New approaches to chemical control of nematodes on bananas : field experiments in the Ivory Coast

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SUMMARY

Two field experiments were conducted in the Ivory Coast to evaluate the efficacy of new treatment protocols for chemical control of nematode on bananas. In these experiments the concept was to apply the chemical treatment on an individual plant basis at the time of harvest to protect the following crop. When chemicals are applied simultaneously to all plants in a plantation efficacy may be less because the nematode populations may fluctuate between plants of different ages and the treatments may not be needed by some plants at that time. In addition, chemicals may be wasted because under tropical conditions their persistence will be quite short (runoff and/or leaching). These treatments were compared to a standard sequence of nematicide treatment applied three times per year. Treatments at harvest provided better control of *Radopholus similis* and resulted in plant growth and yield at harvest identical to those obtained with the standard treatment sequence. This technique should reduce the number of nematicide applications in certain conditions from three to two per year to obtain identical levels of nematode control and plant growth responses.

RÉSUMÉ

Une nouvelle approche dans la lutte chimique contre les nématodes du bananier : expérimentations en Côte d'Ivoire

Deux expérimentations ont été conduites en Côte d'Ivoire pour évaluer l'efficacité d'un nouvel itinéraire technique dans la lutte chimique contre les nématodes du bananier. Au cours de ces expérimentations, le concept fut d'appliquer le traitement nématicide au moment de la récolte individuellement pour chaque bananier afin de protéger le cycle suivant. Quand les traitements sont appliqués simultanément à tous les plants l'efficacité globale est réduite car la période optimale de traitement varie entre plants d'âges différents, de même que l'infestation par les nématodes. De plus, le traitement peut être inefficace parce qu'en conditions tropicales sa persistance dans le sol sera courte (ruissellement et/ou écoulement vertical). Ces traitements, appliqués individuellement au moment de la récolte, furent comparés à la séquence traditionnelle de trois traitements nématicides par an. Les résultats ont montré une meilleure efficacité sur le contrôle des populations de *Radopholus similis.* D'un point de vue agronomique, les résultats sur la croissance et la récolte furent identiques à ceux obtenus avec la séquence traditionnelle. Cette technique devrait réduire le nombre des applications de nématicide, dans certaines conditions, de trois à deux par an pour des résultats nématologiques et agronomiques au moins identiques.

Early investigations into techniques for control of nematodes in banana plantations were made by Loos and Loos (1960), Luc and Vilardebó (1961) and Blake (1961). Between 1960 and 1972, the fumigant nematicide DBCP was used extensively on commercial bananas in West Africa, Central and South America. Treatments were usually applied twice a year using hand held injectors. Treatment was difficult and required constant supervision; consequently, non-fumigant nematicides (fenamiphos, ethoprop, carbofuran) began to be used commercially in 1972 before DBCP was withdrawn from use. In addition to good efficacy, these compounds were easier to apply than the fumigant. In the Ivory Coast and in Cameroun, it was recommended to apply these products three times per year, regardless of the chemical, in order to maintain populations of *Radopholus similis* at low levels throughout the year.

Since 1972, additional chemicals were used (isazophos, aldicarb, cadusafos) while use of others declined (carbofuran, fenamiphos). However, the initial concept of nematode management on bananas never changed :

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nematicides are applied to the entire crop three times per year based on calendar dates. This practice resulted in the loss of interest in previous nematode management practices such as paring of corms, corm-coating with nematicide at planting, and periods of fallow or alternative crops. Recently, some of these practices have been re-established and refined (cleaning of the planting material, use of *in vitro* produced plants, alternate use of different nematicides, cultivated fallow) to reflect a broader sense of integrated pest management (Gowen & Quénéhervé, 1990).

