Effect of cadusafos compared with three other non-fumigant nematicides on the control of nematodes and on the yield of banana cv. Poyo in the Ivory Coast

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SUMMARY

Three field experiments were conducted in the Ivory Coast to evaluate the efficacy of a new organo-phosphate nematicide, cadusafos (formerly ebufos, Rugby®), compared with three other non-fumigant nematicides for control of nematodes on bananas. The activity of cadusafos in controlling all nematode populations in these experiments was better than the other compounds even when used at a lower dosage (2 g a.i./plant). Analysis of horticultural measurements, including growth and harvest, clearly illustrated the damaging components occuring on bananas in the Ivory Coast : lengthening of the duration of phenological phases and reduction of the harvest. Application of cadusafos increased yield 15.6 % over treatment with aldicarb and 48.8 % over the non-treated control (cumulative results of three harvests).

RÉSUMÉ

Effet du cadusafos comparé à celui de trois autres nématicides non fumigants sur le contrôle des nématodes et le rendement des bananiers cv. Poyo en Côte d'Ivoire

Trois expérimentations ont été menées en Côte d'Ivoire pour évaluer l'efficacité d'une nouvelle molécule nématicide, le cadusafos (nom commercial : Rugby®) pour le contrôle des nématodes en bananeraies. L'efficacité du cadusafos dans le contrôle des populations de nématodes au cours de cette étude fut supérieure à celle des autres nématicides, et ceci même à plus faible dose (2 g m.a. par plant). L'analyse des résultats agronomiques, exprimés en terme de croissance et de récolte, a clairement confirmé les différents types de dommages observés dans les bananeraies de Côte d'Ivoire : allongement des cycles végétatifs et réduction de la récolte. L'application de cadusafos a entraîné une augmentation de rendement allant de 15,6 % par rapport à l'application d'aldicarbe et jusqu'à 48,8 % par rapport au témoin non traité (résultats cumulés de trois récoltes).

In the Ivory Coast banana plants (*Musa* AAA, cv. Poyo) are subject to attack by several species of plant parasitic nematodes (Luc & Vilardebó, 1961; Fargette & Quénéhervé, 1987) including *Radopholus similis*. The control of nematodes, using nematicides applied three times per year, has proven profitable for all commercial plantations in West Africa for a number of years (Vilardebó, 1984; Sarah *et al.*, 1988; Quénéhervé *et al.*, 1991). However, due to problems and concerns about the use of nematicides in banana plantations, there is a need to continually seek new nematicides in order to increase the flexibility of chemical management strategies. The purpose of this study was to compare the efficacy of cadusafos with that of three other non-fumigant nematicides, aldicarb, isazophos and fenamiphos, against nematode populations and the effect on banana yield. Experiments were located on three sites with different objectives : a preliminary nematicide trial near Azaguié (site 1, Marcel 3); a horticultural trial near Aboisso (site 3, Bia 3-71); and both a nematicide and horticultural trial near Azaguié (site 2, 2 Thé).

Material and methods

Experiments were conducted from 1984 to 1988 at different locations in the Ivory Coast on commercial irrigated banana plantations (*Musa* AAA, cv. Poyo) being replanted in infested fields.

For each trial, banana plants (*Musa* AAA, cv. Poyo) were planted with mother plants (bullheads). The trials were monitored for two vegetative cycles using normal cultural practices (double propping with bamboo, overhead sprinkler irrigation when needed, fertilization, control of weeds, control of the banana borer weevil and aerial spraying of fungicides). Granular nematicides were spread within the planting hole and on the soil surface during vegetation after planting in a circle of 0.8 m diameter around the main sucker.
24 banana plants cv. Poyo. Each block was separated from one another by a drain.

In the field, each banana plant was labelled with a code number and phenological stages were monitored weekly. Time of flowering, of harvest and bunch weight

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were recorded separately for each banana plant. Horticultural results were expressed as growth (intervals between phenological stages in days) and harvest. Parameters that were measured and compared (analysis of variance followed by a Newman-Keuls test) for each treatment included : the intervals between planting and flowering (IPF), planting and harvest (IPH), flowering and harvest (IFH), harvest and harvest (IHH), average bunch weight in kg (BW), percentage of harvested bunches (HB), total harvest weight (THW), percentage of uprooted plants (UP).

The growth data for each treatment were measured as the median observation (e.g. IPF recorded when fifty percent of the banana plants in the considered plot is flowered). 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. The application of the median over the arithmetic mean is sometimes preferred in biological populations with skewed distribution (Wisiol, 1987). Use of the median is also preferred in cases where it may be difficult or impossible to obtain and measure all of the items to calculate a mean (Sokal & Rholf, 1981). These two situations are commonly encountered in experiments on perennial plants in which the harvest may be spread over a long period of time. In banana plantations, particularly during the early cycles after planting, the bunch distribution curve is highly skewed to right. In these cases, the median is a more meaningful statistic than the arithmetic mean in the estimate of the growth parameters.

Nematode populations were sampled every 28-32 days for each treatment. Roots of bananas, and corm when mentioned, were sampled and analysed according to the method described by Quénéhervé and Cadet (1986) 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 or corm, belonging to the mother plant or bullhead (RPM, EPM), of the first principal sucker (R1Y, E1Y), of the second principal sucker (R2Y, E2Y), of the pruned suckers (R2YØ, E2YØ), etc. 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. Then, a statistical analysis was conducted on the 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.

