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Potential of Foliar, Dip, and Injection Applications of Avermectins for Control of Plant-Parasitic Nematodes[1]

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Abstract: Studies were conducted to determine the potential of two avermectin compounds, abamectin and emamectin benzoate, for controlling plant-parasitic nematodes when applied by three methods: foliar spray, root dip, and pseudostem injection. Experiments were conducted against *Meloidogyne incognita* on tomato, *M. javanica* on banana, and *Radopholus similis* on banana. Foliar applications of both avermectins to banana and tomato were not effective for controlling any of the nematodes evaluated. Root dips of banana and tomato were moderately effective for controlling *M. incognita* on tomato and *R. similis* on banana. Injections (1 ml) of avermectins into banana pseudostems were effective for controlling *M. javanica* and *R. similis*, and were comparable to control achieved with a conventional chemical nematicide, fenamiphos. Injections of 125 to 2,000 µg/plant effectively controlled one or both nematodes on banana; abamectin was more effective than emamectin benzoate for controlling nematodes.

Key words: abamectin, avermectins, control, emamectin benzoate, ivermectin, *Meloidogyne incognita*, *Meloidogyne javanica*, nematode, *Radopholus similis*.

The burrowing nematode, *Radopholus similis* (Cobb) Thorne, is one of the most important biotic factors affecting banana, *Musa acuminata* Colla, production worldwide (Gowen and Quénéhervé, 1990; Pinochet, 1977). Other endoparasitic nematodes, such as *Pratylenchus coffeae* (Zimmermann) Filipjev & Schuurmans Stekhoven, *P. goodeyi* Sher & Allen, and *Helicotylenchus multicinctus* (Cobb) Golden, also are important parasites of banana; however, burrowing nematode is considered the most damaging species in commercial plantations (Gowen and Quénéhervé, 1990; Quénéhervé, 1993; Vilardebo, 1971) and in most smaller banana plantings in certain parts of the tropics (Sarah, 1989). Most research on control of these nematodes, especially burrowing nematode, has focused on cultivars in the Cavendish group grown in intensive cropping systems for export (Quénéhervé, 1993). Currently, nematode control in intensively grown plantations relies primarily on the use of soil-applied chemical nematicides. In Africa, nematicides are applied three times per year based on calendar dates to maintain low populations of *R. similis* (Quénéhervé, 1993). In certain parts of Central America, granular organophosphate and carbamate insecticide nematicides are applied one to two times per year around the root mass of the daughter plant immediately after harvesting the previous crop (H. Espinoza, pers. comm.). The repeated use of conventional nematicides for nematode control has led to concern in many banana-producing countries for environmental and worker safety, residue import tolerances, and groundwater contamination. For these reasons, safer alternative methods for nematode control are needed to reduce risks to the environment and humans. In addition, loss of efficacy through biodegradation is becoming an increasing concern with the use of soil-applied granular nematicides (Anderson, 1989).

The avermectins are a family of 16-membered macrocyclic lactones produced by the soil microorganism, *Streptomyces avermitilis* MA-4680 (NRRL 8165). These compounds are important tools in animal health, human health, and crop protection (Campbell, 1989; Dybas, 1989). The major component of the fermentation, avermectin

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B_1 (=abamectin), is a mixture of B_{1a} (≥80%) and B_{1b} (≤20%) (Campbell, 1989; Dybas, 1989; Dybas et al., 1989) and is currently registered for use in more than 50 countries as an insecticide, acaricide, and nematicide. One of its derivatives, ivermectin, an endectocide, is used widely in animal health for the control of nematode and arthropod parasites of animals (Shoop et al., 1995). Emamectin benzoate, a second-generation avermectin derivative, is being developed for control of lepidopterous pests on a variety of vegetable crops worldwide (Jansson and Dybas, 1997). The discovery, spectrum of activity, safety, and applications of avermectins for control of arthropods and nematodes have been reviewed extensively (Campbell, 1989; Dybas, 1989; Fisher and Mrozik, 1992; Jansson and Dybas, 1997; Lasota and Dybas, 1991; Shoop et al., 1995).

The present studies were conducted to determine the potential of the avermectins for controlling *R. similis* and *Meloidogyne javanica* (Treub) Chitwood when applied as foliar sprays and root dips, and as injections into the pseudostem of banana. Jutsum (1988) found that injections of ivermectin into the stem of tomato seedlings were effective at controlling root-knot nematode, *M. incognita* (Kofoid & White) Chitwood. The present studies also determined the effectiveness of avermectins for controlling *M. incognita* on tomato, *Lycopersicon esculentum* Mill., when applied as foliar sprays or root dips.

