Parasitic nematodes on *Musa* AAA (Cavendish subgroup cvs ‘Grande naine’, ‘Valery’ and ‘Williams’)

*M. Araya*¹ and *T. Moens*²

**Abstract**

Among the biotic factors affecting yield, banana-root nematodes are second only to black Sigatoka (*Mycosphaerella fijiensis*). The three commercial cultivars, ‘Grande naine’, ‘Valery’ and ‘Williams’ are equally susceptible, and in plantations in Costa Rica usually only polyspecific communities occur, consisting of a mixture of the migratory endoparasitic *Radopholus similis* and *Pratylenchus coffeae*, the ecto-endoparasitic *Helicotylenchus multicinctus*, and the sedentary endoparasitic *Meloidogyne incognita*, or rarely *M. javanica*. Based on their frequencies and population densities the relative importance of nematode genera in Costa Rica was established in decreasing order as follows: *R. similis* > *Helicotylenchus* spp. > *Meloidogyne* spp. > *Pratylenchus* spp. *R. similis* is the most abundant nematode, accounting for 82 to 97% of the overall root population. High populations of *R. similis* are found throughout the year and in all counties producing bananas. The nematodes damage the root and corm tissue. *R. similis* enters the root mainly by the root tip, but any portion of the entire root length may be invaded. Adults and juveniles occupy an intercellular position in the cortical parenchyma, in which they move actively, causing damage as they feed on the cytoplasm of the surrounding cells. The four nematode genera develop and complete their life cycle inside the banana roots. In highly infected roots, *R. similis* sometimes crosses the endodermis and invades the stele. Reddish brown lesions appear throughout the cortex. In some Costa Rican banana growing areas, crop losses on nematode infected plantations can be high, up to 30-50%. Infected plants have poor root anchorage and the ability of the root system to take up water and nutrients is reduced, which results in losses in bunch weight and crop longevity, and a lengthening in the plant production cycle. Pathogenicity studies have shown that *R. similis* restricts banana root system growth and reduces the concentration of K in the root dry matter. All the phenological stages can be infected by any of the four genera, but again, *R. similis* is the most frequent and the most abundant at any stage. Even the roots of very small peepers (suckers 10 cm high) can be infected, and in the case of *R. similis*, it is common to find nematodes in the corm tissue also. This suggests that root infection of these young suckers in infected plants is caused by either *R. similis* coming from the corm or from the soil.

