Evaluation of fosthiazate (Nemathorin® 10G) for the control of nematodes in banana fields in Martinique

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EVALUATION OF FOSTHIAZATE (NEMATHORIN® 10G) FOR THE CONTROL OF NEMATODES IN BANANA FIELDS IN MARTINIQUE

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ABSTRACT

Chabrier, C., J. Hubervic and P. Quénéhervé. 2002. Evaluation of fosthiazate (Nemathorin® 10G) for the control of nematodes in banana fields in Martinique. Nematropica 32:137-147.

The effectiveness of fosthiazate (Nemathorin® 10G) was evaluated on bananas against plant-parasitic nematodes and black weevil, *Cosmopolites sordidus*, in four field trials in Martinique. In the first trial, two rates of fosthiazate (2.0 and 3.0 g a.i./mat) were compared with aldicarb (Temik® 10G), applied at 2.0 g a.i./mat. In the three other studies, fosthiazate, at 1.5 and 2.0 g a.i./mat applied 3 times per year, was compared with alternate applications of 3 reference nematicides: cadusafos (3.0 g a.i./mat), aldicarb (2.0 g a.i./mat) and fenamifos (3.0 g a.i./mat). A non treated check was included in all 4 experiments. Trials 3 and 4 had high levels of weevil so a standard insecticide *vs.* banana weevil, fipronil (0.2 g a.i./mat), was applied on the check plots. The burrowing nematode, *Radopholus similis*, was the dominant nematode species, followed by the spiral nematode *Helicotylenchus multicinctus* in trials 1, 3 and 4 whereas root-knot nematodes, *Meloidogyne* spp., dominated the nematofauna in trial 2 and were present at all sites. The lance nematode, *Hoplolaimus seinhorsti*, was only important on trial 2. Fosthiazate was as effective as the standard nematicides in trials 1 and 2 and significantly more effective in trials 3 and 4 against the burrowing nematode, *R. similis*. Few differences were observed in the control of *H. multicinctus* whereas both rates of fosthiazate significantly reduced infection by *Meloidogyne* spp. and *H. seinhorsti*. Fosthiazate was as effective against *C. sordidus* as fipronil. Fosthiazate treatments increased banana yields up to 35% compared to check plots by preventing toppling-over.

Key words: black weevil, burrowing nematode, chemical control, *Cosmopolites sordidus*, fosthiazate, *Helicotylenchus multicinctus*, *Hoplolaimus seinhorsti*, Martinique, *Meloidogyne* spp., Musa AAA, *Radopholus similis*, root-knot nematode.

RESUME

Chabrier, C., J. Hubervic and P. Quénéhervé. 2002. Evaluation du fosthiazate (Nemathorin® 10G) pour le contrôle des nématodes en bananeraies à la Martinique. Nematropica 32:137-147.

L'efficacité du fosthiazate (Nemathorin® 10G) contre les nématodes phytoparasites du bananier et contre le charançon noir du bananier, *Cosmopolites sordidus*, a été évalué sur quatre sites en Martinique. Lors du premier essai, deux doses de fosthiazate (2.0 et 3.0 g de matière active/plant) ont été comparées avec l'aldicarbe (Temik® 10G) appliqué à 2.0 g m.a./plant. Pour les trois autres études, le fosthiazate a été évalué à deux doses (1.5 et 2.0 g m.a./plant), appliqué trois fois par an et comparé à une rotation de trois nématicides de référence: le cadusafos (3.0 g m.a./plant), l'aldicarbe (2.0 g m.a./plant) et le fenamifos (3.0 g m.a./plant). Sur les deux derniers sites, particulièrement infestés par *C. sordidus*, deux traitements insecticides (fipronil, 0.2 g m.a./plant) par an ont été appliqués sur les parcelles de référence. Sur les essais 1, 3 et 4, le nématode endoparasite *Radopholus similis* a été l'espèce dominante, suivi par *Helicotylenchus multicinctus*. Le nématode à galle *Meloidogyne* spp., présent sur chaque site, a dominé la nématofaune de l'essai 2 avec *Hoplolaimus seinhorsti*. Le fosthiazate a fait preuve d'une efficacité comparable au traitement de référence sur deux sites, significativement supérieure sur les deux autres sites contre *R. similis* tandis que peu de différences significatives ont été observées contre *H. multicinctus*. Le fosthiazate a de plus significativement réduit les populations de *Meloidogyne* spp. et d'*H. seinhorsti*. Enfin, le fosthiazate a donné des résultats comparables à ceux du fipronil contre le charançon *C. sordidus*. En réduisant les risques de chute des plants, le fosthiazate a permis une augmentation de rendement pouvant atteindre 35% par rapport aux parcelles de référence.