From our experiments conducted in the Ivory Coast from 1981 to 1988, many drawbacks in the initial concept of nematode management on bananas became apparent from experimental results concerning :

— discrepancies between the horticultural results (considered separately on plant growth and yield at harvest) and the effective control of nematodes,

— seasonal fluctuations and natural regulation of nematode populations,

— environmental factors affecting the efficacy of the applied chemicals,

— differential phytotoxicity to the vegetative and the reproductive phases of the banana plant relative to the use of some chemicals,

— environmental awareness and related problems (harmful effects on the health of agricultural laborers, contamination of water and fauna),

— loss of efficacy due to natural accelerated biodegradation following repeated use of the same compound.

Therefore in the experiments herein reported, the concept was to apply the chemical treatment then it is believed that it will be more efficient :

— on an individual plant basis at the proper time based on fluctuations of nematode populations (in respect to soil type, climate and the phenological phases of the banana plant),

— on an individual plant basis because when chemicals are applied simultaneously to all plants in a plantation efficacy may be less due to their short persistence in tropical conditions (runoff and/or leaching),

— at a time other than flowering to avoid problems of phytotoxicity that can occur with some chemicals applied during the reproductive period,

— with respect to a grower's constraints such as labor avalaibility.

Material and methods

Two trials were conducted on commercial, irrigated banana (*Musa* AAA cv. Poyo) plantations and monitored for two cycles using normal cultural practice : double propping with bamboo, overhead sprinkler irrigation when needed, fertilization, control of weeds, control of the banana borer weevil and aerial spraying of fungicides against Sigatoka disease. At each site, a standard sequence of nematicide applications (three times per year) was compared to nematicide treatments applied only at harvest and mulched with vegetative parts of the harvested banana plant using various nematicides, dosages and in some cases additional treatments. An additional treatment was the fumigant nematicide (EDB) applied to the soil surface at the rate of 8 cm^3 diluted in 12 liters of water per plant, in a circle of 0.8 m diameter around the main sucker. Non-fumigant nematicides were spread on the soil surface in the same area. The phenological stages of each banana plant were monitored weekly. Time of flowering, of harvest and bunch weight were recorded separately for each plant. Agronomic results were expressed as growth intervals (in days) between phenological stages and harvest. Parameters that were measured and compared using analysis of variance followed by a Newman-Keuls test for each treatment included : intervals between harvest and harvest (IHH), average bunch weight in kg (BW), percentage of harvested bunches (HB), total harvest weight (THW) and percentage of uprooted plants (UP).

The growth data for each treatment were measured as the median observation. The average weight per bunch (BW) was calculated as the mean at fifty percent of the harvest. The total harvest weight (THW) was calculated at the end of the harvest and expressed in metric tons per hectare. Additional details on the method of assessment of horticultural results are already published (Quénéhervé *et al.*, 1991).

Site 1, Cotivor 21

This trial was located near Azaguié on sandy soil (9.0 % clay, 25.6 % silt, 60.9 % sand, 2.4 % org. matter, pH 6.0). Treatments were arranged in a completly randomized design with six replications during the first cycle of a banana field established on December 10, 1983. Each plot consisted of at least 48 banana plants. Seven treatments were applied and are described in Table 1. Nematode populations were sampled every 28-32 days for each treatment until flowering and recommencing 1 month after harvest of the fruit. Sampling was made on previously selected banana plants of the same phenological age, based on their dates of harvest. Roots of bananas were sampled and analysed according to the method described by Quénéhervé and Cadet (1982) with six replicates per sampling date. Standardized extraction techniques were used on soil (Seinhorst, 1962) and roots (Seinhorst, 1950). Results of infestation were expressed as nematode densities per dm^3 of soil and per gram of roots belonging to each type of sucker. In order to estimate the level of infestation corresponding to the whole plant for each sampling date, a " global root infestation " was calculated as the mean of the partial infestation on the different parts of the root system. A statistical analysis was conducted on the