**Resumen - Nematodos parásitos de *Musa* AAA (subgrupo Cavendish cvs ‘Grande naine’, ‘Valery’ y ‘Williams’)**

Entre los factores bióticos que afectan el rendimiento en banano, los nematodos son el segundo en importancia después de la Sigatoka negra (*Mycosphaerella fijiensis*). Los tres cultivares comerciales ‘Grande naine’, ‘Valery’ y ‘Williams’, son igualmente susceptibles y en las plantaciones locales, usualmente solo comunidades polyspecíficas ocurren, consistiendo de una mezcla de los endoparásitos migratorios *Radopholus similis* y *Pratylenchus coffeae*, el ecto-endoparásito *Helicotylenchus multicinctus* y el endoparásito sedentario *Meloidogyne incognita* o raramente *M. javanica*. Basado en las frecuencias y densidades poblacionales, la importancia relativa de los géneros de nematodos en Costa Rica se estableció en orden decreciente como sigue: *R. similis* > *Helicotylenchus* spp. > *Meloidogyne* spp. > *Pratylenchus* spp. *R. similis* es el nematodo más abundante y representa de un 82-97% de la población total en las raíces. Altas poblaciones de *R. similis* se encuentran durante todo el año en todos los cantones productores de banana. El daño
se localiza en las raíces y cormo. *R. similis* penetra las raíces principalmente por la parte terminal (caliptra), pero cualquier parte de la raíz puede ser invadida. Adultos y juveniles ocupan una posición intercelular en el parénquima cortical donde ellos se mueven activamente causando daño conforme se alimentan del citoplasma de las células vecinas. Los cuatro géneros de nematodos se desarrollan y completan su ciclo de vida dentro de las raíces de banano. En raíces altamente infectadas, *R. similis* algunas veces pasa la endodermis e invade el cilindro vascular. Coloraciones café rojizas aparecen a través de toda la corteza. En algunas plantaciones locales infectadas las pérdidas en rendimiento alcanzan hasta un 30-50%. Plantas infectadas carecen de buen anclaje y la habilidad de las raíces para absorber agua y nutrientes se reduce, lo que resulta en pérdida de peso del racimo y longevidad de la planta y se alarga los intervalos entre ciclos de producción. Estudios de patogenicidad muestran que *R. similis* restringe el crecimiento del sistema radical y reduce la concentración de K en las raíces. Todos los estados fenológicos de la planta de banano pueden ser infectados por cualquiera de los cuatro géneros, pero nuevamente *R. similis* es el más frecuente y abundante en cualquier estado de desarrollo de la planta. Aún raíces de hijos muy pequeños (10 cm de altura) pueden ser infectadas y en el caso de *R. similis* es común también encontrarlo en el cormo. Esto sugiere que la infección de las raíces en hijos nuevos de plantas infectadas, ocurre igualmente de *R. similis* procedente del cormo o del suelo.

**Introduction**

Banana is an important crop in Costa Rica accounting for almost 17% of the agricultural gross national product. In 2003, 1.85 million tonnes were exported, produced on 42,000 ha, generating a total income of US $541 million FOB (Sánchez and Zuñiga 2004). Besides the constraints of banana market requirements and demands, there are other limiting factors. Among the biotic factors affecting yield, banana-root nematodes are second only to black Sigatoka (*Mycosphaerella fijiensis*). Nematodes reduce bunch weight and plant longevity, and increase the crop cycle duration (Quénéhervé 1991).

In Costa Rican plantations (Araya *et al*., 1995, 2002) usually only polyspecific communities occur, consisting of a mixture of *Radopholus similis*, *Helicotylenchus multicinctus*, *Meloidogyne incognita*, *M. javanica*, and *Pratylenchus* spp. Here we report some research results related to the parasitic behaviour and nematode damage under controlled conditions on commercial banana plantations in Costa Rica.

**Host suitability**

The commercial cultivars planted are ‘Grande naine’, ‘Valery’ and ‘Williams’, which are part of the *Musa* AAA Cavendish subgroup. All these cultivars are equally susceptible to *R. similis* (Figure 1) and their reaction to each of the other three most important

![Figure 1. *Radopholus similis* numbers in banana (*Musa AAA* subgroup Cavendish cvs ‘Valery’, ‘Grande naine’ and ‘Williams’). Each bar is the mean ± standard error of 250 root samples. Each sample contains roots of 5 plants.](image-url)
Musa parasitic nematodes is similar. This reaction agrees with pot experiments, carried out under our conditions with R. similis (Moens et al. 2003) and with the other nematodes (Araya et al. 2003). Also, other researchers found similar results, inoculating Cavendish subgroup cultivars with R. similis (Stoffelen et al. 2000, Viaene et al. 2000 and 2003), M. incognita (Pinochet et al. 1998, Van den Bergh et al. 2002a, b), P. coffeae (Viaene et al. 1998, Stoffelen et al. 1999a, 2000, Viaene et al. 2000, Van den Bergh et al. 2002a) and H. multicintus (Barekye et al. 2000).

Nematode frequencies and populations

In surveys in Costa Rica from 1994 to 1999, looking at root samples extracted from five plants on each occasion, R. similis was the most abundant nematode, ranging from 82 to 86%, while Helicotylenchus spp., Meloidogyne spp. and Pratylenchus spp. varied respectively from 8 to 10%; 5 to 9% and < 1% of the root population (Araya et al. 1995, 2002). The four nematode genera detected are well known pathogens in banana roots (McSorley and Parrado 1986, Sarah 1989, Gowen 1995, Sarah et al. 1996, Bridge et al. 1997, De Waele and Davide 1998, Marin et al. 1998).

