Use of Avermectins for the Control of Meloidogyne incognita on Tomatoes

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Abstract: The efficacy of avermectins B_1 and B_2 for control of *Meloidogyne incognita* on tomato was studied in pots and field plots for two seasons. Avermectins were applied as granules and liquid in furrows or by low pressure drip irrigation systems, at rates ranging from 0.093 to 0.34 kg a.i./ha, as single or multiple applications. Levels of control comparable to those obtained by oxamyl and aldicarb at 3.36 kg a.i./ha were achieved by the avermectin with only 1/10 the volume of chemicals applied to the environment. Avermectin protection of the roots remained constant throughout the first 5 weeks giving slightly longer protection than oxamyl or aldicarb. *Key words: Lycopersicon esculentum*, root-knot nematodes, furrow irrigation, low pressure drip irrigation, PVC injector. Journal of Nematology 15(4):503-510. 1983.

The avermectins are a new class of macrocyclic lactones isolated from the organism *Streptomyces avermitilis* (4,8). They have potent, broad spectrum anthelmintic activity when administered at 10–300 ppm (body weight) to sheep, cattle, dogs, and poultry infected with various common gastrointestinal parasites (3,5). Avermectins are also insecticidal (10), miticidal (11), and nematicidal (2,12).

The avermectins have a nematicidal action different from that of the organophosphates and organocarbamates. They are antagonists of α-aminobutyric acid (GABA) (6), as opposed to the acetylcholinesterase inhibition by the organophosphate and organocarbamate, and their potential efficacy is greater than the current nematicides. Their major disadvantage is their low solubility (> 1 ppm in H_2O) and rapid decomposition in soil.

The objective of this study was to evaluate the efficacy of avermectins on the control of *Meloidogyne incognita* by maximizing their low water solubility and short residual time in the soil. Greenhouse and field experiments were carried out comparing conventional methods of application with multiple applications at low concentrations, as drenches, or through low pressure drip lines.

MATERIALS AND METHODS

Experiment 1: This experiment was conducted in the greenhouse to determine the efficacy of liquid and granular formulations of avermectins for *Meloidogyne incognita* control on tomatoes, *Lycopersicon esculentum* Mill. cv. Tropic. Tomato seedlings were germinated in a mixture of vermiculite and UC mix 1 (soil, Canadian peat moss, and redwood shavings at a ratio of 2:1:1) in seed trays and grown for 2 weeks in the greenhouse. Uniform seedlings were transplanted into 15-cm plastic pots containing a steam sterilized mixture of 1/3 sand and 2/3 loam soil. Plants received a weekly application of Hoagland's full strength nutrient solution (7). Two days after transplanting, each pot was infested with 6,000 *M. incognita* larvae in 15 ml aqueous suspension injected into the soil around each plant. All plants were maintained in a greeenhouse at 26 C.

Chemical treatments were avermectin B_1 0.03 soluble liquid and 0.3 granules at 0.28 kg a.i./ha single application and three multiple applications, each at 0.093 kg a.i./ha. Oxamyl-L 24% and aldicarb 15 G each were applied at 3.36 kg a.i./ha or three multiple applications each at 1.12 kg a.i./ha.

Test plants were inoculated with nematode larvae just before the first addition of the chemicals. Multiple applications were made every 21 days for a total of three applications. The liquid form of avermectin was injected into three holes around each plant; the granular form was mixed into 1 cm of surface soil and watered. Each treatment had six replications. Plants were harvested 90 days after inoculation and fresh shoot weight, root weight, and root galling index were recorded (1).

Experiment 2: Avermectin B_1 and B_2,

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aldicarb, and oxamyl were evaluated for their field control of *M. incognita*. Experimental plots were established in summer 1981 on a sandy loam soil at the South Coast Field Station near Tustin, California. The experimental design was completely randomized with treatments replicated five times. Plots consisted of one row 3.6 m long with 0.75-m row spacing. Nitrogen fertilizer was added as recommended by soil testing.

