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Vegetable Crop Response to EPTC Applied Preemergence Under Low-Density Polyethylene and High Barrier Plastic Mulch

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The continued phase-out of methyl bromide (MBr) challenges vegetable growers' abilities to control weeds in plasticulture production. Herbicides, such as EPTC (*S*-ethyl dipropylthiocarbamate), may be needed as part of a MBr alternative system. An experiment was conducted during the springs of 2008 and 2009 in Ty Ty, GA, to determine tomato, pepper, eggplant, and watermelon tolerance to EPTC applied under mulch. Treatments consisted of a factorial arrangement of four rates of EPTC (0, 2, 3, or 4 kg ai ha^{-1}) and two plastic mulch types (low density polyethylene [LDPE] mulch or a high barrier mulch [HBM]). Each crop was planted 28 d after applying herbicides and laying mulch. EPTC, regardless of rate, applied under LDPE mulch did not impact plant growth, fruit number produced, or fruit weights for any crop. Conversely, pepper, tomato, and eggplant heights were reduced 65 to 72%, 30 to 75%, and 9 to 32%, respectively, by EPTC at 2 to 4 kg ai ha^{-1} when applied under HBM. Similar trends were observed for crop yield; fruit number and weight were reduced by 71 to 84% for pepper, 36 to 76% for tomato, and 7 to 15% for eggplant when EPTC was applied at 2 to 4 kg ai ha^{-1} as compared to the no EPTC HBM control. Watermelon stem lengths, fruit number, and fruit weights were not impacted by EPTC applied under HBM mulch. It appears as though HBMs reduce the loss of EPTC through volatilization, thereby increasing the dose present at time of planting. EPTC could be included as part of a MBr alternative system for tomato, pepper, eggplant, and watermelon when applied under LDPE mulch, and may also be applied at labeled rates with the HBM utilized in this experiment for watermelon.
Nomenclature: *S*-ethyl dipropylthiocarbamate (EPTC); bell pepper, *Capsicum annuum* L. CPSAN; eggplant, *Solanum melongena* L. SOLME; tomato *Solanum lycopersicum* L. LYPES; watermelon, *Citrullus lanatus* L. CITLA.
Key words: High barrier mulch, low density polyethylene mulch, methyl bromide alternative, virtually impermeable film.

El proceso de salida del mercado del bromuro de metilo (MBr) es un desafío en las habilidades de los agricultores para controlar la maleza en sistemas de producción de hortalizas en plasticultura. Herbicidas tales como EPTC, pueden ser necesarios como parte de un sistema alternativo al MBr. Durante la primavera de 2008 y 2009 se realizó un experimento en Ty Ty, GA para determinar la tolerancia del tomate, pimiento, berenjena y sandía al EPTC aplicado bajo cubierta. Los tratamientos consistieron en un arreglo factorial de cuatro dosis de EPTC (0, 2, 3 o 4 kg ia ha^{-1}) y dos tipos de cubierta de plástico (polietileno de baja densidad [LDPE] o una cubierta de barrera alta [HBM]). Cada cultivo fue sembrado 28 días después de aplicar los herbicidas y de colocar las cubiertas. Sin importar la dosis, el EPTC aplicado bajo cubierta LDPE no afectó el crecimiento de la planta, el número de frutos producidos o peso del fruto, en ninguno de los cultivos. Por lo contrario, las alturas del pimiento, del tomate y de la berenjena se redujeron del 65 al 72%, del 30 al 75% y del 9 al 32%, respectivamente, con EPTC aplicado debajo de HBM en dosis de 2 a 4 kg ia ha^{-1}. Tendencias similares se observaron en el rendimiento del cultivo; el número y el peso de los frutos se redujeron de 71 a 84% para el pimiento, de 36 a 76% para el tomate y de 7 a 15% para la berenjena, cuando el EPTC se aplicó en dosis de 2 a 4 kg ia ha^{-1} comparado con el testigo sin HBM o EPTC. Ni el largo de las guías de la sandía, ni el número y peso de sus frutos fueron afectados por EPTC aplicado debajo de la cubierta HBM. Aparentemente, la cubierta HBM reduce la pérdida de EPTC por volatilización, incrementando así la dosis presente en el momento de la siembra. El EPTC podría ser incluido como parte de un sistema alternativo al MBr para tomate, pimiento, berenjena y sandía, cuando se aplica debajo de una cubierta LDPE, y también podría ser aplicado en sandía en las dosis recomendadas, utilizando cubierta HBM como la empleada en este experimento.

Methyl bromide (MBr) has been used as a soil fumigant since the mid 1900s to control a broad spectrum of pests including weeds, diseases, and nematodes (Julian et al. 1998; Malathrakis 1999; Minuto et al. 1999a; Noling and Becker 1994). Because of its effectiveness, it was readily adopted for use on many high value vegetable crops (Ragsdale and Wheeler 1995). In 1987, the Montreal Protocol defined MBr as a Class I ozone-depleting substance (Anbar et al. 1996). Accordingly, the manufacture and importation of MBr to developed countries has since been phased out. In 2006, the U.S. Environmental Protection Agency (EPA) began a critical use exemption process that permits the use of MBr in the instance where there are no technically, environmentally or economically effective alternatives available to the user (EPA 2008). In Georgia, four critical use exemption requests (pepper, tomato, eggplant, and cucurbits), were submitted to the EPA and approved, allowing Georgia vegetable producers limited supplies of MBr through 2011 (EPA 2011). Although limited quantities of MBr are currently available for Georgia growers, the increased cost of MBr resulting from the reduced supply has limited its economic feasibility (Gilreath et al. 2005; Noling 2002). Alternative fumigant research has yielded promising results, particularly for disease and nematode control, although the methods are often less effective in

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controlling some weeds, especially nutsedge (*Cyperus* spp.), when compared to MBr (Culpepper et al. 2006; Garibaldi et al. 2008; Gilreath et al. 2005; Harrison and Fery 1998; MacRae et al. 2010; Yates et al. 2002).

