EFFECTS OF FURFURAL ON NEMATODE POPULATIONS AND GALLING ON TOMATO AND PEPPER

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ABSTRACT

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A commercial formulation of furfural (Multiguard® Protect) was evaluated in greenhouse trials over three seasons for effects on parasitic and beneficial nematode populations in roots and soil, plant growth, and galling on tomato and bell pepper caused by *Meloidogyne incognita*. 'Tiny Tim' tomato (*Solanum lycopersicum* = *Lycopersicon esculentum*) and 'Capistrano' bell pepper (*Capsicum annuum*) were transplanted into pots containing treated and untreated field soil which was naturally infested with *M. incognita*, microbivorous nematodes, and soil microorganisms. In several tests, furfural increased *M. incognita* J2 populations in tomato and pepper roots but reduced galling. High rates of furfural provided effective management of galling on tomato. On pepper, populations of *M. incognita* were lower than on tomato, and no reduction in galling occurred. No furfural treatments exhibited consistent levels of phytotoxicity to either tomato or pepper. Effects of furfural on beneficial microbivorous nematodes were mild, with substantial populations surviving in soil and roots treated with both post-plant, and high preplant rates of furfural.

Key words: furfural, *Meloidogyne incognita*, microbivorous nematodes, root-knot nematodes, vegetable production.

RESUMEN

Kokalis-Burelle, N. 2007. Efectos del furfural sobre las poblaciones de nematodos y el agallamiento en tomate y pimiento. Nematropica 37:307-316.

Se evaluó el efecto de una formulación comercial de furfural (Multiguard® Protect) sobre las poblaciones de nematodos fitoparásitos y benéficos en raíces y suelo, el crecimiento de las plantas, y el agallamiento en tomate y pimiento causado por *Meloidogyne incognita*, en ensayos de invernadero. Se transplantó tomate 'Tiny Tim' (*Solanum lycopersicum* = *Lycopersicon esculentum*) y pimiento 'Capistrano' (*Capsicum annuum*) en macetas con suelo tratado y no tratado, infestado naturalmente con *M. incognita*, nematodos microbívoros, y microorganismos del suelo. En varios ensayos, el tratamiento con furfural aumentó las poblaciones de J2 de *M. incognita* en tomate y pimiento, pero redujo el agallamiento. Se obtuvo manejo efectivo del agallamiento en tomate con altas dosis de furfural. En pimiento, las poblaciones de *M. incognita* fueron más bajas que en tomate, y no se observó reducción en el agallamiento. Ninguno de los tratamientos de furfural mostró niveles de fitotoxicidad en tomate o pimiento. Los efectos del furfural sobre los nematodos microbívoros fueron leves, y se observó alta supervivencia de poblaciones en el suelo y raíces tanto con el tratamiento post-siembra como con las altas dosis de furfural aplicadas presiembra.

Palabras clave: furfural, *Meloidogyne incognita*, nematodos microbívoros, nematodos agalladores, producción de hortalizas.

INTRODUCTION

The loss of methyl bromide and the pending re-registration of all chemical fumigants (EPA, 2007) have left growers with increasingly limited options for nematode control in high-value vegetable and ornamental crop production systems. Furfural (2-furancarboxaldehyde) is an aromatic aldehyde that is industrially prepared from organic agricultural waste material, including sugarcane, via hydrolysis of bagasse, and purification by distillation (Burger, 2005a). Raeder *et al.* (1925) and Flor (1926) discovered furfural's fungicidal properties. Later, Canullo *et al.* (1992) reported control of *Sclerotium rolfsii* in soil along with increases in *Trichoderma* spp. and bacterial antagonists of *S. rolfsii.* Recently, furfural applied through drip irrigation alone and in combination with other compounds, including metam sodium, reduced incidence of several soilborne plant pathogens including *Sclerotinia sclerotiorum, Pythium* spp., *Phytophthora* spp., and *Fusarium oxysporum* on ornamental crops (Gerik, 2005a, b; Gerik *et al.*, 2006).

