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Efficacy of Fluensulfone in a Tomato–Cucumber Double Cropping System

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Abstract: Vegetable crops in the southeastern United States are commonly grown on plastic mulch with two crop cycles produced on a single mulch application. Field trials were conducted in 2013 and 2014 in two locations to evaluate the efficacy of fluensulfone for controlling *Meloidogyne* spp. when applied through drip irrigation to cucumber in a tomato–cucumber double-cropping system. In the spring tomato crop, 1,3-dichloropropene (1,3-D), fluensulfone, and a resistant cultivar significantly decreased root galling by 91%, 73%, and 97%, respectively, compared to the untreated control. Tomato plots from the spring were divided into split plots for the fall where the main plots were the spring treatment and the subplots were cucumber either treated with fluensulfone (3.0 kg a.i./ha. via drip irrigation) or left untreated. The fall application of fluensulfone improved cucumber vigor and reduced gall ratings compared to untreated subplots. Fluensulfone reduced damage from root-knot nematodes when applied to the first crop as well as provided additional protection to the second crop when it was applied through a drip system.
Key words: cucumber, drip application, fluensulfone, management, *Meloidogyne* spp., nematicide, root-knot nematodes, tomato.

Vegetable crops in the southeastern United States are commonly grown on plastic mulch. In addition to helping to retain moisture and fertilizer, plastic mulch also increases soil temperature earlier in the season, which allows for earlier planting dates compared to bare-ground systems (Lament, 1993). Soil fumigants are usually applied prior to plastic mulch application for control of soilborne diseases, nematodes, and weeds. Once a fumigant has been applied, plastic mulch is laid over the treated area to help retain the fumigant in the soil which may provide greater efficacy and application safety. Because of the expense associated with applying new plastic each time a crop is grown and removing the old plastic from the field, growers commonly produce multiple crops on one application of plastic mulch. This practice is known as double cropping. A common double-crop sequence in the southeast United States is a tomato–cucurbit rotation. Tomatoes (*Solanum lycopersicum* L.) are planted on new plastic in the spring and then followed by a cucurbit crop in the fall. Several pests affect both tomato and cucurbit crops, including the root-knot nematode (*Meloidogyne* spp.). Infection of roots by *Meloidogyne* spp. leads to root galls and yield reduction (Karssen et al., 2013), and may predispose plants to secondary invaders (Back et al., 2002).

Controlling *Meloidogyne* spp. on the second crop has been an area of interest, with several studies evaluating different control options in double-cropping systems. Desaeger and Csinos (2006) evaluated different fumigant nematicides for control of *Meloidogyne* spp. on a first crop of tomato or eggplant followed by a second crop of melon or squash. They found that galling and yield loss were low in the first crop, but that galling and yield loss increased substantially in the second crop, particularly in the untreated control, and that fumigants applied through drip irrigation prior to planting the second crop reduced galling compared to the control. *Meloidogyne* spp. can also be managed with resistant crops. Tomato and pepper cultivars with resistance to *Meloidogyne* spp. are available and some studies have demonstrated the ability of these cultivars to reduce root galling and yield loss in a double-cropping system (Hanna, 2000; Thies et al, 2004). The resistance to *Meloidogyne* spp. in tomato is controlled by the *Mi* gene (Smith, 1944), which has been bred into many tomato cultivars available today. However, this resistance has been documented to be broken at soil temperatures >28°C (Dropkin, 1969) and by highly virulent populations of nematodes (Roberts et al., 1990; Castagnon-Serono, 1996; Kaloshian et al., 1996).

Until recently, methyl bromide (MeBr) was the primary fumigant used on the first crop. Methyl bromide has broad-spectrum activity against a wide variety of pests, including nematodes. However, use of MeBr has been banned via the Montreal Protocol as it has been identified as an ozone-depleting substance (U.S. Environmental Protection Agency, 2000). With the use of MeBr being phased out, efforts have been made to discover alternatives for nematode management. Other fumigant nematicides are still available, including 1,3-D, chloropicrin, and dimethyl disulfide. These fumigants are still the primary nematicide choice for the first crop, although they are costly, difficult to apply, require buffer zones and long intervals between treatment and planting (plant back), and pose worker safety concerns. In addition, the future use of these products is unclear since they are heavily regulated by the EPA.