INTRODUCTION

In the French West Indies, the burrowing nematode, *Radopholus similis* (Cobb), remains the primary nematode problem in banana fields (Vilardebo *et al.*, 1988; Loridat, 1989; Gowen and Quénéhervé, 1990). Current recommendations are to apply nematicides from 1 to 3 times per year to manage nematode problems in Martinique and the Guadeloupe islands. As for any high value cash crop, the number of treatments per year depends on many factors such as the calendar date, the cropping cycle, the type of vegetative materials at planting, soil type, level of nematode infestations estimated from routine nematode analysis and most important the farmer's economic assets. Recently, following the increased use of banana vitroplantlets after an appropriate fallow period, the number of nematicide applications has been drastically reduced in Martinique (Chabrier and Quénéhervé, 2001). However, due to natural reintroduction of nematodes, the application of 2 to 3 nematicide treatments becomes necessary 3 to 4 years after planting to prevent toppling over of plants and production decline which may reach more than 33% in the French West Indies (Vilardebo *et al.*, 1988).

Currently, eight chemicals with nematicidal activity are authorized by the Pesticide Registration Committee from the French Ministry of Agriculture for application on bananas in Martinique and the Guadeloupe islands. Among them, aldicarb (Temik® 10G), cadusafos (Rugby® 10G), and terbufos (Counter® 10G) are the most commonly used. Nematode control based on a low number of alternative compounds presents some constraints and risks for the applicators and for the environment. These constraints include: i) a high mammalian toxicity level; ii) the risk of developing accelerated biodegradation (Anderson and Lafuerza, 1992; Pattison *et al.*, 2000) and iii) some of these compounds have poor efficacy against *Meloidogyne* spp. Moreover, some of these products will loose their authorization of use (European list of authorized substances) in 2003 (Malézieux, 2002). For these reasons, there is always a need to enlarge the range of available alternative products to be applied by growers.

Fosthiazate is a recently developed organophosphate (Woods *et al.,* 1991) which has demonstrated promising efficacy against the burrowing nematode, *R. similis*, in Costa-Rica and Panama banana plantations (Guzman-Gonzalez *et al.*, 1994; Hintz, 1998). This organophosphate has also been proven to be efficient against *Pratylenchus* sp. on potatoes (Kimpinski *et al.*, 1997), *Meloidogyne* spp. on tobacco (Rich *et al.*, 1994; Pullen and Fortnum, 1999) and peanut (Minton *et al.*, 1993), and against *Belonolaimus longicaudatus* on turfgrass (Giblin-Davis *et al.*, 1993). The purpose of this study was to compare, in the banana growing conditions of Martinique, the efficacy of this new organophosphate with that of other nematicides regarding both advantages of its lower toxicity levels (LD50 oral rat: 230/440 mg/kg, ADI: 4.2 µg/kg) (Tomlin, 1998) and of its potential efficacy against root-knot nematodes (Pullen and Fortnum, 1999).

MATERIALS AND METHODS

Experiments were conducted from 1993 to 1999 and located at four sites in Martinique under different soil types and field histories. Trials 1, 2 and 3 were set on an Ultisol (Ferralitic and Halloysic soils) comprising from 15 to 20% sand, 8 to 15% silt, 69 to 72% clay; 2.5 to 3.0% organic mater content and with pH varying from 4.8 to 5.3. These clay soils are most common in Martinique at lower elevations. The fourth trial was set on an Andosol developed on volcanic ashes. This sandy soil (77 to 82% sand, 11 to 14% silt and 2 to 3% clay) contained 11.8% of organic mater with a pH of 5.2. Such soils, characteristic of elevated areas (rainfall above 4000 mm/year), comprise about 25% of banana plantations in Martinique.