Nematode frequency was very stable in the different years (Table 1). The highest frequency, above 95%, was always found for R. similis, followed by Helicotylenchus spp., ranging from 52 to 60%. The four nematode genera counted were detected in all counties and all months of the year. The favorable climatic conditions (Figure 2), without a dry season and only small variations in temperature, promote adequate plant growth throughout the year. This may explain the low variation observed in nematode population densities and frequencies.

Table 1. Absolute frequency by year (1994-1999) of the banana (Musa AAA) root parasitic nematodes in Costa Rica as a percentage of the total number of samples.

<table>
<thead>
<tr>
<th>Year</th>
<th>94</th>
<th>95</th>
<th>96</th>
<th>97</th>
<th>98</th>
<th>99</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of samples</td>
<td>11 688</td>
<td>10 618</td>
<td>11 253</td>
<td>10 929</td>
<td>12 707</td>
<td>14 525</td>
<td>71 720</td>
</tr>
<tr>
<td>Percentage of samples with nematode species</td>
<td>95</td>
<td>96</td>
<td>96</td>
<td>99</td>
<td>98</td>
<td>97</td>
<td>97</td>
</tr>
<tr>
<td>Mean</td>
<td>56</td>
<td>56</td>
<td>52</td>
<td>54</td>
<td>56</td>
<td>60</td>
<td>56</td>
</tr>
<tr>
<td>R. similis</td>
<td>68</td>
<td>59</td>
<td>51</td>
<td>57</td>
<td>48</td>
<td>47</td>
<td>56</td>
</tr>
<tr>
<td>Helicotylenchus</td>
<td>15</td>
<td>13</td>
<td>11</td>
<td>13</td>
<td>13</td>
<td>14</td>
<td>13</td>
</tr>
</tbody>
</table>

The distribution of the root samples per nematode population density interval clearly indicated that R. similis accounted for the highest population (Figure 3). From the 71 720 recorded root samples, only 2324 (3%) were free of the nematode and 37 489 (52%) contained more than 10 000 individuals per 100 g of roots. These high populations and frequencies were probably encouraged by the long-term banana monoculture and the affinity between this nematode and the type of commercial banana planted (Musa AAA) (Orton and Siddiqi 1973). The high populations of R. similis agree with its high reproductive fitness in vitro on carrot discs (Fallas and Sarah 1995, Stoffelen et
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M. Araya and T. Moens (1999b) and on banana plants under controlled conditions (Fallas *et al.* 1995, Binks and Gowen 1997, Stoffelen *et al.* 1999c).


*Helicotylenchus* spp. was absent in 31,608 (44%) of the samples and in only 1,779 (2%) reached levels above 10,000 nematodes per 100 g of roots (Figure 3). *Helicotylenchus* spp. populations were lower than *R. similis*, in agreement with other results (Gómez 1980). More likely, this is because this nematode does not reproduce as fast as *R. similis* and the life cycles of the nematodes differ. *H. multicinctus* was found to have a life cycle of 42 days at 28°C on *Arabidopsis thaliana* and the adult females laid 4 eggs per day for a period of 10-12 days (Orion and Bar-Eyal 1995). In contrast, the *R. similis* life cycle was completed in 20-25 days at 24-32°C on banana roots and the adult females laid 4-5 eggs per day for 15 days (Loos 1962). This means that *R. similis* could be expected to have more generations and more individuals per generation in the same period of time.