Fumigant nematicides applied to a first crop provide adequate nematode control; however, their efficacy may not persist long enough to provide satisfactory nematode control on the second crop (Lembright, 1990; Giannakou et al., 2002). The use of chisel-injected

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fumigants on the second crop is not an option because the plastic mulch would be destroyed during application. Therefore, drip-applied nematicides are used for control of *Meloidogyne* spp. on the second crop. Drip-applied fumigants, such as 1,3-D and metam sodium, may be applied through the drip irrigation system prior to planting the second crop. However, the soil distribution of drip-applied fumigant nematicides can be limited since they have to move through the irrigation water before volatilizing (Csinos et al., 2002). The carbamate oxamyl is commonly applied as both a foliar and drip application for control of *Meloidogyne* spp. on a second crop. While commonly considered a nematicide, oxamyl is actually a nematistat which temporarily paralyzes nematodes until concentrations of the active ingredient fall below a toxic level (Wright, 1981; Rich et al., 2004); therefore, multiple applications of oxamyl may be needed throughout the growing season to achieve adequate control.

Fluensulfone is a new nonfumigant fluoroalkenyl nematicide, which received EPA registration in 2014 on cucurbit and fruiting vegetables crops under the trade name Nimitz (Adama USA, Raleigh, NC). Fluensulfone may be applied with preplant incorporation (PPI) or through drip irrigation. There are little published data on the efficacy of fluensulfone against *Meloidogyne* spp., but preliminary data suggest that fluensulfone can be an effective nematicide (Csinos et al., 2010; Oka et al., 2012). Our objective was to evaluate the efficacy of fluensulfone for reducing *Meloidogyne* spp. populations and root galling in a tomato–cucumber (*Cucumis sativus* L.) double-cropping system.

Materials and Methods

Site description and general management: Four field trials were conducted in the spring and fall of 2013 and 2014. Two trials were conducted each year at two separate locations: the University of Georgia Hort Hill Farm in Tifton, GA, on a Tifton loamy sand (90% sand, 6% silt, 4% clay; pH 5.6; 1% organic matter; fine, loamy, kaolinitic thermic Plinthic Kandiudults) and the University of Florida Plant Science Research and Education Unit in Citra, FL, on an Arredondo sand (97% sand, 2% silt, 1% clay; pH 6.4; 0.45% organic matter; loamy, siliceous, semiactive, hyperthermic, Grossarenic Paleudults). Trials consisted of a spring tomato crop followed by a fall cucumber crop. Tomato plots were arranged in a randomized complete block design with six replications. Cucumber plots utilized a split-plot design with six replications where the treatments on tomato in the spring were the main plot and the treatments on cucumber were the subplots. Each location had a history of vegetable crops and was infested with *Meloidogyne* spp. The Tifton field was infested with *M. incognita* and the Citra field was infested with a mixture of *M. incognita*, *M. arenaria*, and *M. javanica*.

In 2013, land was harrowed and rototilled on 25 February and 4 March in Citra and Tifton, respectively. In 2014, land was harrowed and rototilled on 12 March and 11 March for Citra and Tifton, respectively. Tomato plots were 10.7 m long and 0.8 m wide with a 2-m alley between plots.

A single 10-mm drip line with 30.5-cm emitter spacing was placed 5 cm below the soil line at the same time as plastic was laid. Preplant fertilizer and subsequent drip fertilizer applications were made according to University of Georgia and University of Florida Extension recommendations. All herbicide, insecticide, and fungicide applications followed the University of Georgia and University of Florida Extension recommendations.

Treatments: Treatments on the first crop of tomato included 1,3-D, fluensulfone PPI, a resistant cultivar (PS 01522935), and an untreated control. The 1,3-D was applied as a preplant injection using a Yetter injection rig calibrated to deliver 112 liters/ha on 5 March and 13 March in Citra in 2013 and 2014, respectively, and on 8 March and 14 March in Tifton for years 2013 and 2014, respectively. A virtually impermeable film plastic was laid on the 1,3-D plots immediately after application using a tractor drawn bed shaper. Fluensulfone was applied to spring tomato crops as a PPI on 25 March and 9 April in Citra in 2013 and 2014, respectively, and on 27 March and 10 April in Tifton in 2013 and 2014, respectively. Treatments were applied using a CO_2 powered backpack sprayer with a four nozzle boom calibrated to deliver 187 liters/ha. Fluensulfone was immediately incorporated into the soil using a PTO driven rototiller. Plastic mulch (virtually impermeable film) was then applied to the fluensulfone plots and to the resistant cultivar and untreated plots. Tomato seedlings ('PS 01522935' and the susceptible 'Tribute') were transplanted on 9 April and 21 April in Citra in 2013 and 2014, respectively, and on 8 April and 22 April in Tifton in 2013 and 2014, respectively. Both tomato varieties are resistant to tomato yellow leaf curl virus and tomato spotted wilt virus.