Trial 1 (Savane Haut) was initiated in December 1993 at the CIRAD plantation estate of Rivière Lézarde, as a new plantation of Cavendish banana sword suckers, planted immediately after the mechanical destruction of an old banana field infested with *R. similis* (6 000 individuals/100g of fresh roots). This experiment was destroyed by the tropical storm Debby only 8 months after planting (on September the 9th, 1994) and a few weeks before harvest. Only two nematicide applications occurred, 1 and 5 months after planting. Four monthly nematode samplings were collected, starting from the end of the 4th month to the day before the storm. For trial 1, the proportion of harvested plants was replaced by the proportion of toppled-over plants. Storm had broken some plants, but, as risk of breaking is not clearly linked with nematode infestations contrary to toppling (Gowen and Quénéhervé, 1990), broken plants were not included in the damage estimate.

Trial 2 (Laurencine), was started in May 1996 at the CIRAD plantation estate of Rivière Lézarde and trial 4 (Grand Boudou) began in April 1997. Both were planted with vitroplantlets of Cavendish banana cv. Grande Naine on a former banana field following a 5-month fallow period. At these sites, initial populations of *R. similis* were lower than on the other sites (less than 100 individuals/100 g roots). Trials 2 and 4 were monitored during three complete cycles of production, 27 and 30 months respectively.

Trial 3 (Rivière) was established in November 1997 on a 2-year-old banana field infested with an average of 18,700 *R. similis*/100 g of fresh roots at the Jonction plantation estate in order to replace trial 1. Data were collected over 16 months.

For each trial, the experimental design was a randomized complete-block with four replicates. All plots consisted of 72 plants (42 observed plants surrounded by a belt of border plants) for a surface area ranging from 350 m^2 (density of 2,050 plants/ha, trials 1 and 3) to 400 m^2 (density of 1,800 plants/ha, trials 2 and 4). In each trial, we compared fosthiazate at two different rates to untreated control plots and a standard nematicide program. In trial 1, 2 g of Temik® 10G/mat was applied on the treated control plots 1 and 5 months after planting. In the other three trials, the control treatments consisted of an alternate application of 3 different compounds every 4 months (2 g of aldicarbe—Temik® 10G per mat, 3 g of cadusafos—Rugby® 10G per mat, 3 g of fenamifos—Nemacur® 10G per mat). All these compounds were applied directly on the soil as granular formulations in a crown of *ca.* 40 cm around the plant base. Fosthiazate 10G was tested in trial 1 at 2.0 and 3.0 g/mat, 1 and 5 months after planting whereas in the other trials fosthiazate 10G was applied at 1.5 and 2.0 g/mat every 4 months.

Due to high levels of infestation by black weevil, *Cosmopolites sordidus* (Germar), on trials 3 and 4, 0.2 g fipronil—Regent® 5GR per mat was applied twice a year on the check plots in order to estimate the effectiveness of fosthiazate against black weevils.

Starting 5 months after planting, the roots from 10 chosen plants per plot were collected monthly from a cubic 0.27 m^3 volume close to the plant base. In all plots, each plant was sampled every 4 months. Nematodes were extracted using the centrifugation-flotation method (Jenkins, 1964, adapted by Coolen & d'Herde, 1972) and enumerated under a stereomicroscope in a Malassez cell slide. Counts were expressed as the number of nematodes per 100 g of fresh roots (Sarah *et al.*, 1996).

Plants were also observed monthly for symptoms of phytotoxicity. Bananas were measured (height and circumference) during vegetative growth and at flowering for each cycle of production. Yield parameters (bunch weight, proportion of harvested bunches, number of fruit per bunch, duration of production cycle) were recorded for each harvest. These data were used to calculate an annual raw yield indicator, expressed in metric ton ha^{-1} $year^{-1}$ and calculated according to the following formula:

ARY = plant density × proportion of harvested plants × average bunch weight × (365/duration of production cycle).

Two weeks after harvest, black weevil injury was estimated in each plot by peeling the corm of each plant (Vilardebo, 1973). The percentage of injured plants and the coefficient of infestation, which corresponds to the proportion of the corm circumference showing weevils tunnels, were used as indicators.