Cumulative sums of the nematode infestation were calculated (by species and for all species combined), occuring respectively on the roots (and/or the corm) of the main sucker, of the entire root system, of the main and following suckers. Correlations were conducted in order to find relationships between horticultural results and levels of nematodes *[log 10 (x + 1)]*, as calculated above. Linear regression equations were computed for relationships having significant ($P < 0.05$) correlation coefficients.

A canopy level irrigation occurred in the dry season (about 24 mm of water per irrigation and per week).

Site 1, Marcel 3

Treatments in this experiment were arranged in a randomized complete block design with six replications on a sandy-clay soil (15.2 % clay, 12.6 % silt, 62.1 % sand, 1.8 % org. matter, pH 6.3). Each plot consisted of at least 48 banana plants. Blocks were separated from each other by a drain.

Seven treatments were applied at planting : cadusafos [1 g a.i./plant (CA1), 2 g a.i./plant (CA2), 4 g a.i./plant (CA4), 2 g a.i. by corm-coating (CA2C), Rugby® 10G, FMC]; aldicarb (ALD), [2.5 g a.i./plant, Temik® 10G, Rhône-Poulenc]; isazophos (ISA), [2.5 g a.i./plant (T6), Miral® 10G, Ciba-Geigy] and untreated control (CTR). Granular nematicides were spread in the planting hole and on the soil surface just before planting with bullheads (mother plants) on May 22, 1984. This trial was monitored for six months in order to follow the nematode population fluctuations.

Site 2, Deux Thé

Treatments in this experiment were arranged in a randomized complete block design with six replications on a sandy clay soil (12.3 % clay, 14.2 % silt, 53.9 % sand, 1.6 % org. matter, pH 4.7). Each plot consisted of at least 48 banana plants. Blocks were separated from each other by a drain.

Six treatments were applied : cadusafos [1 g a.i./plant (CA1), 2 g a.i./plant (CA2), 3 g a.i./plant (CA3), Rugby® 10G, FMC]; aldicarb (ALD), [2.5 g a.i./plant, Temik® 10G, Rhône-Poulenc]; fenamiphos (FEN), [2.5 g a.i./plant, Nemacur® 10G, Bayer] and untreated control (CTR). Granular nematicides were spread in the planting hole and on the soil surface in vegetation. Then treatments were applied on a regular basis every three to four months after planting with bullheads on December 2, 1985 (29 Apr. 86; 17 Jul. 86; 12 Nov. 86; 18 Mar. 87). This trial was monitored for two vegetative cycles in order to follow nematode population fluctuations and banana yield.

Site 3, Bia 3-77

Treatments in this experiment were arranged in a randomized complete block design with six replications on an alluvial loamy soil. Each plot consisted of at least 24 banana plants cv. Poyo. Each block was separated from one another by a drain.

Seven treatments were applied : cadusafos [1 g a.i./plant (CA1), 2 g a.i./plant (CA2), 4 g a.i./plant (CA4), 2 g a.i./plant by corm-coating at planting (CA2C), Rugby® 10G, FMC]; aldicarb (ALD), [2.5 g a.i./plant, Temik® 10G, Rhône-Poulenc]; isazophos (ISA), [2.5 g a.i./plant, Miral® 10G, Ciba-Geigy] and untreated control (CTR). Granular nematicides were spread over the planting hole and the soil surface in vegetation. Then treatments were applied on a regular basis every three to four months after planting with bullheads on April 20, 1984 (21 Aug. 84; 7 Nov. 84; 2 Apr. 85; 23 Jul. 85; 5 Nov. 85; 10 Apr. 86). This trial was monitored for three vegetative cycles in order to follow the banana yield.

Results

NEMATICIDAL ACTIVITY AND RESIDUAL EFFECTS OF THE PRODUCTS APPLIED AT PLANTING AT SITE 1 (AZAGUIÉ, MARCEL 3)

At this site five nematodes species were found associated with banana plants, four endoparasites : *Radopholus similis, Hoplolaimus pararobustus, Helicotylenchus multicinctus* and *Meloidogyne incognita* and one ectoparasite : *Cephalenchus emarginatus. R. similis* was the main endoparasitic species extracted from roots and corm (respectively 71 % and 94.5 %) during the time of the experiment while *H. pararobustus* was the most predominant endoparasite in the soil (30.1 %). *C. emarginatus* was the predominant ectoparasite in the soil (61.2 %) (Table 1).

M. incognita was encountered very sporadically in soil and root samples; it was not included in the analysis.

At this site, chemicals were applied only at planting. All chemicals were effective in reducing nematode populations in the soil, the root system and the corm, but efficacies varied with chemical and dose (Figs 1, 2). The comparative activity of each chemical treatment, expressed in percentage reduction of the cumulative infestation for each nematode species in soil, roots and corm over 6 months after application (Table 2), indicated a slight dosage effect with cadusafos between 1, 2 and 4 g a.i. per plant. The treatment applied to the planting material by coating (CA2C) seemed less effective against nematodes in the soil and in the roots than against nematodes in the corm when compared to the same dosage applied in the plantation hole (CA2). Isazophos was the least effective product in reducing nematode populations, especially in the corm.

In this experiment cadusafos showed a wide range of efficacy and reduced the populations of the different species almost equally. Aldicarb and isazophos had a lower impact on populations of *H. multicinctus* and *H. pararobustus.*

Nematode population data were analysed by the Friedman two-way analysis of variance (Table 3). The classifications according to the sum of the ranks were

Table 1

Occurrence in percent of nematode species in soil, roots and corm from the control plots at site 1 (Marcel 3) and at site 2 (2 Thé).