Treatments for the second crop of cucumber were arranged in a split-plot design. Cucumber plots were 4 m long and 0.8 m wide with a 2-m alley between plots. Plots either received a fluensulfone drip application (3.0 kg a.i./ha) or were left untreated. Drip applications of fluensulfone were applied on 7 August and 4 August in Citra in 2013 and 2014, respectively, and 8 August and 5 August in Tifton in 2013 and 2014, respectively. Beds were given a pretreatment irrigation cycle of 1 hr to allow for adequate bed moisture at time of application. Fluensulfone was injected and then water was allowed to run for an additional 15 min to flush any remaining fluensulfone from the lines. Formulated fluensulfone was mixed in a 3-liter bottle for injections in Tifton and was mixed in 48 liters of water for injections in Citra. Untreated plots were given the same amount of water as treated plots. Thirteen cucumber seedlings, 'Impact', were transplanted into plots on 14 August and 18 August for Citra in 2013 and 2014, respectively, and on 15 August and 19 August for Tifton in 2013 and 2014, respectively.

Data collection: In all trials, soil cores were collected from the middle of plots prior to treatment application and then again after root gall ratings to assess *Meloidogyne* spp. population densities before and after treatment. Five soil cores 1.9 cm diam. and 20-cm deep were taken from the middle of each plot. Samples were sent to the University of Georgia Nematology Lab (Athens, GA) and juveniles of *Meloidogyne* spp. were counted per 100 cm^3 of soil. Nematode count data were transformed using $\log_{10}(x+1)$ to normalize the data and then were back transformed using $10^x - 1$ to represent the number of J2 per plot.

Plant vigor was rated in all trials to evaluate treatment effects. Vigor ratings were on a 0 to10 scale with 0 being a dead plant and 10 being live, vigorous, healthy plant. Tomato was evaluated for vigor at 14 and 21 d after transplanting (DAP) in 2013 and 14, 21, and 28 DAP in 2014. A vigor rating was conducted on cucumber 14 and 28 DAP in 2013 and 21 and 28 DAP in 2014.

Each crop in each trial was harvested multiple times. In 2013, tomato plants were harvested 65 and 76 DAP in Citra and 70, 78, and 91 DAP in Tifton. In 2014, tomatoes were harvested 64 and 73 DAP in Citra and 62 and 71 DAP in Tifton. Every third plant in the plot was harvested for a total of eight plants per plot. All ripe fruit was picked for the first harvest and plants were stripped of all fruit for the final harvest. In 2013, cucumbers were harvested from all plants in the plot 43, 47, 50, 54, and 57 DAP in Citra and 40, 47, and 54 DAP in Tifton. In 2014, cucumbers were harvested 52 and 58 DAP in Citra and 42, 51, and 55 DAP in Tifton.

Roots were rated for galling on the final harvest date for each crop to determine *Meloidogyne* spp. damage. Gall ratings were on a 0 to 10 scale with 0 being no visible galls and 10 being 100% of the root system galled. In the tomato plots, five tomato plants were exhumed from a 2-m section in the middle of the plot rated for galling. This area then served as the alley between the split-plot cucumber plots. For cucumber, seven plants per plot were exhumed for gall ratings.

Statistical analysis: Data were analyzed using mixed model analysis of variance (GLIMMIX PROC, SAS Institute, Cary NC) to test for interactions between treatments and locations. Tomato data were analyzed as a randomized complete block design and cucumber data were analyzed as a split-plot design. All data were combined across years and, when possible, across locations when no treatment × location interaction existed ($P > 0.05$). Year was considered a random variable. All mean differences are reported according to Student's t tests $\alpha = 0.05$ using the PDIFF operation.