Table 1

Treatments applied at site 1, Cotivor 21

	Products and dosages	Timing of application
ALD	aldicarb (Temik®, Rhône-Poulenc), 2.5 g a.i./plant	Application at harvest (1st and 2nd cycle)
ISA1	isazophos (Miral®, Ciba-Geigy), 2.5 g a.i./plant	Application at harvest (1st and 2nd cycle)
ISA2	isazophos, 3.5 g a.i./plant	Application at harvest (1st and 2nd cycle)
ISA3	isazophos, 2.5 g a.i./plant	Application at harvest (1st and 2nd cycle) followed by an additionnal treatment with isazophos (24 Oct. 84; 12 Jul. 85)
ISA4	isazophos, 2.5 g a.i./plant and ethylene di-bromide (EDB 95 EC), 8 cc/plant	Application at harvest (1st and 2nd cycle) followed by an additionnal treatment with EDB (24 Oct. 84; 12 Jul. 85)
CTR	Control	No further nematicide application since the two first applications during the first cycle (10 Dec. 83; 28 Mar. 84)
STD	alternate use of isazophos and fenamiphos (Nemacur®, Bayer) respectively at 2.5 and 3.0 g a.i./plant	Application three times per year (10 Dec. 83; 28 Mar. 84; 18 Jul. 84; 24 Oct. 84; 14 Mar. 85; 12 Jul. 85; 5 Nov. 85)

Table 2

Treatments applied at site 2, Diby

	Products and dosages	Timing of application
ISA1	isazophos (Miral®, Ciba-Geigy), 2.5 g a.i./plant	Application at harvest (1st cycle)
ISA2	isazophos, 5.0 g a.i./plant	Application at harvest (1st cycle)
ISA3	isazophos, 2.5 g a.i./plant	Application at harvest (1st cycle) followed by an additionnal treatment with isazophos (15 Nov. 84)
ISA4	isazophos, 2.5 g a.i./plant and ethylene di-bromide (EDB 95 EC), 8 cc/plant	Application at harvest (1st cycle) followed by an additionnal treatment with EDB (15 Nov. 84)
CHL	chlordecone (Curlone®), 3.0 g a.i./plant	Application three times per year (21 Mar. 84; 18 Jul. 84; 15 Nov. 84; 19 Mar. 85)
CTR	Control	No further nematicide application since the two first applications during the first cycle (21 Mar. 84 and 18 Jul. 84)
STD	alternate use of isazophos and fenamiphos (Nemacur®, Bayer) respectively at 2.5 and 3.0 g a.i./plant	Application three times per year (21 Mar. 84; 18 Jul. 84; 15 Nov. 84; 19 Mar. 85)

different nematode fluctuations by a Friedman two-way analysis of variance followed by a multiple range test, in order to classify the tested treatments according to their efficacy in reducing the nematode populations.

Site 2, Diby

This agronomic trial was located near Diby on an alluvial loamy soil (18.8 % clay, 54.1 % silt, 23.7 % sand, 1.4 % org. matter, pH 4.5). Treatments were arranged in a completly randomized design with six replications during the first cycle of an established banana field. Each plot consisted of at least 24 banana plants. The treatments are described in Table 2.

Rainfall records were collected daily on each site. Canopy level irrigation occurred in the dry season (about 24 mm of water per irrigation per week).

Results

NEMATICIDAL ACTIVITY

At site 1, Cotivor 21, *Radopholus similis* was the main endoparasitic species (79.4 %) with *Helicotylenchus multicinctus*, *Hoplolaimus pararobustus* and *Meloidogyne incognita*, comprising respectively 3.7 %, 6.8 % and 8.3 % of the overall root population.

The results of the different treatments were summarized in terms of percentage reduction of the nematode population in soil and roots during the second and third cycles (Table 3). The highest reductions were obtained with the ectoparasitic species *Cephalenchus emarginatus* in the soil, but these reductions were not statistically different among nematicide treatments or from cycle 2 to cycle 3. Considering the endoparasitic species, treatment differences were observed with the root population of *R. similis* (Tables 3 & 4). The best reduction was obtained after treatment with aldicarb applied at time of harvest, regardless of the cycle. All other treatments applied at the time of harvest gave better results than the standard treatment sequence (alternate use of isazophos and fenamiphos three times per year) which was similar to the control.