Materials and Methods

Nematode cultures: Most species used in these studies were cultured in vivo in a glasshouse at Ricerca, Inc., Painesville, Ohio. *Radopholus similis* was obtained from the USDA ARS, Nematology Laboratory, BARC West, Beltsville, Maryland, in 1989 and has been maintained on banana at Ricerca since 1989. This culture was cultured on Cavendish banana (12 to 24 weeks old) grown in a soil:sand:peat (3:2:1) mixture in tubs (150 liters) in a glasshouse that was maintained under a 14:10 (L:D) photophase with day- and night-time temperatures ranging between 26.1 ± 0.2°C and 14.4 ± 0.2°C, respectively, and 53.7 ± 1.2% RH. Soil temperatures were maintained continuously at approximately 22.8 ± 0.2°C. Additional cultures of *R. similis* were obtained from the USDA ARS, Horticultural Research Laboratory, Orlando, Florida, in 1995 and 1996, and from the USDA ARS, Nematology Laboratory, Beltsville, Maryland, in 1996 where they had been cultured on carrot, *Daucus carota* L., and corn, *Zea mays* L., respectively. These cultures were maintained on monoxenic carrot discs (Moody et al., 1973) in a controlled-environment chamber set at 12:12 (L:D) and 26.0 ± 0.3°C. Nematodes from these cultures were used only to supplement those extracted from the glasshouse culture when additional inoculum was required. *Meloidogyne javanica* and *M. incognita* race 4 were obtained from the Department of Plant Pathology, North Carolina State University, Raleigh, North Carolina, in 1989. Cultures were maintained on tomato, *L. esculentum* cv. Rutgers, grown in tubs (150 liters) in a glasshouse. Soil temperatures for the *M. javanica* and *M. incognita* cultures were maintained at 28.3 ± 0.2°C by placing tubs on benches equipped with heating coils.

Tomato experiments: Two studies were conducted to determine the effectiveness of abamectin and emamectin benzoate at controlling disease symptoms associated with *M. incognita* on tomato. In the first study, avermectins were applied to 3-week-old tomato seedlings by foliar spray and root dip. Seedlings were grown in pots (10-cm diam.) in a sand:soil mix (1:1) in a glasshouse as described above. Foliar sprays were applied with a CO_2 track sprayer equipped with disc cone nozzles (Teejet no. 8001, Sprayer Systems, Wheaton, IL) at a rate of 153.2 liters/ha at 3.4 kg/cm^2 and a speed of 3.5 km/hour (Jansson et al., 1996, 1997). Parafilm was placed over the soil surface before applications were made to eliminate potential root uptake of applied compounds because other researchers have shown that inadvertent application of avermectins to soil (from runoff on leaves) reduced gall formation of *M. incognita* on tomato (Cayrol et al., 1993).

To apply compounds as root dips, roots of transplants were washed thoroughly to remove all sand and soil and then dipped in glass beakers (500 ml) containing the appropriate treatment. Plants were held in the treatment solutions for 15 to 30 minutes and then planted in a 1:1 sand:soil mixture in plastic pots (10-cm diam.). Plants were maintained under slight to moderate water stress to encourage root uptake during dipping.

A 0.16EC formulation of emamectin benzoate (Merck, Whitehouse Station, NJ) and a 0.15EC formulation of abamectin (Merck, Whitehouse Station, NJ) were used. Final test concentrations (180 and 60, and 192 and 64 µg a.i./ml for abamectin and emamectin benzoate, respectively) were prepared by diluting formulated material in deionized water containing 100 µl a.i./liter of Triton X-155 (Sigma Chemical, St. Louis, MO). Test concentrations were applied to tomato plants either alone or in combination with a 0.06% concentration of a nonionic surfactant, LeafAct 80A (Pure Gro, West Sacramento, CA). Blank formulation treatments containing no active ingredient also were prepared as described above. Avermectin and blank formation treatments were compared with tomato seedlings treated with fenamiphos (1.25 g a.i./pot, Bayer, Kansas City, MO) incorporated into the sand:soil mixture of potted tomato seedlings, and with nontreated plants.