The chemical treatments consisted of avermectin B_1 0.3 G and avermectin B_2 0.3 G at 0.28 kg a.i./ha, aldicarb 20 G at 3.36 kg a.i./ha, and oxamyl-L 24% at 3.36 kg a.i./ha prior to planting. The granular formulations were mixed with sand in a liter salt shaker and distributed evenly on the bed surface. All treatments were rototilled to a depth of 15 cm. Twelve 4-week-old tomato seedlings (cv. Tropic) were transplanted into each plot following treatment and sprinkle irrigated until established. For the balance of the crop season the plot was furrow irrigated. One plant from each treatment was removed each week for the first 5 weeks and rated for root galling using a 0–5 rating system (1). Twelve weeks after treatment the experiment was terminated, the fresh roots and shoots were weighed, roots rated for galling, and the percentage of newly developed galls was recorded (first generation galls).

Experiment 3: This experiment was conducted during the summer of 1982 at the same site as experiment 2 with a change in the method of irrigation. In this experiment, a low pressure drip irrigation system was used to apply liquid formulations of nematicides. The irrigation water from the main was passed through a series of filters and pressure regulators which reduced the pressure to about 0.34 kg/cm². A portion of the water was then forced (using a 0.14-kg/cm² line reducer) through a 0.64-cm spaghetti line inserted into a PVC canister. The water spiraled upwards, mixing with the previously added chemical, and was eventually forced out through another 0.64-cm spaghetti line and back into the 1.3-cm tubing. Each of the 1.3-cm lines was split five times, one line to each replicate. Twelve lateral spaghetti lines, 1.3 cm diameter and 46 cm long, were placed 30 cm apart along the 1.3-cm tubes at the appropriate plots. The irrigation water running at 0.34 kg/cm² passed through a 12-liter/hr emitter. Plots consisted of one bed, 3.6 m long with 0.75-m row spacing. The plots were irrigated three times weekly.

The treatments consisted of avermectin B_1 0.3 G at 0.34 kg a.i./ha, avermectin $B_1$0.03 SL at 0.34 kg a.i./ha single application and at three multiple applications, each at 0.08 kg a.i./ha. Oxamyl-L 24% was applied at 3.36 kg a.i./ha as a single application and at 0.84 kg a.i./ha at each of three application times. Aldicarb was applied only at the start of the experiment at 3.36 kg a.i./ha. The granular formulations were evenly distributed on the bed surface and rototilled to a depth of 15 cm. The liquid applications were applied in the first irrigation at transplanting. The second and third multiple applications were applied at 3 and 6 weeks after transplanting. Four-week-old tomato seedlings (cv. UC 82) were transplanted at 12 plants per 3.6 m plot. The soil was pH 7.8.

One plant from each plot was removed each week for the first 5 weeks; at the final sampling, five plants per plot were removed. Fresh weight of total fruit, fresh and dry weight of shoots, and dry weights of roots were recorded. The root systems were rated for galling using the 0–5 rating system and the numbers of eggs per gram of root were determined for each plant.

Experiment 4: This experiment was designed as a continuation of experiment 3 but conducted at the Citrus Experiment Station near Riverside, California, during the summer of 1982. Soil type was Hanford coarse sandy loam, pH 7.4.

The field was previously cropped to fig infested with *M. incognita*. The chemical treatments were all multiple doses, except avermectin B_1 0.3 G which was applied only once at the rate of 0.34 kg a.i./ha at the start of the experiment. Avermectin B_1 0.03 SL was applied at the rate of 0.168 kg a.i./ha at the start of the experiment and every week thereafter for a total of three treatments (total of 0.504 kg a.i./ha) and at the rate of 0.038 kg a.i./ha at the start of the experiment, after 3 days, and after 6 days (total dose of 0.114 kg a.i./ha) This sequence was repeated after 2 weeks giving a total of 0.228 kg a.i./ha.

Oxamyl-L 24% and aldicarb 15 G were applied at the rate of 1.68 kg a.i./ha at the start of the experiment, followed by two subsequent applications at 2-week intervals for a total of 5.04 kg a.i./ha. They were also applied at the rate of 0.38 kg a.i./ha at the start of the experiment, 3 days later, and at 6 days later for a total of 1.11 kg a.i./ ha. This treatment was repeated in 2 weeks for a total 2.28 kg a.i./ha.