Results

Spring treatments in tomato: The population densities of *Meloidogyne* spp. before treatments were applied in the spring were very low for both locations in 2013 and for Citra in 2014 (<1/100 cm^3 of soil). Although population densities of the nematode were greater in Tifton in 2014 (22/100 cm^3), there were no differences among the plots prior to treatment. There were also no significant treatment × location interactions for plant vigor, fruit weight, or galling; therefore, the data were combined between locations (Table 1). Spring treatments did not have an effect ($P = 0.65$) on plant vigor at 14 d after treatment compared to an untreated control. Vigor data were similar for other rating dates (data not shown). Likewise, the treatments did not have an effect ($P = 0.17$) on plant yield. Gall ratings were lower ($P < 0.0001$) among treated plots compared to the untreated controls (Table 1). The resistant cultivar had the lowest gall ratings but was not significantly lower than the 1,3-D treatment. Plants in the fluensulfone treatment had more galling than the resistant cultivar, but there was no difference between root galling in the fluensulfone and 1,3-D treatments. There was a treatment × location interaction ($P = 0.0004$) for nematode numbers in soil (Table 2). In both locations, the nematicide treatments and the resistant cultivar significantly reduced the number of J2 in the soil at harvest compared to the untreated control; however, there were no differences among these treatments.

Fall treatments in cucumber: There were no significant treatment × location interactions for plant vigor, root galling, or nematode population densities; therefore, the data were combined between locations (Table 3). Moreover, there were no interactions between main plot (spring) and subplot (fall) treatments for any of the variables. Cucumber vigor was influenced by both the main plot ($P = 0.0066$) and subplot ($P = 0.0060$) treatments. The application of fluensulfone to

Table 1. Effect of nematicide treatment on tomato vigor, fruit yield, and root-knot galling by *Meloidogyne* spp. in Citra, FL, and Tifton, GA, in 2013 and 2014.

Treatment	Vigor[a]	Yield (kg/plot)	Galling[b]
1,3-Dichloropropene	6.71 a[c]	19.05 a	0.35 bc
Fluensulfone	7.41 a	22.03 a	1.10 b
Resistant cultivar	6.67 a	17.77 a	0.11 c
Untreated	7.16 a	19.60 a	4.11 a
	P value	*P* value	*P* value
Treatment	0.6537	0.1728	<0.0001
Location*treatment	0.7833	0.4467	0.1882

[a] Plant vigor was recorded 14 d after planting on a 0 to 10 scale with 0 being a dead plant and 10 being a completely healthy plant.

[b] Gall ratings were conducted on a 0 to 10 scale with 0 being no visible galls and 10 being 100% of root system galled.

[c] Data are the means of two years, two locations, and six replications ($N = 24$). Means with same letter within a column are not significantly different ($P < 0.05$).

Table 2. Effect of nematicide treatment on the population densities of *Meloidogyne* spp. second-stage juveniles (J2) per 100 cm^3 soil after tomato harvest.

Treatment	Tifton, GA[a] J2 density	Citra, FL J2 density
1,3-Dichloropropene	18.75 b[b]	13.92 b
Fluensulfone	274.42 b	48.66 b
Resistant cultivar	24.91 b	12.08 b
Untreated	869.67 a	186.92 a
	P value	*P* value
Treatment	<0.0001	0.0005

[a] Nematode densities have been transformed using log $(x + 1)$ to normalize data and then a back transformation was made using $10^x - 1$. Data are not combined because there was a treatment × location interaction ($P = 0.0004$).

[b] Data are the means of two years and six replications ($N = 12$). Means with same letter within a column are not significantly different ($P < 0.05$).

Table 3. Effect of spring/fall treatments on cucumber vigor, root galling caused by *Meloidogyne* spp., and population densities of *Meloidogyne* spp. second-stage juveniles (J2) after cucumber harvest.

