Efficacy of Various Application Methods of Fluensulfone for Managing Root-knot Nematodes in Vegetables

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Abstract: Fluensulfone is a new nematicide in the flouroalkenyl chemical group. A field experiment was conducted in 2012 and 2013 to evaluate the efficacy of various application methods of fluensulfone for control of *Meloidogyne* spp. in cucumber (*Cucumis sativus*). Treatments of fluensulfone (3.0 kg a.i./ha) were applied either as preplant incorporation (PPI) or via different drip irrigation methods: drip without pulse irrigation (Drip NP), pulse irrigation 1 hr after treatment (Drip +1P), and treatment at the same time as pulse irrigation (Drip =P). The experiment had eight replications per treatment and also included a PPI treatment of oxamyl (22.5 kg a.i./ha) and a nontreated control. Compared to the control, neither the oxamyl nor the fluensulfone PPI treatments reduced root galling by *Meloidogyne* spp. in cucumber. Among the drip treatments, Drip NP and Drip +1P reduced root galling compared to the control. Cucumber yield was greater in all fluensulfone treatments than in the control. In a growth-chamber experiment, the systemic activity and phytotoxicity of fluensulfone were also evaluated on tomato (*Solanum lycopersicum*), eggplant (*Solanum melongena*), cucumber, and squash (*Curcurbita pepo*). At the seedling stage, foliage of each crop was sprayed with fluensulfone at 3, 6, and 12 g a.i./liter, oxamyl at 4.8 g a.i./liter, or water (nontreated control). Each plant was inoculated with *Meloidogyne incognita* juveniles 2 d after treatment. There were six replications per treatment and the experiment was conducted twice. Foliar applications of fluensulfone reduced plant vigor and dry weight of eggplant and tomato, but not cucumber or squash; application of oxamyl had no effect on the vigor or weight of any of the crops. Typically, only the highest rate of fluensulfone was phytotoxic to eggplant and tomato. Tomato was the only crop tested in which there was a reduction in the number of nematodes or galls when fluensulfone or oxamyl was applied to the foliage compared to the nontreated control. This study demonstrates that control of *Meloidogyne* spp. may be obtained by drip and foliar applications of fluensulfone; however, the systemic activity of fluensulfone is crop specific and there is a risk of phytotoxicity with foliar applications.

Key words: cucumber, fluensulfone, management, *Meloidogyne* spp., nematicide, oxamyl, tomato, vegetable crops.

Root-knot nematodes, *Meloidogyne* spp., are the most economically important plant-pathogenic nematodes affecting vegetable crops in tropical and subtropical regions of the world (Sikora and Fernandez, 2005). The pathogen enters the root and establishes a feeding site which results in large gall formation in a susceptible host. These large galls impair the ability of the plants to uptake water and nutrients which can lead to symptoms such as wilting, stunting, chlorosis, and ultimately yield loss (Karssen et al., 2013). In addition, infection by *Meloidogyne* spp. may predispose a plant to secondary pathogens (Back et al., 2002).

Many vegetable crops are grown in a plasticulture system in which *Meloidogyne* spp. have traditionally been controlled through the use of fumigant nematicides and biocides such as methyl bromide (MeBr), 1,3-dichloropropene, chloropicrin, or a mixture of these compounds. The plastic mulch is applied over the top of the fumigated soil to slow the dissipation of the highly volatile fumigant and prevent it from escaping the treated area, thereby increasing the efficacy of the compound. Fumigant nematicides can be highly efficacious against nematodes; however, they are costly, require specialized application equipment and buffer zones, are highly volatile, present worker safety concerns, and require a long period of time between treatment and planting date (plant-back interval) due to the risk of phytotoxicity. As of 2005, MeBr was banned via the Montreal Protocol and its use was discontinued in 2014 except in certain situations where it may still be applied through the use of critical use exemptions.