	Helicotylenchus			*Hoplolaimus*			*Radopholus*			*Cephalenchus*			*Meloidogyne*		
	soil	roots	corm	soil	roots	corm	soil	roots	corm	soil	roots	corm	soil	roots	corm
Site 1	2.8	4.5	3.1	30.1	18.0	2.4	4.6	71.0	94.5	61.2	2.3	0.0			
Site 2*	26.8	3.7	13.3	14.7	6.8	6.0	7.1	79.4	80.7	38.5	1.9	0.0	10.4	8.3	0.0

(*) : addition of 2.4 % of other species in the soil.

Table 2

Percentage reduction of the cumulative nematode populations in soil, roots and corm during the first vegetative cycle relative to treatments at site 1 (Marcel 3).

	Helicotylenchus			*Hoplolaimus*			*Radopholus*			*Cephalenchus*
	soil	roots	corm	soil	roots	corm	soil	roots	corm	soil
Cadusafos (CA1)	47.0	58.2	83.2	61.7	49.9	21.8	27.6	60.6	56.0	48.4
Cadusafos (CA2)	17.6	69.1	74.7	68.8	69.2	31.8	87.9	84.5	67.3	75.2
Cadusafos (CA4)	73.5	92.7	86.9	86.2	81.4	10.9	93.1	86.5	92.5	77.4
Cadusafos (CA2C)	41.2	— 30.9	69.3	56.4	38.9	23.6	68.9	57.2	92.3	52.3
Aldicarb (ALD)	— 2.9	25.4	71.5	26.4	27.6	1.8	72.4	76.8	84.4	56.1
Isazophos (ISA)	— 444	— 174	16.8	17.5	7.2	— 25.5	41.4	56.2	23.0	53.3

Table 3

Classification of the treatments according to the sum of ranks at site 1 (Marcel 3) during the first 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).

Helicotylenchus		*Hoplolaimus*		*Radopholus*		*Cephal.*		*Melo.*	Comb. Endo
soil	roots	soil	roots	soil	roots	corm	soil	soil	
p = 0.0183	p = 0.0015	p = 0.0041	p = 0.0004	p = 0.0376	p = 0.0012	p = 0.0144	p = 0.0015	NS	p = 0.0001
CA4 (12)	CA4 (9)	CA4 (9)	CA4 (7)	CA4 (12)	CA4 (11.5)	CA2C (15.5)	CA4 (11)		CA4 (96.5) *a*
CA2C (19)	CA2 (16)	CA2 (17.5)	CA2 (12.5)	CA2 (18.5)	CA2 (16)	CA4 (17)	CA2 (15.5)		CA2 (154) *ab*
CA1 (20)	CA1 (20)	CA1 (20.5)	CA2C (23)	CA2C (23)	ALD (17)	ALD (19.5)	CA2C (22.5)		CA1 (184.5) *b*
ALD (25)	ALD (23)	CA2C (24)	CA1 (26)	ALD (23.5)	CA2C (24.5)	CA1 (21.5)	ISA (24.5)		CA2C (190.5) *bc*
CTR (25.5)	CTR (30)	ALD (28)	ALD (31)	CA1 (27.5)	CA1 (28)	CA2 (27)	ALD (25)		ALD (199 *bc*
CA2 (29)	ISA (34)	ISA (34)	ISA (34)	ISA (29)	ISA (30)	ISA (30.5)	CA1 (27.5)		ISA (252.5) *cd*
ISA (37.5)	CA2C (36)	CTR (35)	CTR (34.5)	CTR (34.5)	CTR (41)	CTR (37)	CTR (42)		CTR (267) *d*

