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Control of the burrowing nematode (*Radopholus similis* Cobb) on banana: impact of the banana field destruction method on the efficiency of the following fallow

Christian Chabrier[a,*], Patrick Queneherve[b]

[a] *CIRAD-FLHOR, BP 153 97 202, Fort de France Cedex Martinique, France*
[b] *IRDB, BP.8006 97 259, Fort de France Cedex Martinique, France*

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Abstract

Nematode control in the large commercial banana plantations is currently based on the application of two to four nematicide treatments per year. These repeated pesticide applications lead to many drawbacks in terms of toxicity both for the applicators and for the environment. In Martinique (French West Indies) during the last 10 year, an alternative culture system based on the previous cleanup of lands contaminated by plant-parasitic nematodes (mainly the burrowing nematode *Radopholus similis*), by way of either a fallow period or an appropriate crop rotation before planting with nematode-free banana vitroplants, has been set up. However, a simple natural fallow period is often not sufficient to eliminate the burrowing nematodes and to clean the land properly. Several factors have to be considered, such as the efficiency of the destruction of the old banana plants and the evolution of the flora susceptible to *R. similis*. In this study, we compared the chemical destruction of banana plants by an injection of glyphosate in the pseudo-stems to the usual mechanical destruction using a spading-machine. The application of this technique strongly improved the benefits of the successive fallow (only 12.2% of *R. similis* infested plants compared to 76% after mechanical destruction) with a gain of 14% and 29% (first and second production cycle) of output in ton per hectare with no application of nematicide.

Keywords: Weed; Burrowing nematode; Fallow; Glyphosate; *Musa*; Nematode control; *Radopholus similis*

1. Introduction

One of the most damaging pathogen of *Musa* sp. worldwide is the burrowing nematode *Radopholus similis* Cobb. This plant-parasitic nematode is distributed throughout most banana-growing areas in the world, causing significant banana yield reduction (Gowen and Quénéhervé, 1990; Sarah, 1990). In general, in the intensive banana cropping systems producing fruit for export, the primary means for alleviating yield losses caused by this nematode is based on chemical control with two to four nematicide applications per year. As an example, in Martinique close to 950 kg of nematicides (and related insecticide/nematicide products) were applied on approximately 10,000 ha of plantation in 1997 (Balland et al., 1998). The repeated use of these products on a large scale may result in many environmental problems, mainly due to the high toxicity of these products (Risède and Tézenas-du-Montcel, 1997; Lacher et al., 1997).

During the last 15 years, many studies have been conducted in Africa and in the Caribbean both by CIRAD-FLHOR and IRD on the conception and improvement of alternative culture systems based on (i) the sanitation of contaminated banana fields and on (ii) the planting with nematode-free banana plants produced by tissue culture (vitroplants). This type of control strategy allowed banana producers to delay the application of nematicides for 1 or 2 years after planting (Sarah et al., 1983; Mateille and Foncelle, 1988; Mateille et al., 1992; Quénéhervé, 1993).

These techniques were also developed in Martinique during the last decade (Ternisien, 1989; Ternisien and Ganry, 1990; Marie et al., 1993). However, results were inconsistent and recontamination with the burrowing nematode *R. similis* was commonly observed following

*Corresponding author. Tel.: +33-596-71-21-88; fax: +33-596-63-07-24.

E-mail address: chabrier@cirad.fr (C. Chabrier).

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the first production cycle in fields that had been replanted with nematode-free banana vitroplants.

Until 1998 in Martinique and Guadeloupe, the banana fields in the large commercial plantations were destroyed mechanically, either by the passage of heavy disc harrows or more recently by the use of spading machines (this tractor-drawn machine is an articulating digger, which spades produce an effect similar to hand spading). These machines cut banana corms and pseudo-stems in pieces, every corm fragment being capable of developing as a volunteer plant. In order to improve the fallow efficiency, a study comparing two methods of destruction of the banana plants (mechanical and chemical) was made on the experimental domain of Rivière-Lézarde between 1998 and 2000. During this study, the dynamics of reinfestation by the burrowing nematode *R. similis* by spread from plant to plant and its impact on the horticultural parameters of the following yields were analyzed on two successive production cycles.