Meloidogyne incognita eggs were collected from the roots of severely galled tomato plants by shaking roots vigorously in a 1% NaOCl solution for 4 minutes (Hussey and Barker, 1973). Egg suspensions were poured through nested 250-, 44-, and 26-µm-pore sieves, and eggs were collected from the 26-µm-pore sieve after rinsing in tap water to remove NaOCl. Eggs were resuspended in water; aliquots (1 ml) were removed, diluted, and examined with a dissecting microscope to count eggs. This aqueous suspension of inoculum was pipetted into openings on the soil surface of each potted tomato transplant 24 hours after treatment to achieve a density of 2,200 eggs/pot.

Treatments were arranged in a completely randomized design with five replications. Root damage was assessed 28 days after treatment by washing roots in water and visually inspecting roots for the presence of galls using a rating system from 0 to 10, where 0 = complete and healthy root system with no galls; 1 = very few small galls visible; 2 = small root galls more numerous and easily visible; 3 = numerous small galls, some of which have grown together, but root function is not seriously impaired; 4 = first appearance of big galls, but majority of the roots are still functioning; 5 = about 25% of the root system is out of function because of severe galling; 6 = up to 50% of the root system is out of function because of severe galling; 7 = about 75% of the root system is out of function because of severe galling; 8 = no healthy roots remain; the nourishment of the plant is interrupted, but the plant is still green; 9 = root system is completely galled, rotting, and dying; and 10 = death of plant and roots (Zeck, 1971).

In the second study, only the effectiveness of root-dip applications was assessed. Avermectins and blank formulations (without a.i.) were applied at three concentrations (60, 120, and 180 µg a.i./ml for abamectin and 64, 128, and 192 µg a.i./ml for emamectin benzoate). Emamectin benzoate was diluted from a 5SG formulation (Jansson et al., 1997) in place of the 0.16EC. All other methods were similar to those described in the first study.

Banana experiments: Three studies were conducted to determine the effectiveness of the two avermectins against *M. javanica* and *R. similis* on banana. In the first study, 3- to 4-month-old Cavendish banana plants (30 cm tall) grown in pots (12.5-cm diam.) filled with a sand:soil potting medium (1:1) were treated with avermectins by foliar spray, root dip, and injection into the pseudostem. Foliar spray and root-dip applications were made on a single date with methods similar to those described above in the tomato experiments. Concentrations tested were 180 and 60 µg a.i./ml for abamectin and 190 and 63 µg a.i./ml for emamectin benzoate. Injection applications (1 ml aliquot) were

made on two dates. Treatments were injected into the center of the pseodustem immediately above the first leaf axil with a 10-cc syringe (model no. 9604, Becton Dickinson, Rutherford, NJ). Preliminary research demonstrated that downward movement of dyes injected into banana pseudostems was enhanced when injections were made at this site, but downward movement was impaired when injections were made into the crown or between the crown and the first leaf axil (unpubl.). Injections were applied on two dates. The first injection was made when all foliar and dip applications were made (24 hours before inoculation). The second injection (1 ml) was made 14 days later to bring the final test dosages for both compounds to 500 and 250 µg a.i./plant.

Abamectin concentrations were prepared by diluting a 0.15EC formulation; emamectin benzoate concentrations were prepared from a 5SG formulation. All test concentrations were applied in combination with the nonionic surfactant. Blank formulation treatments containing no active ingredient also were prepared as described above. Avermectin and blank formulation treatments were compared with banana plants treated with fenamiphos (250 mg a.i./pot) incorporated into the sand:soil mixture of potted plants, and with untreated plants.

Vermiform stages of *R. similis* were extracted from the roots of banana plants and from carrot discs during a 48-hour period in Baermann trays. Nematode suspensions were concentrated by allowing nematodes to settle and then removing surface water by aspiration. The remaining suspension was stirred continuously. Aliquots (1 ml) were removed, and nematodes were counted under a dissecting microscope. Approximately 600 vermiform nematodes were dispensed around the base of each plant 24 hours after treatment with avermectins.

Treatments were arranged in a completely randomized design with five replications. Nematode counts in root tissue were assessed 28 days after treatment using methods similar to those described by Hooper (1986). Roots were washed and macerated in water in a blender. Each root system was then placed in individual Baermann trays; nematodes were collected from trays after 24 hours. Nematode suspensions were allowed to settle overnight and were concentrated to a volume of 100 ml. Several aliquots (1 ml) were removed, diluted, and the number of nematodes counted under a dissecting microscope. The mean nematode count per aliquot was used to calculate the number of nematodes extracted per plant.