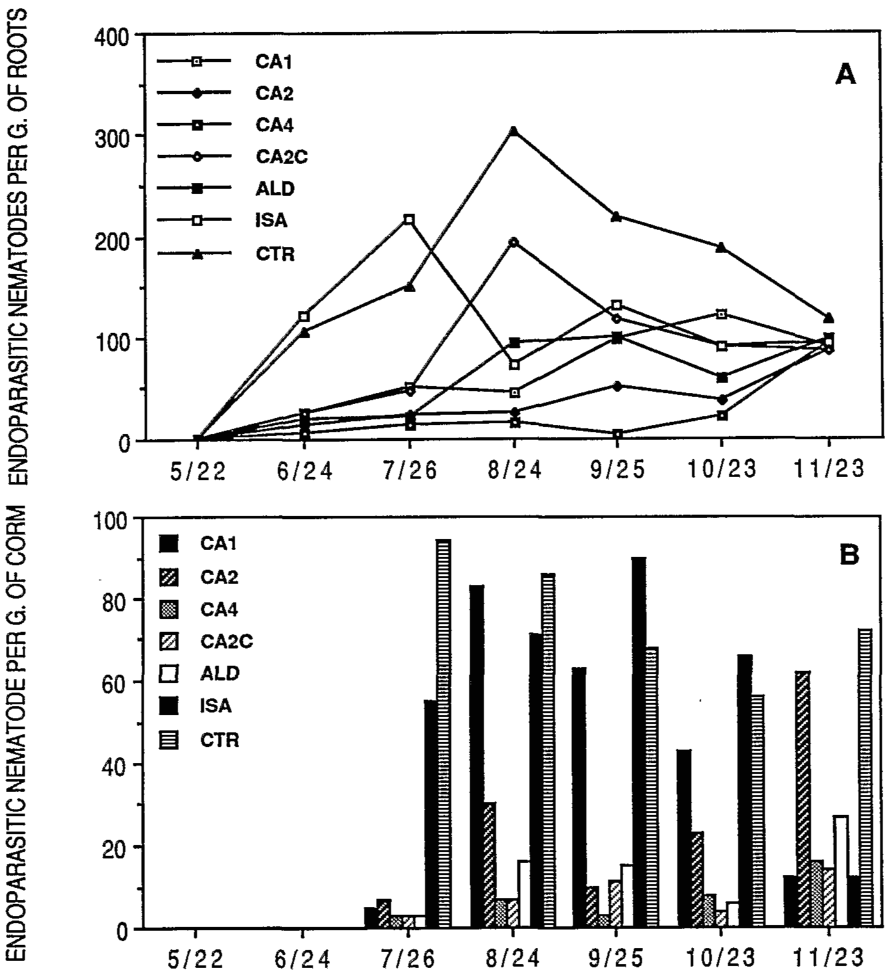

Fig. 1. A : Fluctuation of the combined endoparasitic nematodes species extracted from the roots during six months after treatments at site 1, Marcel 3; B : Infestation of the corm with the combined endoparasitic nematodes species during six months after treatments at site 1, Marcel 3. (Abbreviations used : cadusafos 1 g. a.i., CA1; cadusafos 2 g. a.i., CA2; cadusafos 4 g. a.i., CA4; cadusafos by coating with 2 g. a.i., CA2C; aldicarb 2.5 g. a.i., ALD; isazophos 2.5 g. a.i., ISA; untreated control, CTR.)

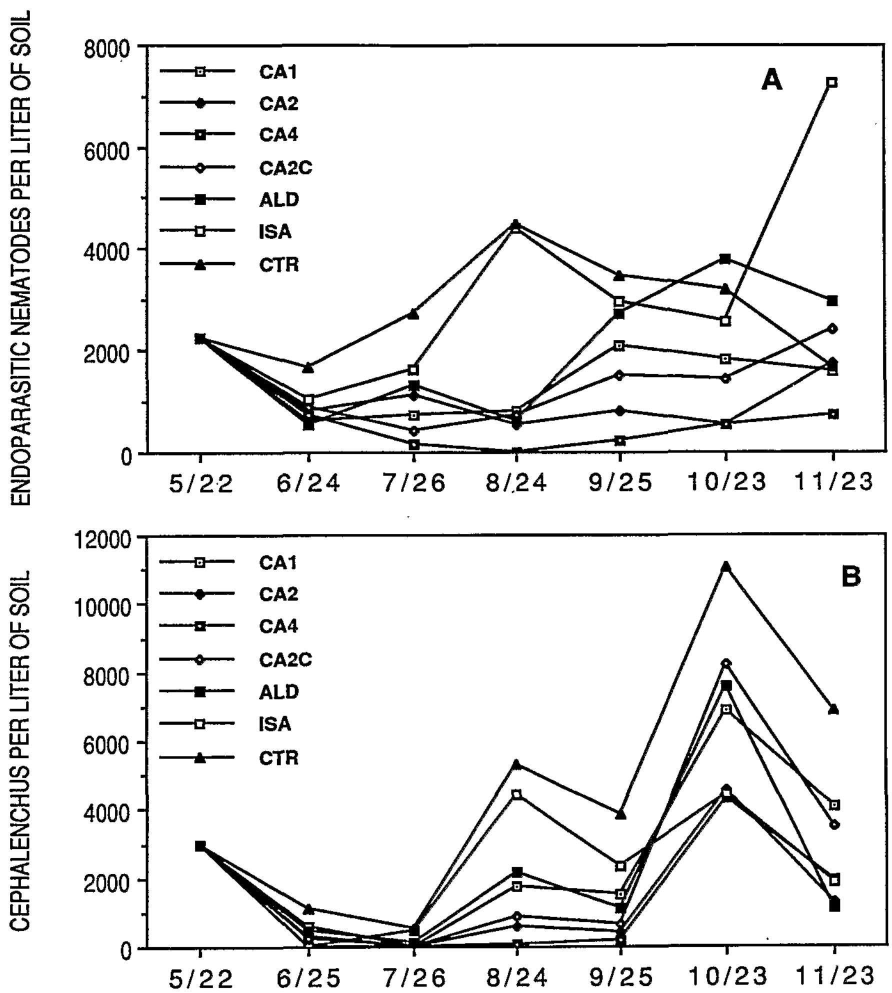

Fig. 2. A : Fluctuation of the combined endoparasitic nematodes species extracted from the soil during six months after treatments at site 1, Marcel 3; B : Fluctuation of *Cephalenchus emarginatus* extracted from the soil during six months after treatments at site 1, Marcel 3. (Abbreviations used : cadusafos 1 g. a.i., CA1; cadusafos 2 g. a.i., CA2; cadusafos 4 g. a.i., CA4; cadusafos by coating with 2 g. a.i., CA2C; aldicarb 2.5 g. a.i., ALD; isazophos 2.5 g. a.i., ISA; untreated control, CTR.)

almost identical for each nematode species and for the global root, corm and soil infestation. According to this classification, three groups or doses of product differed significantly from one to the other. The cadusafos treatment at 4 grams of active ingredient was the most effective in reducing nematode populations.