Treatment[a]	Vigor[c]	Galling[d]	J2[e]
1,3-D/fluen. drip	5.46 a[e]	2.73 c	2.79 b
1,3-D/untreated	5.04 a	3.54 bc	8.59 ab
Fluen. PPI/fluen. drip	4.88 a	3.09 c	7.75 ab
Fluen. PPI/untreated	4.46 ab	5.19 ab	22.72 a
Resistant/fluen. drip	4.99 a	2.94 c	8.56 ab
Resistant/untreated	4.54 ab	3.56 bc	15.29 ab
Untreated/fluen. drip	4.69 ab	4.85 ab	15.76 ab
Untreated/untreated	3.67 b	6.01 a	20.47 ab
Fluensulfone	5.02 A	3.40 B	9.12 A
Untreated	4.43 B	4.58 A	17.22 A
	P value	*P* value	*P* value
Main plot treatment	0.0066	<0.0001	0.2296
Subplot treatment	0.0060	0.0023	0.0772
Main plot* subplot	0.7251	0.5809	0.8855
Location*subplot treatment	0.1622	0.4185	0.5505

[a] The first treatment listed was applied to the spring crop of tomato (main plot) and the second treatment listed was applied to the fall crop of cucumber (subplot). Treatment abbreviations: 1,3-D = 1,3-dichloropropene; fluen. = fluensulfone.

[b] Plant vigor was recorded 14 d after planting on a 0 to 10 scale with 0 being a dead plant and 10 being a healthy plant.

[c] Gall ratings were conducted on a 0 to 10 scale with 0 being no visible galls and 10 being 100% of root system galled.

[d] Densities of J2 per 100 cm^3 of soil. Densities were transformed using log $(x + 1)$ to normalize data and then a back transformed using $10^x - 1$.

[e] Data for the spring/fall treatments are the means of two years, two locations, and six replications ($N = 24$). Means with the same lowercase letters within a column are not significantly different ($P < 0.05$); uppercase letters indicate differences between subplot treatments.

cucumber significantly improved plant vigor 14 d after treatment when compared to untreated control when means were averaged across main plot treatments. The untreated spring plot followed by an untreated fall plot had the lowest numerical vigor ratings. Plants in the 1,3-D treatment had increased vigor compared to plants in the untreated control regardless of whether a subplot treatment of fluensulfone was applied or not. Vigor was improved over the untreated when fluensulfone or the resistant cultivar was the main plot treatment only if fluensulfone was applied again to the second crop.

Cucumber gall ratings were reduced by both the main plot ($P < 0.0001$) and subplot ($P = 0.0023$) treatments. When means were averaged across main plot treatments, cucumber gall ratings were lower when fluensulfone was applied to the cucumber compared to untreated control (Table 3). The 1,3-D and resistant cultivar main plot treatments had lower gall ratings compared to the untreated control. The fluensulfone main plot treatment reduced root galling compared to the untreated control only when a subplot treatment of fluensulfone was applied. Neither the main plot treatments nor the subplot treatments had a significant effect on the number of J2 in the soil at harvest.

For cucumber yield, there was a subplot treatment × location interaction ($P = 0.015$). The main plot treatment ($P < 0.0001$), but not the subplot treatment ($P = 0.29$) affected cucumber yield in Tifton (Table 4), while both the main plot and subplot treatments affected yield in Citra ($P < 0.0001$ and $P = 0.0027$, respectively). The subplot treatment of fluensulfone significantly increased cucumber yield in Citra compared to the untreated control when yields were combined across main plot treatments.

Discussion

Obtaining satisfactory efficacy of a drip-applied nonfumigant nematicide can be difficult to achieve (Noling, 2005). Our results, however, demonstrated that a fall application of fluensulfone through a drip system improved plant vigor and yield, and further reduced root galling caused by *Meloidogyne* spp. when used in combination with nematode control in the spring. In a tomato–cucumber double-cropping system, Colyer et al. (1998) showed that a resistant tomato cultivar as a spring treatment provided better control of *Meloidogyne* spp. than a fall application of the organoposphate ethoprop that was applied through a drip system. Our results with fluensulfone were similar in that the nematicide applied in the fall did not reduce galling of cucumber when compared to the untreated control, whereas the resistant cultivar did reduce galling of cucumber below that of the control.

Oxamyl, a carbamate, is used with PPI, drip, and foliar application for control of *Meloidogyne* spp. on vegetable crops and reduces galling and improves yield (Giannakou and Karpouzas, 2003; Giannakou et al., 2005; Gugino et al., 2006). However, multiple applications throughout the growing season are needed to achieve satisfactory control. In contrast, fluensulfone reduced *Meloidogyne* spp. damage to tomato with a single application at preplant and provided additional reduction of nematode damage to cucumber with single drip application when used in conjunction with nematode control options in the spring. Although not

TABLE 4. Effect of spring/fall treatments on cucumber fruit yield (kg/plot).