Purple nutsedge (*Cyperus rotundus* L.) and yellow nutsedge (*C. esculentus* L.) are the two most troublesome weeds in cucurbits and fruiting vegetable crops in Georgia (Webster 2006). Both nutsedge species are perennial with erect growth habits and triangular stems. This shoot morphology provides nutsedges with the ability to pierce polyethylene mulch (William 1976). According to Wills et al. (1987), newly developing nutsedge rhizomes grow as indeterminate stems sheathed in scaled leaves surrounding pointed meristems. Chase et al. (1998) determined that nutsedge rhizomes in the absence of light remained in a heterotrophic growth phase in which the stem internodes continued to elongate. The continued lengthening of the rhizomes is responsible for forcing nutsedge apices through the plastic and into the light, where photomorphogenic cues that lead to leaf formation and expansion are triggered (Chase et al. 1998). The use of black polyethylene mulch may alter the environmental characteristics of the cropping system to the benefit of nutsedge species. Webster (2005) demonstrated that black LDPE mulch promoted rather than suppressed the growth of purple nutsedge plants relative to a mulch-free check. Under LDPE mulch a single purple nutsedge tuber multiplied to 3,440 shoots covering an area of 22.1 m^2 in 60 wk. Though the use of black LDPE mulch limited the spread and shoot production of yellow nutsedge compared with the non-mulched plots, patch expansion still occurred (Webster 2005).

Although the nutsedges are regarded as weak competitors and are sensitive to crop shading, vegetable yield loss may occur under heavy infestations. William and Warren (1975) noted that season-long purple nutsedge competition (160 plants/0.1 m^2) reduced yields of cabbage (*Brassica oleracea*) 35%, cucumber 43%, and tomato 53%. Full season purple nutsedge interference (200 plants/m^2) reduced eggplant yield 22% (Morales-Payan and Stall 1997), whereas yellow nutsedge interference (12 plants/m^2) reduced watermelon yield over 40% (Buker et al. 2003). Bell pepper may be more sensitive to nutsedge interference than other vegetable crops. Gilreath et al. (2005) reported that nutsedge densities of approximately 5.4 plant/m^2 occurring during crop fruit set reduced bell pepper yield by 31%; Motis et al. (2003) found that severe nutsedge infestations (>30 plants/m^2) reduced bell pepper yields 54 to 74%.

Limited MBr availability coupled with high prices has facilitated the need for a fumigant plus herbicide system in plasticulture production (Noling et al. 2006; Santos et al. 2006a). EPTC (*S*-ethyl dipropylthiocarbamate) is a thiocarbamate herbicide having a high vapor pressure, 3.4×10^{-2} mm Hg at 25 C, with activity on grasses, nutsedges, and broadleaf weeds (Parker et al. 1969; Santos 2009; Senseman 2007; Wallace et al. 2007). An herbicide that offers control of problematic weeds and has a moderate vapor pressure, which may allow it to disperse more uniformly under various mulches, could improve weed control in a MBr alternative system.

Numerous mulch types that vary in their ability to reduce the movement of fumigants from the soil into the atmosphere are available for plasticulture production systems (Austerweil et al. 2006; Minuto et al. 1999b; Ou et al. 2008; Qin et al. 2008; Santos et al. 2006b, 2007; Yates et al. 2002). It is possible that these mulches also impact the volatilization and diffusion of EPTC applied to the soil. The standard mulch in vegetable plasticulture production for the southeastern United States has been low-density polyethylene (LDPE) (Webster 2005; Patterson 1998); however, regulations placed on fumigants by the EPA are forcing growers to consider mulches with greater barrier characteristics.

Before EPTC can be integrated into a MBr alternative system, vegetable tolerances in the field must be determined; crop response to EPTC applied under a high barrier mulch (HBM) has not been documented. The objective of this experiment was to determine the response of tomato, pepper, eggplant, and watermelon to four rates of EPTC applied under two mulch types. Information of this nature will be essential in developing sustainable systems for the replacement of MBr.

Materials and Methods

Experiments were conducted in the spring of 2008 and 2009 in Ty Ty, GA. Soil type, typical for the vegetable production region, was a Tifton loamy sand (fine-loamy, kaolinitic, thermic Plinthic Kandiudult) with 90% sand, 6% silt, 4% clay, 1.0% organic matter, and pH 6.4. The randomized complete block experiment included a factorial arrangement of treatments replicated three times. The factorial arrangement included an herbicide option of EPTC (EPTAM 7E, Gowan Company, Yuma, AZ) at 0, 2, 3, or 4 kg ai ha^{-1} and a mulch option of LDPE mulch (Pliant Corporation, Schaumburg, IL) and a HBM (Blockade agricultural film, Pliant Corporation). The experimental area was chosen for its light weed and nematode pressure. Additionally, the entire area was fumigated in order to eliminate other pests in an effort to focus specifically on crop response to EPTC under various mulches because crop tolerance, not weed control, will determine the potential use of EPTC as part of an MBr alternative system. In addition, presence of microbes in the soil would have potentially increased the rate of degradation of the herbicide, reducing the herbicide effect on the crops. However, this is a condition that would have not been realistic to the practices of the growers. Applying a fumigant and reducing the microbial population of the soil allow for an environment that would show maximum phytotoxic effects of the herbicide on crops. All other aspects of plasticulture production followed recommendations by the University of Georgia Extension Service and the Alabama Cooperative Extension System (Anonymous 1999, 2006, 2009; Kemble et al. 1998).

Soil within the trial area was disk harrowed twice and moldboard plowed 25 to 30 cm deep in January of each year. On February 27, 2008, and February 17, 2009, raised beds (0.9 m wide, 30.5 m long and 15 cm high) were established with a bed-shaper (Superbedder, Kennco Manufacturing Inc., Ruskin, FL). While preparing beds, chloropicrin at 176 kg ai ha^{-1} plus 1,3-D at 115 kg ai ha^{-1} (Pic-Clor 60, Cardinal Professional Products, Woodland, CA) was injected

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20 cm below the bed top using three shanks spread evenly across the bed. Immediately following bed shaping and fumigant application, a plastic layer (High Speed Plastic Mulch Layer, Kennco Manufacturing Inc.) was used to lay a single drip tape 2.5 cm below the bed surface in the center of the bed; apply EPTC at 0, 2, 3, or 4 kg ai ha^{-1} (165 kPa using a spray volume of 37 L ha^{-1}) to the soil surface; and cover the bed with mulch.