2. Materials and methods

The experiment was done at the experimental domain CIRAD-FLHOR of Rivière-Lézarde in June 1998 on the field "Abricot" which had grown in the banana cultivar Grande Naine (Musa AAA) since 1993. The soil was an Ultisol (ferralitic and halloysic soils, comprising 14% sand, 16% silt, 70% clay; 2.6% organic matter; pH 5.4). This clay soil is the most common in Martinique and is representative of the banana fields at lower elevations in the center of Martinique. Plots were arranged in a randomized complete-block design with four replications. The primary plots (ca $500\,m^2$) comprised up to 90 banana plants from which only 54 were monitored for nematode infestations and yields. Banana plants were planted in double-rows (inner rows spaced 1.8 m and wider rows spaced 3.6 m apart) with plants spaced 2.05 m apart on the planting line, leading to an initial density of 1806 banana plants per hectare.

Three destruction methods of the former banana plantation were compared:

1. *Double glyphosate treatment*: Chemical destruction by a glyphosate injection (5 ml of a solution at 90 g a.i./l, Roundup Bioforce®, injected with a Socorex® spot-gun syringe) in the base of the pseudo-stem of the mother plant and any follower suckers (those presenting at least 1 enlarged leaf) with a second passage 3 weeks later to treat escapes and surviving volunteers.

2. *Single glyphosate treatment*: Chemical destruction (similar to treatment 1) followed 3 weeks later by a double cross tilling using a spading-machine (Cortella®) at 40 cm-depth.

3. *Mechanical destruction* by a double cross tilling using a spading-machine (Cortella®) at 40 cm-depth.

The different plots were left as fallow for 6 months, without any other interventions. Weed development was monitored regularly during this fallow period. The main pioneer weeds were collected, identified (Fournet, 1978; Fournet and Hammerton, 1991) and analyzed for nematode infestations. After this 6-month fallow period, all experimental plots were ploughed by a 2-cross tillage with a spading-machine, limited to 40 cm-depth. All plots were then planted with nematode-free vitroplants of the banana cultivar Grande Naine. Standard management practices for Caribbean banana production were followed with regard to weed control, application of chemical fertilizers and irrigation.

Nematode infestations were monitored (i) on the previous banana crop and associated weeds, (ii) on the main weeds during the fallow period, (iii) on the new crop at harvest of the first production cycle (9 months after planting) and (iv) at the end of the flowering period of the second production cycle (15 months after planting). Root samples for nematode assays consisted of 10 cores, collected individually from each plant, and replicated 5 times in each plot. Root cores were chopped, carefully mixed and a 40 g subsample was processed in a mist chamber (Seinhorst, 1950). In parallel, the individual indexation of banana plants for the presence or absence of *R. similis* began at the end of the first cycle for each plant using a qualitative method of nematode extraction with hydrogen peroxide on an aliquot of 5 g root per plant (Gowen and Edmunds, 1973). Nematode abundance was expressed as number per 100 g fresh roots (for bananas) or per gram of dry roots (for weeds) dried for 24 h in a ventilated oven to 60°C. Specific identifications were performed either on fresh material or on fixed material.

The yield parameters were measured individually at the end of each cycle (dates of flowering and harvest, number of hands and fingers per bunch, bunch weight, percentage of harvest).