In the second and third experiments, the effectiveness of injection applications of each avermectin for controlling *M. javanica* on banana was assessed. In the second experiment, avermectins were injected into 5- to 6-month-old Goldfinger banana plants at three dosages (2,000, 1,000, and 500 µg a.i./plant). In the third experiment, 3- to 4-month-old Cavendish banana plants were injected with three different dosages of abamectin (500, 250, and 125 µg a.i./plant); emamectin benzoate was not included in this test. Emamectin benzoate was diluted from a 5SG formation; abamectin was diluted from the 0.15EC formulation in the second experiment and from a supersaturated 1% SL formulation in the third experiment. Blank formulation treatments containing no active ingredient also were prepared as described above. Avermectin treatments were compared with banana plants treated with fenamiphos (250 mg a.i./pot) and with untreated plants as described above. All other methods were similar to those described above.

Meloidogyne javanica eggs were collected from roots of severely galled tomato plants used to culture these nematodes using methods described for *M. incognita* (Hussey and Barker, 1973). Inoculum was pipetted into openings on the soil surface of each potted banana plant 24 hours after treatment to achieve a density of 5,500–6,000 eggs/pot.

In both of these experiments, treatments were arranged in a completely randomized design with five replications. Root damage was assessed 28 days after treatment by washing roots thoroughly in water and rating the severity of galling (Zeck, 1971). Phytotoxicity also was evaluated 1, 2, 7, 14, and 27 days

after treatment in both experiments by recording the percentage of leaves per plant with ≥20% necrosis/leaf.

Data analysis: Data from most experiments were analyzed with least-squares analysis of variance techniques (Zar, 1984). Gall ratings and burrowing nematode counts were square-root transformed to normalize error variance. In all but the first experiment on banana, means were separated with the Waller-Duncan k-ratio *t*-test (Waller and Duncan, 1969). In the first experiment on banana, means were separated based on 95% confidence intervals. Additionally, because certain treatments in the remaining experiments were highly effective for controlling nematodes and resulted in a mean and variance = 0 (e.g., fenamiphos-treated plants), data from these treatments were not analyzed by least-squares analysis of variance. We assumed that the expected values for these treatments were = 0. A 95% confidence interval was calculated for all treatments with a mean > 0. Treatment means were significantly different from those = 0 if 0 was outside the range of the confidence intervals.

Results and Discussion

Meloidogyne incognita experiments on tomato: Root gall damage differed ($P < 0.05$) among treatments in the first study (Table 1). In general, none of the avermectin treatments were as effective as fenamiphos at controlling *M. incognita*. Root dips tended to be more effective than foliar spray applications of avermectins, which were ineffective at controlling nematodes. Other researchers found that foliar sprays of avermectins at

Table 1. Effectiveness of abamectin and emamectin benzoate when applied as a foliar spray or as a root dip with (+) and without (–) surfactant for controlling disease symptoms associated with *Meloidogyne incognita* in the first experiment on tomato.

Formulation and treatment	Concentration (µg a.i./ml)	Application type	Mean (±sem) gall rating/plant[a]	
		Formulated products		
			+ surfactant	– surfactant
Abamectin 0.15EC	180	Foliar spray	5.0 ± 0.0 f-i	5.6 ± 0.1 d-g
Abamectin 0.15EC	60	Foliar spray	5.6 ± 0.1 d-g	5.0 ± 0.1 f-i
Emamectin benzoate 0.16EC	192	Foliar spray	4.6 ± 0.1 hi	5.6 ± 0.1 d-g
Emamectin benzoate 0.16EC	64	Foliar spray	5.0 ± 0.0 f-i	5.8 ± 0.1 c-f
Abamectin 0.15EC	180	Root dip	–[b]	2.5 ± 0.3 k
Abamectin 0.15EC	60	Root dip	3.4 ± 0.1 j	4.8 ± 0.2 g-i
Emamectin benzoate 0.16EC	192	Root dip	–	–
Emamectin benzoate 0.16EC	64	Root dip	4.3 ± 0.5 i	5.2 ± 0.2 f-h
		Blank formulations[c]		
Abamectin 0.15EC	180	Foliar spray	5.8 ± 0.2 c-f	nt
Abamectin 0.15EC	60	Foliar spray	5.6 ± 0.1 d-g	nt
Emamectin benzoate 0.16EC	192	Foliar spray	nt[d]	6.4 ± 0.1 a-d
Emamectin benzoate 0.16EC	64	Foliar spray	nt	6.0 ± 0.1 c-e
Abamectin 0.15EC	180	Root dip	7.0 ± 0.0 a	nt
Abamectin 0.15EC	60	Root dip	6.6 ± 0.2 a-c	nt
Emamectin benzoate 0.16EC	192	Root dip	nt	–
Emamectin benzoate 0.16EC	64	Root dip	nt	6.6 ± 0.2 ab
Nontreated control	–	Foliar spray	5.0 ± 0.5 f-i	5.0 ± 0.0 f-i
Nontreated control	–	Root dip	6.0 ± 0.3 b-e	5.4 ± 0.1 e-h
Fenamiphos 15G	1,250[e]	Soil incorporation		0.4 ± 0.11