The most widely used nonfumigant nematicides used in vegetable production are the carbamates and organophosphates (Rich et al., 2004). Both of these chemistry classes are acetyl cholinesterase inhibitors that do not kill nematodes but paralyze them for the period of time in which the active ingredient is above a toxic level (Opperman and Chang, 1990). Carbamates and organophosphates are generally applied to soil; however, some have been shown to have systemic activity within plants. Ease of application and the reduction in the potential for groundwater contamination are advantages to foliar versus soil application of nematicides. Fenamiphos, an organophosphate that is no longer in use, was shown to have systemic activity against *Meloidogyne hapla* when applied to the leaves of red currant, *Ribes rubrum* (Santo and Bolander, 1979).

The systemic activity of oxamyl, a carbamate, is well documented (Rich and Bird, 1973; Potter and Marks, 1976; Wright et al., 1980; Wright and Womack, 1981; Lawrence and McLean, 2002). Oxamyl is commonly applied to the foliage of plants for control of plant-parasitic nematodes and is known to have ambimobile translocation within plants (Peterson et al., 1978; Hsu and Kleier, 1996).

Fluensulfone is a new nonfumigant nematicide in the fluoroalkenyl chemical class which received an EPA registration in September 2014 for control of plant-parasitic nematodes in cucurbits and fruiting vegetables. It has a unique but unknown mode of action (Kearn et al., 2014) and is a true nematicide (Oka et al., 2009). Unlike fumigant nematicides, fluensulfone is a water-soluble compound and moves through the soil water. It has a lower mammalian toxicity (LD_{50} > 500 mg/kg) than organophosphates and carbamates, which allows for safer application. Reports on appropriate application methods and the efficacy of fluensulfone are limited; however, a few studies have demonstrated positive results with fluensulfone for control of *Meloidogyne* spp. and *Nacobbus aberrans* (Oka et al., 2009; Cabrera-Hidalgo et al., 2015). The systemic activity of fluensulfone is not well defined on a broad range of crops. Oka et al. (2012) reported that a foliar application of fluensulfone on pepper can control *M. incognita*. The objective of this study was to evaluate the efficacy of fluensulfone against *Meloidogyne* spp. when applied by various application methods. In field trials, we evaluated fluensulfone for control of *Meloidogyne* spp. by PPI and three drip application methods, and in a growth-chamber experiment, we investigated the systemic activity of fluensulfone on different vegetable crops.

Materials and Methods

Field application methods

Site description and land preparation: Two field trials were conducted at the University of Georgia Coastal Plains Experiment Station during the summer and fall of 2012. All trials were at the University of Georgia Horticulture Hill Farm Tifton, GA, but each trial was at a different location on the farm, both field sites had a history of vegetable crops and a natural infestation of *Meloidogyne* spp. The soil type was a Tifton sandy loam (83.6% sand, 10.2% silt, and 6.2% clay). Prior to planting, the field sites were harrowed and rototilled. Beds were shaped and low-density polyethylene white plastic was laid using a commercial tractor-drawn bed shaper. Plots were 4.6 m long and 0.8 m wide with a 3-m alley between plot ends. Treatments were arranged in a randomized complete block design with eight replications.

One drip tape line per bed was laid 2 to 4 cm underneath the white plastic mulch. The drip tape had 6-mm walls with 15.54-cm emitter spacing in Trial 1 and 15.24-cm emitter spacing in Trial 2. Two-week-old cucumber seedlings were purchased from Lewis Taylor Farms, Tifton, GA, and used in all trials. Seedlings were transplanted at 15 per plot on 30.5 cm row spacing. Cucumbers (cv. Impact) were planted in Trial 1 on 11 June 2012 and 'Diomede' cucumbers were planted on 7 September 2012 in Trial 2. Foliar and soilborne diseases, insects, and weeds were managed using University of Georgia Extension recommendations.

Granulated (10-10-10) fertilizer with minor nutrients (0.06% B, 9% Cl, 0.06% Cu, 0.36% Fe, 0.15% Mn, and 0.14% Zn) was applied and rototilled into the soil at a rate of 1,120 kg/ha prior to bed formation. Liquid fertilizer (7-0-7) with 2% Ca and 10% S was applied following University of Georgia Extension recommendations weekly beginning 2-wk posttransplant until harvest using a CO_2-pressurized stainless steel tank attached to the drip irrigation system.