Each herbicide and mulch treatment combination plot size was 30.5 m, but plots were then split into four even sections to determine crop response for bell pepper ('Heritage'), tomato ('Bella Rosa'), eggplant ('Santana'), and watermelon ('Delight Seedless'). Transplant holes were mechanically punched through the mulched beds 5 cm deep on March 27, 2008, and March 12, 2009, and each crop was immediately transplanted by hand. Bell pepper was planted with a spacing of 28 cm between plants down the row and 35 cm between plants across the row. Single rows of eggplant and tomato were planted with a spacing of 51 cm between plants. Watermelon was planted in a single row with a 61-cm spacing between plants.

Visual estimates of injury as evaluated by crop stunting, tissue chlorosis and necrosis, and plant loss were taken at least every 3 wk after planting (WAP) using a scale of 0 (no injury) to 100% (plant death). The heights of 10 tomato, pepper, and eggplant plants and stem lengths of 10 watermelon were taken three times during the season at 2 (early season), 4 to 6, and 6 to 8 (late season) WAP. Peppers harvested included jumbo fruit picked once a week for 3 to 4 wk; tomato harvests consisted of picking fruit six to seven times as soon as the fruit initiated color break followed by fruit size grading (extra large, large, medium, small); eggplant was harvested seven to nine times by picking fruit approximately 13 cm in diameter at the widest point having a length of 20 cm; and watermelon was harvested one to three times at maturity (USDA-AMS 1953, 1978, 1991, 2005).

Vegetable injury estimates, heights, and total yield for the season, were subjected to mixed model analysis of variance (MMANOVA) to evaluate the main effects and their interaction. Crops were analyzed individually, and no comparisons were made between crops. MMANOVA was used to partition out the influence of the variables. Mulch and EPTC rate were the main effects in the model, and replication and year were random effects. Regression analysis was used to evaluate the effect of rate and the rate by mulch interaction on the dependent variables when MMANOVA indicated a significant influence ($P \leq 0.05$). Data were combined across years given the lack of a year interaction. The pepper late season injury rating was regressed using an exponential rise to maximum:

$$y = a\left(1 - e^{-bx}\right) \quad [1]$$

where y is crop injury, a is the level of injury in the no EPTC control, and b is the influence of herbicide on increasing injury. Pepper late-season height and yield in number per hectare and kilograms per hectare were regressed using an exponential decay:

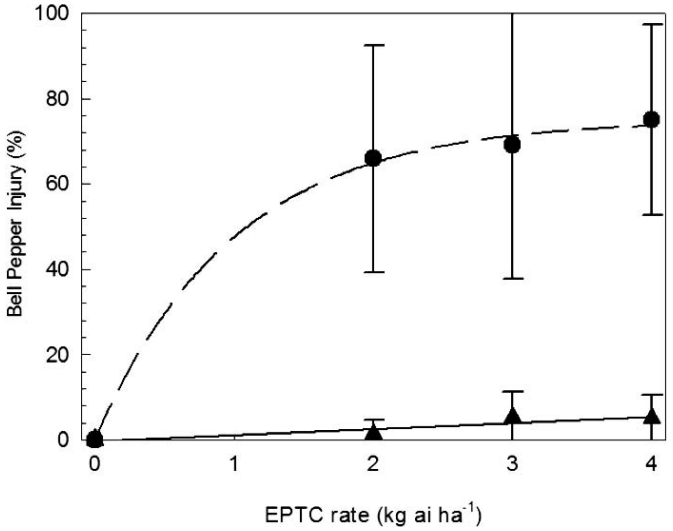


Figure 1. Late-season (6–8 wk after planting) pepper injury from EPTC applied at 0, 2, 3, and 4 kg ai ha^{-1} under low density polyethylene (LDPE) mulch or high barrier mulch (HBM). Data points are the means of three replications with bars indicating the standard error of the mean, LDPE data are represented by the triangles and solid line, and HBM data are represented by the circles and dashed line. LDPE data were linearly regressed with mean separation using 95% asymptotic confidence intervals using the equation $y = 1.4x - 0.28$. HBM data were nonlinearly regressed using an exponential rise to maximum equation $y = 75(1 - e^{-1})$.

$$y = ae^{-bx} \quad [2]$$

where y is crop injury, a is the level of injury in the no EPTC control, and b is the influence of herbicide on decreasing height and yield. Pepper early-season injury and early-season height, and all variables for tomato, eggplant, and watermelon were evaluated using linear regression:

$$y = ax + b \quad [3]$$

All analyses were conducted using SAS version 9.1 (SAS Institute, Cary, NC).

Results and Discussion

Bell pepper, tomato, eggplant, and watermelon were not significantly injured by EPTC at any rate when applied under LDPE mulch. No greater than 5% injury was observed for any crop at both early (data not shown) and late season rating periods (Figures 1–4). EPTC applied under LDPE mulch had no significant impact on plant height for all crops evaluated (Figures 5–8). Bell pepper, tomato, eggplant, and watermelon produced 4,690, 133,400, 344,800, and 235,300 kg ha^{-1} of marketable fruit for nontreated checks; applying EPTC at 2, 3, or 4 kg ha^{-1} under LDPE mulch did not impact the weight (data not shown) or number (Figures 9–12) of marketable fruit produced.

In contrast to LDPE mulch, significant injury was noted for all crops planted in soil treated with EPTC applied under HBM. Only late heights were presented for bell pepper, tomato, and watermelon because the trends were consistent among the evaluation timings. Only the late height for

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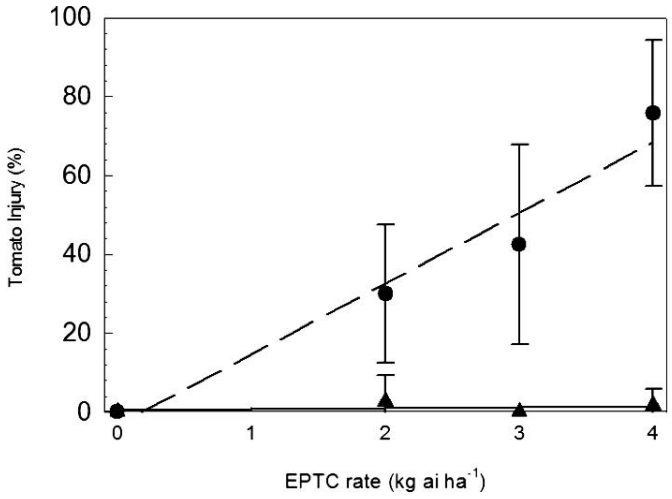


Figure 2. Late-season (6–8 wk after planting) tomato injury from EPTC applied at 0, 2, 3, and 4 kg ai ha^{-1} under low density polyethylene (LDPE) mulch or high barrier mulch (HBM). Data points are the means of three replications with bars indicating the standard error of the mean, LDPE data are represented by the triangles and solid line, and HBM data are represented by the circles and dashed line. Data were linearly regressed with mean separation using 95% asymptotic confidence intervals using the equation $y = 18x - 3.3$ for LDPE and $y = 0.26x + 0.5$ for HBM.

eggplant was presented because a rate effect was not apparent at early height evaluation.

