REVIEW - RESEÑA

SOME CONSIDERATIONS OF PROBLEMS ASSOCIATED WITH THE NEMATODE PESTS OF BANANAS. [ALGUNAS CONSIDERACIONES DE LOS PROBLEMAS ASOCIADOS CON LOS NEMATODOS PLAGAS DEL BANANO].

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ABSTRACT

The importance of the principal nematode pests of dessert bananas is considered. Worldwide *Radopholus similis* is the most damaging species. The effect of nematodes on production is examined. It is apparent that damage is more severe in some localities possibly because of differences in virulence of *R. similis* but also because of varying soil and climatic factors. Rainfall will influence nematode populations, but other environmental and management factors should be considered simultaneously. At present, chemical control is the only realistic means of combating nematodes in such an intensive crop although breeding for nematode resistance should receive greater emphasis. Pre-planting treatments of banana corms are tedious and not always effective; the use of non-volatile nematicides in planting holes is the currently favored practice. Reviews of results using granular non-volatile nematicides and DBCP in established plantings are given. Future work should be directed towards refining methods of application, dosages, formulations and frequency of treatment as well as some coordinated studies on the effect of nematicides, on root development and plant nutrition.

Key Words: Musa, plantains, population dynamics, fumigants, systemic and granular nematicides, resistant varieties.

INTRODUCTION

The genus *Musa* L. originated in South East Asia. Selection and cultivation of varieties during ancient and medieval times led to the gradual spread of the edible forms to Middle Eastern and African societies. It is considered unlikely that bananas reached the Americas in pre-columbian times (41, 48).

Dessert bananas are an important agricultural export crop in some Central and South American countries, the West Indies and parts of Africa and Asia. Bananas are also important as a staple crop with a number of clones used for cooking and referred to as plantains. These clones may have certain genome differences from the dessert forms (47).

All known varieties of banana appear to be susceptible to species of parasitic nematodes of which *Radopholus similis* (Cobb) is the most important. *Helicotylenchus multicinctus* (35, 36, 44), *Meloidogyne sp.* (1, 36, 44), *Pratylenchus coffeae* (24) and *P. goodeyi* (24) can also cause problems.

DISTRIBUTION AND DAMAGE CAUSED BY THE PRINCIPAL NEMATODE SPECIES

Cobb first discovered *R. similis* on banana roots in Fiji in 1893 (4). The species is not endemic to the New World (46) and was probably introduced with plant material many years ago. Subsequent distribution throughout Central and South America and the West Indies has almost certainly been associated with expansion in the cultivation of bananas. The parasite has been reported to reproduce on a number of crops and weeds in Central America (11). The existence of different races has been known for some time (6, 50, 56). Within the race or races specific to banana it seems likely that there are populations with varying abilities to infect other hosts as well as banana. It is now believed that *R. similis* populations in Honduras are less damaging to banana than those in neighbouring Panama (38).

R. similis is absent in some banana growing countries such as Israel, the Canary Islands, Cyprus and Taiwan where one or more of the other species can be quite important (24, 35, 36, 50, 56). *H. multicinctus* is widely distributed in banana plantations and may be numerically dominant to *R. similis* in localities where the species coexist (Gowen, unpublished). Like *Meloidogyne* spp., *Helicotylenchus* spp. are widely distributed and occur on a large number of native and or cultivated plants.

Meloidogyne spp. are probably suppressed by high populations of *R. similis* and *H. multicinctus* which cause extensive root destruction, It is probable that infestations of *Meloidogyne* spp. and *R. reniformis* are overlooked because the greater population densities occur in the feeder root system at some distance from the pseudostem (8, 37).

Rotylenchulus reniformis is found in secondary and tertiary roots in the West Indies and also in association with common weeds of banana fields. The extent to which *R. reniformis* and *Meloidogyne* spp. affect yields has not been established.

