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BANANA NEMATODES AND THEIR CONTROL IN AFRICA

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ABSTRACT

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The most important nematode species in *Musa* production in Tropical Africa is *Radopholus similis* which is present in nearly all the dessert banana plantations (export market) and in many cooking banana production areas (staple). Other nematode species also are widespread but have less economic impact. *Helicotylenchus multicinctus* is the prevailing species on plantains in many regions of West Africa where *R. similis* is absent. *Pratylenchus coffeae* occurs occasionally, although dominant in Levubu, South Africa, and found frequently in eastern Ivory Coast. *Pratylenchus goodeyi* is the most frequently encountered species in the East and Central African highlands where a cooler climate prevails. Nematode control practices are almost exclusive to dessert banana production. These measures rely mainly on the use of nematicides, cultural practices such as fallow, flooding, and the use of clean or in vitro propagated planting material. In contrast, chemical control in cooking bananas is not economically feasible under the present conditions of the subsistence African farmer who cultivates bananas on a self-sufficient basis. Current research programs are emphasizing host-parasite relationships, pest interactions, breeding for resistance, and the implementation of cultural practices, especially in vitro propagation that should reduce the use of nematicides and prevent the spread of undesirable pests in soils in which bananas have not been cultivated. Future prospects for nematode research on *Musa* in Africa are discussed.

Key words: banana, chemical control, *Helicotylenchus multicinctus*, management, *Musa*, plantain, *Pratylencus coffeae*, *P. goodeyi*, *Radopholus similis*.

RESUMEN

Sarah, J. L. 1989. Nematodos del banano y su control en Africa. Nematrópica 19:199–216.

El nematodo de mayor importancia en la producción de *Musa* en Africa tropical es *Radopholus similis*, presente en casi todas las plantaciones de banano (mercado de exportación) y en muchas áreas dedicadas al cultivo del banano de cocción (alimento basico). Otras especies de nematodo que se encuentran ampliamente distribuidas tienen menor impacto económico. *Helicotylenchus multicinctus* es la especie dominante en platano en muchas regiones del Africa Occidental donde *R. similis* esta ausente. *Pratylenchus coffeae* es ocasional, aunque dominante en Levubu, Africa del Sur, y frecuente en la parte Este de Costa de Marfil. *Pratylenchus goodeyi* es la especie dominante en las regiones montaosas de Africa Central y del Este donde prevalece un clima templado. Medidas de control de nematodos se aplican casi exclusivamente al banano de exportación. Estas medidas consisten en el uso

de nematícidas, prácticas culturales, tales como el barbecho, inundación y el uso de material de siembra limpio o plantas propagadas a traves de técnicas in vitro. En contraste, el control químico no es economicamente factible bajo las concidiones de explotación de tipo familiar (autosuficiencia) del pequeño agricultor africano. En la actualidad, los programas de investigación estan enfocados a un mejor conocimiento de la relación parasito hospedero, interacción con otras plagas y enfermedades, fitomejoramiento y la implementación de prácticas culturales, especialmente la propagación in vitro, con el objetivo de reducir el uso de productos químicos y sobre todo evitar la dispersion de plagas nocivas en suelos que nunca han cultivado banano. Se comenta acerca de las perspectivas futuras para investigación nematológica en banano en Africa.

Palabras claves: banano, control químico, *Helicotylenchus multicinctus*, manejo, *Musa*, plátano, *Pratylenchus coffeae*, *P. goodeyi*, *Radopholus similis*.

INTRODUCTION

Only three African countries produce dessert bananas, *Musa* AAA, for significant export market: Ivory Coast, Somalia, and Cameroon (Table 1). Countries of Southern and Northern Africa also are producers but typically for local consumption or regional exports (Table 1). Subtropical countries such as Egypt and South Africa are outside of the optimal climatic conditions for banana production (dryness in summer and cold temperatures in winter) and sufficient yields can only be obtained using highly intensive cropping systems, the extreme case being the cultivation under greenhouses (about 1 000 ha) in Morocco. On the other hand, starchy bananas, mainly *Musa* AAB subgroup plantain in West Africa and mixed AB, AAA, AAB, and ABB (rarely BBB) in East Africa, are cultivated only in the humid tropical regions of Africa were bananas are an important source as a dietary staple (Table 2). Starchy bananas are typically produced in small-holdings of a few hectares without mechanization and no renewal of the banana plot for decades. The most common production systems are: shifting cultivation (bush fallow), mixed intercropping, typically with coffee (*Coffea canephora* (Froehner) Pierre, *C. arabica* L.) or cocoa (*Theobroma cacao* L.), and small mixed gardens in the villages (1,32,51,58,59,70–73). In these systems, banana cultivation is the basis of food production while also providing a cash crop (58). Under these conditions, only unprecise production estimates are available (Table 2).