Treatment[a]	Tifton, GA[b]	Citra, FL
1,3-D/fluen. drip	2.69 a[b]	6.35 a
1,3-D/untreated	2.20 ab	2.66 b
Fluen. PPI/fluen. drip	1.39 bcd	3.94 ab
Fluen. PPI/untreated	0.83 dc	2.50 b
Resistant/fluen. drip	2.26 ab	3.73 ab
Resistant/untreated	2.02 abc	1.91 b
Untreated/Fluen. drip	0.49 d	2.99 b
Untreated/untreated	0.31 d	1.49 b
Fluensulfone	1.72 A	4.35 A
Untreated	1.36 A	2.14 B
	P value	*P* value
Main plot treatment	<0.0001	<0.0001
Subplot treatment	0.2852	0.0027
Main* subplot treatment	0.9903	0.5492

[a] The first treatment listed was applied to the spring crop of tomato (main plot) and the second treatment listed was applied to the fall crop of cucumber (subplot). Treatment abbreviations: 1,3-D = 1,3-dichloropropene; fluen. = fluensulfone.

[b] Data for the spring/fall treatments are the means of two years and six replications ($N = 12$). The locations were not combined because of a subplot treatment × location interaction ($P = 0.0131$). Means with the same lowercase letters within a column are not significantly different ($P < 0.05$); uppercase letters indicate differences between subplot treatments.

directly compared in this study, fluensulfone might be more effective than organophosphate and carbamate nematicides because it kills nematodes rather than causing a reversible paralysis (Oka et al., 2009; Kearn et al., 2014).

Drip application of fluensulfone to the cucumber crop reduced root galling by root-knot nematodes at both locations; however, the level of suppression was greater in Citra than in Tifton. Compared to the control, fluensulfone reduced root gall ratings by 30% in Citra and by 15% in Tifton when averaged across all spring treatments. This difference in the level of nematode suppression may explain why the subplot treatment had a significant effect on yield in Citra but not in Tifton. The increased volume of water used to apply fluensulfone in Citra may have improved distribution of the product throughout the bed, resulting in increased efficacy.

Our primary objective was to evaluate the efficacy of fluensulfone when applied through a drip system to a second crop; however, the efficacy obtained by the PPI application of fluensulfone on first crop tomato is important. Nonfumigant organophosphates and carbamates are often less effective than the fumigant 1,3-D (Giannakou et al., 2002). In this study, fluensulfone provided the same reduction in galling from *Meloidogyne* spp. on tomato as a 1,3-D application. Fluensulfone also reduced the number of J2 in the soil after tomato harvest to the same level as a resistant cultivar and the 1,3-D application. The PPI is a broadcast spray that is then mechanically incorporated into the soil. It does not have to rely on irrigation water to move it to the target zone, which is a disadvantage to using drip-applied pesticides (Desaeger and Csinos, 2006).

In conclusion, our study demonstrated that fluensulfone is an effective tool for managing *Meloidogyne* spp. in double-cropping systems. In addition, the low worker safety concerns, ease of application, no post-application re-entry period, and no requirement for buffer zones associated with using fluensulfone make it a desirable alternative to the more hazardous fumigants.

LITERATURE CITED

Back, M. A., Haydock, P. P. J., and Jenkinson, P. 2002. Disease complexes involving plant parasitic nematodes and soilborne pathogens. Plant Pathology 51:683–697.

Castagnon-Serono, P. 1996. Selection for *Meloidogyne incognita* virulence against resistant genes from the tomato and pepper and specificity of the virulence/resistance determinants. European Journal of Plant Pathology 102:585–590.

Colyer, P. D., Kirkpatrick, T. L., Vernon, P. R., Barham, J. D., and Bateman, R. J. 1998. Reducing *Meloidogyne incognita* injury to cucumber in a tomato-cucumber double-cropping system. Journal of Nematology 30:226–231.

Csinos, A., Laska, J., and Childers, S. 2002. Dye injection for predicting pesticide movement in micro-irrigated polyethylene film mulch beds. Pest Management Science 58:381–384.

Csinos, A., Whitehead, J., Hickman, L., and LaHue, S. S. 2010. Evaluation of fluensulfone for root-knot nematode on tobacco. Phytopathology 100:S28.