The nematicidal potential of furfural was discovered by Walter and Rodríguez-Kábana (1992), and further demonstrated against a variety of phytoparasitic nematodes including *Meloidogyne arenaria, Pratylenchus brachyurus, Heterodera glycines, Helicotylenchus dihystera,* and *M. incognita* (Rodríguez-Kábana *et al.*, 1993; Bauske *et al.*, 1994). The direct mode of action of furfural against nematodes has been described as the destruction of the nematode cuticle (Burger, 2005a). Residues of furfural have not been detected in plant tissue or soil after multiple applications, because the compound, which has a short half life, is degraded through oxidative and reductive analogs to carbon dioxide and acetic acid (Burger, 2005a).

The objectives of this research were to evaluate the effects of furfural on: 1) populations of *Meloidogyne incognita* in naturally infested field soil, and in roots of tomato and bell pepper; 2) populations of beneficial microbivorous nematodes in roots and soil; and 3) plant growth and disease of tomato and bell pepper.

MATERIALS AND METHODS

A commercial formulation of furfural (Multiguard® Protect, Agriguard Company LLC, Cranford, NJ) was evaluated in a series of greenhouse trials at the U.S. Horticultural Research Lab in Ft. Pierce, FL, over three seasons. Effects of pre- and post-plant soil treatments on parasitic and microbivorous nematode populations in roots and soil, plant growth, and galling caused by *M. incognita* on tomato (*Solanum lycopersicum* = *Lycopersicon esculentum*) and bell pepper (*Capsicum annuum*) were evaluated. 'Tiny Tim' tomato and 'Capistrano' bell pepper were transplanted into treated and untreated field soil which was naturally infested with *M. incognita,* as well as microbivorous nematodes, and soil microorganisms.

In the first set of trials, furfural treatments were applied as soil drenches at rates equivalent to: 1) 452 kg/ha, 7 days preplant; 2) 452 kg/ha, 7 days preplant + 28 kg/ha, 2 weeks post-plant; 3) 85 kg/ha, 7 days preplant; 4) 85 kg/ha, 7 days preplant + 28 kg/ha, 2 weeks post-plant; and 5) 28 kg/ha, 2 weeks post-plant. The experiments were performed twice, once in fall 2005 and repeated in winter 2006. In a second set of trials, performed in fall 2006, furfural treatments were: 1) 28 kg/ha, 2 days preplant; 2) 85 kg/ha 7, days preplant; and 3) 452 kg/ha 7, days preplant. An untreated control was included in all experiments.

Infested soil was placed in 10 cm-diam pots. Plants were all transplanted at the same time and treatments were applied as described above. All treatments were replicated 6 times and plants were arranged in a completely randomized design on the greenhouse bench. Plants were grown in the greenhouse, watered daily and fertilized weekly with 20-20-20 liquid fertilizer containing minor elements. Experiments were terminated 7-9 weeks after transplanting and stem length, fresh stem weight, fresh root weight, stem diameter, gall rating, and root condition ratings were taken. Root condition was assessed by performing subjective root ratings using a 1-5 scale for root condition where 1 = healthy and 5 = 100% necrotic roots. Root galling was assessed using a root gall index based on a scale of 0-10, with zero representing no galls and 10 representing severe (100%) galling (Zeck, 1971). Nematodes were extracted from soil and roots using the Baermann funnel technique, and counted using a dissecting microscope. Data were analyzed using ANOVA and LSD procedures (SAS Version 9.1, Cary, NC).

RESULTS

In the first set of trials, under warm fall conditions and high *M. incognita* populations, 452 kg/ha rates of furfural increased *M. incognita* J2 in tomato and pepper roots and soil (Fig. 1A). However, even with significantly increased numbers of nematodes in roots and soil, galling was reduced on tomato at the 452 kg/ha rate (Fig. 2A). Galling rates on pepper were very low and were not reduced by any treatments (Fig. 2A). Some rates of furfural increased beneficial microbivorous nematode populations in roots of tomato and in pepper soil (Fig. 3A). Few effects were observed on plant growth; however, pepper stem length was increased with 85 kg/ha pre- and 28 kg/ha post-plant rates, and tomato shoot weight was decreased with the 28 kg/ha post-plant rate alone (Table 1). All treatments improved pepper root condition (Table 1). Higher root disease ratings in pepper control plants, however, did not correspond to increased *M. incognita* populations in roots or soil (Fig. 1A) or gall rating (Fig. 2A).