In general terms, the importance of nematodes in *Musa* production in Africa is quite variable and depends on the ecological region, cultural practices, susceptibility of the different banana types, nematodes present, production system, and interactions with other pests.

MAIN NEMATODE SPECIES

One of the most important root pathogens of dessert bananas in West Africa is the burrowing nematode *Radopholus similis* (Cobb) Thorne

Table 1. Dessert banana production, soil types, and nematode problems in the main producing countries of Africa (references in the text).

Region and countries	Production (1 000 tons)[x]	Soil characteristics	Main nematode species[y]	Estimated crop loss[z]
Western				
Cameroun	65 (50)	Volcanic (pumice)	Rs, (Hm,Mi,Hp)	20–25%
Ivory Coast	135 (80)	Variable from sandy to clayey pH 4.5–6.5	Rs, (Hm,Hp) in mineral soils	From 30% up to 75% in mineral soils
		Nieky peat soils (10% organic matter) pH 3.5–5.5	Rs,Hm, (Hp) in peat soils	20–25% (with chemical control) and 30–35% (using fallow) in peat soils
Eastern				
Somalia	70 (65)	Alluvial loamy to clay loamy; pH neutral-basic	Rs, (Rr,M)	Unknown, large losses suspected
Southern				
Madagascar		Alluvial	Rs,Zt, (Hm)	35–40%
Mozambique	80	Alluvial	Lourenço Marques: Rs,S,H,M Chimoio: S,P, H,M,Rs	Unknown
South africa	175	Levebu, Natal: Sandy Transvaal: Red clay pH 4.5–5.0	Levubu: Pc, (Hm) Natal: Rs,Hm Elsewhere: Hm,Mj	Up to 75–80%
Northern				
Egypt	210	Sandy to clayey	M in sandy soils H in clay soils	Unknown
Morocco	30	Sandy to clayey	M in sandy soils Rs in some sites	Moderate to large losses suspected

[x]Year 1987. Sources, FAO 1988 and IRFA. Exports are in parentheses.
[y]H = *Helicotylenchus*; Hm = *H. multicinctus*; Hp = *Hoplolaimus pararobustus*; M = *Meloidogyne*; Mi = *M. incognita*; Mj = *M. javanica*; Pc = *Pratylenchus coffeae*; Rs = *Radopholus similis*; Rr = *Rotylenchulus reniformis*; S = *Scutellonema*; Zt = *Zygotylenchus taomasinae*. Less important species are in parentheses.
[z]Average decrease of production caused by *Radopholus similis* alone or with associated species.

(15,30,65,68). This species is widespread and generally encountered in high populations. Other species have been associated with the banana rhizosphere such as *Pratylenchus coffeae* (Zimmerman) Filipjev & Schuurmans Stekhoven, *Helicotylenchus multicinctus* (Cobb) Golden, *Hoplolaimus*

Table 2. Starchy production, use and nematode problems in the main producing countries of Africa (references in the text).

Region and countries	Cultivars	Production (1 000 tons)[x]	Per capita consumption (kg)[x]	Use[y]	Nematode species[z]
Western	Primarily plantains				
Ivory Coast		1 400	100	F	Hm,Mi, (Rs,P)
Ghana		750	80	F	
Nigeria		1 800		F	Hm,Mj
Cameroun		1 000	75	F	H,M,Rs
Eastern	Mixed				
Rwanda		2 100	300	B,F	HL: Pg, (H,M)
Burundi		1 400		B,F	HL: Pg, (Hm,Mj) LL: Rs,Hm
Uganda		4 000	240	F	Pg,Rs,H
Kenya		400		F	
Tanzania		1 500	90	B,F	HL: Pg LL: Rs,Pg, (Hm, Hp,Mi)