Population levels of *R. similis* in the soil and the roots (expressed as global root system) remained lower throughout most of the second and third cycles when aldicarb treatment was applied at the time of harvest as compared to the standard treatment sequence (Fig. 1 A, B). No variations were observed in the fluctuations of the population of *H. pararobustus* (Fig. 1 C, D).

Table 3

Percentage reduction of the cumulative nematode populations in soil and roots during the second and third vegetative cycle relative to treatments at site 1 (Cotivor 21)

	Hoplolaimus		*Radopholus*		*Cephalenchus*
	soil	roots	soil	roots	soil
2nd cycle					
Aldicarb (ALD)	20,5	26,6	– 21,5	69,1	44,9
Isazophos (ISA1)	27,1	36,2	– 8,8	33,8	53,3
Isazophos (ISA2)	25,5	18,4	21,1	26,6	22,2
Isazophos (ISA3)	22,5	26,8	– 49,1	37,5	60,0
Isazophos (ISA4)	38,1	35,9	50,9	6,8	61,8
Standard (STD)	32,3	36,3	24,3	– 5,6	76,4
3rd cycle					
Aldicarb (ALD)	16,4	14,8	59,5	64,2	44,2
Isazophos (ISA1)	*	*	*	*	*
Isazophos (ISA2)	55,4	13,6	72,1	20,9	64,4
Isazophos (ISA3)	45,5	28,8	24,1	39,7	27,4
Isazophos (ISA4)	*	*	*	*	*
Standard (STD)	58,0	24,6	11,4	12,1	49,1

Asterisks (*) indicate unavailable data.