Desaeger, J. A., and Csinos, A. S. 2006. Root-knot nematode management in double-cropped plasticulture vegetables. Journal of Nematology 38:59–67.

Dropkin, V. H. 1969. The necrotic reaction of tomatoes and other host resistant to *Meloidogyne*: Reversal by temperature. Phytopathology 59:1632–1637.

Giannakou, I. O., and Karpouzas, D. G. 2003. Evaluation of chemical and integrated strategies as alternatives to methyl bromide for control of root-knot nematode in Greece. Pest Management Science 59:883–892.

Giannakou, I. O., Karpouzas, D. G., Anastasiades, I., Tsiropoulas, N. G., and Georgiadou, A. 2005. Factors affecting the efficacy of non-fumigant nematicides for control of root-knot nematodes. Pest Management Science 61:961–972.

Giannakou, I. O., Sidiropoulos, A., and Prophtou-Athanasiadou, D. 2002. Chemical alternatives to methyl bromide for control of root-knot nematodes in greenhouses. Pest Management Science 58:290–296.

Gugino, B., Abawi, G. S., and Ludwig, J. W. 2006. Damage and management of *Meloidogyne hapla* using oxamyl on carrot in New York. Journal of Nematology 38:483–490.

Hanna, H. Y. 2000. Double-cropping muskmelons with nematode-resistant tomatoes increases yield, but mulch color has no effect. HortScience 35:1213–1214.

Kaloshian, I., Williamson, V. M., Miyao, G., Lawn, D., and Westerdahl, B. B. 1996. Resistance breaking nematodes identified in California tomatoes. California Agriculture 50:18–19.

Karssen, G., Wesemael, W., and Moens, M. 2013. Root-knot nematodes. Pp. 74–108 *in* R. N. Perry and M. Moens, eds. Plant nematology. 2nd ed. Wallingford: CAB International.

Kearn, J., Ludlow, E., Dillon, J., O'Conner, V., and Holden-Dye, L. 2014. Fluensulfone is a nematicide with a mode of action distinct from anticholinesterases and macrocyclic lactones. Pesticide Biochemistry and Physiology 109:44–57.

Lament, W. J. 1993. Plastic mulches for the production of vegetable crops. HortTechnology 3:35–39.

Lembright, H. W. 1990. Soil fumigation: Principles and application technology. Journal of Nematology 22:632–644.

Noling, J. W. 2005. Nematode management in commercial vegetable production. Gainesville FL: University of Florida IFAS Extension.

Oka, Y., Shimshon, S., and Tkachi, N. 2009. Nematicidal efficacy of MCW-2, a new nematicide of the fluoroalkenyl group, against the root-knot nematode *Meloidogyne javanica.* Pest Management Science. 65:1082–1089.

Oka, Y., Shukar, S., and Tkachi, N. 2012. Systemic nematicidal activity of fluensulfone against the root-knot nematode *Meloidogyne incognita* on pepper. Pest Management Science 68:268–275.

Rich, J. R., Dunn, R. A., and Noling, J. W. 2004. Nematicides: Past and present uses. Pp. 1179–1200 *in* Z. X. Chen, S. Y. Chen, and D. W. Dickson, eds. Nematology advances and perspectives, vol. 2. Wallingford: CAB International.

Roberts, P. A., Dalmasso, A., Cap, G. B., and Castagnone-Sereno, P. 1990. Resistance in *Lycopersicon peruvianum* to isolates of *Mi* gene compatible *Meloidogyne* populations. Journal of Nematology 22:585–589.

Smith, P. G. 1944. Embryo culture of a tomato species hybrid. Proceedings of the American Society of Horticultural Science 44:413–416.

Thies, J., Davis, R. F., Mueller, J. D., Fery, R. L., Langston, D. B., and Miller, G. 2004. Double-cropping cucumber and squash after resistant bell pepper for root-knot nematode management. Plant Disease 88:589–593.

U.S. Environmental Protection Agency. 2000. Protection of stratospheric ozone: Incorporation of Clean Air Act amendments for reductions in Class I, Group VI controlled substances. Federal Register 65:70795–70804.

Wright, D. J. 1981. Nematicides: Mode of action and new approaches to chemical control. Pp. 421–449 *in* B. M. Zuckerman and R. A. Rhode, eds. Plant parasitic nematodes. New York: Academic Press.