The migratory endoparasitic nematodes *R. similis, H. multicinctus* and *P. coffeae* enter banana roots either from soil or through the corm tissue. Root infection is mostly at the tip although *R. similis* may penetrate roots throughout the entire length (3). Primary roots that pass through sites of nematode infection in the corm will also become infected; probably in ratooning bananas most primary roots are infected in this way. In general *H. multicinctus* lesions are more superficial than those of *R. similis* and *P. coffeae* (3). All three species are confined to the root cortex and do not penetrate the vascular tissue.

Root and corm lesions provide sites for several pathogenic fungi (49) which probably hasten the destruction of the tissues. Primary roots may not be infected throughout the entire length and some root function is maintained even if lesions encircle the vascular tissues.

Nematode infected plants are susceptible to uprooting particularly if they are bearing a fruit which causes a great strain on the proximal parts of the primary roots. Uprooting will often occur in winds or after heavy rains have loosened the soil. On fallen plants it is usual to see the remnants of moribund roots which have snapped close to the base of the corm.

The Host Plant

The banana plant is a giant, vegetatively propagated, perennial herb. Once a 'plant' has produced a fruit that particular individual senesces, its root system decays and growth continues from a lateral shoot which develops a new and distinct root system. A new shoot will grow and produce a fruit within 6-9 months, in which time the corm will have grown to approximately 30-40 cm in diameter at soil level supported by 200-500 roots. These primary roots may extend 3-4 metres and the majority will be found in the upper 20-30 cm of soil.

The effect of nematodes on growth and vigour of banana plants is not always apparent. The banana plant can be quite resilient and a plant with a high incidence of root infection may appear as healthy as plants suffering from only minor populations often resulting in no difference in bunch weights (Table 1). However, there may be an overall yield improvement because the main indication of nematode attack in bananas is the total loss of production when an infected plant falls over before the fruit is ready for harvest. In some localities where differences in bunch weights between nematicide-

Table 1. Some examples of of nematode control not affecting bunch weights of fruit at harvest.

Locality	Age of plan-tation (years)	Nematodes per 100 g roots x 100		Bunch weight (kg)		Overall yield improve-ment
		Control	Treated	Control	Treated	%
St. Lucia Gowen unpublished data	1	12	4	22.9	23.4	20
Ecuador Gowen unpublished data	5	30	13	42.5	42.6	24
Costa Rica Figueroa & Mora 1977	7	77	37	35.3	34.3	32

treated and non-treated plants (Table 2) are substantial, a lower incidence of uprooting in treated plants must be taken into account. However, data on uprooting are scarce (Table 3) despite their value for interpretation of nematicide efficacy.

The levels at which nematodes cause economic losses are difficult to define and may vary between seasons of the year and certainly between different sites and populations. Incidence of uprooting will be greater in high-risk areas affected by winds or having loose textured soils.

The apparent differences in pathogenicity as reflected by bunch weights are puzzling and it is possible that in addition to differences in virulence of *R. similis,* ecological or nutritional factors may also be involved.

Assessment Methods

Numbers of *R. similis* in soil are characteristically small and their estimation is of little importance. In the Windward Islands where *H. multicinctus* and *R. reniformis* are present, populations of these species per 100 cm^3 soil may be in hundreds or thousands respectively (Gowen, unpublished data). Standard incubation or centrifugation extraction procedures are adequate for such assessments (28, 58).

The choice of extraction method for root populations may be based on laboratory facilities available. Incubation methods (52) have been improved upon (21) and provide consistent results. These methods are particularly suited to laboratories which are limited in the technical help available. Methods based on comminution and sieving (42, 53) are efficient but require trained personnel, a constant source of tap water and exacting procedures for washing root debris and sieves. Also, the final extract needs to be diluted or centrifuged to obtain clear aliquots for counting.

Ideally samples should be processed on the day of collection as populations may

Table 2. Beneficial effects of applying nematicides with respect to bunch weights and general yield improvement.

Locality and Source	Age of plantation (years)	Bunch weight (kg)		Overall yield improvement %
		Control	Weight	
Panama Wehunt & Edwards, 1968		25.3	31.2	86
St. Vincent Hunt, 1977 (Winban report unpublished)	2	20.6	29.9	267
Ecuador Gowen, 1978 (INIAP report unpublished)	2	33.3	41.6	71
Cameroons Melin and Vilardebo 1973	3	21.8	25.5	38

decline or increase with storage which can affect species differently (59).