3. Results

The control of the nematode infestation before the start of the experiment in the field "Abricot" showed that banana plants were heavily infested by plant-parasitic nematodes (Table 1). Five nematode species were identified: the burrowing nematode *Radopholus similis*, the lance nematode *Hoplolaimus seinhorstii* Luc, the spiral nematode *Helicotylenchus multicinctus* (Cobb) Golden, the root-knot nematode *Meloidogyne* sp. and the reniform nematode *Rotylenchulus reniformis* Lindford & Oliveira. This severe nematode infestation was the cause of more than 40% of toppling-over plants between flowering and the last harvest. Besides bananas, some weeds were also found to be good hosts of plant-parasitic nematodes (e.g., the gramineous

Table 1
Effect of the banana destruction method on the nematode infestations of weeds and *Musa* volunteers

	Nb[a]	*R. similis*	*H. seinhorstii*	*H. multicinctus*	*Meloidogyne* sp.	*R. reniformis*
Previous banana crop						
Musa cv Grand Naine	8	863±402[b]	0	69±112	334±393	0
Clidemia hirta	5	25±29	0	0	9±13	0
Cyperus sphaerulatus	5	0	0	0	0	0
Eleusine indica	5	1±1	1±2	0	1±1	11±10
Paspalum fasciculatum	5	143±189	0	6±12	6±8	0
Peperomia pellucida	5	0	0	0	0	0
Xanthosoma nigrum	5	0	0	0	1756±3591	187±236
Fallow after Treatment 1						
Eleusine indica	5	0	0	0	136±259	1±3
Ipomoea eriocarda	5	0	0	0	0	0
Ipomoea tilliacea	5	0	0	0	0	0
Leptochloa filiformis	5	0	0	0	126±191	11±20
Mikania micrantha	5	0	0	0	0	0
Mimosa pudica	5	0	0	0	186±372	2±4
Phenax sonneratii	5	0	0	37±41	0	169±249
Phyllanthus amarus	5	0	0	0	15±30	7±8
Sida acuta	5	0	0	0	0	0
Solanum americanum	10	3±7	0	6±11	395±782	41±82
Solanum torvum	10	12±23	0	61±184	8±17	182±355
Fallow after Treatment 2 and 3						
Cecropia sp.	5	3±6	0	13±18	3±6	207±131
Cleome aculeata	5	0	0	0	0	0
Eleusine indica	5	4±6	99±144	0	27±56	0
Euphorbia hirta	5	0	3±5	0	0	0
Leptochloa filiformis	5	5±9	0	0	10±17	0
Mimosa pudica	7	0	135±231	0	91±156	15±23
Phenax sonneratii	10	251±503	0	0	332±896	307±367
Phyllantus amarus	5	11±17	0	0	0	2±4
Pilea microphylla	5	0	10±6	0	350±715	0
Solanum americanum	3	0	0	0	19±27	8±11
Solanum torvum	10	70±134	0	0	0	27±30
Urena lobata	5	0	4±8	0	27±53	0
Vernonia cinerea	5	0	0	0	12±24	0
Musa volunteers T2	5	209±281	0	0	1039±1767	0
Musa volunteers T3	10	415±804	51±94	41±113	89±182	74±129

[a] Number of replicates.
[b] Number of individuals per gram of dry root ± standard error.

weed *Paspalum fasciculatum* Willd. for *R. similis* and the Araceae *Xanthosoma nigrum* (Vell.) Stellfeld for *Meloidogyne* sp.).

After destruction of the banana plants, the adventitious flora that developed in the fallow differed according to the destruction method.

On the plots destroyed chemically without mechanical intervening (Treatment 1) we observed that the two creeper weeds *Mikania micrantha* HBK. and *Ipomoea tilliacea* (Willd.) Choisy were the two predominant weed species during the first 3 months. These creeper weeds were never found to be host of the burrowing nematode *R. similis* and on these plots the burrowing nematode was only recovered in very low numbers from the roots of some rare Solanaceae, *Solanum americanum* Mill. and *Solanum torvum* Sw. (Table 1). No *Musa* volunteers were observed after double glyphosate treatment.