Means in both columns combined followed by the same letter do not differ according to the Waller-Duncan *k*-ratio *t*-test (*k*-ratio = 100).

[a] Galls were rated on a scale from 0 (none) to 10 (severe, with plant death).

[b] All plants died (phytotoxicity).

[c] Concentrations are given in terms of equivalent amounts of formulation blank without a.i.

[d] nt = not tested.

[e] mg a.i./pot.

concentrations up to 1,000 mg a.i./liter were not effective at controlling *Meloidogyne* spp. on tomato (Cayrol et al., 1993; Stretton et al., 1987). The high concentration of abamectin (180 µg a.i./ml) applied as a root dip was more effective than all other avermectin treatments at controlling *M. incognita*. Blank formulations were comparable to untreated controls at controlling nematodes. Nwadinobi et al. (1989) reported that abamectin reduced galling and delayed invasion and development of *Meloidogyne* spp. for up to 20 days when roots of 14-day-old tomato seedlings were dipped in a low concentration of abamectin (1 µg a.i./ml).

Severe phytotoxicity was observed in some root-dip treatments. None of the plants dipped in abamectin (180 µg a.i./ml) in combination with the surfactant LeafAct 80A, emamectin benzoate (192 µg a.i./ml) alone, or in combination with the surfactant, or in the blank formulation of emamectin benzoate alone (192 µg a.i./ml equivalent) survived (Table 1). Although root-dip treatments provided a moderate level of efficacy against *M. incognita*, plant health was compromised.

The effectiveness of root-dip applications of avermectins for controlling nematodes was confirmed in the second study in which only root-dip applications were evaluated (Table 2). Abamectin was more effective than emamectin benzoate for controlling nematodes. Gall ratings on plants treated with blank formulations of both avermectins were comparable to those on untreated plants. None of the avermectin treatments were as effective as fenamiphos (1.25 g a.i./pot; ≈2.0 kg a.i./ha broadcast) for controlling gall damage associated with *M. incognita*. No phytotoxicity was observed in the second study. Collectively, these data show that root-dip applications of abamectin may have potential to control nematodes on tomato, albeit the level of control was not comparable to that achieved by fenamiphos. Cayrol et al. (1993) also showed that root-dip treatments of abamectin were effective at reducing root penetration of *M. arenaria* (Neal) Chitwood on tomato.

Radopholus similis experiment on banana:

TABLE 2. Effectiveness of abamectin and emamectin benzoate in combination with a surfactant when applied as a root dip for controlling disease symptoms associated with *Meloidogyne incognita* in the second experiment on tomato.

Formulation and treatment	Concentration (µg a.i./ml)	Application type	Mean (±sem) gall rating/plant[a]
	Formulated products		
Abamectin 0.15EC	180	Root dip	1.6 ± 0.1 e
Abamectin 0.15EC	120	Root dip	2.8 ± 0.1 d
Abamectin 0.15EC	60	Root dip	3.6 ± 0.1 bc
Emamectin benzoate 5SG	192	Root dip	3.8 ± 0.1 abc
Emamectin benzoate 5SG	128	Root dip	4.0 ± 0.0 ab
Emamectin benzoate 5SG	64	Root dip	4.0 ± 0.0 ab
	Blank formulations[b]		
Abamectin 0.15EC	180	Root dip	4.2 ± 0.1 a
Abamectin 0.15EC	120	Root dip	4.0 ± 0.0 ab
Abamectin 0.15EC	60	Root dip	4.0 ± 0.0 ab
Emamectin benzoate 5SG	192	Root dip	3.8 ± 0.1 bc
Emamectin benzoate 5SG	128	Root dip	3.8 ± 0.1 bc
Emamectin benzoate 5SG	64	Root dip	3.8 ± 0.1 bc
Nontreated control	–	Root dip	4.0 ± 0.0 ab
Fenamiphos 15G	1,250[c]	Soil incorporation	0.0 ± 0.0 f

Means followed by the same letter do not differ according to the Waller-Duncan *k*-ratio *t*-test (*k*-ratio = 100). Treatment means that were >0 were significantly different from those = 0 if their 95% confidence interval did not overlap with 0.