The variability in the number of nematodes recovered from banana roots can be great and of difficult interpretation. Variability could be lessened by more intensive sampling. Improved accuracy and reduced labour requirements could be obtained by reliance on methods to assess damage visually. However, it is unfortunate that more attention has not been given to visual means of assessing nematode attack either by evaluations of lesions on corm tissue (50) or on primary roots (39).

Dynamics of Populationsof *R. similis*

Routine assessments of nematode populations in the roots have usually the objective of evaluating control treatments or determination of needs for subsequent nematicide applications. In addition workers have sought to define seasonal variations in populations of *R. similis* or relations between physiological stages of the host and changes in populations of the nematode. In Costa Rica highest endoparasitic populations occur when there are frequent showers permitting good root growth; since, generally, populations decline when the soil is saturated (27). On the other hand, Vilardebo (54) found that in the Cameroons *R. similis* populations are greatest soon after flowering when rainfall was high. Presumably growing conditions in West Africa are quite different from those in Central America. Whilst root populations of *R. similis* might

Table 3. Production data from different localities where toppling accounts for much of the losses.

Locality and Source	Crop cycle	Production yield as % *of* control	No. of plants toppled %	
			Treated	Untreated
St. Vincent[1] Hunt, 1977 Winban Report unpublished	Second ratoon	367	1	50
Ecuador[2] Gowen, 1978 INIAP Annual Report unpublished	First ratoon	183	4	29
St. Lucia[3] Gowen, 1975	Second ratoon	146	0	9
Ivory Coast[4] Guerout, 1974	Second ratoon	376	+	+

[1]St. Vincent: ethoprop 3g a.i./plant/4 months
[2]Ecuador: ethoprop 3g a.i./plant/4 months
[3]St. Lucia: ethoprop 5g a.i./plant decreased to 3g a.i. after first ratoon was harvested

[4]Ivory Coast: 35 percent of the untreated plants failed to produce a bunch as compared with 100 per production i.e. no losses in the treated plots. Treatment: ethoprop 5g a.i./plant/4 months

fluctuate rhythmically, the relations between climate, soil and host physiology with the nematode are not well defined. As *R. similis* is essentially an endoparasite which can complete the life cycle within roots, any factor influencing the size of population is likely to be related to changes in the host condition or physiology.

Under favourable conditions *R. similis* can reproduce new generations in about 3 weeks (30). Population peaks in individual roots probably occur quite rapidly and numbers decline as the volume of available cortical tissue becomes limiting.

With bananas growing under irrigation, the nematodes probably benefit as much as the host crop so the choice of timing for control measures is most likely determined by convenience, economics and persistence of the nematicide rather than the state of the nematode populations.

Although *R. similis* females or juveniles may migrate from banana roots, the numbers of individuals recovered from soil taken from around infected roots, do not suggest the existence of large endemic free-living populations. In the laboratory, *R. similis* will not be active in tap water for more than a few hours, implying intolerance to low levels of oxygen; presumably changes in oxygen levels in the soil greatly influence activities and survival of free-living individuals. Poor survival in soil would partly account for the wide fluctuation in populations which can occur in root samples from the same source. If the main source of infection is from the corm and each infected root is considered as a discrete colony which increases by spreading laterally along the root rather than by migration of individuals to neighbouring roots, then roots which are uninfected are likely to remain so.

Control by cultural, physical and dip treatments

Control of *R. similis* by cultural and physical methods has been examined exhaustively (29, 31). In land maintained free of host plants, *R. similis* disappears within 6 months (51). This information led to investigation of methods for eliminating nematode infection in banana planting material by peeling, chemical dips and hot water treatment of corms. It was thought that if *R. similis*-free material was planted in uninfested land, a new plantation could be kept free of the nematode. Commercial application of this approach has not been successful. Even if preplanting treatments eliminate infection (which is unlikely), reinfection from adjacent plantations is always a probability. This method is only likely to be completely successful when a small quantity of banana material is totally disinfected and is used as the nucleus for an isolated nematode-free nursery.