All data were analyzed using a Fisher's test in an analysis of variance. When results were significant ($P \leq 0.05$), mean values per treatment were compared using a Newman-Keul's test. For nematode populations, the data were analyzed after $\log_{10}(x + 1)$ transformation.

RESULTS

Effect of fosthiazate treatments on nematode populations

At all sites, three nematode species were consistently found associated with banana roots, *R. similis, H. multicinctus* and *M. arenaria. Hoplolaimus seinhorsti* was only found at sites 2 and 4.

In trials 1 and 3, the population levels of *R. similis* and *H. multicinctus* were very high during all of the experiments. The fosthiazate treatments were as effective as aldicarb in reducing the population densities of both species in banana roots in trial 1 and were superior to aldicarb treatments in trial 3 (Tables 1 and 2). At these sites, *M. arenaria* populations were rather low, however, the fosthiazate treatments were significantly more effective in reducing nematode densities than the reference treatments in trial 3, even when fosthiazate was applied at the lower rate of 1.5 g/mat (Table 2).

In trial 2, the population levels of *R. similis* and *H. multicinctus* were very low while infestations by *M arenaria* and *H. seinhorsti* reached high population levels (up to 1,000 individuals in 100 g of banana roots). Fosthiazate treatments were much more effective than the reference treatments against either *M. arenaria* or *H. seinhorsti*, regardless of the production cycle or the application rates (Table 3).

In trial 4, the initial *R. similis* population densities were low but increased on control and reference nematicide plots after the 1st harvest. The fosthiazate treatments, even at the lowest rate of 1.5 g/mat, gave better control of *R. similis*, *H. multicinctus* and *M. arenaria* than the reference treatment (Table 4). *Hoplolaimus seinhorsti* (datas not shown), was only found sporadically at very low levels in this experiment.

Table 1. Effects of nematicide treatments on nematode densities under banana at Savane Haut (Trial 1), Martinique, F.W.I.

	Control: no nematicide	Reference treatment (aldicarbe, 2.0 g/mat 3 times/year)	Fosthiazate 2.0 g/mat 3 times/year	Fosthiazate 3.0 g/mat 3 times/year	
R. similis	22 397 a[x]	6 391 b	6 332 b	4 703 b	HS
H. multicinctus	5 863 a	1 107 b	1 528 b	1 835 b	HS
Meloidogyne sp.	929 a	413 b	238 b	228 b	HS

[x]Data are means of 16 replications (pooled across 4 blocks and 4 sampling dates). Populations are expressed as number of individuals per 100 g of fresh roots.
Statistical tests (Fisher's test and Newman-Keuls test) have been calculated after log (x/1000 +1) transformation. NS = not significant, S = significant (P = 0.05), HS = highly significant (P = 0.01). Means in a row followed by the same letter are not different (P = 0.05) according to Newman-Keuls test.

Effect of fosthiazate treatments on weevil populations

Due to the untimely destruction of trial 1, black weevil damage was only assessed on trials 2, 3 and 4. The black weevil infestations were low in trial 2, ranging from 7.5 to 11.4% of infested corms on the three successive harvests whereas on trials 3 and 4, the weevil damage was very high on untreated control plots ranging from 62.2 to 74.1% of infested corms with a Back Peeling Index ca. 30. At these sites, the treatments with fosthiazate, whatever the application rates, provided a level of control similar to that of the complementary fipronil treatment on the reference treatments against this pest (Table 5).

Effect of fosthiazate treatments on growth parameters and yields

In these trials, we did not observe any differences among treatments on plant height, circumference, harvests intervals or bunch weight. Therefore, two kinds of results are illustrated in Table 6: i) the percentage of toppled-over plants (Trial 1) or

Table 2. Effects of nematicide treatments on nematode densities under banana at Rivière (Trial 3) Martinique, F.W.I.