[a] Galls were rated on a scale from 0 (none) to 10 (severe, with plant death).

[b] Concentrations are given in terms of equivalent amounts of formulation blank without a.i.

[c] mg a.i./pot.

Numbers of *R. similis* in plants treated with foliar sprays of abamectin were highly variable and ranged from a mean (±SEM) of 876 ± 303 in plants treated with abamectin (180 µg a.i./ml) to 228 ± 36 in untreated control plants. None of the foliar spray treatments demonstrated that avermectins had potential for controlling *R. similis;* therefore, these data were excluded from further analysis. Data from all other treatments are shown in Table 3. The remaining treatments differed ($P < 0.05$) in their effectiveness for controlling *R. similis* on banana. Fenamiphos (250 mg a.i./plant) incorporation into soil was the most effective treatment; however, a root-dip application of abamectin (180 µg a.i./ml), a root-dip application of emamectin benzoate (190 µg a.i./ml), and an injection application of abamectin (500 µg a.i./plant) were comparable to fenamiphos for controlling this nematode. All other treatments were less effective for controlling *R. similis.* Concentration responses were apparent for both root-dip and injection applications of both avermectins. Abamectin and emamectin benzoate were comparable in their effectiveness for controlling this nematode, although nematode counts tended to be lower, but not significantly, in plants treated with abamectin compared with those treated with emamectin benzoate.

Meloidogyne javanica experiments on banana: Injection of the 0.15EC formulation of abamectin (2,000 µg a.i./plant) and the associated blank formulation treatment resulted in necrosis of the pseudostem around the injection site that was evident within 1 day after injection and then persisted for the duration of the test (Table 4). Severe foliar necrosis was also observed 27 days after treatment on plants injected with the blank formulation (1,000 µg a.i./plant equivalent of the formulated product). No phytotoxic-

TABLE 3. Effectiveness of abamectin and emamectin benzoate in combination with a surfactant when applied as a root dip and as an injection into the pseudostem for controlling *Radopholus similis* in the first experiment on banana.

Formulation and treatment	Concentration[a]	Application type	Mean no. *R. similis*/ plant (95% CI)[b]
	Formulated products		
Abamectin 0.15EC	180	Root dip	16 (0–33) ab
Abamectin 0.15EC	60	Root dip	148 (0–325) a-g
Abamectin 0.15EC	500	Injection	24 (0–66) a-c
Abamectin 0.15EC	250	Injection	280 (0–613) a-g
Emamectin benzoate 5SG	190	Root dip	64 (17–111) b-d
Emamectin benzoate 5SG	63	Root dip	144 (110–177) de
Emamectin benzoate 5SG	500	Injection	220 (68–353) d-g
Emamectin benzoate 5SG	250	Injection	144 (36–252) c-f
	Blank formulations[c]		
Abamectin 0.15EC	180	Root dip	188 (166–210) e-g
Abamectin 0.15EC	60	Root dip	436 (358–514) h
Abamectin 0.15EC	500	Injection	276 (157–395) e-h
Abamectin 0.15EC	250	Injection	300 (75–525) d-h
Emamectin benzoate 5SG	190	Root dip	196 (82–309) d-g
Emamectin benzoate 5SG	63	Root dip	440 (215–665) f-h
Emamectin benzoate 5SG	500	Injection	120 (48–192) c-g
Emamectin benzoate 5SG	250	Injection	636 (17–1,255) b-h
Nontreated control	–	Root dip	788 (0–1,790) a-h
Nontreated control	–	Injection	616 (294–938) gh
Fenamiphos 15G	250[d]	Soil incorporation	0 (0) a

Means followed by the same letter do not differ according to the 95% confidence interval of means.
[a] Root-dip applications are expressed as µg a.i./ml; injection applications are expressed as µg a.i./plant.
[b] 95% confidence limits of mean.
[c] Concentrations are given in terms of equivalent amounts of formulation blank without a.i.
[d] mg a.i./pot.

TABLE 4. Percentages of leaves per plant displaying ≥20% necrosis at various times after injection with different dosages of abamectin and emamectin benzoate in combination with a surfactant in the second experiment on banana.