Bell pepper was injured 29, 33, and 34% with EPTC at 2, 3, and 4 kg ha^{-1}, respectively, at 2 WAP (data not shown). Given optimum conditions for growth, plants continued to decline and pepper injury increased during the season with 66 to 75% injury noted for these same rates at 6 to 8 WAP (Figure 1). Pepper heights followed a similar trend throughout the season and heights taken just prior to harvest indicated a reduction in plant growth of 65 to 72% when compared to

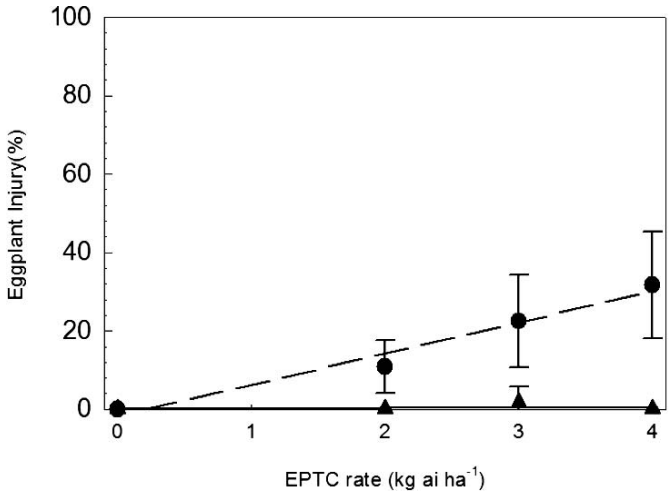


Figure 3. Late-season (6–8 wk after planting) eggplant injury from EPTC applied at 0, 2, 3, and 4 kg ai ha^{-1} under low density polyethylene (LDPE) mulch or high barrier mulch (HBM). Data points are the means of three replications with bars indicating the standard error of the mean, LDPE data are represented by the triangles and solid line, and HBM data are represented by the circles and dashed line. Data were linearly regressed with mean separation using 95% asymptotic confidence intervals using the equation $y = 0.14x + 0.1$ for LDPE and $y = 8x - 1.6$ for HBM.

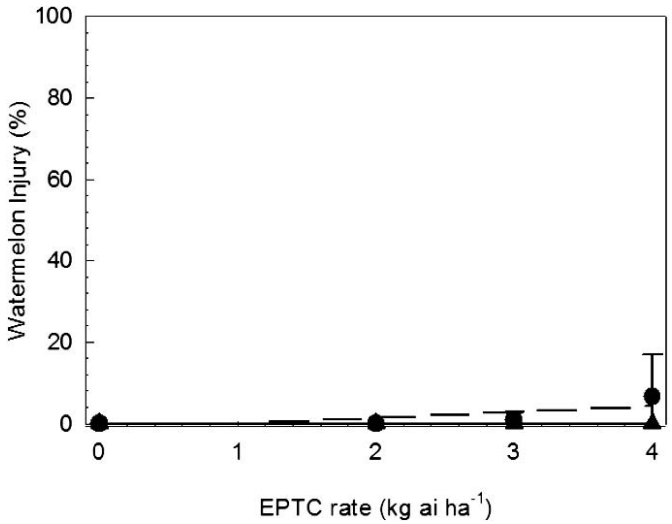


Figure 4. Late-season (6–8 wk after planting) watermelon injury from EPTC applied at 0, 2, 3, and 4 kg ai ha^{-1} under low density polyethylene (LDPE) mulch or high barrier mulch (HBM). Data points are the means of three replications with bars indicating the standard error of the mean, LDPE data are represented by the triangles and solid line, and HBM data are represented by the circles and dashed line. Data were linearly regressed with mean separation using 95% asymptotic confidence intervals using the equation $y = 1.4x - 1.3$ for HBM and no equation for LDPE, which exhibited no injury.

the no EPTC HBM control when EPTC was applied at 2, 3, and 4 kg ha^{-1} (Figure 5). Cumulative pepper fruit numbers (Figure 9) and weights (data not shown) were reduced 71 to 84% with all rates of EPTC.

Tomato was similarly sensitive to EPTC applied under HBM. Early season injury evaluations noted 18, 24, and 31% injury from EPTC at 2, 3, and 4 kg ha^{-1}, respectively (data

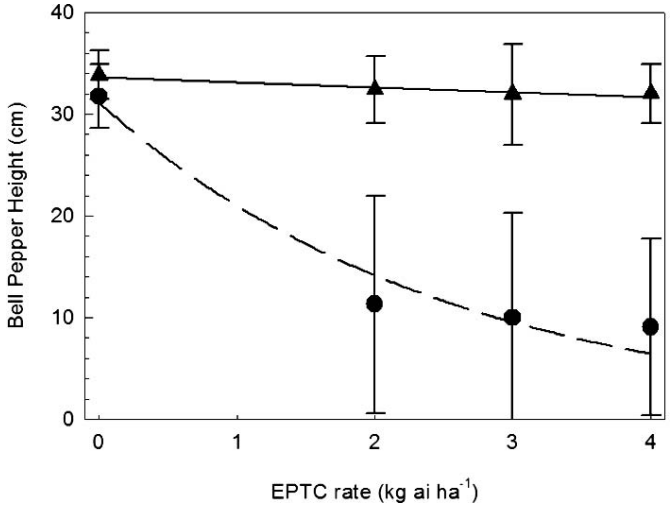


Figure 5. Late-season (5–7 wk after planting) pepper heights with EPTC applied at 0, 2, 3, and 4 kg ai ha^{-1} under low density polyethylene (LDPE) or high barrier mulch (HBM). Data points are the means of three replications with bars indicating the standard error of the mean, LDPE data are represented by the triangles and solid line, and HBM data are represented by the circles and dashed line. LDPE data were linearly regressed with mean separation using 95% asymptotic confidence intervals using the equation $y = -.49x + 34$. HBM data were nonlinearly regressed using an exponential decay equation, $y = 31e^{-0.39x}$.