[x]Year 1987. Sources, FAO 1988 and IRFA.
[y]B = Beer; F = Food.
[z]HL = Highlands; LL = Lowlands. H = *Helicotylenchus*; Hm = *H. multicinctus*; Hp = *Hoplolaimus pararobustus*; M = *Meloidogyne*; Mi = *M. incognita*; Mj = *M. javanica*; P = *Pratylenchus*; Pg = *P. goodeyi*; Rs = *Radopholus similis*.

pararobustus (Schuurmans Stekhoven & Teunissen) Sher and *Meloidogyne* spp. (15,30,68). These nematodes occur less frequently than *R. similis* and are not considered to be major limitating factors in banana production in West Africa. However, *H. multicinctus* is considered as an important pest which causes crop loss in the geographical areas where it is abundant (15,31). Nematodes that are found most frequently attacking plantains include several species of *Helicotylenchus* and *Meloidogyne* (1,6,13,31,51). *Radopholus similis* usually is present in the regions where dessert bananas are cultivated and it is likely that contamination of plantains has originated from nearby banana operations (1,51).

In Southern Africa *R. similis* is widespread in Mozambique and Natal and present in some farms of Transvaal (23,25,40). In Madagascar and Reunion, this species is associated with *Zygotylenchus taomasinae* (De Guiran) Braun & Loof (8,9,68). *Pratylenchus coffeae* also is present but less frequent, exept in Levubu in northern South Africa, where it is the dominant nematode species (23,25). *Helicotylenchus* and *Meloidogyne* also are widespread and very abundant in this country but generally considered as a secondary problem though not negligible (24,31), as compared to *R. similis* in Natal or *P. coffeae* in Levubu (23,25).

In Eastern Africa, *R. similis* is the main nematode species in the dessert bananas in Somalia (7). In the cooking and beer bananas culti-

vated in the African highlands (Kenya, Tanzania, Uganda, Rwanda, Burundi, and eastern Zaire) the dominant species is *Pratylenchus goodeyi* Sher & Allen (12,59,70). This lesion nematode, which was recorded before in the Canary Islands (14), is concomitant with *R. similis* in certain areas (70) of lower altitude. This also is the case with Tanzania on the African mainland and in Zanzibar and the Pemba Islands where the burrowing nematode was introduced recently (59).

The dissemination of *R. similis* throughout Africa is due mainly to the distribution of nematode infested rhizomes used as planting material. For instance, in Somalia introduction probably was through seed material (rhizomes) of cv. Poyo imported from the Ivory Coast (Vilardebo pers. comm.). In South Africa the nematode is supected of having been introduced illegally from Mozambique where it probably came from the Ivory Coast and Angola (25,40), and in Morocco *R. similis* was imported with plant material coming from Central America and Guadeloupe (Ammati, Lavigne, pers. comm.). Starchy bananas have been present in Africa long before the introduction of dessert cultivars for intensive cultivation. Unfortunately, they gradually are becoming infested with *R. similis* in the lowlands because of the lack of control measures, especially the use of noninfested planting material.

DAMAGE AND ECONOMIC IMPORTANCE

The economic importance of nematodes, especially *R. similis* on dessert bananas in Africa can be regarded as serious, and the nematode frequently is the limiting factor to banana production. In the Ivory Coast, Guerout (18) estimated the economic threshold level to be 1 000 *R. similis* per 100 g of roots. ln South Africa the damage threshold level is 20 nematodes per 100 g of roots (25). This difference does not mean that *R. similis* is 50 times more pathogenic in South Africa, but illustrates differences in evaluation of *R. similis* damage to banana in countries with different production systems. The crop loss estimates summarized in Table 1 provide an evaluation of nematode problems in the various banana production areas of Africa. In the Ivory Coast, the losses may reach 30–35% under optimal growing conditions in fertile soils and more than 75% where soils are poor or eroded (57). In fact, in the latter case, the banana plants became almost unproductive after the first harvest. In the Nieky valley (Ivory Coast) characterized by peat soils with more than a 10% organic matter content, crop losses are underestimated when using nematicide-treated plots as a reference (19,44,57). If nematode control has been obtained by means of a fallow a better estimation of actual economic importance of nematodes can be obtained. When fallow is used, crop losses are estimated in the range of 30–35% (56) which is similar to the most fertile mineral soils. In Cameroon,

where volcanic soils are much more fertile than in the Ivory Coast, losses average 35–40% (37,66). The decline in production is due mainly to the decrease of both bunch weight and number of productive plants in contrast to Central America where damage is primarily the result of uprooting (toppling) (42,69). Unproductive plants include those lost from uprooting and those forming bunches that are too small for harvesting. A third (and lesser) component of crop losses is the increase of interproduction time, which also is known as ratooning. Moreover, because of nematode problems, farmers must replant frequently (every 3–6 years on average).