Under cool conditions and low soil nematode populations in the winter trials, the low rates (28 and 85 kg/ha) of furfural increased *M. incognita* J2 populations in tomato and pepper roots (Fig. 1B), similar to the effect with the higher rates (452 kg/ha) in the fall trial (Fig. 1A). As in the fall trials, regardless of the number of *M. incognita* J2 isolated from roots or soil, the two 452 kg/ha preplant treatments significantly reduced galling on tomato (Fig. 2B). The additional post-plant application of 28 kg/ha did not significantly increase control over the 452 kg/ha preplant rate alone (Fig. 2B). Microbivorous nematode populations in roots in the winter 2006 trial did not differ from the control for tomato, but for pepper the 85 kg/ha rate increased these populations (Fig. 3B). There were no differences compared to the untreated control in soil populations of microbivorous nematodes in the winter trial. However, in tomato, the 452 kg/ha rate with 28 kg/ha applied post-plant, which had the lowest level of galling, had significantly more microbivorous nematodes in soil than the 28 and 85 kg/ha rates (Fig. 3B). In the winter trial, pepper was more sensitive to post-plant applications of furfural, which reduced stem diameter, seedling length and shoot weight (Table 2). In general, treatments did not adversely affect tomato plant growth and the 452 kg/ha pre-plant rate alone increased stem length compared to the control (Table 2).

In the second set of trials, increasing rates of furfural reduced *M. incognita* J2 in tomato roots (Fig. 1C). Only the highest preplant rate (452 kg/ha) reduced juve-