Residual effects of the chemicals applied at planting can be deduced from the analyse of nematode fluctuations (Figs 1, 2). The residual effect on the endoparasites appeared to subsist five to six months after the treatments with cadusafos at 2 and 4 g a.i. before population fluctuations again followed a natural pattern. This effect lasted four to five months with treatments with aldicarb, and cadusafos at 1 g. a.i. In this experiment, the effectiveness of isazophos on the fluctuation of nematode populations was delayed. According to the fluctuations of the ectoparasite *C. emarginatus* (Fig. 2 B) as a general trend the residual effects lasted only two to three months before normal population growth, except for the higher doses on this particular ectoparasitic species.

NEMATICIDAL ACTIVITY OF THE CHEMICALS APPLIED BOTH AT PLANTING AND DURING TWO VEGETATIVE CYCLES AT SITE 2 (AZAGUIÉ, DEUX THÉ)

At this site five nematodes species were associated with banana plants, four endoparasites : *R. similis, H. pararobustus, H. multicinctus* and *M. incognita* and one ectoparasite, *C. emarginatus.*

R. similis was the main endoparasitic species extracted from roots and corm during the time of the experiment (respectively 79.4 % and 80.7 %) while *H. multicinctus* was the most predominant endoparasite in the soil (26.8 %) and *C. emarginatus* was the predominant ectoparasite in the soil (38.5 %) (Table 1).

Chemicals were applied at planting and then regularly during the vegetative cycles according to the general practice for nematicidal treatment in the Ivory Coast, which was every three to four months, with respect to the climate (beginning of the first rainy season in April-May; end of the rainy season in July; before the dry season October-November).

The relative efficacy of each chemical was measured in percentage reduction of the cumulative infestation for each species in soil and roots, from planting to flowering (Table 4). There were two applications of the chemicals, the first at planting by incorporating in the planting hole and the second by spreading on the soil surface. As observed at site 1, there was a dosage effect of cadusafos on the endoparasitic populations of *R. similis*. In this experiment, fenamiphos and cadusafos (at 1 g a.i. per plant) treatments seemed to be the least effective in reducing nematode populations. Otherwise, cadusafos showed a wide range of efficacy in reducing populations of different nematode species in the soil and in the roots, while both aldicarb and fenamiphos failed to reduce the population of *H. pararobustus* (Table 4).

From the time of the first harvest to the second flowering, after three surface applications of the different chemicals (Jul. and Nov. 86, Mar. 87) there was a slight decrease in efficacy for all these treatments compared to the previous vegetative cycle, except for *H. multicinctus* (Table 4). This decrease of efficacy was greater for aldicarb, fenamiphos and the lower dosage of cadusafos.

Nematode population data of the first and the second cycle were analyzed by the Friedman two-way analysis of variance (Table 5). Classification according to the sum of the ranks were almost identical for each nematode species as for the global root, corm and soil infestation. According to this classification, three groups of chemicals or doses differed significantly from one to the other and cadusafos at 4 g a.i. was the most effective in reducing nematode populations, followed by treatments with cadusafos at 2 g a.i. and aldicarb at 2.5 g a.i.

EFFECTS OF THE CHEMICAL TREATMENTS ON THE GROWTH

For one of the field trials conducted in Azaguié (site 2, Deux Thé), horticultural results are only available for the first cycle (Table 6) because a local storm destroyed the whole plantation at the time of the second flowering, but results of the horticultural trial conducted in Aboisso (site 3, Bia 3-71) over three cycles are presented in Table 7.

The interval between planting and flowering for the first cycle at site 2, was almost significant (Table 6). Flowering of the control plants was delayed from 14 to 24 days in comparison with those treated. These differences were almost identical to the delay between planting and harvest from 13 to 32 days always in comparison with those treated.

Due to the storm, the only data available for the second cycle are a count of the plants that had already flowered. The differences were highly significant; there were up to 20 % more flowered plants in the treated areas.

At site 3 (Table 7), highly significant differences were observed during the first cycle for the interval between planting and flowering. This interval was delayed up to 20 days on the untreated control plot in comparison with

Table 4

Percentage reduction of the cumulative nematode populations in soil, roots and corm during the first vegetative cycle (from planting to flowering) and second vegetative cycle (from harvest to second flowering) relative to treatments at site 2 (2 Thé).

	Helicotylenchus			*Hoplolaimus*			*Radopholus*			*Cephalenchus*	*Meloidogyne*
	soil	roots	corm	soil	roots	corm	soil	roots	corm	soil	soil
1ST CYCLE											
Cadusafos (CA1)	37.1	79.6	52.9	33.6	11.6	35.8	49.6	59.8	– 12.3	3.1	52.0
Cadusafos (CA2)	76.2	81.5	79.3	59.6	24.4	35.8	63.0	78.8	36.1	65.0	68.0
Cadusafos (CA3)	50.7	92.6	90.9	53.0	37.2	72.8	86.5	82.6	78.2	83.9	58.9
Aldicarb (ALD)	48.0	64.8	81.8	17.0	– 22.1	50.6	57.1	87.9	66.2	46.9	29.1
Fenamiphos (FEN)	41.1	66.7	85.1	27.9	– 22.1	33.3	– 9.2	47.8	23.3	50.5	54.9
2ND CYCLE											
Cadusafos (CA1)	58.5	91.2	56.0	13.4	39.7	12.5	– 36.6	16.7	23.2	28.6	– 2.8
Cadusafos (CA2)	83.2	68.8	60.0	56.0	63.5	25.0	16.9	58.5	28.5	52.7	– 32.7
Cadusafos (CA3)	91.7	100.0	100.0	51.6	73.0	37.5	53.5	74.9	73.5	50.0	51.6
Aldicarb (ALD)	85.2	91.8	88.0	19.7	0.0	37.5	– 14.1	52.6	70.7	28.8	23.8
Fenamiphos (FEN)	67.8	49.4	40.0	– 14.6	– 1.6	25.0	– 51.3	17.2	– 14.6	50.5	41.4

Table 5

Classification of the treatments according to the sum of ranks at site 2 (2 Thé) for the first and second 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).