One plant from each plot was removed at every 10 days over a period of 40 days after planting or treatment initiation. The dry and fresh weights of shoots and roots were recorded and the roots were rated for galling. Twelve weeks after planting, the fresh and dry weights of the shoots, the root galling index, and the yield were recorded.

RESULTS

Experiment 1. Top weights of tomato plants grown 12 weeks in pots treated with various nematicides were not significantly heavier than those in untreated soil; except for oxamyl (1.12 kg/ha), the top weights were numerically heavier than the controls (Table 1). All chemical treatments significantly reduced the gall index. The multiple avermectin B_1 treatment at 0.093 kg a.i./ha was the most effective in reducing galling.

Experiment 2: By 4 weeks after treatment, all chemicals had suppressed gall formation (Table 2). Plants treated with avermectins had the fewest galls. Avermectin B_2 0.3 G was more effective than any other treatment and maintained control for 4 weeks. Oxamyl and aldicarb protection lasted almost 2 weeks, after which the plants rapidly became galled.

At the end of the experiment, 12 weeks after treatment, all treated plants were nearly as heavily galled as the untreated plants. There were no significant differences in total fresh weights of the plants.

Experiment 3: At the end of 5 weeks, all chemical treatments had significantly suppressed root galling (Table 3). Although not significant in this experiment, the avermectin treatments at 0.34 kg a.i./ha were slightly more protective than oxamyl and aldicarb at 3.36 kg a.i./ha.

At harvest (12 weeks) the galling index had increased on all treatments; however, it was somewhat lower in the avermectin treatments than in the oxamyl and aldicarb treatment. There were no significant differences in yield, although aldicarb 15 G was slightly better than the control. There was some suggestion that the liquid formulations of avermectin, as compared with the granular formulation, were slightly phytotoxic to plant growth.

Experiment 4: The avermectin granule formulation lost its protectiveness at about 30 days, and the avermectin liquid formulation applied at weekly intervals lost its effectiveness prior to the third treatment.

Table 1. Influence of *Meloidogyne incognita* on root-gall rating and fresh top weights of tomato plants after 12 weeks in the greenhouse.

Chemical and formulations	Rate (kg/a.i./ha)	Method of application	Total rate applied (kg a.i./ha)	Fresh top weight (g)	Root-gall rating*
Avermectin B_1 0.03 SL	0.28	Single	0.28	197.8 a†	2.00 c
Avermectin B_1 0.3 G	0.09	Multiple‡	0.28	228.6 a	0.83 d
Oxamyl-L 24%	3.36	Single	3.36	224.1 a	3.16 b
Oxamyl-L 24%	1.12	Multiple‡	3.36	175.7 a	2.33 c
Aldicarb 15 G	3.36	Single	3.36	195.6 a	2.17 c
Aldicarb 15 G	1.12	Multiple‡	3.36	202.6 a	1.70 c
Control				189.9 a	4.17 a

*0 = no infection, 1 = 1–20% (trace), 2 = 21–40% (slight), 3 = 41–60% (moderate), 4 = 61–80% (severe), 5 = 81–100% (very severe).

†Means followed by the same letter do not differ at $P = 0.05$ by Duncan's multiple-range test.

‡Applications were made every 3 weeks for a total of three applications.

Table 2. Influence of avermectin, oxamyl, and aldicarb treatments on the control of *Meloidogyne incognita* on tomatoes under furrow irrigation.