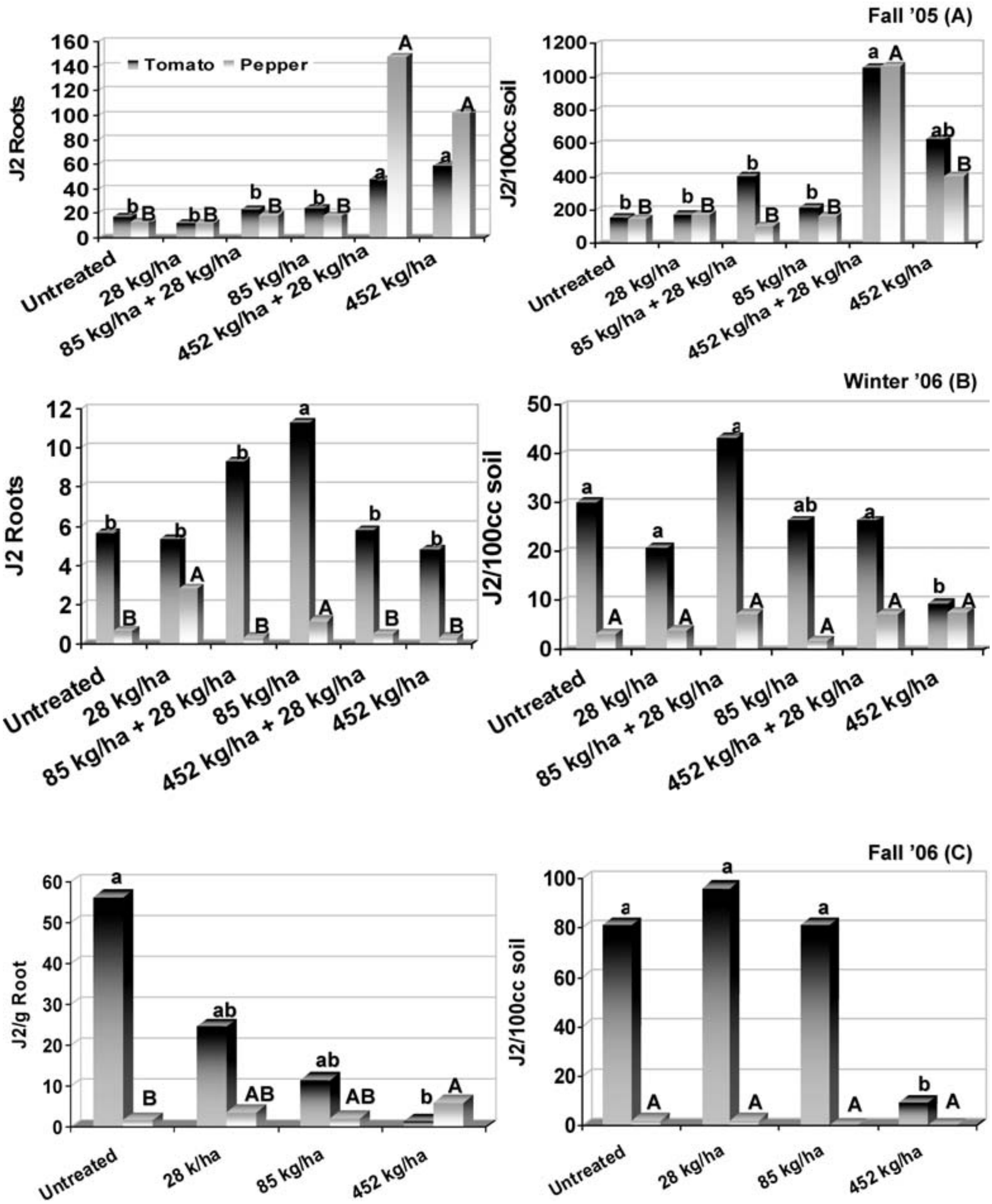

Fig. 1. Effects of furfural treatments on root-knot nematode juveniles (J2) in roots and soil of tomato and pepper in three trials conducted in fall 2005 (A), winter 2006 (B), and fall 2006 (C).

niles in soil of tomato. Gall ratings on tomato reflected the treatments' effects on soil nematodes, with the highest rate (452 kg/ha) of furfural reducing galling on tomato (Fig. 2C). However, an increase in galling on tomato occurred with the

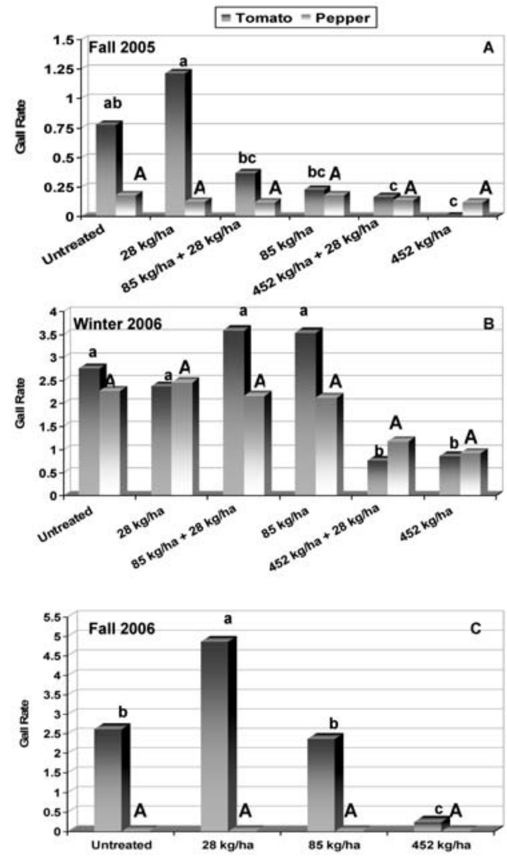

Fig. 2. Effects of furfural treatments on galling of tomato in three trials conducted in fall 2005 (A), winter 2006 (B), and fall 2006 (C). Gall rates were based on a 0-10 scale.

28 kg/ha rate of furfural (Fig. 2C). Greatly reduced numbers of *M. incognita* J2 were extracted from pepper roots and soil compared with tomato (Fig. 1C), however, numbers of juveniles extracted from pepper roots increased with increasing rates of furfural, as seen in the first set of trials. This increase in nematodes extracted from pepper roots was, once again, not reflected in an increase in galling on pepper (Fig. 2C). Also, numbers of microbivorous nematodes extracted from pepper roots increased with the 452 kg/ha rate of furfural (Fig. 3C). Low post-plant application rates (28 kg/ha) close to planting (2 days preplant) reduced pepper shoot weight compared to 452 kg/ha 7 days pre-plant, but did not reduce root weight or affect root condition (Table 3). High preplant rates with a longer planting interval (7 days preplant) increased pepper shoot weight compared to the low rate but adversely affected pepper root condition compared to all other treatments including the untreated control (Table 3). This reduction in root condition corresponded to an increase in *M. incognita* J2 in pepper roots (Fig. 1C) and microbivorous nematodes associated with pepper roots in the high (452 kg/ha) rate (Fig. 3C), but did not correspond to an increase in galling on pepper (Fig. 2C). In general, tomato responded to higher application rates or furfural more favorably with a significant increase in rootweight compared to the control (Table 3).