In South Africa, crop losses caused by *R. similis* may reach 75–80% (23,25,26). In Madagascar, Beugnon and Vilardebo (9) established crop losses reaching 35–40% with mixed population of *R. similis* and *Z. taomasinae*.

For starchy bananas, the actual economic importance of nematodes is very difficult to estimate, due to the damage caused by the banana weevil, *Cosmoplites sordidus* Germar, to the rhizome. Insect damage occurs frequently and in many cases is far more important than the damage caused by nematodes (51,70). This insect pest appears to be the main limitation to *Musa* production in many areas of Africa. In West Africa, *H. multicinctus* is dominant in plantains. Its high numbers, often more than 1 000 per g of roots, can result in significant crop loss (51). In Nigeria, this species is associated with *M. javanica* (Treub) Chitwood, causing crop loss that reaches 50% (6,13). In the volcanic soils of Cameroon *R. similis* appears to have only limited influence on plantain production since losses are below 20% after five harvests (cycles) (36). In the Ivory Coast this species causes severe damage. After only two harvests, crop losses recently have been estimated at 40–50% (Sarah and Hugon, unpubl.).

The damage caused by *P. goodeyi* to bananas and plantains is unknown. It causes root lesions similar to those of *R. similis* (70) but is not as destructive (59). Significant damage due to uprooting has been observed in Tanzania. Losses are consistently higher where *R. similis* is associated with *P. goodeyi* (70). In Rwanda and Burundi, damage seems to be relatively low in farmers' fields, but is more noticeable in the Research Stations of the Institut des Sciences Agronomiques du Rwanda (ISAR) in Rubona (Sarah, unpubl.) and Institut de Recherches Agronomiques et Zootechniques (IRAZ) in Gitega, Burundi (59), where intensive cultivation is practiced. Also, plant tolerance to this nematode appears to be variable among the different cultivars and local banana types (59).

FACTORS INFLUENCING NEMTODE POPULATIONS

Population increase of nematodes is related to environmental factors

and plant development. In West Africa, rainfall is the main factor influencing the level of root and rhizome infection, with populations being reduced sharply during the dry season (6,13,25,37,55,64). In South Africa, low winter temperatures induce a decrease in *H. multicinctus* population levels, with juveniles becoming predominant (25). During the crop cycle, the level of root infection increases gradually until after the emergence of the flower bud (37,52,64). Population increase also is faster in the roots that emerge from suckers, than in those that emerge from the rhizome (52).

Cultural practices have been shown to influence population dynamics. *H. multicinctus* multiplies faster in the roots of pruned suckers, in contrast to *R. similis* which multiplies faster in nonpruned suckers (33).

The predominance of a nematode species over another appears to be influenced by altitude. Such is the case with *P. goodeyi* which is the dominant nematode in the African highlands. In Tanzania, *R. similis* is absent in the higher and cooler zones of the Karagwe district (70). In Burundi, *R. similis* is found in the lowlands of Cibitoke where *P. goodeyi* is absent (12). However, this latter species is encountered frequently in Bukeye at an elevation over 2 000 m (12). In Rwanda, *P. goodeyi* has been found in the roots of Cavendish (AAA) at the ISAR station at Rubona (Sarah, unpubl.). The plants of this station were imported from the IRA station at Nyombe, Cameroon. There is no doubt that the imported seed material was infested with *R. similis*. This species is now absent, suggesting it is not adapted to cooler climates and thus easily displaced by *P. goodeyi*. These observations, and the presence of *P. goodeyi* in the Canary Islands, show that it has a lower temperature preference than *R. similis*.

Soil factors can influence nematode populations. In the Ivory Coast, *R. similis* dominates except in some areas with high organic matter levels as in the Nieky Valley where *H. multicinctus* populations reach higher levels (44). This latter species generally is abundant in the clay to loamy soils of the Ivory Coast (44) and Egypt (Sarah, unpubl.). On the other hand, *Meloidogyne* spp. are more abundant in sandy soils as has been observed in the Ivory Coast (44), Egypt, and Morocco (Sarah unpubl.). *R. similis* appears to be influenced less by soil factors which may be due to its strictly endoparasitic nature (44), but lower populations are generally noted in the clay soils of South Africa (28).