Chemical and formulation	Rate (kg a.i./ha)	Root-gall rating* (weeks 1–4)				Harvest (12 weeks)			
		1st	2nd	3rd	4th	Root-gall rating*	Fresh top wt (g)	% Coalesced roots	% Newly dev. galls (1st gen.)
Avermectin B_1 0.3 G	0.28	0.19 b†	0.39 c	0.40 c	1.42 c	3.80 ab	268.2 a	22	71
Avermectin B_2 0.3 G	0.28	0.60 a	0.80 bc	1.00 c	0.83 c	3.38 b	215.7 a	20	74
Oxamyl-L 24%	3.36	1.01 a	1.38 ab	2.19 b	2.60 b	4.00 ab	219.2 a	37	48
Aldicarb 20 G	3.36	0.81 a	1.20 bc	1.21 bc	1.78 bc	3.98 ab	270.1 a	36	52
Control		1.00 a	2.19 a	3.19 a	3.60 a	4.40 a	225.6 a	32	50

*0 = no infection, 1 = 1–20% (trace), 2 = 21–40% (slight), 3 = 41–60% (moderate, 4 = 61–80% (severe), 5 = 81–100% (very severe).
†Means followed by the same letter do not differ at $P = 0.05$ by Duncan's multiple-range-test.

Table 3. Influence of avermectin, oxamyl, and aldicarb treatments applied through low pressure drip irrigation system on the control of *Meloidogyne incognita* on tomatoes.

Chemical and formulation	Rate (kg a.i./ha)	Method of application	Total applied (kg a.i./ha)	Root-gall rating* (weeks 1–5) 1st	2nd	3rd	4th	5th	Harvest (89 days) Fresh top wt (g)	Root-gall rating*	Eggs/gram roots ($\times 10^2$)	Yield (kg)
Avermectin B_1 0.03 SL	0.34	Single	0.34	1.0 a†	1.0 b	1.4 cd	1.0 d	1.0 d	430.7 bcd	2.12 f	71 a	7.6 a
Avermectin B_1 0.03 SL	0.08	Multiple	0.24	0.0 b	1.0 b	1.2 d	1.2 d	1.4 d	408.4 bcd	2.84 de	60 a	7.7 a
Avermectin B_1 0.3 G	0.34	Single	0.34	1.0 a	1.0 b	1.8 bcd	1.2 d	1.6 cd	469.4 bcd	2.36 ef	112 a	8.7 a
Oxamyl-L 24%	3.36	Single	3.36	0.0 b	1.0 b	2.6 b	1.8 bcd	1.8 cd	419.4 bcd	3.88 b	86 a	8.0 a
Oxamyl-L 24%	0.84	Multiple	2.52	0.0 b	1.0 b	2.2 bcd	1.4 cd	2.2 cd	405.7 cd	3.68 bc	106 a	7.6 a
Aldicarb 15 G	3.36	Single	3.36	0.0 b	1.0 b	1.2 d	2.2 bcd	1.6 cd	515.0 b	3.16 cd	84 a	9.8 a
Control				1.0 a	1.6 a	4.2 a	4.6 a	4.2 a	473.1 bc	4.88 a	112 a	8.8 a

*0 = 0 infection, 1 = 1–20% (trace), 2 = 21–40% (slight), 3 = 41–60% (moderate), 4 = 61–80% (severe), 5 = 81–100% (very severe).
†Means followed by the same letter do not differ at $P = 0.05$ by Duncan's multiple-range test

Table 4. Influence of avermectin, oxamyl, and aldicarb treatments applied through low pressure drip irrigation system on the control of *Meloidogyne incognita* on tomatoes.