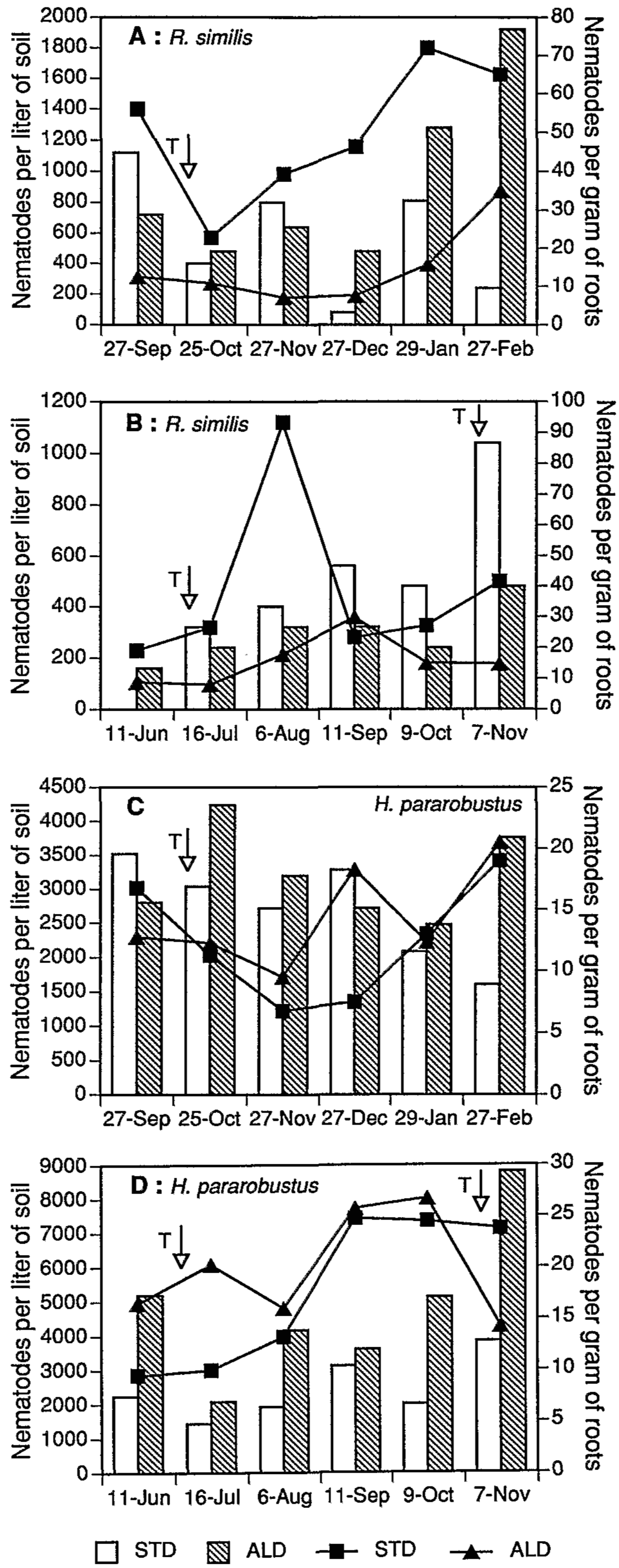

Fig. 1. Effect on the fluctuations of nematodes in the soil (histogrammes) and in the roots (lines) of nematicide treatments applied at harvest compared to the standard treatment sequence. A : *R. similis* during the second cycle; B : *R. similis* during the third cycle; C : *H. pararobustus* during the second cycle; D : *H. pararobustus* during the third cycle. (Abbreviations used : standard sequence of nematicide applications : STD; aldicarb applied at the time of the harvest; ALD; date of treatment; T.)

Table 4

Classification of the treatments according to the sum of ranks at site 1 (Cotivor 21) for the second and third vegetative cycle (Friedman Two-way analysis of variance). Sums of ranks in a column followed by the same letter are not significantly different according to a multiple range test (P > 0.05).

	Hoplolaimus		*Radopholus*		*Cephalenchus*	Comb. endo.
	soil	roots	soil	roots	soil	
2nd cycle						
	p = 0.045	p = 0.0748	NS	p = 0.001	p = 0.0632	NS
	ISA4 (16)	ISA4 (17)		ALD (6.5)	STD (13)	
	STD (19)	STD (18)		ISA3 (18.5)	ISA3 (17.5)	
	ISA2 (20.5)	ISA1 (18)		ISA1 (20.5)	ISA1 (21.5)	
	ISA3 (20.5)	ISA3 (23)		ISA2 (23)	ISA4 (24)	
	ISA1 (23)	ALD (25.5)		CTR (31)	ALD (27)	
	ALD (31)	ISA2 (30)		ISA4 (31.5)	CTR (31)	
	CTR (38)	CTR (36.5)		STD (37)	ISA2 (34)	
3rd cycle						
	p = 0.0034	NS	p = 0.0289	p = 0.0084	NS	p = 0.0004
	ISA2 (11)		ISA2 (9)	ALD (8)		ISA2 (58) a
	STD (11)		ALD (14.5)	ISA3 (14.5)		ALD (65.5) a
	ISA3 (17)		ISA3 (19.5)	ISA2 (20)		ISA3 (65.5) a
	ALD (22)		STD (22.5)	STD (20.5)		STD (68.5) a
	CTR (29)		CTR (24.5)	CTR (27)		CTR (102.5) b

Asterisk (*) indicates unavailable data; NS : not significant; Comb. Endo. : Combined endoparasites; the other abbreviations used for chemicals are defined in Table 1.

Table 5

Effects of nematicide treatments on the growth and harvest of banana plants at site 1 (Cotivor 21), during the second and third ratoons (means followed by a same letter are not different (p = 0.05) according to a Newman-Keuls test).

