Bionematicides for management of root knot nematode on tomatoes

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Abstract

Root-knot nematodes (*Meloidogyne* sp.) are widely distributed throughout California and are the most important nematode pest of tomatoes (*Solanum lycopersicon)*. Current control methodology relies on the use of Metam sodium, 1,3-Dichloropropene (Telone II, 1,3-D), and nematode resistant varieties. During two years of field trials on tomatoes, QL Agri, Meadowfoam, Neem Cake, DiTera, and Root Feed were tested and compared to an untreated control and a chemical standard (1,3-D) for management of root knot nematode (*Meloidogyne javanica*). Each trial consisted of five replicates of 6 or 8 treatments in a randomized complete block design. At harvest, DiTera ($P \leq 0.05$) and Neem Cake ($P \leq 0.05$) both had a greater average size of tomatoes than 1,3-D. DiTera also had a greater average size of both red ($P \leq 0.10$) and green tomatoes ($P \leq 0.05$) than 1,3-D. A QL Agri + Meadowfoam treatment had a greater yield of red tomatoes than 1,3-D ($P \leq 0.10$). Numerically, all treatments except Meadowfoam had a lower root gall rating at harvest than untreated. Numerically, root-knot juveniles in the soil at harvest were lower than the untreated for the high rate of QL Agri, QL Agri + Meadowfoam, DiTera DF and 1,3-D. Several of the products tested appear to have value in managing nematode effects on tomatoes. Some of the products tested have also been observed in various trials to possibly act as plant growth regulators stimulating growth of roots or shoots even in the presence of nematodes.

Keywords: 1,3-dichloropropene, DiTera, *Lycopersicon esculentum*, Meadowfoam, *Meloidogyne javanica*, Neem Cake, QL Agri, Quillaja, Root Feed

INTRODUCTION

Root-knot nematodes (*Meloidogyne* sp.) are widely distributed throughout California and are the most important nematode pest of tomatoes (*Solanum lycopersicon).* Only about a dozen nematicidal active ingredients have ever achieved registration in California, and several of the most effective of these lost their registrations owing to groundwater contamination, air pollution, or carcinogenicity (Ferris, 2021). Current control methodology relies on the use of metam sodium, 1,3-Dichloropropene, and nematode resistant varieties (UC IPM Online, 2013). Increased use of resistant tomato varieties has resulted in the finding of resistance breaking nematode populations in some fields (Kaloshian et al., 1996). The purpose of this study was to evaluate the effectiveness of several bionematicides for management of the root-knot nematode, *Meloidogyne javanica*, on tomatoes.

MATERIALS AND METHODS

Two randomized complete block field trials with 5 replicates per treatment were conducted at University of California South Coast Research and Extension Center in Irvine, California USA. The test sites were in a field with a history of root-knot nematode (*Meloidogyne javanica,* RKN). The previous crop was lima beans (*Phaseolus vulgaris*). Single row plots were 4 m long plus a 1-m buffer on either end. The soil type was a sandy loam (66% sand, 21% silt, 13% clay, 0.6% organic matter, pH 7.6, and CEC 0.68 milimhos cm^{-1}).

Treatments in the first trial were DiTera DF (a toxin produced by the fungus *Myrothecium verrucaria*) (Valent BioSciences Corporation, Libertyville, IL) at 56 kg ha^{-1}, QL Agri (*Quillaja*, NemaQ, an extract of the soapbark tree) (Monterey Ag Resources, Fresno, CA) at 12 and 23 L ha^{-1}, Meadowfoam seed meal (Full Circle Ag, Aloha, OR) at 673 kg ha^{-1}, QL Agri at 12 L ha^{-1} plus Meadowfoam at 673 kg ha^{-1}, Neem Cake (ProSpinach, Eden, ID) at 673 kg ha^{-1}, 1,3-dichloropropene (Telone II, 1,3-D, Dow AgroSciences, Indianopolis, IN) at 84 L ha^{-1}, and an untreated control. Treatments in the second trial were Ditera DF at 56 kg ha^{-1}, QL Agri at 23 L ha^{-1}, Meadowfoam at 673 kg ha^{-1}, Root Feed (nitrogen 9.00%, potassium 5.00%, calcium 12.9%, magnesium 1.2%, boron 0.12%, molybdenum 0.03%) (Stoller USA, Houston, TX) at 94 L ha^{-1}, 1,3-D at 84 L ha^{-1}, and an untreated control 1,3-D was injected in the soil 14-days preplant. Ditera DF, QL Agri and Root Feed were applied at planting via surface spray in 2 L of water per replicate, followed by irrigation. Meadowfoam and Neem Cake were sprinkled onto plots at planting, followed by tilling to a 10 cm depth, and sprinkler irrigation.