Currenlty, few banana exporting countries are expanding areas of production, although there is room for increased production of bananas and plantains, as alternative subsistence and local market crops. Wherever plantings are planned, techniques for vegetative propagation (26) by which large numbers of plants can be produced in a relatively short period of time should provide a good opportunity for disseminating banana plants free of *R. similis*. There is some reason to suspect that *R. similis* infections in banana plantations establihsed recently in Belize (40) could have been avoided by use of known technology.

Dip treatment of corms with DBCP (1, 2-dibromo-3-chloropropane) was a common practice in many countries (7, 13, 50) but is probably infrequent today since new granular nematicides applied in the planting hole are as effective and less laborious. Some phytotoxicity with the use of DBCP dips was reported in the West Indies and dipping was replaced by soil injection treatments 6-8 weeks after planting (9). Crop rotation for nematode control is not feasible in a perennial such as banana and studies have indicated that such practices are uneconomic (34, 43).

Nematode resistance

Almost all dessert bananas grown commercially are similar genetically (47); the majority belong to the Cavendish sub-group of the triploid group, *Musa* AAA. The remainder of the group includes Gros Michel and some other clones of minor importance (47).

All known *Musa* AAA clones are susceptible to *R. similis* and other important nematode species although the idea persisted for many years that Gros Michel bananas are less susceptible to *R. similis* than those in the Cavendish subgroup. This idea may have resulted from the increased incidence of *R. similis* damage which occurred throughout tropical America as a result of the widespread and rapid change from Gros Michel to the Panama disease resistant Cavendish clones. However, root inoculation tests have not shown differences in susceptibility between the subgroups (18). It has been suggested that Gros Michel is more tolerant to *R. similis* because of its greater vigour and greater resistance to uprooting by winds. Gros Michel apparently produces more roots than Cavendish clones (55). *R. similis* is absent in some Gros Michel plantations in central Ecuador. Conceivably the distribution of *R. similis* increased when Cavendish clones were introduced into commercial plantations. In the past, distribution of *R. similis* in Gros Michel may have been controlled inadvertently by methods used to obtain material free of Panama disease (55) which involved rigorous paring and selection of the planting material that may have helped to eliminate endoparasitic nematodes.

With no known resistance to *R. similis* in the triploid clones, some attention has been given to the search for nematode resistance in diploids *Musa* AA (18, 39, 57). However, presently, no artificially produced commercial clone, specifically resistant to nematodes, has been developed although there has been some success in breeding for clones resistant to fungal pathogens (45).

A wild diploid with resistance to *R. similis* (but not to species of *Pratylenchus* or *Meloidogyne)* has been reported (39) but the incorporation of any such resistance in a commercially acceptable dessert fruit is probably still many years away.

Chemical Control

At present, chemical control of nematodes by repeated applications of nematicides seems the only effective treatment. Early work on chemical control in banana plantations was based on soil injection of the available fumigant nematicides (32). The use of DBCP in established bananas varies from country to country and results of some experimental work are summarised in Table 4.

Fumigant injection is usually made to a depth of 15-20 cm and a number of injections are effected in a semi-circle 30-45 cm from the base of each plant. In parts of Central and South America, a second series of injections is made at 60 cm, but the economic value of such a laborious task is doubtful.

Granular formulations of non-volatile nematicides have several advantages over the fumigant DBCP; they are easily applied by sprinkling on the soil and efficiency is not affected by the soil condition at the time of application. However, rainfall or irrigation is needed to transport the active ingredient into the soil. Early experimentation with these new compounds was encouraging once the timing of applications was determined. Annual applications of phenamiphos (Nemacur) did not provide sufficient yield response (10) and even treatment at 6-month intervals did not result in adequate nematode kill (10, 22, 33). Subsequently, dosages of either 3g a.i. phenamiphos or 5g a.i. ethoprop (Mocap) applied at 4-month intervals were found to be effective when their use was started at planting (17, 23). Recent work has indicated that good control of nematodes and increased yields might be expected from the use of any of the granular nematicides registered for use on bananas at dosages of 2-3 g a.i. per plant applied every 4 months (Table 5). There is some reason for believing that the frequency of application can be decreased to 6-month intervals (5, 12) 25) although the level of nematode control may not be as satisfactory (33, Hunt pers.com.).