Formulation and treatment	Dosage (µg a.i./plant)	Application type	Percentage of leaves per plant (mean ± sem) with ≥20% necrosis		
			Day after treatment		
			1	2	27
Formulated products					
Abamectin 0.15EC	2,000	Injection	26.6 ± 14.0	26.6 ± 14.0	48.4 ± 5.9
Abamectin 0.15EC	1,000	Injection	10.0 ± 6.2	10.0 ± 6.2	31.6 ± 5.4
Abamectin 0.15EC	500	Injection	0.0 ± 0.0	0.0 ± 0.0	29.2 ± 4.9
Emamectin benzoate 5SG	2,000	Injection	5.0 ± 5.0	5.0 ± 5.0	24.5 ± 5.3
Emamectin benzoate 5SG	1,000	Injection	10.0 ± 6.2	11.6 ± 7.3	27.4 ± 6.5
Emamectin benzoate 5SG	500	Injection	14.0 ± 5.9	15.6 ± 6.8	23.2 ± 3.3
Blank formulations[b]					
Abamectin 0.15EC	2,000	Injection	39.6 ± 16.8	59.6 ± 16.9	52.8 ± 4.8
Abamectin 0.15EC	1,000	Injection	5.0 ± 5.0	6.6 ± 6.6	56.2 ± 3.2
Abamectin 0.15EC	500	Injection	25.0 ± 0.0	25.0 ± 0.0	29.0 ± 3.2
Emamectin benzoate 5SG	2,000	Injection	15.6 ± 6.8	15.6 ± 6.8	33.6 ± 4.7
Emamectin benzoate 5SG	1,000	Injection	20.6 ± 5.6	20.6 ± 5.6	30.8 ± 6.4
Emamectin benzoate 5SG	500	Injection	15.0 ± 6.2	16.6 ± 7.3	27.2 ± 5.4
Nontreated control	–	Injection	11.6 ± 7.3	11.6 ± 7.3	21.2 ± 6.1
Fenamiphos 15G	250[a]	Soil incorporation	13.0 ± 8.4	13.0 ± 8.4	22.2 ± 5.3

[a] mg a.i./pot.
[b] Dosages are given in terms of equivalent amounts of formulation blank without a.i.

ity was observed on plants receiving the lowest concentration (500 µg a.i./plant) of abamectin. Slight necrosis was observed around the injection site on plants receiving the 5SG formulation of emamectin benzoate (2,000 µg a.i./plant); however, plants recovered rapidly from these symptoms (Table 4). No phytotoxicity was observed in the second experiment with the 1% SL formulation of abamectin at concentrations between 125 and 500 µg a.i./plant (data not shown).

In general, root gall ratings on banana were lower than what might be expected for a comparable test against *M. incognita* on tomato. Morphology of gall formation on the larger, fleshy roots of banana differed from that on young tomato plants. Penetration of banana roots by *M. javanica* results in distortions and tip bifurcations, as well as the formation of small single galls on fine roots (Gowen and Quénéhervé, 1990). Parasitized roots with these morphological features cannot be compared with those on tomato.

Despite variation in root morphology caused by nematode penetration, the data showed that symptoms of disease associated with *M. javanica* were controlled effectively by injections of abamectin at all dosages tested (Table 5). Abamectin was significantly more effective than emamectin benzoate, and control was comparable to applications of fenamiphos (250 mg a.i./pot). Results were confirmed in the subsequent experiment. Injections of abamectin (125, 250, and 500 µg a.i./plant) were comparable to soil applications of fenamiphos at controlling *M. javanica* (Table 6).

Data from these studies showed that avermectins have potential for controlling nematode parasites on certain plants. Previous researchers have shown that avermectins have potential for controlling plant-parasitic nematodes when applied as a root dip, bulb dip, or directly to the soil in various crops (Blackburn et al., 1996; Garabedian and Van Gundy, 1983; Preiser et al., 1981; Putter et al., 1981; Roberts and Matthews, 1995; Sasser et al., 1982). When sprayed onto foliage, avermectins had little downward movement, which resulted in limited control of *M. incognita,* even when applied at concentrations up to 1,000 mg a.i./

TABLE 5. Effectiveness of abamectin and emamectin benzoate in combination with a surfactant when applied as a shoot injection for controlling disease symptoms associated with *Meloidogyne javanica* in the second experiment on banana.