Field treatments: The six treatments were a PPI of fluensulfone (Nimitz, ADAMA Agricultural Solutions Ltd., Raleigh, NC), a PPI of oxamyl (Vydate L, DuPont Crop Protection, Wilmington, DE), drip application of fluensulfone Drip NP, Drip +1P, and Drip =P. The rate of fluensulfone used in all treatments was 3.0 kg a.i./ha and the rate of oxamyl was 22.5 kg a.i./ha. The PPI of fluensulfone and oxamyl was 21 and 11 d before planting for Trials 1 and 2, respectively. All PPI treatments were applied using a CO_2-pressurized backpack sprayer with a four-nozzle boom calibrated to deliver 187 liter/ha with 8002VS tips. This treatment was incorporated (15–20 cm in depth) into the soil immediately after application with a PTO-driven rototiller before the plastic was laid. Drip applications of fluensulfone were made 10 and 3 d after planting (DAP) for Trials 1 and 2, respectively. All drip treatments were applied using a CO_2-pressurized bottle attached to a manifold system that allowed injection of nematicide to be made to each drip irrigation treatment. Plots were irrigated 24 hr prior to all nematicide treatments to ensure that soil was at field capacity throughout the bed. Volumetric water content (VWC) was recorded in m^3/m^3 at the time of injections using a soil moisture sensor (10HS soil moisture sensors; Decagon, Pullman, WA.). Three sensors were placed 13 cm below the soil line in one bed receiving each injection treatment: one in the center of the bed, another 18 cm from the center of the bed, and another on the bed shoulder. At the time of injection, the VWC was 26% (middle), 27% (18 cm), and 28% (shoulder) for Trial 1, and 32% (middle), 24% (18 cm), and 22% (shoulder) for Trial 2.

Pulse irrigation consists of a water event being turned on and then off for a period of time before then being turned back on. Pulse irrigation is used in an effort to conserve the amount of water used during an irrigation event (Karmeli and Peri, 1974). All drip treatments had the following injection cycle: 15 min of irrigation prior

to injection and an additional 15 min of irrigation after injection to ensure that the nematicide was flushed from the lines. The pulse irrigation involved four cycles of turning the water on and off for 15-min intervals with each interval delivering 45 to 61 liters of water per plot for a total of 215 to 240 liters of water at the end of the fourth cycle. The Drip NP treatment received no additional pulse irrigation. The Drip +1P received pulse irrigation 1 hr after the injection cycle and fluensulfone in the Drip =P was injected during the second cycle of the pulse irrigation.

Field data collection: Plant vigor ratings were conducted 21 and 26 DAP to evaluate the effect of treatment on aboveground plant parts. Vigor ratings were evaluated on a 0 to10 scale with 0 being a dead plant and 10 being live, vigorous, healthy plant. Stand counts were recorded 17 DAP for Trial 2 due to high seedling mortality from *Pythium* spp. Cucumbers were harvested once a week for three consecutive weeks at 39, 45, and 52 DAP for Trial 1 and 47, 55, and 60 DAP for Trial 2. All marketable fruit was harvested and fruit weights and fruit counts were recorded for each plot.

In all trials, five soil cores (2.5-cm diam. $\times$ 20-cm deep) were collected from the middle of plots prior to treatment application and then again after root gall ratings to assess densities of *Meloidogyne* second-stage juveniles (J2) before treatment and after crop harvest. The soil samples were sent to the University of Georgia Nematology Lab (Athens, GA) and J2 were counted per 100 cm^3 of soil. Root galling from *Meloidogyne* spp. was assessed from seven plants per plot after the last harvest 52 and 60 DAP for Trials 1 and 2, respectively. Root-gall ratings were measured on a 0 to 10 scale with 0 being no visible galls and 10 being 100% of root system infested with galls. Not all plots in Trial 2 had seven live plants at the time of gall ratings, so all live plants were recorded from these plots.

Systemic activity

General methods: Meloidogyne incognita was cultured on eggplant (cv. Black Beauty). Culture roots containing egg masses were placed in a mist chamber for 6 d to allow eggs to hatch and J2 were collected daily on nested 75- and 25-μm-pore sieves. The inoculum was stored at 4.4°C for no more than 7 d until time of inoculation.