For both trials at harvest, total fruit weight, and weight of red and green fruit was obtained from 5 plants per replicate. In the first trial, the average size of fruit based on weight was also determined. In the second trial, six weeks after planting, one plant from each replicate was evaluated for total weight, plant height, root length, total plant length, and root gall rating. In both trials, soil samples for nematodes were taken pre-plant to establish the presence of the population, and at harvest. Soil samples consisted of 12, 2.5-cm diameter cores per replicate to a 30-cm depth. Nematodes were extracted from 1 L of soil by elutriation followed by sugar centrifugation (Byrd et al., 1976). Root gall ratings with 0 = no galling, and 10 = heavily galled were also conducted at harvest. Data were analyzed with analysis of variance (ANOVA) followed by Fisher's least significant difference test.

RESULTS

In the first trial, at harvest, the QL Agri + Meadowfoam treatment had a greater yield of total fruit and of red tomatoes than 1,3-D ($P \le 0.10$) (Table 1). Numerically, all treatments except 1,3-D had a greater total fruit yield than untreated. Numerically, all treatments except the low rate of QL Agri and 1,3-D had a greater yield of red fruit than untreated. Numerically, all treatments except the high rate of QL Agri and 1,3-D had a greater yield of green tomatoes than untreated.

Table 1. Yield (kg/5 plants) of tomatoes for first trial.

Treatments	Rate (ha)	Total fruit weight 0.1	Red fruit weight 0.1	Green fruit weight
Untreated		4.5[a] ab[b]	3.7 ab	0.9
DiTera DF	56 kg	5.4 ab	4.0 ab	1.4
QL Agri	12 L	4.7 ab	3.2 a	1.5
QL Agri	23 L	5.2 ab	4.4 ab	0.8
Meadowfoam	673 kg	6.1 ab	4.8 ab	1.3
QL Agri + Meadowfoam	12 L + 673 kg	7.2 a	5.9 b	1.4
Neem Cake	673 kg	5.0 ab	4.0 ab	1.0
1,3-D	84 L	4.0 b	3.2 a	0.8

[a]Each figure is the mean of 5 replicates.

[b]Means not followed by the same letter are significantly different from each other according to Fisher's protected least significant difference test at $P \le 0.05$ or $P \le 0.10$.

DiTera DF ($P \le 0.05$) and Neem Cake ($P \le 0.10$) both had a greater average size of tomatoes than 1,3-D (Table 2). DiTera DF also had a greater average size of both red ($P \le 0.10$) and green tomatoes ($P \le 0.05$) than 1,3-D. Numerically, Neem Cake and DiTera DF had a greater average size of fruit than untreated. Numerically, all treatments had a greater average size of green fruit than untreated.

In the second trial, six weeks after planting, DiTera DF had a greater plant weight ($P \le 0.05$) than the untreated (Table 3). DiTera DF and all of the other treatments were numerically greater than the untreated with respect to plant weight, plant height, and total plant length. Numerically, root length was greater than the untreated for all treatments except DiTera DF and QL Agri. Numerically, root gall ratings were lower for DiTera DF, Root Feed, and

1,3-D.

Table 2. Average size of fruit (g/5 plants) for first trial.

Treatments	Rate (ha)	Total fruit	Red fruit	Green fruit
		0.05	0.1	0.05
Untreated		50.8[a] ab[b]	57.1 ab	35.0 a
DiTera DF	56 kg	59.1 b	63.7 c	49.2 b
QL Agri	12 L	49.8 ab	53.5 abc	43.4 ab
QL Agri	23 L	53.8 ab	57.9 abc	38.0 a
Meadowfoam	673 kg	53.3 ab	55.7 abc	45.8 a
QL Agri + Meadowfoam	12 L + 673 kg	54.4 ab	60.5 bc	37.8 a
Neem Cake	673 kg	55.7 ab	58.9 abc	45.3 a
1,3-D	84 L	48.8 a	52.1 a	39.5 a

[a]Each figure is the mean of 5 replicates.

[b]Means not followed by the same letter are significantly different from each other according to Fisher's protected least significant difference test at P≤0.05 or P≤0.10.

Table 3. Plant ratings for second trial six weeks after planting.

Treatments	Rate (ha)	Weight of plant (g)	Plant height (cm)	Root length (cm)	Total length of plant (cm)	Root gall rating (0-10)
		0.05			0.1	0.05
Untreated		4.88[a] ab[b]	19.16	16.30	35.46 abc	1.90 ab
DiTera	56 kg	15.92 b	21.30	16.10	37.40 abcd	1.30 ab
QL Agri	23 L	5.93 a	20.40	15.64	36.04 abcd	2.30 ab
Meadowfoam	673 kg	7.81 ab	20.46	16.42	36.88 abcd	2.50 b
Root Feed	94 L	9.80 ab	23.90	16.72	40.62 bcd	1.45 ab
1,3-D	84 L	10.08 ab	24.90	18.40	43.30 d	0.30 a

[a]Each figure is the mean of 5 replicates.

[b]Means not followed by the same letter are significantly different from each other according to Fisher's protected least significant difference test at P≤0.05 or P≤0.10.