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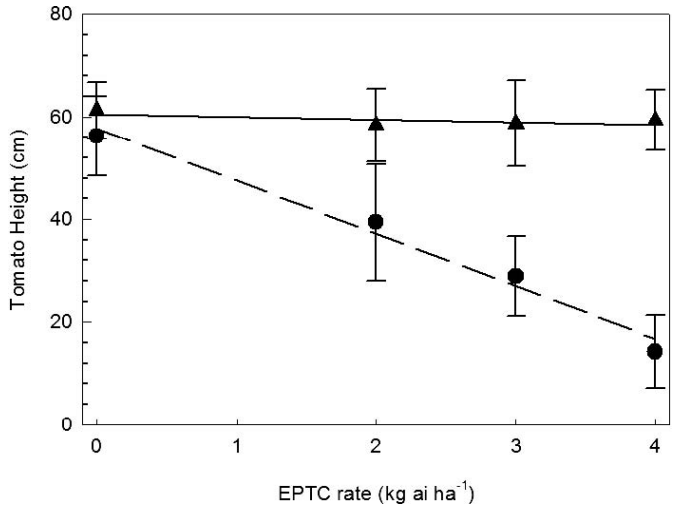


Figure 6. Late-season (5–7 wk after planting) tomato height with EPTC applied at 0, 2, 3, and 4 kg ai ha^{-1} under low density polyethylene (LDPE) mulch or high barrier mulch (HBM). Data points are the means of three replications with bars indicating the standard error of the mean, LDPE data are represented by the triangles and solid line, and HBM data are represented by the circles and dashed line. Data were linearly regressed with mean separation using 95% asymptotic confidence intervals using the equation $y = -0.53x + 60$ for LDPE and $y = -10x + 58$ for HBM.

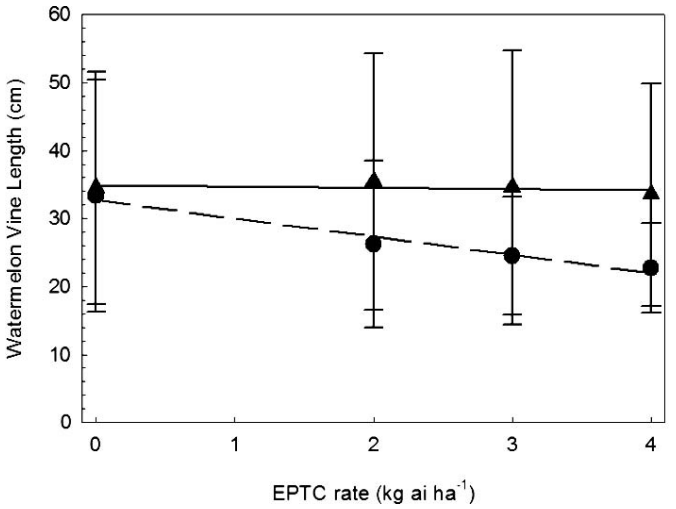


Figure 8. Late-season (4 wk after planting) watermelon stem length with EPTC applied at 0, 2, 3, and 4 kg ai ha^{-1} under low density polyethylene (LDPE) mulch or a high barrier mulch (HBM). Data points are the means of three replications with bars indicating the standard error of the mean, LDPE data are represented by the triangles and solid line, and HBM data are represented by the circles and dashed line. Data were linearly regressed with mean separation using 95% asymptotic confidence intervals using the equation $y = -0.22x + 35$ for LDPE and $-2.7x + 33$ for HBM.

not shown). Given optimum conditions for growth, plants continued to decline and late-season visual evaluations increased to 30, 43, and 76% (Figure 2). A similar linear decrease in tomato plant height was noted with a reduction of 30, 48, and 75% with 2, 3, and 4 kg ai ha^{-1} of EPTC, respectively (Figure 6). Tomato fruit numbers and weights were reduced for each harvest (data not shown), and when yields were combined over the six to seven harvests, a linear decrease was noted. Total number of tomato fruit harvested from the HBM control was 678,000 and declined linearly as the rate of EPTC increased from 2 kg ai ha^{-1} EPTC (435,000 fruits) to 4 kg ai ha^{-1} EPTC (156,000 fruits) (Figure 10). A similar trend was also noted for tomato fruit weights (data not shown).

Eggplant injury ranged from 9 to 32% with 2 to 4 kg ai ha^{-1} of EPTC throughout the entire season (Figure 3). Eggplant heights at 6 to 8 WAP were reduced 17, 29, and 35% at 2, 3,

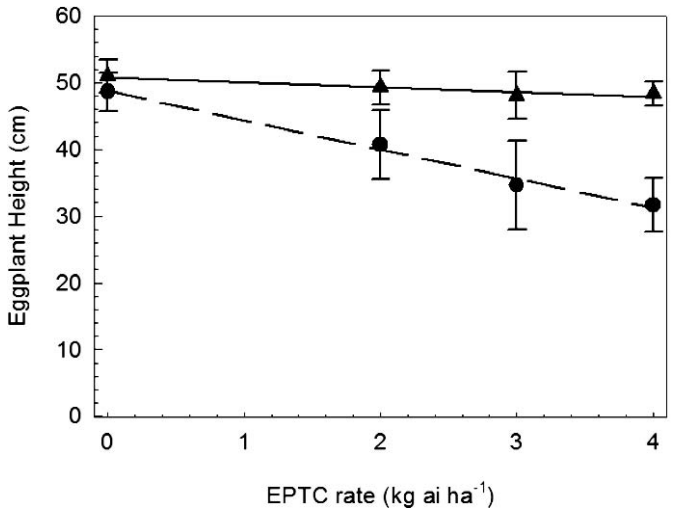


Figure 7. Late-season (5–7 wk after planting) eggplant height with EPTC applied at 0, 2, 3, and 4 kg ai ha^{-1} under low density polyethylene (LDPE) mulch or high barrier mulch (HBM). Data points are the means of three replications with bars indicating the standard error of the mean, LDPE data are represented by the triangles and solid line, and HBM data are represented by the circles and dashed line. Data were linearly regressed with mean separation using 95% asymptotic confidence intervals using the equation $y = -0.72x + 51$ for LDPE and $y = -4.4x + 49$ for HBM.