More than 33,564 (46%) samples were free of *Meloidogyne* spp. and only 1113 (2%) showed densities higher than 10,000 nematodes per 100 g of roots (Figure 3). This low population density and frequency could be related to the feeding behavior of *R. similis*. Pinochet (1977) and Santor and Davide (1992) found that the presence of *R. similis* on the galls, induced by *M. incognita*, caused deterioration and disintegration of the giant cells, which, in turn, affected the development and reproduction of *M. incognita*. 

![Figure 2. Average of 15 years (1998-2003) of the monthly mean, maximum and minimum temperature (°C) and rainfall (mm) in a Costa Rican export banana-growing area.](image-url)
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<table>
<thead>
<tr>
<th>Nematodes per 100 g of roots</th>
<th>Radopholus similis</th>
<th>Helicotylenchus spp.</th>
<th>Meloidogyne spp.</th>
<th>Pratylenchus spp.</th>
<th>Total nematodes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 a 2500</td>
<td>2324</td>
<td>0</td>
<td>0</td>
<td>0</td>
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<tr>
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<td>8046</td>
<td>8080</td>
<td>0</td>
<td>1205</td>
<td>9931</td>
</tr>
<tr>
<td>5001 a 10000</td>
<td>8248</td>
<td>3823</td>
<td>850</td>
<td>4</td>
<td>12584</td>
</tr>
<tr>
<td>10001 a 20000</td>
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<td>1444</td>
<td>0</td>
<td>0</td>
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</tr>
<tr>
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<td>20113</td>
<td>16012</td>
<td>251</td>
<td>0</td>
<td>22977</td>
</tr>
<tr>
<td>&gt; 50000</td>
<td>1364</td>
<td>325</td>
<td>10</td>
<td>0</td>
<td>17019</td>
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</table>

Figure 3. Frequency of nematodes according to the specific ratios per 100 g of fresh roots in 71720 banana (*Musa* AAA) root samples recorded from 1994 to 1999. Total nematodes = *R. similis* + *Helicotylenchus* spp. + *Meloidogyne* spp. + *Pratylenchus* spp.
Pratylenchus spp. were only present in 9548 (13%) samples, with just 49 (0.08%) above 10,000 nematodes per 100 g of roots (Figure 3). This is reasonable, because Pratylenchus spp. has the same habitat as *R. similis* and a longer life cycle (Siddiqi 1972). This means that while they compete for the same feeding site, *R. similis*, with its higher reproduction rate, suppresses the growth of *Pratylenchus* spp.

When all nematodes were pooled (total nematodes), only 423 samples (1%) were nematode free and 45,256 (63%) samples contained more than 10,000 nematodes per 100 g of roots (Figure 3). Similar frequency, abundances and distributions were observed when sampling was done at flowering and harvest of individual plants on three experiments (Figures 4, 5 and 6). Only in the experiment carried out on the newest farm (Figure 6), which was planted about nine years ago, produced samples free (4%) of any parasitic nematode (Araya *et al.* 2003).

### Nematode populations according to sucker height and phenological stage of the plant

The suitability of different phenological stages of the plant for parasitic nematodes was evaluated in five experiments by sampling roots of suckers of different heights and by sampling plants at flowering, harvest and 30, 60 and 90 days after harvest (Araya *et al.* 2003). On three farms, Anabel, Calinda, and Esmeralda, no difference in the *R. similis* population was found among suckers from 10 to 350 cm height or even with recently flowered or harvested plants (Figure 7). The lowest *R. similis* population found on any of the farms and at any sucker height or plant stage, was higher than 14,000 nematodes per 100 g of roots.

Helicotylenchus spp. populations were low with the exceptions of those found on the Anabel and Nueva Esperanza farms. On Anabel, the highest populations were observed in suckers of 340-350 cm height, while on Nueva Esperanza, populations increased up to the flowering stage (Figure 8). When individual plants were sampled five times progressively (at flowering, at harvest, and 30, 60 and 90 days after harvesting), the *R. similis* population decreased as plants aged on the three farms. The lowest population was consistently found to be at 90 days after harvest (Figure 9). Nevertheless, the nematodes that remain in the harvested plants act as a reservoir and can become a source of inoculum for the other members of the plant production unit.