Two-week-old tomato (cv. Florida 47), eggplant (cv. Night Shadow), cucumber (cv. Rockingham), and squash (cv. Payroll) were purchased from Lewis Taylor Farms, Tifton, GA, and used in all trials. All transplants had at least two true leaves at time of planting. Seedlings were transplanted into black cone-tainer pots (5 cm $\times$ 25 cm) that were filled with 3:3:1 sand, pasteurized field soil, and a peat-based potting mix. Plants were then placed in a growth chamber at 28°C and 75% humidity, with 12-hr photoperiod for 2 d before treatments were applied.

Treatments and design: The experiment was conducted in the spring and summer of 2012 in growth chambers. Treatments consisted of a foliar application of fluensulfone at a rate of 3, 6, and 12 g a.i./liter, oxamyl at a rate of 4.8 g

a.i./liter, a nontreated inoculated control (positive control), and a nontreated noninoculated control (negative control). Both positive and negative controls received a foliar application of water at the same time nematicide treatments were applied. Foliar sprays were applied outdoors using a backpack sprayer calibrated to deliver 234 liters/ha using 8004 TeeJet tips. The soil surface was covered with plastic cling wrap that was sealed to the pot with a rubber band to prevent nematicide contact with the soil. The cover was removed after treatments had dried, and the plants were placed back into the growth chamber for an additional 2 d before being inoculated with nematodes. Plants were inoculated with *M. incognita* by pipetting 1,500 J2 into three holes 2.5 cm from the base of the transplants. Plants were returned to the growth chamber for a period of 4 wk and were watered daily using an overhead wand nozzle and fertilized once per week with a 20-20-20 (NPK) water-soluble fertilizer. Each treatment had six replications. The experiment was arranged in a randomized complete block design and was conducted twice.

Data collection: Plant vigor rating was made 12-d posttreatment to determine phytotoxicity. At 28 d after treatment, plant tops were cut from the soil line, dried at 60°C for 48 hr, and then weighed. Nematicidal activity of the treatments was evaluated by washing the soil from roots and examining a 1.5 g representative root sample that was stained using the acid fuchsin-glycerin method (Byrd et al., 1983). Female root-knot nematodes and nematode galls within the sample were counted. The number of females and galls found in a sample was used to estimate the total number of nematodes and galls on the root system.

Statistical analysis

All statistical analyses were performed with JMP Pro, V. 11 (SAS Institute, Cary, NC). For the field experiment, the effect of nematicide treatment on root galling by *Meloidogyne* spp., numbers of J2 before treatment and at harvest, plant vigor, and yield was determined with analysis of variance (ANOVA). Nematode numbers in soil were transformed using $\log_{10}$ (x + 1) to normalize the data and then back transformed using 10^{x-1} to represent the number of J2 per plot. For the growth-chamber experiment, ANOVA was used to determine whether the foliar nematicide treatments reduced plant vigor and weight and whether the treatments reduced nematode infection of roots. For both experiments, trial and its interaction with nematicide treatment were included in the model to determine whether the treatments were consistent between the trials. Comparisons among means were made using Student's *t*-test on the least square means.

RESULTS

Field experiment

Prior to treatment application, there were no differences in numbers of J2 among treatments. Numbers of J2 averaged 120 and 312 J2 per100 cm^3 of soil in Trial 1

and 2, respectively. The effect of the nematicide treatments on the number of J2 in soil at harvest, root galling, and yield was consistent between trials (i.e., number of trial × treatment interaction); therefore the data for the trials were combined (Fig. 1). After the last cucumber harvest, the number of J2 was lower ($P \leq 0.05$) in the Drip +1P than the control; all other treatments were not different from the control (Fig. 1A). Compared to the
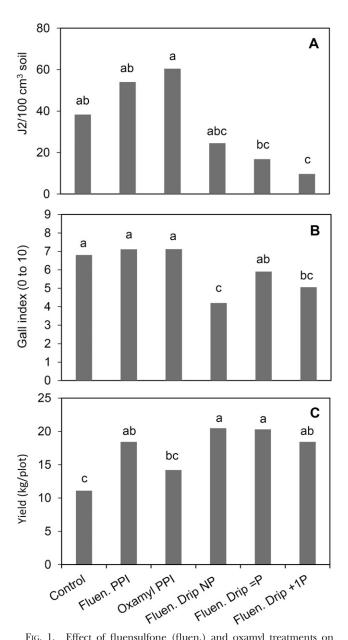