On the plots destroyed with single glyphosate treatment followed 3 weeks later by a double cross tilling with a spading machine (Treatment 2) we observed an immediate emergence of the Euphorbiaceae (*Euphorbia heterophylla* L., *Phyllanthus amarus* Schum. & Thonn.) and of *Cleome aculeata* L. After 1 month, these pioneer weeds were then dominated by the Poaceae (*Eleusine indica* (L.) Gaertn., *Echinochloa colona* (L.) Link., *Digitaria horizontalis* Willd., *Paspalum* spp., *Leptochloa filiformis* Beauv.) and Cyperaceae (*Cyperus* spp.). Three months after soil tillage, some Solanaceae (*Solanum americanum* Mill. and *Solanum torvum* Sw.), one Urticaceae (*Phenax sonneratii* (Poir.) Wedd.) and many

Table 2
Percentage of plants infested in *Radopholus similis* and nematode population densities at harvest during the two banana production cycles according to treatments

	% IP[a]	*R. similis*	*H. seinhorsti*	*H. multicinctus*	*Meloidogyne* sp	*R. reniformis*
Cycle 1						
T1	12.2 a	755 a	45 a	41 a	754 a	5 a
T2	29.3 a	2174 a	54 a	246 a	1480 a	11 a
T3	76.0 b	11,633 b	62 a	478 a	1043 a	35 a
ANOVA	HS	HS	ns	ns	ns	ns
Cycle 2						
T1	n.e.	1537 a	0 a	925 a	1625 a	100 a
T2	n.e.	2737 a	0 a	475 a	4825 a	75 a
T3	n.e.	11,587 b	37 a	663 a	1487 a	0 a
ANOVA		HS	ns	ns	ns	ns

[a] IP = Plants infested with *R. similis*.
$^{**}P = 0.01$; ns: not significant; ne: not evaluated. Letters in columns correspond to the homogeneous groups (test of Tukey–Kramer $P = 0.05$).

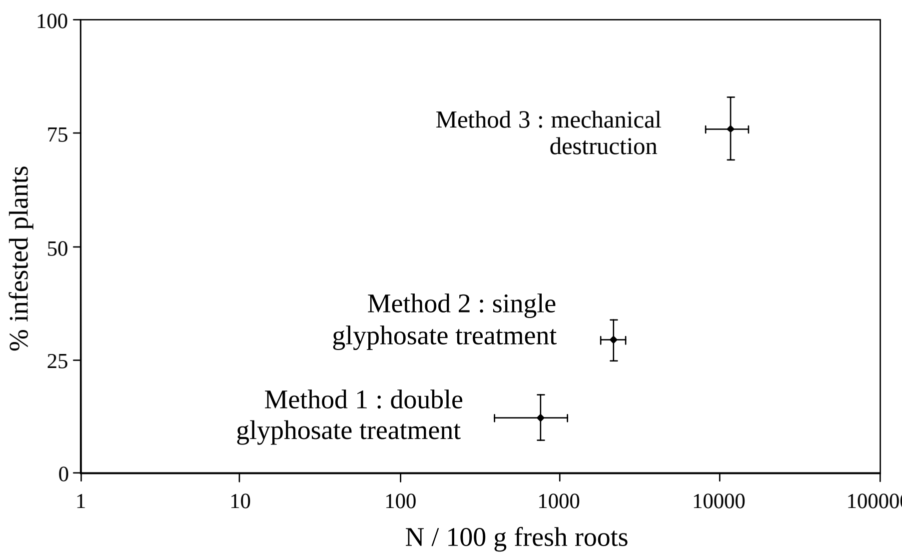

Fig. 1. Effect of the previous banana destruction method on the relation between the percentage of *R. similis* infested plants and the level of root infestation at the end of the first banana production cycle.

Musa volunteers were also present. As illustrated in Table 2, many of these weeds besides the *Musa* volunteers were also found to be good hosts of the burrowing nematode *R. similis*.