CONTROL METHODS

Control methods are not implemented for plantains or cooking bananas that are cultivated in the traditional way using mixed cropping systems. Under these circumstances the use of chemicals is not possible because of the high cost involved to the small farmer, and the risk of

using toxic compounds that require adequate labeling and trained users. Only a complete transformation of farming practices and of the socio-economic environment could make this approach possible. Such a change is not likely to happen in the near future. A reasonable approach to nematode control could be the creation of regional cooperatives where seed treatments would be carried out by trained personel who would then distribute the planting material. In this same scheme, post-plant application of nematicides also could be considered for small monoculture systems. On the other hand, in the traditional setting, nematode as well as other pest and disease control can be achieved only by using suitably adapted cultivation techniques. The workshop of the International Network for the Improvement of Banana and Plantain (INIBAP) held in Bujumbura, Burundi, in December 1987, made important recomendations on this subject (5). Consequently, only control methods for dessert banana (intensive cultivation) are presented here.

Quarantine measures and propagation control: After the first detection of *R. similis* in South Africa, regulatory measures were taken on certain farms of Northern Transvaal to eradicate this pest and to avoid spread (23,25,29). Infested farms were placed under quarantine and the removal of planting material was prohibited. Only rhizomes from certified *R. similis*-free areas were allowed to be propagated. Eradication of the nematode on infested farms was attempted by rouguing and burning all plants, fumigating the surrounding area, and using a 9-month fallow period on the whole site. These drastic measures were quite successful, reducing the level and spread of nematode infestation in five of the eight treated sites (25).

Preplant treatments of soil: The economic importance of nematodes is compounded by methods of intensive cultivation such as high planting density, monoculture, and rapid replanting after the destruction of the previous crop. Therefore, it seems logical to try to control nematodes by interupting the monocultural succession by means of fallow and/or crop rotation.

The main problem of natural fallow, which is the simplest way to manage the intercrop period, is the polyphagism of the principal plant parasites that attack a given crop. The use of clean fallow seems to be the best way to decrease soil inoculum, although this method may not eradicate *R. similis* which can survive long periods in decaying roots or pieces of rhizome (28). In South Africa, a 10-month clean fallow cannot avoid reinfection of plants afterward even though *R. similis* was not detectable in soil samples (28). These results are similar to those obtained in Panama where an 18-month clean fallow period did not eradicate *R. similis* which rapidly reinfected the following banana crop (49). However, a decrease in the level of nematode infestation may allow a reduction in the number of nematicide applications. In the Ivory Coast,

a 12-month clean fallow period in the organic soils of the Nieky Valley resulted in an undetectable level of *R. similis* in the soil, using a bioassay. Although the nematode was detected in banana roots after planting, the population build up was very slow, resulting in five fewer nematicide applications (30 kg a.i./ha) with an increase in production of 10 tons per ha per crop during four crops (56).

In spite of some advantages, clean fallow also presents serious drawbacks. Firstly, the site needs regular tillage or herbicide application to prevent, or at least limit, the development of weeds which might be hosts of nematodes. Secondly, if the soil is left for a long period without a cover crop, erosion risks which are serious in tropical countries are increased, especially during the early period of the rainy season. Finally, the soil is not a neutral medium, but a complex ecosystem. A long absence of a cover crop might cause a serious decrease in fertility by reducing the organic matter content, leaching of the soluble mineral elements, and by decreasing of some useful microorganisms closely associated with the plant rhizosphere. Because of these disadvantages, an alternative to clean fallow is the use of a nonhost cover crop to maintain or even improve soil fertility. Experiments are being conducted to find the best grass and legume cover crops. Milne and Keetch (27,39) have established a list of 44 nonhosts plants of *R. similis* in South Africa. Among these are some cash crops such as pineapple (*Ananas comosus* (L.) Merr.) which is used as rotation by some farmers in the Ivory Coast. In some regions of the Ivory Coast, the weed *Chromolaena odorata* (L.) King & Robinson (Asteraceae) rapidly covers uncultivated fields eliminating *R. similis*. Some growers are using this kind of natural fallow with good results.