Chemical and formulation	Rate (kg a.i./ha)	Method of application	Total applied (kg a.i./ha)	Root-gall rating* (days)				Harvest (84 days)			
				10	20	30	40	Fresh top wt (g)	Root-gall rating*	Eggs/gram root (× 10²)	Yield (kg)
Avermectin B_1 0.03 SL	0.168/wk	Multiple	0.50	0.00 c†	0.48 b	0.82 b	0.82 c	583.1 a	2.52 b	53.10 de	6.6 abc
Avermectin B_1 0.03 SL	0.038/3 days	Multiple	0.23	0.10 bc	0.40 b	0.80 c	1.32 c	518.6 a	3.00 ab	47.11 e	8.8 ab
Avermectin B_1 0.3 G	0.34	Single	0.34	0.46 bc	0.68 b	2.21 ab	3.20 ab	580.2 a	3.50 ab	89.80 bcd	6.0 bc
Oxamyl-L 24%	1.68/2 wks	Multiple	5.04	0.32 bc	0.28 b	0.80 c	1.24 c	576.2 a	3.56 ab	96.80 abc	4.7 c
	0.38/3 days	Multiple	2.28	0.36 bc	0.28 b	1.41 bc	1.66 bc	619.8 a	2.44 b	59.81 cde	7.6 abc
Aldicarb 15 G	1.68/2 wks	Multiple	5.04	0.58 b	0.44 b	1.6 abc	1.76 bc	601.5 a	3.36 ab	78.42 bcde	8.5 ab
Aldicarb 15 G	0.38/3 days	Multiple	2.28	0.16 bc	0.96 b	1.2 bc	2.80 abc	571.0 a	3.62 ab	115.06 ab	9.6 ab
Control	—			1.28 a	2.20 b	2.80 a	3.68 a	54k,7 a	4.40 a	134.23 a	4.4 c

*0 = no infection, 1 = 1–20% (trace), 2 = 21–40% (slight), 3 = 41–60% (moderate), 4 = 61–80% (severe), 5 = 81–100% (very severe).
†Means followed by the same letter do not differ at $P = 0.05$ by Duncan's multiple-range test.

The other multiple applications appeared to lose their effectiveness slowly over the 40-day period (Table 4).

After 12 weeks all treatments were heavily galled, only slightly less so than the controls. Egg production was less in the avermectin liquid formulations, and fruit yields were higher in the avermectin (0.038 kg a.i./ha/3 days) and the oxamyl (1.68 kg a.i./ha/2 weeks) treatments. The liquid formulations of avermectin was different from that used in experiment 3, and it did not appear to be phytotoxic.

DISCUSSION

On a weight basis of active ingredients, the avermectins, both granules and liquid formulations, were at least 10 times more effective than oxamyl or aldicarb in reducing root-knot infections and galling of tomato roots in artificially irrigated situations. The low solubility of the avermectin did not appear to be a serious problem where the plants are frequently irrigated, as a more constant supply of avermectins is provided with every irrigation. Whereas the highly water-soluble compounds such as oxamyl and aldicarb may leach extensively, the period of avermectin effectiveness was related to frequent irrigations. The soil residual time of avermectins appeared to remain constant throughout the first 5 weeks. Whereas the oxamyl treatments lost effectiveness between the 2nd and 3rd weeks and just prior to the second multiple treatment, the aldicarb treatment appeared to have lost its protectiveness after the 3rd week. Multiple applications of very low concentrations through irrigation systems may have promise for reducing the total amount of chemicals needed for this crop season. The best field treatment occurred when avermectin was applied at 0.038 kg a.i./ha on each of 3 consecutive days and then repeating the treatment again in 3 weeks. With this type of treatment, we attempted to distribute as much of the chemical in the root zone as quickly as possible. If one additional treatment had been applied at 6 weeks, there might have been a significant reduction in galling at the end of the crop season.

When compared with previous studies (unpublished) using oxamyl and aldicarb in drip irrigated tomatoes, single applications of aldicarb granules at 3.36 kg a.i./ha performed similarly to the aldicarb granular treatments. Aldicarb gave only early protection, and the plants were heavily galled at the end of the season. The best oxamyl treatments were multiple biweekly applications of 1.12 kg a.i./ha for a total 6.73 kg a.i./ha. Similar results have been obtained with aldicarb sulfone, a breakdown product of aldicarb, used through a drip system. Biweekly applications of 1.12 kg a.i./ha oxamyl through drip irrigation systems, a registered treatment in California, can give practical and economical control of root-knot nematodes in annual crops.

Using avermectins resulted in a reduction of chemicals required to control root-knot nematodes. Their water insolubility and rapid degradation in the soil also suggests that avermectins will not become contamination problems in agricultural ground water. Based on our results and results of others (1,2,9) avermectins appear to have great potential in the irrigated agriculture of annual crops.

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