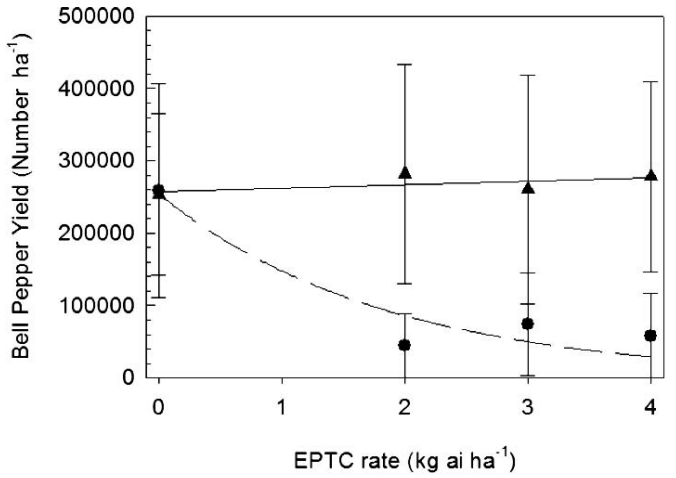


Figure 9. Cumulative pepper harvests (three to four harvests) as number of fruits per hectare with EPTC applied at 0, 2, 3, and 4 kg ai ha^{-1} under low density polyethylene (LDPE) mulch or high barrier mulch (HBM). Data points are the means of three replications with bars indicating the standard error of the mean, LDPE data are represented by the triangles and solid line, and HBM data are represented by the circles and dashed line. LDPE data were linearly regressed with mean separation using 95% asymptotic confidence intervals using the equation $y = 4716x + 257889$. HBM data were nonlinearly regressed using an exponential decay equation $y = 253533e^{-0.54x}$.

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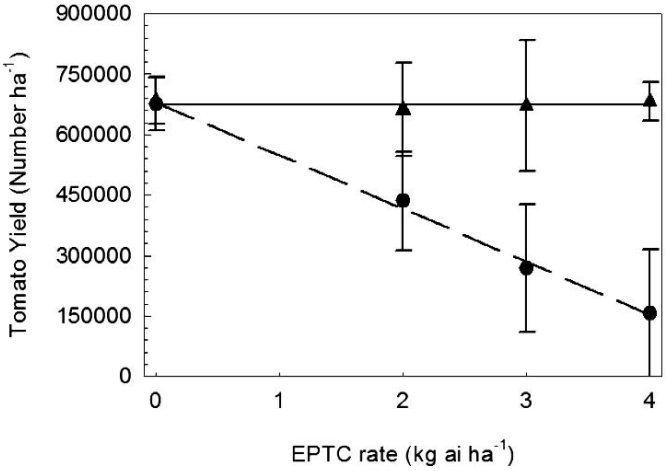


Figure 10. Cumulative tomato harvests (six to seven harvests) as number of fruit per hectare with EPTC applied at 0, 2, 3, and 4 kg ai ha^{-1} under low density polyethylene (LDPE) mulch or high barrier mulch (HBM). Data points are the means of three replications with bars indicating the standard error of the mean, LDPE data are represented by the triangles and solid line, and HBM data are represented by the circles and dashed line. Data were linearly regressed with mean separation using 95% asymptotic confidence intervals using the equation $y = -827x + 676458$ for LDPE and $y = -131750x + 679992$ for HBM.

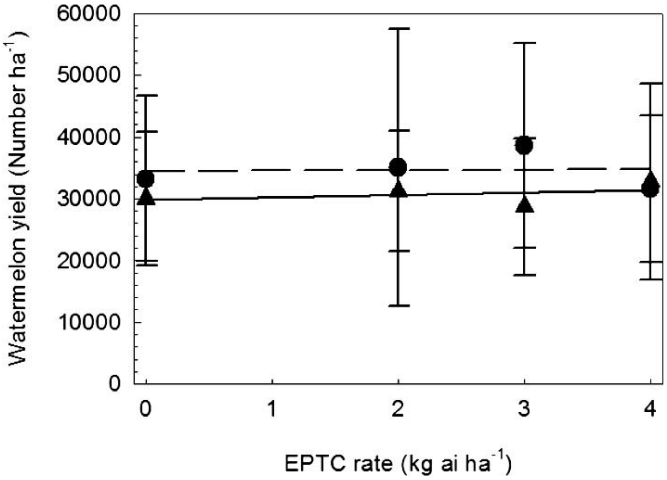


Figure 12. Cumulative watermelon harvests (one to three harvests) as number of fruit per hectare with EPTC applied at 0, 2, 3, and 4 kg ai ha^{-1} under low density polyethylene (LDPE) mulch or high barrier mulch (HBM). Data points are the means of three replications with bars indicating the standard error of the mean, LDPE data are represented by the triangles and solid line, and HBM data are represented by the circles and dashed line. Data were linearly regressed with mean separation using 95% asymptotic confidence intervals using the equation $y = 403x + 29770$ for LDPE and $y = 75x + 34455$ for HBM.

and 4 kg ai ha^{-1}, respectively, when compared to the no EPTC HBM control (Figure 7). Eggplant yield decreased linearly 7 to 19% when EPTC was applied at rates between 2 and 4 kg ai ha^{-1} under HBM (Figure 11).

Watermelon injury from EPTC at 2, 3, and 4 kg ai ha^{-1} caused only 6 to 12% stunting at 6 to 8 WAP (Figure 4). Watermelon stem lengths were not impacted by EPTC applied under HBM at any observation period (Figure 8) and no differences in yield were noted when comparing the number (Figure 12) or weight (data not shown) of watermelon harvested during individual harvests or for the cumulative harvest data.