In Cameroon, fallow is practiced routinely for nematode control. One-quarter (on average) of the field area is kept free of bananas for 1 year. The soil is mantained for several months under natural fallow; then, a 3–4 month peanut crop is cultivated. Finally, the soil is kept under clean fallow during the dry season before planting bananas at the begining of the rainy season.

In 1976 and 1982, exeptionally large rainfall caused flooding of hundreds of hectares in the Nieky Valley in the Ivory Coast. This natural disaster caused a sharp decrease in nematode populations resulting in an increase in banana production in the zones were the flooding had lasted 5–7 weeks (56). Although abundant data was taken, the actual reason for the rapid decline in nematode populations in flooded soil was not determined. Jacq and Fortuner (22) hpothesized that sulfate reduction by soil bacteria under anaerobic conditions was the main cause. Afterwards, a flooding experiment was carried out and gave similar results (34). However, the authors suspected that starvation was a more credible hypothesis to explain such a rapid nematode disapearance. In

general, flooding is seldom practiced and has limitations. It requires embankments to make watertight partitions between plots and a continual supply of water to maintain the flooded condition. In spite of these constraints, this method is economically beneficial under the conditions that prevail in the Nieky Valley.

Because of the prolonged overcast conditions that prevail in the humid tropical areas of Africa, solarization is not used. However, some trials have been carried out recently in South Africa with encouraging results (Quilici, unpubl.).

Preplant soil fumigation is an old and expensive method for rapid soil treatment with generally short-term efficacy. Except in South Africa this kind of treatment has been abandoned following the generalized increase in use of nonfumigant nematicides. In South Africa, DD and methyl bromide treatments do not reduce soil populations sufficiently to avoid postplant chemical applications (25,26). Experiments were carried out sporadicaly using EDB and, more recently, 1,3-D. Although results were promising, soil fumigation is not used at present, is not encouraged, and is not expected to be used in the future.

Planting material: Soil treatment is insufficient to avoid a rapid contamination of roots and rhizomes, because planting material is generally the principal source of infestation. It is therefore recommended that soil treatments be complemented with the use of disinfected or nematode-free planting material.

The simplest disinfecting technique consists of peeling the rhizomes to eliminate nematode lesions. However, this is not sufficient since nematodes may be located deep within the cortex and produce no visible symptoms. Also, this method cannot be applied to small rhizomes or to spade-suckers, which are not large enough to endure such rough handling. The storage of peeled rhizomes during 2 weeks prior to planting causes a sharp reduction in the nematode population (45), but storage cannot be applied to small seed material which needs to be planted quickly in order to avoid loss of vigor.

Hot water treatments are implemented in some production areas of Tropical America and Australia (10,11,42,60). This technique was tested unsuccessfully in West Africa (38), and is not recommanded in South Africa (25) due to the cost and the equipment needed for such treatment.

In South Africa, the main practice for disinfecting planting material is to dip the rhizomes in a nematicide solution (2 500 ppm fenamiphos) for 30 minutes (25). This technique was improved in the mid-1960's in West Africa (20) by the use of "pralinage" considered to be one of the most efficient methods. It consists of peeling and then coating the planting material with a nematicidal mud (20,35,69). This technique is simpler and cheaper than hot water immersion of rhizomes and allows a

reduction in rate of infection of roots in a "nematode-free" soil and thus, the assurance of good establishment of the banana plantation in its first 2 years which is profitable for the generally short crop duration in West Africa. Pralinage is used widely in the Ivory Coast and Cameroon following a 10–12 month fallow or 5–7 week flooding.

Obviously, the best way to avoid plant and soil contamination is to use nematode-free planting material. At present, this can be done easily by using plants propagated in vitro. Large-scale experiments have been conducted in West Africa since 1985. In the oldest implementation done in the Ivory Coast, the soil had been left in natural fallow and the weed *C. odorata* had overgrown eliminating the other species. The following year in vitro plantlets were planted. After 2.5 years of banana cultivation there was no apparent build up of *R. similis*.

Much interest exists in establishment of new production areas using in vitro propagation of banana primarily to avoid contamination of "virgin" soils by *R. similis*. The establishment of banana plantations using plants from in vitro culture has been done in Algeria and Morocco, where bananas usually are cultivated in large greenhouses, and in Egypt and Yemen on a larger scale (more than 300 ha in Yemen). Experiments are currently being conducted in Mauritania, Guinea Bissau, Congo, Gabon, Zimbabwe, Reunion, and Comores to evaluate production, economic feasibility, and pest control with material propagated using in vitro culture.