	Control: no nematicide	Reference treatment (rotation of aldicarbe, cadusafos and fenamifos)	Fosthiazate 2.0 g/mat 3 times/year	Fosthiazate 3.0 g/mat 3 times/year	
R. similis	10 182 a[x]	7 638 b	5 059 c	5 764 c	HS
H. multicinctus	19 208 a	11 951 b	8 149 c	7 598 c	HS
Meloidogyne sp.	1 989 a	1 490 b	801 c	644 c	HS

[x]Data are means of 56 replications (pooled across 4 blocks and 14 sampling dates). Population are expressed as number of individuals per 100 g of fresh roots.
Statistical tests (Fisher's test and Newman-Keuls test) have been calculated after log (x/1000 +1) transformation. NS = not significant, S = significant (P = 0.05), HS = highly significant (P = 0.01). Means in a row followed by the same letter are not different (P = 0.05) according to Newman-Keuls test.

Table 3. Effects of nematicide treatments on nematode densities under banana at Laurencine (Trial 2), Martinique, F.W.I.

	Control: no nematicide	Reference treatment (rotation of aldicarbe, cadusafos and fenamifos)	Fosthiazate 1.5 g/mat 3 times/year	Fosthiazate 2.0 g/mat 3 times/year	
R. similis					
1st cycle	23[x]	16	16	16	NS
2nd cycle	152	3	3	13	NS
3rd cycle	464	73	32	15	NS
Average	238 a	34 b	18 b	15 b	NS
H. multicinctus					
1st cycle	49	65	32	26	NS
2nd cycle	23	6	1	18	NS
3rd cycle	55	30	100	39	NS
Average	43	31	48	28	NS
Meloidogyne sp.					
1st cycle	1 516 a	538 b	573 b	539 b	HS
2nd cycle	3 901 a	3 776 a	1 564 b	815 c	HS
3rd cycle	7 835 a	3 105 b	2 690 b	2 250 b	HS
Average	4 768 a	2 616 b	1 727 c	1 297 c	HS
H. seinhorstii					
1st cycle	1 133	1 193	1 002	1 014	NS
2nd cycle	797 a	614 a	324 b	366 b	HS
3rd cycle	673 a	526 ab	368 b	390 b	S
Average	842 a	741 b	529 b	556 a	NS

[x]Data are means of 20 replications (1st cycle), 24 replications (2nd cycle), 28 replications (3rd cycle) and 72 replications (Total) pooled across 4 blocks and sampling dates. Population are expressed as numbers of individuals per 100 g of fresh roots.
Statistical tests (Fisher's test and Newman-Keuls test) have been calculated after log (x/1000 +1) transformation. NS = not significant, S = significant (P = 0.05), HS = highly significant (P = 0.01). Means in a row followed by the same letter are not different (P = 0.05) according to Newman-Keuls test.

the percentage of harvested plants (Trials 2 and 4) and ii) the annual raw yield index which accounts for all growth and yield data during vegetative and reproductive stages.

In trial 1, the destruction of plants by the tropical storm varied from one plot to one another. Therefore, the percentage of toppled-over plants was less severe on fosthiazate treated plants than on the reference plots (Table 6).

In trial 2, no differences were observed on yield, regardless of the vegetative cycle. The percentage of harvested plants remained high, even at the third cycle, ranging from 83.6 to 86.6%. Consequently the combined effects of *M. arenaria* and

Table 4. Effects of nematicide treatments on nematode densities under banana at Grand Boudou (Trial 4), Martinique, F.W.I.

	Control: no nematicide	Reference treatment (rotation of aldicarbe, cadusafos and fenamifos)	Fosthiazate 1.5 g/mat 3 times/year	Fosthiazate 2.0 g/mat 3 times/year	
R. similis					
1st cycle	1 490 a[x]	1 298 a	608 b	375 b	HS
2nd cycle	4 558 a	5 440 a	1 833 b	1 786 b	HS
3rd cycle	3 604 a	3 051 a	871 b	1 164 b	HS
Total	3 266 a	3 236 a	1 075 b	1 115 b	HS
H. multicinctus					
1st cycle	509 a	418 ab	298 b	276 b	S
2nd cycle	1 616 a	732 b	747 b	655 b	HS
3rd cycle	1 518 a	689 c	1 163 b	576 c	HS
Total	1 252 a	623 b	790 b	512 b	HS
Meloidogyne sp.					
1st cycle	1 189 ab	1 460 a	802 c	569 c	HS
2nd cycle	3 552 a	3 024 a	1 727 b	1 666 b	HS
3rd cycle	2 447 a	1 949 ab	1 620 b	1 943 b	S
Total	2 402 a	2 120 a	1 412 b	1 461 b	HS

[x]Data are means of 28 replications (1st cycle), 28 replications (2nd cycle), 40 replications (3rd cycle) and 96 replications (Total) pooled across 4 blocks and sampling dates. Population are expressed as numbers of individuals per 100 g of fresh roots.
Statistical tests (Fisher's test and Newman-Keuls test) have been calculated after log (x/1000 +1) transformation. NS = not significant, S = significant (P = 0.05), HS = highly significant (P = 0.01). Means in a row followed by the same letter are not different (P = 0.05) according to Newman-Keuls test.