On the plots destroyed mechanically with the spading machine (Treatment 3) we observed weed emergence comparable to treatment 2 with many more *Musa* volunteers. In December 1998, these banana volunteers occupied 30–50% of the total surface in these plots compared to 10–20% under treatment 2 and none in treatment 1. As already observed for treatment 2, many of these weeds were good hosts of the burrowing nematode (e.g. *Phenax sonneratii* and *Solanum torvum*) while *Musa* volunteers were the most important source of inoculum (Table 1).

The complete results of the nematode analysis done on banana plants at harvest of the first production cycle and at the flowering period of the second production cycle are grouped in Table 2 and illustrated in Fig. 1.

The double injection of glyphosate alone leaded to a very significant decline both in the number of infested plants by *R. similis* (reduction of 84%) and on the root infestation level (reduction of 93%, from 11,633 *R. similis*/100 g against 755 *R. similis*/100 g, during the first production cycle and reduction of 87%, from 11,587 *R. similis*/100 g against 1537 *R. similis*/100 g during the second production cycle) compared to the fallow that developed after mechanical plant destruction.

The combined method (single injection of glyphosate followed by a soil tillage) occupies an intermediate position in terms of nematode infestations (2174 and 2787 *R. similis*/100 g during the first and second production cycles).

After this first banana production cycle, the different methods applied to settle the fallow 15 months before had no significant effects on the other plant-parasitic nematode species (Table 2).

Regarding the yield parameters (Table 3), the presence of the burrowing nematode after treatment 3 is only noticeable during the first production cycle in terms of the higher percentage of plants toppling over plants (10.7%) and of the lower coefficient of harvested bunches (86.1%) compared to the two other treatments. From a global viewpoint, we observed a gain of 8.2 t/ha/yr of the gross yearly output between treatments 1 and 3.

During the second cycle (Table 3), the conformation and the weight of bunches were also affected with a significant reduction of the number of fingers and hands by bunch as well as the average bunch weight (reduction of 9%, from 36.1 to 32.8 kg per bunch between treatments 1 and 3). This negative effect of the presence of the burrowing nematode after treatment 3, added to the percentage of decline of harvested bunches (76.7%) leading to a significant difference of 29% of gross yearly output between treatments 1 and 3.

4. Discussion

The sanitation of lands previously cultivated with bananas and infested by the burrowing nematode *R. similis* is a recurrent problem but seems now more acute because of (i) the availability of land is increasingly limited, specially for the small banana producers in the Caribbean and (ii) the application of pesticides is increasingly restricted. Many authors studied the survival of *R. similis* in soil (Tarjan, 1961; Loos, 1961) and after cultural practices (cultivated or bare fallow), physical treatments (immersion, heat treatment) or chemical treatments (fumigation, application of granulated nematicides) in order to eradicate this harmful pest (see review in Gowen and Quénéhervé, 1990).

Unfortunately, the banana nematodes are also able to parasite numerous other cultivated plants and weeds (Edward and Wehunt, 1971; Keetch, 1972; Mateille et al., 1994; Quénehervé et al., 2002). Results of this study confirm that the presence of *Musa* volunteers constitutes the most important source of inoculum of *R. similis*. But beside these *Musa* volunteers, many common weeds such as the Urticaceae *Phenax sonneratii*, numerous Poaceae, *Eleusine indica*, *Paspalum fasciculatum*, *Leptochloa filiformis* and the Solanaceae *Solanum americanum* and *Solanum torvum* were also significant reservoirs of *R. similis*.

The destruction method of banana plants (by a chemical or a mechanical way) has an important influence on the composition of the flora in the subsequent fallow. Soil tillage favored the multiplication of *Musa* volunteers as well as the development of some

Table 3
Effect of the previous banana destruction method on the yield of a successive banana crop over two production cycles