FIG. 1. Effect of fluensulfone (fluen.) and oxamyl treatments on A) population densities of *Meloidogyne* spp. second-stage juveniles (J2), B) root gall indices, and C) cucumber yield in a field experiment conducted in the summer and fall of 2012. PPI is a preplant incorporation of the nematicides; Drip is a drip application of the nematicide with no pulse irrigation; Drip =P is drip application at the beginning of pulse irrigation; and Drip +1P is pulse irrigation 1 hr after drip application. Bars are the means of two trials with eight replications each ($n = 16$); letters above bars indicate statistical differences ($P > 0.05$). Gall indices are on a 0 to 10 scale based on the percentage of the root system with galls: 0 = no galling and 10 = 91% to 100% galling.

nontreated control, neither the oxamyl nor the fluensulfone PPI treatments reduced root galling by *Meloidogyne* spp. in cucumber (Fig. 1B). Among the drip treatments, only the Drip NP and Drip +1P reduced galling compared to the control.

Stand counts were recorded in Trial 2 because of high seedling mortality due to damping-off from *Pythium* spp. The average number of cucumber plants per plot was similar for all the fluensulfone treatments and ranged from 11 to 14 plants; however, the number of plants was lower ($P \leq 0.05$) in the oxamyl (10 plants) and control plots (8 plants). Plant vigor was lower ($P \leq 0.05$) in the nontreated control than in any of the fluensulfone drip treatments and was intermediate for the fluensulfone and oxamyl PPI treatments. On a 0 to 10 scale, vigor ranged from 4.6 to 6.0 in nematicide-treated plots and was 3.5 in the control plots when averaged across trials. Cucumber yield (fruit weight per plot) was greater for all fluensulfone treatments than in the control (Fig. 1C). The oxamyl PPI was the only nematicide treatment that did not produce a greater cucumber yield than the control.

Growth-chamber experiment: Foliar applications of fluensulfone reduced plant vigor and dry weight of eggplant and tomato in some instances (Table 1), but had no effect on cucumber or squash (data not shown). Typically, only the highest rate of fluensulfone (12 g a.i./liter) reduced the vigor and weight of eggplant and tomato compared to the nontreated control; however, vigor of eggplant was also reduced by the 3-g rate in Trial 2 and vigor of tomato was reduced by all rates of fluensulfone in Trial 1. The foliar application of oxamyl had no effect on the vigor or weight of any of the crops. The phytotoxic effects of fluensulfone were not consistent between the two trials, with reductions in plant vigor and weight occurring more commonly in Trial 1 than in Trial 2.

Tomato was the only crop tested in which there was a reduction in the number of nematodes or galls when fluensulfone or oxamyl was applied to the foliage compared to the nontreated control (Fig. 2); data for the other crops are not shown. The effect of the nematicides on nematode numbers and galling in tomato was consistent between the two trials of the experiment; therefore, the trials were combined. Oxamyl was more effective in reducing nematode numbers than all but the highest rate of fluensulfone.

DISCUSSION

The three different drip-application methods of fluensulfone were not equally effective in reducing nematode populations and galling. Both the Drip NP and Drip +1P reduced root galling in cucumber from *Meloidogyne* spp.; however, the application of fluensulfone at the same time as Drip =P did not reduce galling. It is

TABLE 1.   Effect of foliar-applied fluensulfone (fluen.) and oxamyl on plant vigor and aboveground dry weight (g) in two trials.