In the second trial, at harvest, Root Feed had a lower yield of red tomatoes and a lower total yield (P≤0.10) than the untreated (Table 4). Except for Root Feed, the yield of green tomatoes was numerically equal to or greater than the untreated. For all treatments, the total yields and the yields for red fruit were numerically lower than the untreated.

Table 4. Yield (kg/5 plants) of tomatoes in second trial.

Treatments	Rate (ha)	Total fruit	Red fruit	Green fruit
		0.1	0.1	0.05
Untreated		11.0[a] bc[b]	5.5 bc	0.6 a
DiTera	56 kg	5.5 ab	2.8 ab	1.0 a
QL Agri	23 L	7.7 abc	3.9 abc	1.4 a
Meadowfoam	673 kg	7.3 ab	3.7 ab	1.2 a
Root Feed	94 L	5.0 a	2.5 a	0.5 a
1,3-D	84 L	9.4 abc	4.7 abc	1.0 a

[a]Each figure is the mean of 5 replicates.

[b]Means not followed by the same letter are significantly different from each other according to Fisher's protected least significant difference test at P≤0.05 or P≤0.10.

In the first trial, at P≤0.05, 1,3-D had a lower root gall rating and a lower level of root knot nematode in soil than untreated (Table 5). Numerically, all treatments except

Meadowfoam had a lower root gall rating at harvest than untreated. Numerically, root-knot juveniles in the soil at harvest were lower than the untreated for the high rate of QL Agri, QL Agri + Meadowfoam, DiTera DF and 1,3-D. In the second trial, the root gall ratings for all treatments except 1,3-D were numerically greater than the untreated. Root-knot juveniles in the soil were numerically lower than the untreated for all treatments but only statistically so for 1,3-D (P≤0.10).

Table 5. Root-knot nematode data for first and second trials.

Treatments	Rate (ha)	Trial 1		Trial 2	
		Root gall rating (0-10)	Juveniles L^{-1} of soil	Root gall rating (0-10)	Juveniles L^{-1} of soil
		0.05	0.05	0.05	0.05
Untreated		6.6[a] b[b]	10,350 b	8.5 ab	2,496 a
DiTera DF	56 kg	4.9 b	8,040 b	9.5 b	1,916 ab
QL Agri	12 L	6.2 b	10,390 b	[c]	
QL Agri	23 L	5.4 b	9,970 b	9.3 b	1,410 ab
Meadowfoam	673 kg	7.2 b	13,860 b	9.3 b	1,632 ab
QL Agri + Meadowfoam	12 L + 673 kg	5.9 b	10,160 b		
Neem Cake	673 kg	6.2 b	15,180 b		
Root Feed	94 L			9.7 b	1,945 ab
1,3-D	84 L	0.7 a	3,120 a	6.9 a	398 b

[a]Each figure is the mean of 5 replicates.

[b]Means not followed by the same letter are significantly different from each other according to Fisher's protected least significant difference test at P≤0.05.

[c]Treatment not included in this trial.

DISCUSSION AND CONCLUSIONS

As we move away from traditional fumigant and nonfumigant nematicides toward bionematicides with different modes of action, the most effective application methods, rates, and timing, and interpretation of results become less straightforward. In the USA, DiTera DF and QL Agri are registered as nematicides, while Root Feed is registered as a fertilizer. These products have also been observed (Westerdahl, pers. commun.) to mimic plant growth regulators, stimulating growth of roots or shoots, which could account for some of the results observed.

DiteraDF is a killed-microbial product of the fungus *Myrothecium verucaria*. The mode of action of DiTera is due primarily to the presence of many, relatively low-molecular-mass, water-soluble, compounds, which act synergistically (Wilson and Jackson, 2013). It has been shown to kill nematodes via contact as well as to inhibit hatching and development of eggs, cause muscle paralysis, feeding inhibition, depletion of lipids, and changes in sensory perception affecting activities such as host and mate-finding (Twomey et al., 2002; Rehberger et al., 2002). In addition to activity to nematodes, increased plant health, shoot and root weights, greening, and root proliferation have also been observed in trials by others (Spence and Lewis, 2010).

QL Agri is an extract of *Quillaja saponaria* a tree endemic to Chile that is rich in secondary plant metabolites including saponins, glycosides, polyphenols, and tannins that are found in the cortex, leaves and flowers (Insunza et al., 2001). Aqueous extracts have been shown to have nematicidal effects against a variety of nematode species and to increase root growth (Martın and Magunacelaya, 2005).

Tomatoes have a relatively high tolerance to root-knot nematode compared to many other crops, making statistically significant yield increases at harvest difficult to obtain, even with a fumigant such as 1,3-D. The level of root-knot juveniles in soil at harvest was lower in the second trial than in the first. In field trials, low levels of root-knot nematode have been observed to stimulate the growth of untreated plants relative to those that are treated with nematicides (Westerdahl, pers. commun.). This can result in more rapid maturation of fruit in the untreated than in the treated. This is illustrated by the second trial in which the yield of red tomatoes was greatest in the untreated, while the levels of green fruit were greatest in the treated plots. Several products tested appear to have value in managing nematode effects on tomatoes.

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