GROWTH		*HARVEST*		
IHH (days)	IPH (days)	BW (kg)	HB (%)	THW (t/ha)
p + 0.0191	p = 0.0304	p = 0.0912	NS	p = 0.0117
ALD (249) a	ALD (536) a	STD (30.4)	ALD (86.8)	ALD (39.2) a
STD (262) b	STD (545) ab	ALD (30.0)	ISA1 (81.2)	STD (37.6) a
ISA3 (263) b	ISA4 (549) ab	ISA2 (29.6)	ISA2 (80.1)	ISA2 (37.1) a
ISA4 (264) b	ISA3 (550) ab	ISA4 (29.4)	ISA3 (78.3)	ISA1 (37.0) a
ISA2 (265) b	ISA2 (552) ab	ISA1 (29.1)	STD (77.7)	ISA4 (35.5) ab
ISA1 (266) b	ISA1 (554) ab	ISA3 (28.8)	ISA4 (76.7)	ISA3 (35.3) ab
CTR (271) b	CTR (561) b	CTR (26.6)	CTR (58.6)	CTR (30.4) b
IHH (days)	IPH (days)	BW (kg)	HB (%)	THW (t/ha)
		NS	p = 0.0023	p = 0.0881
*	*	ALD (28.8)	ISA4 (50.0) a	ISA4 (21.9)
*	*	ISA3 (28.4)	ISA2 (45.2) ab	ISA2 (18.7)
*	*	ISA2 (27.2)	ISA1 (42.0) abc	STD (18.4)
*	*	STD (26.5)	STD (40.9) abc	ALD (16.5)
*	*	ISA1 (26.3)	ALD (34.6) abc	ISA1 (16.1)
*	*	ISA4 (26.3)	ISA3 (30.7) bc	ISA3 (13.8)
*	*	CTR (26.3)	CTR (26.6) c	CTR (11.9)

Asterisk (*) indicates unavailable data; NS : not significant; Comb. Endo. : Combined endoparasites; the other abbreviations used for chemicals are defined in Table 1.

HORTICULTURAL RESULTS

Site 1, Cotivor 21

Statistical analysis of the plant growth during the 2nd cycle showed significant differences on the interval between consecutive harvest (Table 5). The average interval in plots treated with aldicarb at the time of the first harvest was smaller (at least 13 days) than those of other treatments including the untreated control. When considering the harvest, treatment differences in the average weight of bunches were significant at $p < 0.10$ with a noticeable reduction in weight of the untreated control. The average total harvest weights were highest in the standard treatment or when aldicarb or isazophos were simply applied at harvest.

Due to a local hurricane during the fruiting period of the third cycle, it was only possible to analyse the results with the bunches previously harvested. Significant treatment effects occurred only with respect to the number of harvested bunches.

Site 2, Diby

Treatments differences occurred ($p < 0.0006$) in the interval between planting and second harvest (Table 6). The four treatments applied at harvest resulted in the shortest intervals (from 30 to 13 fewer days than controls) compared to the standard sequence which averaged 10 days shorter than the untreated control. Statistical analysis of the harvest showed treatment differences ($p < 0.0001$) in the average weight of the marketable bunches with three separate groups. Compared to control bunch weight, treatment with the insecticide chlordecone reduced the average bunch weight of 3.3 kg and treatment with isazophos followed by an additionnal treatment with EDB reduced the average bunch weight of 7.1 kg. All other treatments, including the untreated control were not significantly different. Treatment differences in total harvest weight were significant at $p < 0.10$ and the classification of treatments was similar to that for bunch weight. Three of the four treatments applied at the time of harvest gave higher yields (from 1.0 to 5.4 tons per hectare) than the standard treatment sequence.

Table 6

Effects of nematicide treatments on the growth and harvest of banana plants at site 2 (Diby), during second ratoon (means followed by a same letter are not different ($p = 0.05$) according to a Newman-Keuls test).

GROWTH	*HARVEST*		
IPH (days)	BW (kg)	HB (%)	THW (t/ha)
p = 0.0006	p = 0.0001	NS	P = 0.0659
ISA2 (534) a	ISA2 (30.7) a	ISA2 (78.0)	ISA2 (37. 8)
ISA1 (541) ab	ISA1 (29.7) a	CHL (74.4)	ISA1 (34.0)
ISA4 (548) ab	ISA (29.4) a	ISA3 (73.5)	ISA3 (33.4)
ISA3 (551) ab	CTR (27.9) a	ISA1 (73.4)	STD (32.4)
CHL (553) ab	STD (27.8) a	ISA4 (73.0)	CTR (29.5)
STD (564) bc	CHL (24.6) b	STD (71.1)	CHL (29.5)
CTR (574) c	ISA4 (20.8) c	CTR (67.1)	ISA4 (24.6)

Abbreviations used : IPH : planting and harvest; BW : bunch weight; HB : harvested bunches; THW : total harvest weight. The other abbreviations used for chemicals are defined in Table 2.