	Eggplant				Tomato			
	Vigor[a]		Dry weight		Vigor		Dry weight	
Treatment	Trial 1	Trial 2	Trial 1	Trial 2	Trial 1	Trial 2	Trial 1	Trial 2
No Mi[b]	9.5 a[c]	8.2 a	1.65 a	1.30 a	8.7 ab	8.5 a	2.31 a	1.70 a
Nontreated control	8.7 ab	7.8 ab	1.30 ab	1.10 a	9.2 a	8.8 a	1.80 bc	1.80 a
Oxamyl 4.8 g a.i./liter	7.8 ab	7.8 ab	1.10 ab	1.10 a	9.2 a	8.5 a	1.90 bc	1.30 a
Fluen. 3 g a.i./liter	6.8 b	6.7 c	1.05 b	0.90 a	7.8 b	8.7 a	1.80 c	1.60 a
Fluen. 6 g a.i./liter	6.8 b	6.8 bc	1.1 ab	0.90 a	7.8 b	8.5 a	2.10 ab	1.50 a
Fluen. 12 g a.i./liter	2.8 c	6.5 c	0.40 c	0.80 a	6.2 c	8.0 a	1.49 d	1.60 a

[a] Vigor was rated on a 0–10 scale with 0 being a dead plant and 10 being a live vigorous healthy plant.
[b] All plants were inoculated with *Meloidogyne incognita* (Mi) except the negative control.
[c] Data are the means of six replications. Means within a column with the same letter do not significantly differ ($P > 0.05$). Foliar application of the nematicides had no effect on vigor or dry weight of squash or cucumber.

possible that the Drip =P treatment diluted the active ingredient in the nematicide before causing substantial nematode mortality. Like the carbamates and organophosphates, fluensulfone is soluble in water and therefore there is a risk of losing the active ingredient from the root zone with excessive rainfall or irrigation (Rich et al., 2004). The number of J2 in the soil after the last cucumber harvest was numerically lower than the nontreated control in all three drip treatments, but was only significantly lower in the Drip +1P treatment. Numbers of J2 at the end of the season can be variable making it difficult to detect significant differences among treatments. These results support an earlier study demonstrating that Drip NP suppressed root galling of cucumber by *Meloidogyne* spp. but not numbers of J2 at final harvest (Morris et al., 2015).

The PPI of fluensulfone and oxamyl did not reduce either root galling or numbers of J2 in soil in this study. This result contradicts previous studies demonstrating suppression of *Meloidogyne* spp. with PPI applications of
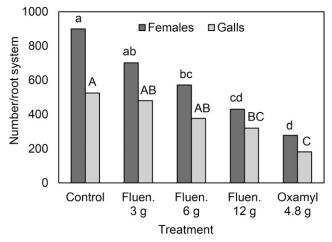

FIG. 2.   Average number of *Meloidogyne incognita* females and galls in tomato seedlings treated with a foliar application of fluensulfone (fluen.) at three rates and of oxamyl; the control was treated with water. Bars are the means of two trials with six replications each ($n = 12$); letters above bars within a category indicate statistical differences ($P > 0.05$).

fluensulfone (Langston and Sanders, 2009; Langston et al., 2014; Morris et al., 2015). Research results with PPI of oxamyl have been mixed, with some studies showing reductions in *Meloidogyne* spp. (Gugino et al., 2006; Langston et al., 2014), whereas other studies observing no effect of the nematicide (Davis et al., 2001; Westphal and Egel, 2004; Langston and Sanders, 2009; Ploeg and Becker, 2013). The irrigation event, 24 hr prior to the application of the nematicides, may have diluted their concentrations in the PPI treatments to a level that decreased their efficacy.

Cucumber yields were greater for all fluensulfone treatments, including the PPI treatment in which there was no measurable suppression of *Meloidogyne* spp. Perhaps the fluensulfone PPI treatment reduced numbers of J2 early in the season, thus permitting improved seedling growth. This assumption is supported by the plant vigor ratings early in the season which were greatest for all drip treatments, intermediate for fluensulfone and oxamyl PPI treatments, and lowest in the control. Improved yields may have also resulted from suppression of other plant-parasitic nematodes by the fluensulfone treatments. The lower yield in the control and the oxamyl-treated plots compared to the fluensulfone-treated plots may have been due, in part, to damping-off from *Pythium* spp. in Trial 2. In that trial, plant stand was significantly lower in the control and oxamyl treatment than in the other treatments.