DISCUSSION

Use of broad spectrum soil fumigants such as methyl bromide to control soilborne pathogens, nematodes, and weeds has enabled intensive cultivation of many vegetable and ornamental crops without knowing their impact on the organisms being controlled, or other microflora in the soil. The loss of methyl bromide and the increasing regulatory constraints for remaining soil fumigants are driving researchers to investigate other methods for controlling soilborne pests which include reduced-risk chemicals, cultural practices, and biological control strategies.

Microorganisms are among many factors that affect the fate of agricultural chemicals in the soil. Microorganisms are either capable of utilizing a chemical as a nutrient source or cometabolizing compounds (Racke, 1990) which, in turn, affect the entire soil food web, including nematodes, which are often used as ecological indicators. Furfural has been reported to increase

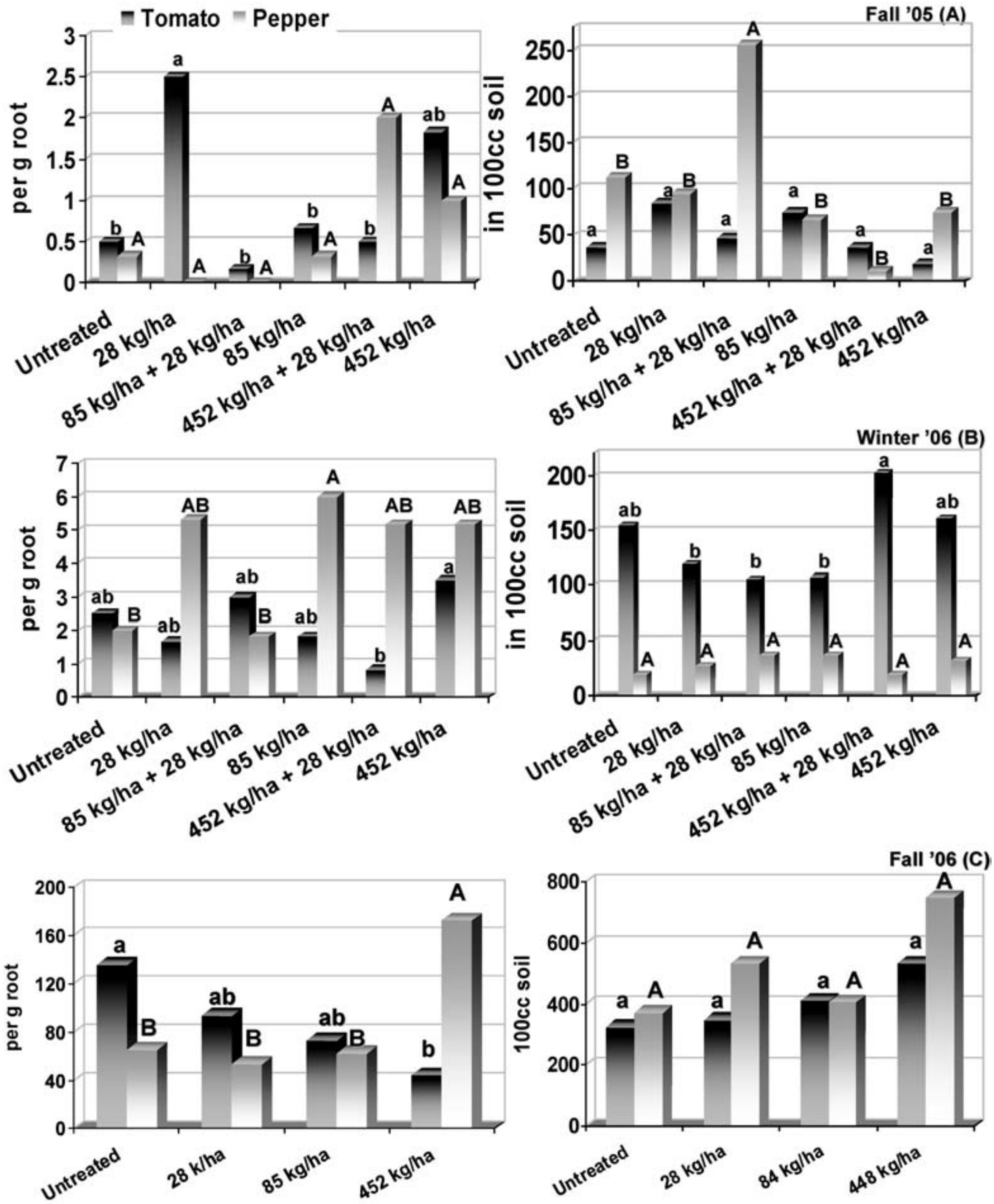

Fig. 3. Effects of furfural treatments on microbivorous nematode in roots and soil of tomato and pepper in three trials conducted in fall 2005 (A), winter 2006 (B), and fall 2006 (C).

many beneficial and nematode antagonistic microorganisms including *Penicillium purpurogenum*, *Pseudomonas* spp., chitinolytic bacteria (Canullo *et al.,* 1992; Bauske *et al.,* 1994), and increase nonparasitic nematode populations (Bauske *et al.,* 1994).

Table 1. The effect of furfural on Tomato and Pepper seedlings, Fall trial, 2005.

	Stem diameter (mm)		Stem length (cm)		Shoot weight (g)		Root weight (g)		Root condition[y]	
	Tomato	Pepper	Tomato	Pepper	Tomato	Pepper	Tomato	Pepper	Tomato	Pepper
Control	6.65	6.48	38.17	34.87 b[z]	37.85 ab	28.10	11.89	12.75	1.20	1.62 a