	Treatment			Average	CV
	1	2	3		
First cycle of production					
Interval planting–flowering (days)	187.4	196.4	194.7	193.4	4.1 ns
Interval planting–harvest (days)	270.2	277.9	276.3	275.4	1.8 ns
Number of hands/bunch	7.1	7.1	7.1	7.2	3.7 ns
Number of fingers/bunch	124.6	123.7	124.8	125.6	7.1 ns
Bunch weight (kg)	28.4	28.3	28.1	28.3	6.3 ns
Proportion of toppling over	1.4 a	1.1 a	10.7 b	3.6	5.7**
Coefficient of harvest (%)	95.0 a	92.6 a	86.1 b	91.5	2.7**
Gross yield (t/ha/yr)	66.3	62.6	58.1	62.4	8.6 ns
Second cycle of production					
Interval planting–flowering (days)	411.5	423.4	423.7	419.6	1.8 ns
Interval planting–harvest (days)	512.2	522.3	522.3	519.0	1.3 ns
Number of hands/bunch	8.3 a	8.3 a	7.8 b	8.1	2.1*
Number of fingers/bunch	160.5 a	162.6 a	152.3 b	158.5	2.4*
Bunch weight (kg)	36.1 a	35.2 a	32.8 b	34.7	2.7**
Proportion of toppling over	4.0 b	7.1 b	14.2 a	8.4	28.7*
Coefficient of harvest (%)	88.5 a	85.0 a	76.7 b	83.4	3.3**
Gross yield (t/ha/yr)	41.4 a	38.2 b	32.1 c	37.2	3.4**

Gross yield: average bunch weight × % harvested bunches × density/ha × 365/interval planting–harvest.
CV = coefficient of variation in percent; ns: not significant; Letters in the same line correspond to the homogeneous groups (Test of Newman–Keuls, $P \leqslant 0.05$).
** $P \leqslant 0.01$.
* $P \leqslant 0.05$.

weeds of the Euphorbiaceae, Poaceae and Solanaceae. The absence of soil tillage and the complete chemical destruction of banana plants and volunteers, before the fallow consolidated, limited the survival of *R. similis* in the soil. Results show that at the end of the first production cycle still 12.2% of the banana plants remained infested by *R. similis*, even in the absence of *Musa* volunteers. One can hypothesize that trace nematode infestations were probably maintained on some weeds such as the Solanaceae *Solanum americanum* and *Solanum torvum* during the fallow period after chemical destruction.

From an economic point of view, this simple method of banana removal decreased the proportion of topped plants and increased the gross yearly banana yield in the first production cycle. These differences were accentuated during the second production cycle with a difference of 29% in t/ha/yr between the chemical destruction treatment and the mechanical one usually adopted by banana growers.

This method appears also to be an environment-friendly control method of the burrowing nematode since the problem of water contamination by the repeated use of nematicides led the French Governmental Agencies to rationalize the application of inputs in agriculture and obliged producers to review their practices in order to reduce to a minimum the application of the pesticides (Contrat Territoriaux d'Exploitations). This method of chemical destruction of banana plants before imposing a fallow resolves some of these preoccupations and presents many advantages: (i) avoids use of at least four nematicide applications in the first 2 years, (ii) allows adaptation of the fallow duration to the growers' time imperatives, (iii) reduces the passage of heavy tilling machines on fields. As it is well known that in the Caribbean, the repeated passage of these machines may compact soil (Dorel, 1993) and contributes to the reduction of their agronomic potential (Dorel et al., 2000).

However, in order to understand the residual source of *R. similis* infestation and to improve this technique, it would be useful to conduct further studies in different locations (i) on the thorough research and identification of weeds which are potentially hosts of *R. similis*, and on the cultural practices to apply in order to eliminate them; and (ii) on other possible recontamination sources (irrigation water, run-off water, topographic location of infested fields, etc.).

This new technique of banana field destruction by injection of glyphosate in the banana pseudo-stem may hold considerable promise for managing the burrowing nematode *R. similis* in bananas when rehabilitating nematode infested lands. Numerous banana producers in Martinique and Guadeloupe have already adopted this technique of banana field destruction with glyphosate, before growing a rotation crop such as pineapple or sugar cane, or before a fallow to achieve eradication of the burrowing nematode.

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