Helicotylenchus			*Hoplolaimus*			*Radopholus*			*Cephal.*	*Melo.*	Comb. Endo
soil	roots	corm	soil	roots	corm	soil	roots	corm	soil	soil	
1ST CYCLE											
NS	NS	NS	NS	NS	NS	p = 0.0059	p = 0.0003	NS	NS	NS	p = 0.0001
						CA3 (15.5)	ALD (12)				CA3 (154) *a*
						ALD (15.5)	CA3 (15)				CA2 (192) *ab*
						CA2 (19.5)	CA2 (20)				ALD (206.5) *ab*
						CA1 (28.5)	CA1 (28)				CA1 (227.5) *b*
						FEN (33.5)	FEN (32)				FEN (244) *bc*
						CTR (34.5)	CTR (40)				CTR (299) *c*
2ND CYCLE											
p = 0.0011	p = 0.0004	p = 0.0021	p = 0.0189	p = 0.0047	NS	p = 0.0066	p = 0.0197	p = 0.0074	p = 0.0056	NS	p = 0.0001
CA3 (11)	CA3 (7)	CA3 (8.5)	CA3 (10)	CA3 (10.5)		CA3 (8)	CA3 (8.5)	ALD (10)	CA3 (11)		CA3 (94.5) *a*
CA2 (14.5)	ALD (14.5)	ALD (14)	CA2 (15)	CA2 (13.5)		CA2 (16)	ALD (16.5)	CA3 (12)	CA2 (11.5)		ALD (164.5) *b*
ALD (16)	CA1 (19)	CA2 (21)	CA1 (21.5)	CA1 (17)		CTR (20.5)	CA2 (21.5)	CA2 (23)	FEN (20.5)		CA2 (168) *b*
FEN (22)	CA2 (23.5)	CA1 (24.5)	ALD (22)	FEN (27)		ALD (23.5)	CA1 (25.5)	CA1 (24)	ALD (24)		CA1 (210.5) *bc*
CA1 (26.5)	FEN (29)	FEN (26)	CTR (27.5)	ALD (29)		FEN (29)	FEN (26)	CTR (27)	CA1 (29)		FEN (238) *c*
CTR (36)	CTR (33)	CTR (32)	FEN (30)	CTR (29)		CA1 (29)	CTR (29)	FEN (30)	CTR (30)		CTR (258.5) *c*

Table 6

Effects of nematicidal treatments on growth and harvest of banana plants at site 2 (2 Thé), on first crop and flowering of the second fruit (means followed by a same letter are not different (p = 0.05) according to a Newman-Keuls test).

GROWTH				*HARVEST*		
IPF (days)	IFH (days)	IPH (days)	F2 (%)	BW (kg)	HB (%)	THW (t/ha)
p = 0.0568	NS	p = 0.0910	p = 0.0012	NS	NS	NS
CA2 (218)	CA3 (93)	CA3 (315)	CA3 (53.0) *a*	FEN (29.9)	CA2 (86.3)	CA2 (41.7)
CA3 (222)	CA2 (101)	CA2 (319)	CA2 (50.4) *ab*	CA3 (29.7)	ALD (86.3)	CA3 (41.5)
CA1 (222)	FEN (102)	FEN (329)	FEN (48.4) *ab*	ALD (29.4)	CA1 (81.6)	FEN (40.4)
FEN (227)	ALD (106)	CA1 (333)	CA1 (44.1) *abc*	CTR (29.0)	CA3 (81.3)	CA1 (40.0)
ALD (228)	CTR (106)	ALD (334)	ALD (39.6) *bc*	CA1 (28.5)	FEN (79.2)	ALD (39.4)
CTR (242)	CA1 (111)	CTR (347)	CTR (33.7) *c*	CA2 (28.4)	CTR (72.5)	CTR (37.2)

Abbreviations used : IPF : interval between planting and flowering; IFH : flowering and harvest; IPH : planting and harvest; THW : total harvest weight; BW : bunch weight; HB : harvested bunches; F2 : flowered plants in cycle 2. The other abbreviations used for chemicals are defined in the text and in Table 4.

Table 7

Effects of nematicidal treatments on growth and harvest of banana plants at site 3 (Bia 3-71), respectively on first crop, second and third ratoon (means followed by a same letter are not different (p = 0.05) according to a Newman-Keuls test).