Control measures after planting: Propping and guying are used currently in Africa for dessert banana production to avoid, or at least limit, uproot losses. In West Africa, propping is typically done with either two crossed bamboo poles or sometimes only one (vertical propping). In South Africa, guying is used more widely.

Presently, nematode control practices after planting involve use of nematicides. Through the mid 1980's the compounds used most widely were fenamiphos and isazophos. The use of ethoprop diminished during the 1970's since it's efficacy was not as great as the other two compounds. Carbofuran was abandoned after a few years of use, due to a sharp decrease in efficacy (57) which may have been a consequence of accelerated biodegradation. Aldicarb and oxamyl have been evaluated more recently (55,56). Oxamyl is applied in a liquid formulation to the soil with a spot-gun or directly to the leaf axis or to the pseudostem after harvest (4). The most recent introduction was cadusafos, a non-systemic organophosphate which offers a promising new nematicide able to control nematodes in banana plantings.

The optimum time of application, dose, and number of applications per year is determined by the nematode population dynamics and nematicide efficacy (persistance, edaphic, and climatic factors). In Cameroon and the Ivory Coast the amount of nematicide applied annu-

ally is split into in three applications (37,55,57,66,67); however, two applications may be sufficient in other areas such as in Somalia (Vilardebo, pers. comm.) or in South Africa (26) where climatic and edaphic factors are not as favorable to nematodes. These applications are made during intermediate seasons, avoiding the peak periods of the rainy and dry season (37,68). The optimum time of application will allow a good penetration and diffusion of the compounds into the soil without or with limited run off and/or leaching. Better control is expected since both plant and nematodes are more active during the intermediate periods (68).

Drip irrigation is beginning to be used in some banana plantations in the Ivory Coast. This allows liquid nematicide formulations to be applied directly into the irrigation system, thus reducing the cost of application and obtaining better distribution of the nematicide in the rhizosphere. In case of granular applications, the release of the active ingredient can be controled more effectively when using drip irrigation systems.

SOIL FACTORS AFFECTING NEMAIODE CONTROL AND NONTARGET EFFECTS OF NEMATICIDES

Physical factors: Granules need a certain amount of water to release their active ingredient into the soil, but heavy rainfall will increase the risks of run off and/or leaching of chemicals. Very simple cultural techniques, such as mulching, may minimize these risks. The development of drip irrigation may provide an effective solution to these problems by permiting treatments during dryer periods. However, this practice is expensive and can only be adopted in export banana production and other highly profitable enterprises.

In soils with a high level of organic matter, such as the peat soils of the Nieky Valley in the Ivory Coast, the active ingredients of nematicides are adsorbed. Thus, the efficacy of chemical treatments is reduced greatly (19,57).

Biological factors: In the mid-1980's, about ten years after nematicide treatments were applied regularly in banana fields, growers and researchers experienced a decrease in fenamiphos efficacy (54). The phenomenon was observed in plantations where this product had been used exclusively for some time. A similar situation has occured in banana plantations in Central America (2,3). This loss in efficacy did not appear where growers had made alternate applications of isazophos and fenamiphos, indicating that rotation of chemicals is a sound management practice that is recommended currently in large banana operations (2,3,54).

Soil microbiological studies have revealed the appearance of specialized microorganisms capable of rapid degradation of the

fenamiphos molecule in soils treated during a long period of time with this compound (2,3). A similar phenomenon was demonstrated with carbofuran in other crops (2,3,16,21,46) which could explain the decrease in efficacy of carbofuran observed 10 years earlier on banana farms (57). Accelerated biodegradation problems have been reported for different carbamate and organosphosphate pesticides (2,3,21,46).

Nontarget effects of nematicides: Many nematicides are suspected of producing nontarget effects which affect the physiology of plant. Such action may be beneficial, as with isazophos which is generally less effective as a nematicide than fenamiphos and aldicarb, but which generally gives an equivalent yield (55,57). In other cases, nontarget effects may be depressive, as has been noted for carbofuran and, more clearly, for aldicarb (55). The effects observed with the latter two nematicides were similar. Both caused good vegetative growth, but their use resulted in a reduction in the number of hands (55). Similarly, carbofuran has a major depressive effect on flowering of pineapple and on development of the fruit (fruitlet number) (50). These observations should lead to additional studies that will increase understanding of physiological interactions and thus, more knowledgeable use of nematicides to avoid deleterious nontarget effects.