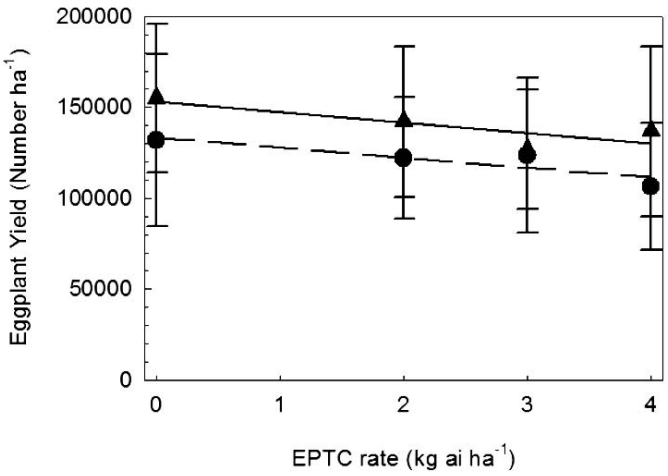


Figure 11. Cumulative eggplant harvests (seven to nine harvests) as number of fruit per hectare with EPTC applied at 0, 2, 3, and 4 kg ai ha^{-1} under low density polyethylene (LDPE) mulch or high barrier mulch (HBM). Rate by mulch interaction was not significant. Data points are the means of three replications with bars indicating the standard error of the mean, LDPE data are represented by the triangles and solid line, and HBM data are represented by the circles and dashed line. Data were linearly regressed with mean separation using 95% asymptotic confidence intervals using the equation $y = -5707x + 152950$ for LDPE and $y = -5488x + 133322$ for HBM.

In this study, crop tolerance of vegetables to EPTC in plasticulture production was directly influenced by the mulch type used. This study was novel in using EPTC in combination with tomato, eggplant, watermelon, and bell pepper and a high barrier mulch. As previous research with other fumigants suggests, high barrier mulches may reduce the volatilization of EPTC, which would increase the dose plants receive at time of transplanting (Austerweil et al. 2006; Minuto et al. 1999b; Ou et al. 2008; Qin et al. 2008; Santos et al. 2006b, 2007; Yates et al. 2002). Increasing the plant-back interval would not be a viable option because it would affect the length of the marketing season and would likely not be included in a grower's management plan. EPTC could be included as part of a MBr alternative system for tomato, pepper, eggplant, and watermelon when applied under LDPE mulch; EPTC application following label rates in combination with a HBM can be considered for watermelon. In order to comply with regulatory requirements on fumigant labels, growers that are required to use HBM fumigant gas emission reduction will not be able to safely use EPTC for fruiting vegetables such as bell pepper, eggplant, and tomato.

Literature Cited

Anbar, A. D., Y. L. Yung, and F. P. Chavez. 1996. Methyl bromide: ocean sources, ocean sinks, and climate sensitivity. Global Biogeochem. Cycles 10:175–190.

Anonymous. 1999. Commercial Watermelon Production Handbook. University of Georgia Extension Bulletin #996. http://www.agmrc.org/media/cms/B996_B3D54FD90A36C.pdf Accessed: June 25, 2010.

Anonymous. 2006. Commercial Tomato Production Handbook. University of Georgia Extension Bulletin #1312. http://www.caes.uga.edu/Publications/pubDetail.cfm?pk_id=7470&pg=al&ak=C. Accessed: June 25, 2010.

https://doi.org/10.1614/WT-D-11-00016.1 Published online by Cambridge University Press