GROWTH				*HARVEST*		
IPF (days)	IFH (days)	IPH (days)		BW (kg)	HB (%)	THW (t/ha)
p = 0.0026	NS	p = 0.0003		NS	NS	NS
CA2 (199) *a*	CA4 (79)	CA4 (280) *a*		CTR (35.9)	CA2C (87.5)	CA2C (55.8)
CA4 (201) *a*	CA1 (80)	CA2 (282) *a*		ALD (34.3)	CA4 (86.5)	CTR (53.0)
ISA (203 *ab*	CA2C (82)	CA1 (288) *ab*		CA2C (34.1)	CA2 (86.0)	CA2 (52.3)
CA1 (208) *abc*	CA2 (83)	ISA (289) *ab*		ISA (33.6)	CA1 (85.5)	CA1 (52.2)
ALD (211) *abc*	ISA (83)	ALD (295) *abc*		CA4 (33.5)	ALD (85.4)	ALD (51.9
CA2C (217) *bc*	ALD (84)	CA2C (299) *bc*		CA2 (33.3)	CTR (81.6)	CA4 (51.8)
CTR (219) *c*	CTR (89)	CTR (308) *c*		CA1 (33.0)	ISA (77.4)	ISA (47.9)
IHF (days)	IFH (days)	IPH (days)	IHH (days)	BW (kg)	HB (%)	THW (t/ha)
p = 0.0043	p = 0.0103	p = 0.0001	p = 0.0186	p = 0.0021	NS	p = 0.0008
CA2 (155) *a*	ISA (86) *a*	CA2 (531) *a*	CA2 (249) *a*	CA2 (45.0) *a*	CA4 (91.6)	CA4 (65.5) *a*
ALD (157) *a*	CA2 (93) *ab*	CA4 (533) *a*	ISA (252) *ab*	CA4 (44.1) *a*	CA2 (84.9)	CA2 (63.4) *a*
CA2C (158) *a*	CA4 (94) *ab*	ISA (539) *a*	CA4 (253) *ab*	CA1 (40.1) *ab*	ISA (82.8)	CA2C (60.3) *a*
CA4 (158) *a*	CA2C (96) *ab*	CA1 (550) *ab*	CA2C (261) *ab*	ISA (40.0) *ab*	CA1 (82.5)	ISA (57.5) *a*
CA1 (164) *ab*	CA1 (97) *ab*	CA2C (560) *b*	CA1 (262) *ab*	CA2C (39.5) *ab*	CA2C (81.9)	CA1 (56.2) *a*
ISA (166) *ab*	CTR (103) *b*	ALD (566) *b*	ALD (271) *ab*	ALD (39.4) *ab*	ALD (75.6)	ALD (51.0) *ab*
CTR (172) *a*	ALD (108) *b*	CTR (588) *b*	CTR (275) *b*	CTR (36.0) *b*	CTR (69.1)	CTR (41.8) *b*
IHF (days)	IFH (days)	IPH (days)	IHH (days)	BW (kg)	HB (%)	THW (t/ha)
		p = 0.0001	p = 0.0017	NS	p = 0.0132	p = 0.0008
*	*	CA4 (780) *a*	CA4 (247) *a*	CA2 (37.0)	CA2 (83.8) *a*	CA2 (51.7) *a*
*	*	CA2 (782) *a*	CA2 (251) *a*	ISA (36.5)	CA4 (82.0) *ab*	CA4 (50.7) *a*
*	*	ISA (812) *ab*	ISA (274) *a*	CA4 (36.3)	CA1 (81.2) *ab*	CA2C (50.2) *a*
*	*	CA2C (835) *b*	CA2C (275) *a*	CA2C (36.3)	CA2C (79.5) *ab*	CA1 (49.5) *a*
*	*	CA1 (843) *b*	ALD (289) *ab*	CA1 (34.8)	ISA (69.5) *ab*	ISA (46.2) *a*
*	*	ALD (855) *b*	CA1 (293) *ab*	CTR (34.3)	ALD (68.3) *ab*	ALD (41.5) *ab*
*	*	CTR (908) *c*	CTR (324) *b*	ALD (33.6)	CTR (63.8) *b*	CTR (33.6) *b*

NS : not significant. Asterisks indicate (*) unavalaible data. Abbreviations used : IPF : interval between planting and flowering; IFH : flowering and harvest; IPH : planting and harvest; IHH : harvest and harvest; IHF : harvest and flowering; THW : total harvest weight; BW : bunch weight; HB : harvested bunches. The other abbreviations used for chemicals are defined in the text.

those treated. These differences were not followed by significant differences between flowering and harvest of the first fruit but increased the delay between planting and harvest up to 28 days in comparison with the treated plots.

Application of cadusafos, as the sole treatment by coating, did not affect the growth rate which remained similar to the control.

During the second cycle, there were significant differences in the interval between harvest of the first fruit and flowering of the second fruit; up to 17 days. The interval between flowering and harvest of this fruit was up to 22 days.

Unfortunately it was not possible to follow the flowering of the third fruit. However, the period from harvest to harvest was highly significant; up to 77 days shorter than the untreated control.

All the changes in intervals were cumulative and the time of harvest was significantly reduced by application of nematicide, up to 28 days for the first cycle, up to 57 days for two cycles and up to 128 days for three cycles.

Effects of the chemical treatments on the harvest

In Azaguié (site 2), treatments showed no significant effect on the bunch weight, the number of marketable harvested bunches and the total harvest weight during the first cycle.

In Aboisso (site 3), results obtained during the first cycle were also not statistically different. During the second cycle, significant treatment effects occurred in all the parameters measured. The bunch weights were up to 9 kg heavier than the control; the number of harvested bunches were up to 22.5 percentage points greater; and consequently, the total harvest in tons per hectare was up to 23.7 tons greater than the control.

During the third cycle, treatments affected the number of harvested bunches up to 20 percentage points greater than controls and the total harvest in tons per hectare up to 18.1 tons greater than controls.