28 kg/ha post-plant	6.87	6.67	37.00	38.75 a	35.33 c	28.46	12.80	12.81	1.17	1.35 b
85 kg/ha pre-plant + 28 kg/ha post-plant	6.67	6.25	35.5	38.63 a	36.46 bc	26.87	12.06	15.47	1.22	1.28 b
85 kg/ha pre-plant	6.65	6.13	36.33	35.63 ab	39.05 a	28.61	12.31	13.02	1.22	1.30 b
452 kg/ha pre-plant + 28 kg/ha post-plant	6.87	6.02	35.67	35.68 ab	37.67 abc	27.59	12.01	14.87	1.23	1.32 b
452 kg/ha pre-plant	6.58	6.33	36.00	36.00 ab	36.72 abc	25.57	12.46	13.79	1.15	1.30 b
LSD (0.05)	NS	NS	NS	3.56	2.40	NS	NS	NS	NS	0.24

[y]Root Condition Rating is 1-5, 1 = white roots, 5 = totally discolored roots.
[z]Treatments were replicated six times, means with the same letter are not significantly different.

Table 2. The effect of furfural on Tomato and Pepper seedlings, Winter trial, 2006.

	Stem diameter (mm)		Stem length (cm)		Shoot weight (g)		Root weight (g)		Root condition[y]	
	Tomato	Pepper	Tomato	Pepper	Tomato	Pepper	Tomato	Pepper	Tomato	Pepper
Control	4.83	5.72 a[z]	30.67 b	37.33 a	55.61 a	78.25 a	9.62	41.00	1.47	1.83
28 kg/ha post-plant	5.50	5.27 b	33.17 ab	33.42 b	51.58 a	67.08 b	9.35	39.50	1.58	1.40
85 kg/ha pre-plant + 28 kg/ha post-plant	5.38	5.57 ab	35.47 ab	35.47 ab	54.87 a	72.42 ab	10.02	43.67	1.32	1.40
85 kg/ha pre-plant	5.58	5.48 ab	36.47 ab	35.67 ab	50.96 a	70.83 ab	8.92	42.08	1.48	1.72
452 kg/ha pre-plant + 28 kg/ha post-plant	5.40	5.63 ab	30.65 b	34.00 ab	36.46 b	75.17 ab	13.01	44.42	1.22	1.80
452 kg/ha pre-plant	5.10	5.53 ab	42.42 a	34.52 ab	46.38 ab	77.50 a	10.98	43.33	1.61	1.50
LSD (0.05)	NS	0.42	9.29	3.65	13.18	9.91	NS	NS	NS	NS

[y]Root Condition Rating is 1-5, 1 = white roots, 5 = totally discolored roots.
[z]Treatments were replicated six times, means with the same letter are not significantly different.