Anonymous. 2009. Commercial pepper production handbook. University of Georgia Extension Bulletin #1309. http://www.caes.uga.edu/Publications/pubDetail.cfm?pk_id=7461&pg=al&ak=C (verified 25 June 2010).
Austerweil, M., B. Steiner, and A. Gamliel. 2006. Permeation of soil fumigants through agricultural plastic films. Phytopathology 34:491–501.
Buker, R. S. III., W. M. Stall, S. M. Olson, and D. G. Shilling. 2003. Season-long interference of yellow nutsedge (*Cyperus esculentus*) with direct-seeded and transplanted watermelon (*Citrullus lanatus*). Weed Technol. 17:751–754.
Chase, C. A., T. R. Sinclair, D. G. Shilling, J. P. Gilreath, and S. J. Locascio. 1998. Light effects on rhizome morphogenesis in nutsedges (*Cyperus* spp.): implications for control by soil solarization. Weed Sci. 46:575–580.
Culpepper, A. S., T. L. Grey, and T. M. Webster. 2006. Purple nutsedge (*Cyperus rotundus*) response to methyl bromide alternatives applied under four types of mulch. Pages 148. *in* Proceedings of the Southern Weed Science Society Annual Meeting. Southern Weed Science Society. Champaign, IL.
[EPA] U.S. Environmental Protection Agency. 2008. The Phaseout of Methyl Bromide. http://www.epa.gov/Ozone/mbr/. Accessed: June 25, 2010.
[EPA] U.S. Environmental Protection Agency. 2011. List of Critical Uses. http://www.epa.gov/Ozone/mbr/cueuses.html. Accessed: October 4, 2011.
Garibaldi, A., M. Baudino, A. Minuto, and M. L. Gullino. 2008. Effectiveness of fumigants and grafting against tomato brown root rot caused by *Colletotrichum coccodes*. Phytoparasitica 36:483–488.
Gilreath, J. P., T. N. Motis, and B. M. Santos. 2005. *Cyperus* spp. control with reduced methyl bromide plus chloropicrin doses under virtually impermeable film in pepper. Crop Prot. 24:285–287.
Harrison, H. F. and R. L. Fery. 1998. Responses of leading bell pepper varieties to bentazon herbicide. HortScience 33:318–320.
Julian, J. W., G. H. Sullivan, and S. C. Weller. 1998. Assessment of potential impacts from the elimination of methyl bromide in the fruit and vegetable trade. HortScience 33:794–797.
Kemble, J. M., E. J. Sikora, E. H. Simonne, G. W. Zehnder, and M. G. Patterson. 1998. Guide to commercial eggplant production. Alabama Cooperative Extension System, ANR-1098. http://www.aces.edu/pubs/docs/A/ANR-1098/. Accessed: June 25, 2010.
MacRae, A. W., G. Vallad, and J. Noling. 2010. Evaluation of all components of the 3-way fumigant system for use in central Florida tomato. Pages 17. *in* Proceedings of Annual International Research Conference on Methyl Bromide Alternatives and Emissions Reductions. Methyl Bromide Alternatives Outreach, Fresno, CA.
Malathrakis, N. E. 1999. Soil fumigation with methyl bromide: advantages and disadvantages. Pages 46. *in* Third International Workshop on Methyl Bromide Alternatives for the Southern European Countries. Agricultural Ministry of Greece, The European Commission DGXI. Crete, Greece.
Minuto, A. G., C. Clini, and M. L. Gullino. 1999a. Replacement of methyl bromide on vegetable crops in Italy. Pages 46. *in* Third International Workshop on Methyl Bromide Alternatives. Agricultural Ministry of Greece, The European Commission DGXI. Crete, Greece.
Minuto, A., G. Gilardi, M. L. Gullino, and A. Garibaldi. 1999b. Reduced dosages of methyl bromide applied under gas-impermeable plastic films for controlling soilborne pathogens of vegetable crops. Crop Prot. 18:365–371.
Morales-Payan, J. P. and W. M. Stall. 1997. Effect of purple nutsedge (*Cyperus rotundus*) population densities on the yield of eggplant (*Solanum melongena*). HortScience 32:431.
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. 2002. Reducing methyl bromide field application rates with plastic mulch technology. University of Florida Bulletin #ENY046. http://edis.ifas.ufl.edu/in403. Accessed: June 25, 2010.
Noling, J. W. and J. O. Becker. 1994. The challenge of research and extension to define and implement alternatives to methyl bromide. J. Nematol. (Suppl.) 26:573–586.
Noling, J. W., J. P. Gilreath, and D. A. Botts. 2006. Alternatives to methyl bromide soil fumigation for Florida vegetable production. Pages 121–126. *in* S. M. Olson and D. N. Maynard, eds. Vegetable Production Handbook for Florida, 2006–2007. Gainesville, FL: IFAS, University of Florida.
Ou, L.-T., J. E. Thomas, L. H. Allen Jr., J. C. Vu, and D. W. Dickson. 2008. Comparison of surface emissions and subsurface distribution of cis- and trans-1,3-dichloropropene and chloropicrin in sandy field beds covered with four different plastic films. J. Environ. Sci. Health Part B 43:376–381.
Parker, C., K. Holly, and S. D. Hocombe. 1969. Herbicides for nutgrass control—conclusions from ten years of testing at Oxford. PANS 15:54–63.
Patterson, D. T. 1998. Suppression of purple nutsedge (*Cyperus rotundus*) with polyethylene film mulch. Weed Technol. 12:275–280.
Qin, R., S. Gao, J. A. McDonald, H. Ajwa, S. Shem-Tov, and D. A. Sullivan. 2008. Effect of plastic tarps over raised-beds and potassium thiosulfate in furrows on chloropicrin emissions from drip fumigated fields. Chemosphere 72:558–563.
Ragsdale, N. N. and W. B. Wheeler. 1995. Methyl bromide risks, benefits, and current status in pest control. Rev. Pestic. Toxicol. 3:21–44.
Santos, B. M. 2009. Drip-applied metam potassium and herbicides as methyl bromide alternatives for *Cyperus* control in tomato. Crop Prot. 28:68–71.
Santos, B. M., J. P. Gilreath, T. N. Motis, J. W. Noling, J. P. Jones, and J. A. Norton. 2006a. Comparing methyl bromide alternatives for soilborne disease, nematode and weed management in fresh market tomato. Crop Prot. 25:690–695.
Santos, B. M., J. P. Gilreath, T. N. Motis, M. von Hulten, and M. N. Siham. 2006b. Effects of mulch types and concentrations of 1,3-dichloropropene plus chloropicrin on fumigant retention and nutsedge control. HortTechnology 16:637–640.
Santos, B. M., J. P. Gilreath, and M. N. Siham. 2007. Comparing fumigant retention of polyethylene mulches for nutsedge control in Florida spodosols. HortTechnology 17:308–311.
Senseman, S. A., ed. 2007. Herbicide Handbook. 9th ed. Champaign IL: Weed Science Society of America.
[USDA-AMS] U.S. Department of Agriculture-Agricultural Marketing Service. 1953. United States standards for grades of eggplant. http://www.ams.usda.gov/AMSv1.0/getfile?dDocName=STELPRDC5050264. Accessed: June 25, 2010.
[USDA-AMS] U.S. Department of Agriculture-Agricultural Marketing Service. 1978. United States standards for grades of watermelon. http://cuke.hort.ncsu.edu/cucurbit/wmelon/wmhndbk/wmusdagrades.pdf. Accessed: June 25, 2010.
[USDA-AMS] U.S. Department of Agriculture-Agricultural Marketing Service. 1991. United States standards for grades of fresh tomatoes. http://www.ams.usda.gov/AMSv1.0/getfile?dDocName=STELPRDC5050331. Accessed June 25, 2010.
[USDA-AMS] U.S. 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 25, 2010.
Wallace, R. W., A. L. Phillips, and J. C. Hodges. 2007. Processing spinach response to selected herbicides for weed control, crop injury, and yield. Weed Technol. 21:714–718.
Webster, T. M. 2005. Patch expansion of purple nutsedge (*Cyperus rotundus*) and yellow nutsedge (*Cyperus esculentus*) with and without polyethylene mulch. Weed Sci. 53:839–845.
Webster, T. M. 2006. Weed survey—southern states: vegetable, fruit, and nut crops subsection. Proc. South. Weed Sci. Soc. 59:260–277.
William, R. D. 1976. Purple nutsedge (*Cyperus rotundus*): tropical scourge. HortScience 11:357–364.
William, R. D. and G. F. Warren. 1975. Competition between purple nutsedge and vegetables. Weed Sci. 23:317–323.
Wills, G. D. 1987. Description of purple and yellow nutsedge (*Cyperus rotundus* and *Cyperus esculentus*). Weed Technol. 1:2–9.
Yates, S. R., J. Gan, S. K. Papiernik, R. Dugan, and D. Wang. 2002. Reducing fumigant emissions after soil application. Phytopathology 92:1344–1348.

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