H. seinhorsti, which dominated in this field, may have little economic importance.

Generally, in banana field experiments, the effects of nematicide treatments on yield are not significant during the first cycle of production whereas differences tended to increase with time. This was especially true in trial 4. The fosthiazate treated plots gave higher yields than the untreated plots, but only after second cycle of production.

Side effect of fosthiazate

Trial 2, which was infested by low population densities of burrowing nematodes, should have highlighted possible phytotoxicity or physiological disorders associated with fosthiazate treatments, if such effects exist. The absence of differences between fosthiazate treated plots and untreated plots did not indicate phytotoxicity or physiological disorders.

DISCUSSION

In the French West Indies, the major nematode damage on bananas is toppling of plants (CIRAD, unpublished). Due to consistently strong winds, plants heavily infected with nematodes usually fall down

Table 5. Effects of nematicide treatments on Black Weevil damage to banana observed at harvest in three different trials.

Trial no.	Cycle	Indicator %	Untreated control	Reference treatments	Fosthiazate 1.5 g/mat 3 times/year	Fosthiazate 2.0 g/mat 3 times/year	
2	1	IM[x]	7.5	2.7	2.7	0.6	NS
		BPI[y]	2.1	0.3	0.4	0.3	NS
	2	IM	6.7	2.6	0.0	0.7	NS
		BPI	2.2	1.2	0.0	0.1	NS
	3	IM	11.4 a	2.0 b	0.0 b	2.9 b	HS
		BPI	2.4 a	0.2 b	0.0 b	0.4 b	HS
3		IM	72.1 a	26.7 b	8.6 b	28.0 b	HS
		BPI	35.3 a	8.5 b	2.7 b	6.3 b	HS
4	1	IM	62.2 a	4.2 b	10.3 b	13.2 b	HS
		BPI	11.1 a	0.3 b	0.8 b	1.2 b	HS
	2	IM	83.6 a	14.4 b	16.3 b	24.1 b	HS
		BPI	27.5 a	2.7 b	2.8 b	3.8 b	HS
	3	IM	74.1 a	24.1 b	30.1 b	33.7 b	HS
		BPI	30.4 a	5.0 b	4.9 b	7.0 b	HS

Infested mat = Percentage of infested plants.
[y]Back Peeling Index = Percentage of attacked area after peeling of corm.
Statistical tests (Fisher's test and Newman-Keuls test) have been calculated after log (x/1000 +1) transformation.
NS = not significant, S = significant (P = 0.05), HS = highly significant (P = 0.01). Means in a row followed by the same letter are not different (P = 0.05) according to Newman-Keuls test.

several weeks before harvest. Our experiments conducted in volcanic soils of Martinique confirmed that the two components of nematode damage by *R. similis* and *H. multicinctus* are i) toppling over of the most severely infected plants and ii) reduction of the longevity of plantation. In other parts of the world, nematode damage can be observed on bunch weights, vegetative growth, and most insidiously on the duration of phenological phases (Gowen and Quénéhervé, 1990; Quénéhervé, 1993). The results of several multi-location trials have shown that nematode damage and nematicide efficacy on bananas are closely linked to the soil type (Guérout *et al.*, 1976; Sarah and Vilardebo, 1979; Quénéhervé, 1988; Fogain *et al.*, 1996).