Discussion

In West Africa, the advantages associated with the new granular nematicides have tended to narrow the concept of nematode management in bananas to chemical control exclusively with only slight variation depending on local conditions. Treatments are usually based on calendar dates three times per year and the spatial scale of control is the entire banana field. The concept has been to maintain the nematode population level below a threshold level during the entire year. Problems arose because nematode threshold levels vary in time and depend on many controlled and uncontrolled factors (Quénéhervé *et al*, 1991). Also, due to tropical conditions of soil type and climate, the potential efficacy of these chemicals is rarely attained when applied during vegetative growth and differs greatly not only between fields but also from plant to plant. Due to these reasons the real efficacy of treatments in terms of nematode control and effect on the yield is often unpredictable. However treatment efficacy can be improved by considering the biological factors governing nematode fluctuations and environmental factors which affect nematicide activity.

R. similis is the most damaging species on bananas in the conditions of the Ivory Coast. The levels of this species closely follow the renovation of the root system of the banana plant; populations are always greater in the newly emerged roots and in the portion of soil close to the rhizome. After flowering, the rhizogenic activity is displaced from the main sucker to the following suckers, displacing the multiplication sites of *R. similis* (Quénéhervé, 1989*a*, *b*). But the main growth of these following suckers occurs only after harvest, due to physiological changes within the rhizome and it appears that it is at this very moment that the root system needs protection against nematodes; a delay in treatments following harvest may be of importance in determining their efficacy. It is also noteworthy that population of *R. similis* in the soil exhibits a negative relationship with rainfall (in quantity and number of days), so that it is unworthwhile to apply a nematicide against *R. similis* just prior to the rainy season.

Runoff and vertical leaching occur under the tropical conditions of the banana growing areas of the Ivory Coast. In some extreme conditions the runoff percentage can reach 90 % of every precipitations (rainfall or irrigation), while in others conditions (organic soils) vertical leaching is the main problem (Fritsch, pers. comm.). Except in the rare sandy loam soil conditions, most precipitation is subject to either heavy runoff or vertical leaching, leading to heavy losses of every fertilizers and pesticides applied on the soil surface. Solutions to the problem include splitting applications of these products, incorporating them in the soil and applying vegetative mulch.

The nematological results observed during two ratoon crops were promising; better control of *R. similis* was achieved when treatment occurred during the active rhizogenic activity of the rhizome just after the harvest. In the long term, it is obvious that with this type of treatment the increase of the nematode populations may be higher some months later when compared to the standard sequence. That is when an additionnal treatment may be needed if there is a linkage of factors (either biological or edaphic) acting positively on the nematode fluctuations (active rhizogenic activity, low interspecific nematode interaction, optimal water conditions, soil type, etc.).

The agronomic results were satisfactory since no significant differences were observed between the standard treatment sequence and the treatments applied at harvest. Furthermore, the general trend was a slightly higher number and greater weight of the harvested bunches with the treatments applied at the harvest compared to the standard treatment sequence.

Because of the various concerns of high input production systems it may be time to develop a more rational approach to nematicide treatments in commercial banana plantations. We think that by treating plants on an individual basis at a time and frequency that is more appropriate to their needs. The potentially harmful or deletarious effects of nematicides may be diminished without any loss of yield.

Additional studies are required to optimize scheduling of different nematicides and dosages, particularly of compounds proven to be very active against nematodes on bananas such as aldicarb (Sarah *et al.*, 1989; Quénéhervé *et al.*, 1991) and cadusaphos (Quénéhervé, Mateille & Topart, 1991).

From the growers point of view, this is an important change in their standard practices which does not involve additionnal cost. Many cultural practices in banana fields (pruning, propping, harvest and in some case irrigation) are done to individual plants as needed. Why should it not be possible to do the same when it comes to sanitary practices?

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