Table 3. The effect of furfural on Tomato and Pepper seedling fall trial, 2006.

	Stem diameter (mm)		Stem length (cm)		Shoot weight (g)		Root weight (g)		Root condition[y]	
	Tomato	Pepper	Tomato	Pepper	Tomato	Pepper	Tomato	Pepper	Tomato	Pepper
Untreated Control	4.82	6.11	26.88 b[z]	32.85	93.13	43.11 ab	7.46 b	9.54	2.27	2.40 b
28 kg/ha 2 days pre-transplant	5.08	4.88	29.47 ab	28.35	100.02	23.09 b	9.15 ab	6.97	1.75	1.72 b
85 kg/ha 7 days pre-transplant	4.85	6.07	34.93 a	31.32	77.85	36.89 ab	9.79 ab	8.02	1.52	2.52 b
452 kg/ha 7 days pre-transplant	5.15	6.07	29.15 ab	30.42	95.62	46.18 a	15.03 a	8.26	1.98	3.65 a
LSD (0.05)	NS	NS	6.48	NS	NS	21.99	6.79	NS	NS	0.97

[y]Root Condition Rating is 1-5, 1 = white roots, 5 = totally discolored roots.
[z]Treatments were replicated six times, means with the same letter are not significantly different.

Rodríguez-Kábana (2005a) found that drench applications of furfural applied at 448 kg/ha or higher controlled reniform (*Rotylenchulus reniformis*) and spiral (*Helicotylenchus dihystera*) nematodes on soybean in greenhouse trials, however, rates of 672 kg/ha or greater were necessary to provide acceptable herbicidal activity for a variety of weeds excluding nutsedge (Rodríguez-Kábana, 2005a). Results reported here for rates effective in controlling *M. incognita* are consistent with those previously reported for *R. reniformis* and *H. dihystera*. Post-plant rates were investigated in the first set of trials because in previous research, high rates of furfural have been reported as herbicidal alone (400 L/ha) (Burger, 2005b; Rodríguez-Kábana, 2005a), and when combined at 400 kg/ha with other compounds including MITC generators (Rodríguez-Kábana, 2005b). None of the rates tested in these trials exhibited high levels of phytotoxicity to the crop plants, although pepper did appear more sensitive to treatments with respect to reductions in plant growth. Field trials should be conducted to determine possible yield impacts on pepper. Although not reported, all furfural treatments reduced emergence of a small seeded weed (*Oxalis* spp.), supporting previous reports of some herbicidal activity (Burger, 2005b; Rodríguez-Kábana, 2005a).

In the studies reported here, furfural sometimes enhanced populations of microbivorous and parasitic nematodes. However, increases in *M. incognita* populations did not correspond with increases in galling. These effects varied depending on the host plant and rate of treatment, and may indicate influences on soil microoganisms, on which microbivorous nematodes feed, or a direct effect on the host plant such as an induced resistance response to parasitic nematodes, resulting in reduced gall formation. Induced resistance in the host plants may be in response to shifts in soil microorganisms, which were not evaluated in these studies. High rates of furfural sometimes resulted in higher levels of root damage on pepper, which may have contributed to higher numbers of microbivorous nematodes isolated from pepper roots, due to increased microbial activity.

Regardless of the effects of furfural on nematode and microbial ecology, high rates of furfural effectively managed galling caused by *M. incognita* on tomato; whereas, lower rates and post-plant applications were not effective. Although increased numbers of *M. incognita* J2 were sometimes isolated from roots and soil of both tomato and pepper treated with furfural, galling on pepper was not significantly different from the untreated control in any season. Although gall rates for pepper were lower than for tomato, these increases in *M. incognita* populations could pose problems for subsequent crops. Further studies on both the direct and indirect effects of furfural on nematodes, plant physiology, and microbial ecology are underway.

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