Foliar uptake of pesticides is dependent on a number of characteristics of the pesticide and the plant surface including molecular weight, lipophilicity, and concentration of the chemical and surface permeability and stomatal uptake in the plant leaf (Wang and Liu, 2007). In the growth-chamber study, both fluensulfone and oxamyl reduced nematode infection and galling of tomato roots when applied to tomato foliage suggesting that the nematicides were taken up by the plant and systemically translocated to the root tissue. Nematicide neither reduced nematode numbers nor galling in eggplant, cucumber, or squash when applied to foliage. The lack of observed systemic activity in eggplant, cucumber, and squash may be due to lower cuticle permeability in these crops than in tomato. Cuticle permeability to

a given molecule is known to vary among crop species (Buchholz et al., 1998). Previous studies have also shown systemic activity of oxamyl in tomato (Rich and Bird, 1973; Stephan and Trudgill, 1983), but this study is the first to report the systemic activity of fluensulfone in tomato.

Our results contradict previous studies demonstrating that foliar applications of oxamyl to cucumber seedlings suppressed root invasion and development of *M. incognita* (Wright et al., 1980; Wright and Womack, 1981). Because only a small fraction of oxamyl is translocated from the foliage to the roots, higher concentrations of the chemical are needed in foliar than in soil applications to reduce nematode infection and development (Wright et al., 1980; Wright and Womack, 1981). In our study, the concentration of oxamyl that contacted the leaf surface may have been too low to reduce infection of the roots by *M. incognita*. In other crops, single foliar applications are not effective in suppressing nematode infection of roots, whereas multiple foliar applications, even at lower concentrations than the single application, are effective (Rich and Bird, 1973; Jatala and Jensen, 1974; Garabedian and Hague, 1982).

Phytotoxicity of fluensulfone was observed in eggplant and tomato following foliar applications, particularly at the higher rate (12 g a.i./liter) of the nematicide. These phytotoxic effects were more apparent in Trial 1 than in Trial 2. In Trial 1, treatments were applied on a cloudy day with a daytime high of 18.8°C, whereas in Trial 2, treatments were applied on a clear sunny day with a daytime high of 29.8°C. Although there are no published reports of the photodegradation of fluensulfone or of any other fluoroalkenyl class pesticides, the sunlight in Trial 2 could have increased photodegradation of fluensulfone thereby reducing the concentration of the chemical and phytotoxicity. The photodegradation of some pesticides, such as certain carbamates, can be quite rapid with studies showing that <20 % of the initial concentration remaining 12 hr after application (Samanidou et al., 1988). More research is needed to evaluate the possibility of photodegradation of fluensulfone.

The fluensulfone used in these trials was formulated as an emulsifiable concentrate (EC), whereas the oxamyl treatment was formulated as a water-soluble liquid. Phytotoxicity was observed only with the fluensulfone treatments. It is unclear whether fluensulfone or the emulsifiers and solvents in the EC formulation caused the crop injury. Oxamyl is known to provide enhanced growth and vigor in plants (Barker et al., 1988).

The registration of fluensulfone marks the first nonfumigant nematicide to receive a label for use in the United States in over 20 years. Its unique chemistry and mode of action, coupled with the expanding restrictions on soil fumigants and market loss of many nonfumigant nematicides (Rich et al., 2004), may make fluensulfone an important tool for managing plant-parasitic nematodes. This study demonstrates that control of *Meloidogyne* spp. may be obtained by drip and foliar applications of fluensulfone. The results with pulse irrigation, however, were

inconsistent and the benefit of utilizing this technique remains unclear. Although systemic control of *M. incognita* was obtained with fluensulfone in tomato, the potential for crop injury makes foliar application risky with this pesticide. Because phytotoxicity as well as systemic activity of fluensulfone varies among crop species, the utility of fluensulfone as a foliar spray will need to be evaluated on a case by case basis for different crops.

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