone. In peanut (*Arachis hypogaea* L.) varieties grown in Texas, carfentrazone injury ranged from 7 to 52% in one location and 9 to 16% in a second location (Grichar et al. 2010) when applied at 0.03 and 0.04 kg ai ha^{-1}. One study concluded that injury may be related to precipitation. Ogbuchiekwe et al. (2004) observed an injury level of 10 (on a scale of 0–10) at one location and 6.8 at a second site with carfentrazone applied POST at 11.3 g ai ha^{-1}. They concluded that the higher level of precipitation at the first location may have influenced the higher level of injury. Field injury of tomato with carfentrazone in Florida has followed a similar pattern with an application to dry soil in the row middles followed by a rainfall event of as little as 2.5 cm.

In this research, severe injury occurred with root uptake of carfentrazone on tomato. Both the drench and subsurface trials had increased plant injury and reduced growth as the rate of carfentrazone increased. The drench trial, however, was

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had higher injury and greater growth reduction than the subsurface trial, when comparing similar rates. When comparing the 1× rate of carfentrazone (35.1 g ha^{-1}), in the drench trial vs. the subsurface trial, injury was 66 and 24.5%, respectively. When carfentrazone was applied at the 1× rate, the tomato plants had estimated growth of 4.8% vs. 39.9% for the drench and subsurface trials, respectively. This may have been due to two main factors (or a combination of these factors): the lower solution concentration of the subsurface trial in relation to the drench trial (2 L vs. 400 ml) and the time that the tomato plants spent to absorb those solutions, about 5 d for the subsurface trial and only 2 d for the drench trial. The subsurface trial better represents what happens in the field when carfentrazone root uptake injury is observed. Tomato injury levels are usually low (10% or less) when observed in the field. This still leaves a level of concern, since a 10% injury level in the subsurface trial was estimated to have reduced tomato growth and shoot dry weight by 33 and 9.5%, respectively. This could lead to a delay in harvest time or possibly a reduction in yield itself.

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