On bananas, the weevil galleries located in the corm base induced severe necrosis which impeded new root emission. By their direct injuries, weevil, like burrowing nematode, may be the direct cause of toppling-over of plants and subsequently, of the reduction of plantations longevity. When both pests are present, it is particularly difficult to assign damage to *R. similis* or to *C. sordidus* as the sole cause of toppling as a synergy seems to exist (Speijer *et al.*, 1993). Moreover, the banana black weevil, *C. sordidus* (Germar), is a major pest in the French West Indies

[x]Table 6. Effects of nematicide treatments on the percentage of harvested banana plants (or toppled over, trial 1) and the annual raw banana yields in the different trials.

Trial no.	Cycle	Indicator	Untreated control	Reference treatments	Fosthiazate 1.5 g/mat 3 times/year	Fosthiazate 2.0 g/mat 3 times/year	
1	1	% TO[x]	57.5	57.5	29.4	17.5	NS
2	1	% HP[y]	92.7	93.4	92.6	95.8	NS
		ARY[z]	46.2	47.9	46.1	47.7	NS
	2	% HP	92.7	94.6	93.3	92.2	NS
		ARY	70.9	74.9	74.6	76.0	NS
	3	% HP	84.8	86.2	86.6	83.6	NS
		ARY	58.5	58.4	58.3	58.4	NS
4	1	% HP	70.8	82.7	91.7	85.6	NS
		ARY	32.7	36.9	40.8	36.0	NS
	2	% HP	37.5 b	84.5 a	94.0 a	89.1 a	HS
		ARY	28.4 b	65.9 a	76.2 a	71.8 a	HS
	3	% HP	47.6 c	80.4 b	95.8 a	89.1 ab	HS
		ARY	31.9 b	47.5 ab	65.9 b	62.5 b	S

[x]TO = percentage of toppling over plants.
[y]HP = percentage of harvested plants.
[z]ARY = annual raw yields expressed in metric ton·ha^{-1}·year^{-1}.
Statistical tests (Fisher's test and Newman-Keuls test) have been calculated after log (x/1000 +1) transformation. NS = not significant, S = significant (P = 0.05), HS = highly significant (P = 0.01). Means in a row followed by the same letter are not different (P = 0.05) according to Newman-Keuls test.

(Mestre, 1997). The only chemical available to control the weevil is fipronil (Regent® 5 GR). However, the repeated use of a single pesticide may enhanced pesticide biodegradation (Anderson and Lafuerza, 1992) or development of resistance (Collins *et al.*, 1991).

In our studies, Nemathorin® 10G (granular formulation of 10% fosthiazate) was very effective not only in reducing populations of several nematodes but also in reducing the damage resulting from the black weevil attacks. Nemathorin® increased raw yield of banana up to 38.7% over our reference treatments (application of 3 nematicides per year alternately: aldicarb, cadusafos and fenamifos, completed by 2 applications of fipronil per year) without evidence of phytotoxicity or adverse physiological effects. Such side effects have been demonstrated with other nematicides. Aldicarb and carbofuran negatively affect the number of fruits per bunch when applied at fruit initiation in banana (Sarah *et al.*, 1988). A depressive effect of fenamifos on plant growth and bunch weight was also observed by Sarah and Vilardebo (1979).

Our results complete the information obtained from Costa Rica and Panama on the efficacy of fosthiazate against burrowing nematodes (Guzman-Gonzalez *et al.*, 1994; Hintz, 1998) and provide a new insight on its effectiveness in controlling black weevil.

The effect of Nemathorin® in reducing populations of root-knot nematode as observed in trial 2 is consistent with previous observations of the efficacy of fosthiazate on *Meloidogyne* spp. in other crops such as tobacco (Rich *et al.*, 1994; Pullen and Fortnum, 1999) and peanut (Minton *et al.*, 1993). Nonetheless, further studies should confirm this efficacy in bananas with nematode extraction procedures more appropriate for these sedentary endoparasites (e.g., mist chamber). Root-knot nematodes, which can become the predominant nematode species in banana roots when the burrowing nematodes are not present, may be responsible for direct and indirect damage to bananas (Gowen and Quénéhervé, 1990; De Waele, 2000). The synergies between root-knot nematodes and other pathogens, e.g., *Fusarium oxysporum* or *Ralstonia solanacearum* have already been reported in the French West Indies on tomato (Deberdt *et al.*, 1989) and in India on banana (Pathak *et al.*, 1999). It is advisable to have an effective nematicide, such as fosthiazate, against root-knot nematodes.

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