Formulation and treatment	Dosage (µg a.i./plant)	Application type	Mean (±sem) root gall rating/plant[a]
	Formulated products		
Abamectin 0.15EC	2,000	Injection	0.0 ± 0.0 c
Abamectin 0.15EC	1,000	Injection	0.0 ± 0.0 c
Abamectin 0.15EC	500	Injection	0.0 ± 0.0 c
Emamectin benzoate 5SG	2,000	Injection	1.6 ± 0.2 b
Emamectin benzoate 5SG	1,000	Injection	1.6 ± 0.2 b
Emamectin benzoate 5SG	500	Injection	0.4 ± 0.2 b
	Blank formulations[b]		
Abamectin 0.15EC	2,000	Injection	1.6 ± 0.2 b
Abamectin 0.15EC	1,000	Injection	2.6 ± 0.2 a
Abamectin 0.15EC	500	Injection	3.0 ± 0.5 a
Emamectin benzoate 5SG	2,000	Injection	3.4 ± 0.2 a
Emamectin benzoate 5SG	1,000	Injection	2.8 ± 0.5 a
Emamectin benzoate 5SG	500	Injection	3.6 ± 0.2 a
Nontreated control	–	Injection	3.0 ± 0.2 a
Fenamiphos 15G	250[c]	Soil incorporation	0.0 ± 0.0 c

Means followed by the same letter do not differ according to the Waller-Duncan *k*-ratio *t*-test (*k*-ratio = 100). Treatment means that were > 0 were significantly different from those = 0 if their 95% confidence interval did not overlap with 0.

[a] Galls were rated on a scale from 0 (none) to 10 (severe, with plant death).

[b] Dosages are given in terms of equivalent amounts of formulation blank without a.i.

[c] mg a.i./pot.

liter (Cayrol et al., 1993; Stretton et al., 1987). In all cases, the application rates needed to provide satisfactory nematode were cost-prohibitive. Rapid sorption to the soil matrix effectively inactivates avermectins (Bull, 1985; Chukwudebe et al., 1996; Wislocki et al., 1989). Additionally, root uptake of avermectins was shown to be minimal (Chukwudebe et al., 1996; Wislocki et al., 1989). Thus, only a small percentage of avermectins applied to soil may contact nematodes or be taken up by roots.

TABLE 6. Effectiveness of abamectin in combination with a surfactant when applied as an injection into the pseudostem for controlling disease symptoms associated with *Meloidogyne javanica* in the third experiment on banana.

Treatment	Dosage (µg a.i./plant)	Application type	Mean (±sem) gall rating/plant[a]
	Formulated products		
Abamectin 1% SL	500	Injection	0.2 ± 0.2 b
Abamectin 1% SL	250	Injection	0.0 ± 0.0 b
Abamectin 1% SL	125	Injection	0.4 ± 0.4 b
	Blank formulations[b]		
Abamectin 1% SL	500	Injection	2.6 ± 0.4 a
Abamectin 1% SL	250	Injection	2.4 ± 0.7 a
Abamectin 1% SL	125	Injection	3.2 ± 0.5 a
Nontreated control	–	Injection	2.4 ± 0.5 a
Fenamiphos 15G	250[c]	Soil incorporation	0.0 ± 0.0 b

Means followed by the same letter do not differ according to the Waller-Duncan *k*-ratio *t*-test (*k*-ratio = 100). Treatment means that were > 0 were significantly different from those = 0 if their 95% confidence interval did not overlap with 0.

[a] Galls were rated on a scale from 0 (none) to 10 (severe, with plant death).

[b] Dosages are given in terms of equivalent amounts of formulation blank without a.i.

[c] mg a.i./pot.

These studies showed that root-dip and pseudostem-injection applications of avermectins may have potential for controlling certain plant-parasitic nematodes on tomato and banana. Of the two application types, effective nematode control comparable to soil-applied fenamiphos was achieved with injections of 125 to 2,000 µg a.i./banana plant. Of the two avermectin compounds evaluated, abamectin was more effective than emamectin benzoate against *M. javanica* and *R. similis* on banana. Both compounds were comparable in their effectiveness for controlling *M. incognita* on tomato.

Intensive banana production currently relies on the use of organophosphate and carbamate insecticide-nematicides for control of *R. similis* and other nematodes. Because of the increased scrutiny being placed on conventional nematicides that pose significant risks to workers, handlers, and the environment, there is an immediate need to identify safer alternatives for controlling nematodes in banana. Based on results from the present studies, additional research on the potential of injection applications of abamectin into banana for nematode control is warranted.

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