REGRESSION ANALYSIS

Regression analysis were performed with all the horticultural results obtained at site 2 (Deux Thé) and the *log (x + 1)* transformed data of the nematode infestations in any combinations (by species and for all species combined; occuring respectively on the roots and/or the corm of the main sucker, or on the entire root system, or on the main and following suckers).

It is noteworthy that the strongest negative relationships ($p < 0.01$) occurred when the number of harvested bunches were regressed on the *R. similis* infestations in the roots of the main sucker when considering the interval between planting and flowering.

In conclusion, the observed relationships with the nematode infestations (all species combined) in the roots of the main sucker, were positive with the growth criteria (IPF, IPH), negative with the harvest criteria (HB, TWH).

EFFECTS OF THE CHEMICAL TREATMENTS ON THE YIELD

For ease of comparison, banana yields are usually represented by the harvest per area of surface and per unit of time. In the experiment at site 3 (Bia 3-71) the results, over three harvests, are presented in Figure 3. Treatments with cadusafos at 2 and 4 grams of active ingredient were similar, based on the combined result of the growth and harvest over three consecutive cycles. The result obtained after application of cadusafos at the lower dosage (1 g a.i.) was similar to the results obtained after application of aldicarb.

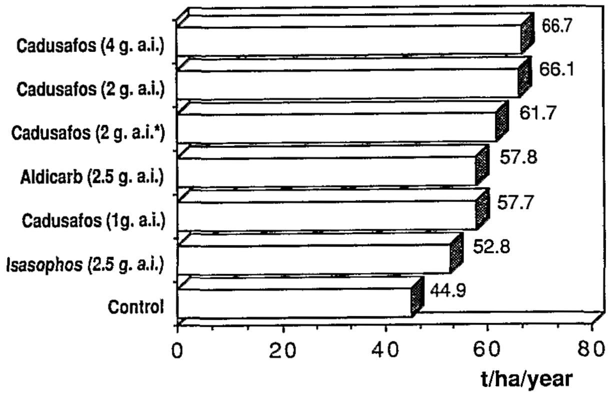

Fig. 3. Results of yield expressed in tons per hectare and per year in the horticultural trial at site 3, Bia 3-77, calculated on the results of three consecutive harvests with the different nematicide treatments, applied three time per year. (Asterisk indicates that this particular object (Cadusafos 2 g. a.i.) the treatment at planting was applied by corm-coating.)

Table 8

Most significant correlations and linear regression equations for relationships between horticultural results and nematode infestations at site 2 (2 Thé).

Dep. var *(y)*	Cycle	Independent. var. *(x)*	Coeff. r^2	Linear regression equation
IPF	1	comb. sp. [IPF; R-ms]	0.619	—
IPH	1	comb. sp. [IPF; R-grs]	0.585	—
BW	1	NS		
HB	1	*Radopholus* [IPF; R-ms]	0.857**	$y = 86.86 - 9.09\ x$
THW	1	comb. sp. [IPF; R-ms]	0.605	—

Abbreviations used : Dep. var. : Dependent variable; IPF : interval between planting and flowering; IPH : planting and harvest; IHH : harvest and harvest; IFH : flowering and harvest; THW : total harvest weight; BW : bunch weight; HB : harvested bunches; UP : uprooted plants; comb. sp. : combined species; R : roots; C : corm; ms : main sucker; msf : main sucker and followers; grs : global root system. Asterisks indicate significance at $p < 0.05$ (*), $P < 0.01$ (**), and $P < 0.001$ (***). Coefficients significant at $P < 0.10$ are unmarked. NS : not significant. Regression equations were computed only for relationships having significant ($P < 0.05$) correlation coefficients. Dashes indicate no equations.

Discussion

These experiments conducted in mineral soil in the Ivory Coast confirmed several previous observations (Quénéhervé *et al.,* 1990). This study confirmed the components of nematode damages in banana plantations in mineral soil in terms of growth and harvest : *i)* lengthening of the vegetative cycle without reduction of the total harvest; *ii)* lengthening of the vegetative cycle with reduction of the total harvest; *iii)* reduction of the longevity of the plantation. In fact, all these types of damages were mixed in each experimentation, and if the most evident proof of damage was the observation of toppling plants, the most insidious remained the lenghtening of the vegetative cycle.

From a nematological point of view, during this study, cadusafos and aldicarb, were the most effective chemicals in reducing nematode populations in the two experiments where nematode populations were monitored. When the first application was incorporated in the planting hole, nematicidal activity of cadusafos lasted between 5 and 6 months. This product showed an equal range of activity over the different nematodes species encountered, while some other nematicides seemed to fail in reducing population of *H. pararobustus.* Reduction of the nematode populations is always more difficult when the product is applied on the soil surface during the vegetative cycle. From this study it appears that the reduction percentage of the cumulative nematode populations in the corm was a consistent and representative indicator of the efficacy of these chemicals in preventing the nematode infestation.

As a general trend, all treatments reduced the length of the phenological phases (IPF, IFH, IHH, IPH_n) in comparison with the control. Results of the harvest demontrated that these growth effects did not directly result in significant differences in terms of harvest. Phenological phases are so long that many environmental factors can vary during the period from vegetative phase to reproductive phase. Results of the regression analysis confirm previous observations (Quénéhervé *et al.,* 1991) of the great pathogenicity of *R. similis.* In conclusion of this study, cadusafos, provided increases in yield range from 15.6 % over treatment with aldicarb to 48.8 % over the non treated control. Therefore, cadusafos can be considered as a new and active compound to be used in nematode control on banana plants in mineral soils in the Ivory Coast.

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