PRESENT AND FUTURE PERSPECTIVES

The majority of the studies on banana nematodes carried out in Africa have been conducted on 'Cavendish' type bananas, which are grown for export markets. This research activity has been reduced significantly in recent years but continues with good cooperation between research teams in French speaking West Africa and the Caribbean (Martinique and Guadeloupe) (53). The most important research projects in progress deal with nematode-fungal interactions, screening bananas and plantains for nematode resistance, cultural practices, in vitro propagation, and pathogenicity studies (53). Nematode interaction studies with soil fungi, their physiological response to the different banana cultivars and the dynamics of reinfection after introduction of clean planting material are being conducted in the Ivory Coast, Martinique, and Montpellier, France (53). The research includes both laboratory and field studies.

Breeding for resistance to nematodes is perhaps the most complex and long-term area of research in nematode control. The difficulty of working with a plant that is as genetically complex as banana probably has been the main obstacle in producing resistant cultivars (43,61). Long-term funding and the adoption of proper screening methods for lesion-forming nematodes also are essential (17,43,61). A new breeding program, supported by the European Economic Community, has been initiated in Guadeloupe in cooperation with French, Belgian, and West

African laboratories. This program involves several new approaches: hybridization from new diploids collected from Papua New Guinea and Southern Asia and use of in vitro methods such as somaclonal embryogenesis, callogenesis, neoformation, and protoplasts (63). Screening of germplasm for resistance to lesion-forming nematodes is being conducted in Montpellier, France, and will later be carried out in Guadeloupe. This program also includes germplasm that has resistance to other important pests and diseases, especially Black Sigatoka (Black Leaf Streak) caused by *Mycosphaerella fijiensis* Mulder and Stover, considered to be the most important limitation to *Musa* production on a worldwide basis.

Emphasis is being placed on cultural practices oriented towards small-size plantings. Of special interest is the cultivation of food crops compatible with bananas in an intercropping system. Other studies are exploring the use of cover crops and improving the efficiency of fallow and flooding (53).

The use of in vitro techniques for establishing commercial banana plantations in Africa has been successful. The complementation of this pest-free propagation method with other cultural practices is one of the main topics of study in West Africa and the Antilles (53).

Although few pathogenitiy studies are currently in progress, there is a need to determine the damage that several nematode species, especially members of the genus *Pratylenchus*, actually cause to plantains and some local banana types. It also is important to determine if pathotypes exist among the African populations of *R. similis*. Variability of this nematode was demonstrated in Central America and the Caribbean where several pathotypes are recognized (41,47,48,62).

Starchy bananas are important socio-economic crops at the small and subsistance farmer level. Unfortunately, little research has been done to improve productivity. Increasing efforts have begun in recent years through surveys in the Ivory Coast (1,51) and East Africa (59,70). The establishment of a world research network as proposed by International Network for the Improvement of Banana and Plantain (INIBAP) should contibute to support and coordination of these research efforts. The INIBAP workshop on nematodes and rhizome borers held in Bujumbura, Burundi in 1987 made some interesting proposals for nematode management and research programs focused on cooking bananas (5). Perhaps, the most immediate priority is to increase knowledge of the impact of nematodes in the traditional cropping systems for species such as *H. multicinctus* and *P. coffeae* in the lowlands and *P. goodeyi* in the highlands in order to establish adapted management systems for their control. Of equal importance is the interrelationship of nematodes and the banana weevil, *C. sordidus*, in the destruction of rhizomes. Another important consideration is to avoid dissemination of

R. similis. Many in areas Africa are free of this pest. It is, therefore, of prime importance to protect them from infestation through the use of nematode-free rhizomes, the main source of propagation. The establishment of plantations and small household orchards with certified plants (in vitro plantlets) is desireable and certainly the most highly recommended way to control soil-borne pests of banana and plantain. However, this difficult task is complicated by the propagation requirements of the different local types of *Musa* preferred by small farmers and damage due to improper handling and extensive distribution of planting material. For this purpose, the role of INIBAP and other international organizations is essential in helping local authorities in quality control and distribution of nematode-free planting material.

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