Much of the original work with granular nematicides was done in new plantations (15, 16, 22, 33) probably because in some countries replanting is or has been considered a necessity every 5-8 years. Also, it is difficult to perform banana experiments in established plantations because of heterogeneity in banana spacing and in density and development of plants. The application of nematicides in planting holes (16, 23) provides the benefit of satisfactory control from the early stages of plant growth.

In established ratooning bananas, with high populations of nematodes in the roots, good nematode kill is more difficult to achieve and the effectiveness of the granular nematicides under these conditions has not been convincingly demonstrated. The failure of surface applications of granular nematicides to provide adequate control in roots may be due to the relatively shallow penetration of these products (20) under conditions of low rainfall or inadequate irrigation. Under such conditions control by injec-

Table 4. Yield improvements with the use of DBCP in different banana growing countries.

Country and Source	Dose/ plant (ml)	Dose / ha (litre)	Frequency of application in months	Improvement over non-treated %
Honduras Wehunt and Edwards 1968		9.5*	4	15
Panama Wehunt and Edwards, 1968		7.6*	4	86
Cameroons Melin and Vilardebo 1973	4.0*	9	6	25-149
Madagascar Beugnon and Vilardebo 1973	4.0		6	42
St. Lucia Gowen 1976	5.7*	9.7	6	14
St. Vincent Gowen 1975	6.6*	11.2	6	30
St. Vincent Gowen 1975	15.0*	25.5	6	50

* Subsequent dosages of 3.78 litres/ha
*Nemagon 75% EC

tion of DBCP to depths of 15-20 cm results in better control.

The organophosphate and organo-carbamate nematicides may be effective at dosages of 0.5 mg a.i./kg in soil and can prevent nematodes from attacking banana roots at concentrations of 1-5 mg/kg soil (20). The concentrations in the superficial soil layer around treated banana plants probably exceed these levels for several weeks after treatment. Some of these nematicides are systemic and cause the decline of populations established within roots but there is no evidence to suggest that the active material is

Table 5. Non-volatile nematicides registered for use on bananas and their effective dosages and frequencies of application

Product	Status of plan- tation	Dosage a.i. g per plant	Frequency of appli- cation (months)	Yield % of Control	Country and Source
Phenamiphos	new	3	4	129	St. Lucia Gowen, 1978
"	"	3	4	122	St. Lucia Hunt, 1977 Winban Report unpublished
"	"	2	4	137	St. Lucia Winban Report Hunt, 1977 unpublished
"	"	3	4	361	St. Lucia Hunt, 1977 Winban Report unpublished
"	"	2.5	4	254	Ivory Coast Guerout, 1974
"	"	5	6	132	Cameroons Melin and Vilardebo 1973
Aldicarb	"	3	4	170	Ecuador Gowen, INIAP Report 1978 unpublished
"	Establi- shed 5 years	3	4	123	Ecuador Gowen, INIAP Report 1978 unpublished
"	7	3	6	132	Costa Rica Figueroa and Mora, 1977

Table 5 - Continued

"	7	2	6	132	Costa Rica Figueroa and Mora, 1977
Carbo-furan	new	1.5	4	120	St. Lucia Hunt, 1977 Winban Report unpublished
"	"	2.0	4	109	St. Lucia Hunt, 1977 Winban Report unpublished
"	"	2.0	4	349	St. Vincent Hunt, 1977 Winban Report unpublished
"	"	2.5	4	128	St. Lucia Gowen, 1978
Ethoprop	"	3	4	367	St. Vincent Hunt, 1977 Winban Report unpublished
"	"	3	4	172	Ecuador Gowen, INIAP Report, 1978 unpublished
"	Establi-shed 5 years	3	4	116	Ecuador, Gowen, INIAP Report 1978 unpublished
"	new	5	6	130	Camerons Melin and Vilardebo 1973

translocated to other roots. The systemic activity is apparently dependent on continuous contact between roots and nematicide (Gowen, unpublished data).

Nematicides in Irrigation

The application of DBCP through irrigation water (14) has been tried in bananas

(56) but there is little published on the subject. In Ecuador, DBCP has been applied through overhead sprinkler systems at 32-36 litres/ha every 6-months. Applications are usually made in the evenings and water is applied before and after delivery of the nematicide. Several of the non-volatile nematicides are available in liquid formulations and probably have a future when used in irrigation but their use with sprinklers or flooding may pose severe environmental and toxicological questions. Ideally, liquid formulations will be at their most efficient in drip-irrigations systems.

Research Priorities for the Future

It is possible that other nematodes parasitic on bananas will be found but it is unlikely that future surveys will reveal any species that have a greater worldwide importance than *R. similis*. The time has come for more collaborative work with other disciplines to understand more why *R. similis* causes serious problems in some localities (high risk areas) and not in others, to determine the relative virulence of populations of the nematodes, and the effects of ecological factors on the expression of nematode damage.

It is known that a plant produces up to 500 primary roots but, under certain circumstances, subjective observations would suggest that a plant can produce an acceptable fruit with less roots. The root damage thresholds and even the functional longevity of a healthy root are still important unknowns.

The last 20 years has seen the development of several chemicals for control of nematodes. Although proven to be effective, the use of these nematicides for bananas may be limited for economic or toxicological reasons and their efficiency cannot be guaranteed for all situations. Future work must lead to refinements in application methods, dosages, formulations and frequency of treatment.

The non-volatile nematicides have an effect on the rate of fruit production (15, 23) which is difficult to explain and requires further investigation. Possible interactions of fertilizers and nematicides and their relation to root efficiency and growth provide areas for some interesting research.

Banana nematologists are always faced with the dilemma posed by the use of props to support bunches in nematicide trials and the risk of masking overall effects on yields by decreased incidence of toppling. Irrespective of nematode damage, propping is essential to prevent losses from breakage of the pseudostem; it might be argued that under certain (as yet undefined) conditions in which plant growth is vigorous and management is at a high level, the application of a nematicide as well as propping may not be economically justified. Only some long established field trials would answer some of these rather important queries.

For the majority of growers and research workers there is little doubt to the value of applying nematicides and it is unlikely that they will be replaced by other methods of control at least for the immediate future. Breeding for nematode resistant varieties is a long-term objective worthy of more attention. The dangers of maintaining such an important crop as bananas on one genetic type should be sufficient to encourage overall genetic improvements (48).

RESUMEN

La importancia de los principales nematodos de banana dulce es considerada. A través del mundo *Radopholus similis* es la especie más dañina. El efecto de nematodos en producción es examinado. Es aparente que el daño más severo en algunas localidades es quizás debido a diferencias en virulencia de *R. similis*, pero también debido a factores variantes de tierra y clima. Las lluvias influencian las poblaciones de

nematodos, pero otros factores de medio ambiente y dirección deben ser considerados simultáneamente. Actualmente el control químico es el único medio de combatir nematodos en cultivo tan intensivo, a pesar de esto el mejoramiento para resistencia de nematodo debe recibir un énfasis mayor. Tratamientos de pre-siembra de cormos de banana son tediosos y no siempre efectivos; el uso de nematicidas no volátiles en el hoyo de siembra es la práctica favorable usada corrientemente. Se presenta un examen de los resultados obtenidos sobre el uso de nematicidas granulados no volátiles y DBCP en plantaciones establecidas. Trabajos futuros deberán ser dirigidos hacia métodos de aplicación refinados, dosis, formulaciones y frecuencia de tratamiento como también algunos estudios coordinados sobre el efecto de nematicidas en el desarrollo de raíces y nutrición de plantas.
Claves: Musa, plátanos, dinámica de poblaciones, fumigantes, nematicidas granulados y sistémicos, variedades resistentes.

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