### Pathogenicity and symptoms of *Radopholus similis*

Moens *et al.* (2003) found a linear reduction of root weight when *R. similis* was inoculated at densities increasing from 0.14 to 2.24 nematodes per mL of substrate, corresponding to 254 to 2128 *R. similis* per pot, respectively. Root weight decreased by 3.9 g (16%) with each successive inoculation of 1000 nematodes (Figure 10A). Sarah *et al.* (1993) found that after exposing ‘Valery’ plants in 1.8 L pots to *R. similis* populations from different places around the world, root weights decreased from 19 to 80%, 8 weeks after inoculation with 300 individuals. Also, Marin *et al.* (1999), using ‘Grande naine’ plants in 1.4 L pots inoculated with 200 *R. similis* from different countries, observed root weight reductions of up to 21% after 8 weeks. Hahn *et al.* (1996) found decreases in root weight ranging from 8 to 26% in ‘Valery’ plants in 0.8 L pots 8 weeks after inoculation with 100 *R. similis*, and up to 30% 12 weeks after inoculation.
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<table>
<thead>
<tr>
<th>Nematodes per 100 g of roots</th>
<th>0</th>
<th>1 a 2500</th>
<th>2501 a 5000</th>
<th>5001 a 10000</th>
<th>10001 a 20000</th>
<th>20001 a 50000</th>
<th>&gt; 50000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radopholus similis</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>15</td>
<td>35</td>
<td>43</td>
<td>8</td>
</tr>
<tr>
<td>(0,00%)</td>
<td></td>
<td>(1,94%)</td>
<td>(14,56%)</td>
<td>(33,98%)</td>
<td>(41,75%)</td>
<td>(7,77%)</td>
<td></td>
</tr>
<tr>
<td>Helicotylenchus spp.</td>
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<td>24</td>
<td>20</td>
<td>2</td>
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<td>0</td>
</tr>
<tr>
<td>(3,88%)</td>
<td></td>
<td>(22,33%)</td>
<td>(23,30%)</td>
<td>(19,42%)</td>
<td>(1,94%)</td>
<td>(0,00%)</td>
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<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>(0,00%)</td>
<td></td>
<td>(0,00%)</td>
<td>(0,00%)</td>
<td>(0,00%)</td>
<td>(0,00%)</td>
<td>(0,00%)</td>
<td></td>
</tr>
<tr>
<td>Pratylenchus spp.</td>
<td>81</td>
<td>77</td>
<td>77</td>
<td>77</td>
<td>77</td>
<td>77</td>
<td>77</td>
</tr>
<tr>
<td>(78,64%)</td>
<td></td>
<td>(77,00%)</td>
<td>(77,00%)</td>
<td>(77,00%)</td>
<td>(77,00%)</td>
<td>(77,00%)</td>
<td></td>
</tr>
<tr>
<td>Total nematodes</td>
<td>0</td>
<td>1</td>
<td>3</td>
<td>11</td>
<td>29</td>
<td>42</td>
<td>14</td>
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<td>(0,00%)</td>
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<td>(1,00%)</td>
<td>(3,00%)</td>
<td>(11,00%)</td>
<td>(29,00%)</td>
<td>(42,00%)</td>
<td>(14,00%)</td>
</tr>
</tbody>
</table>

Figure 4. Frequency of nematodes according to the specific ratios in 103 individual banana (*Musa AAA*) root samples recorded on the Productora Tropical farm. Total nematodes = *R. similis* + *Heliocytlenchus* spp. + *Meloidogyne* spp. + *Pratylenchus* spp.
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Parasitic nematodes on *Musa* AAA C.A. Gauggel et al.

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<th>Pratylenchus spp.</th>
<th>Total nematodes</th>
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</thead>
<tbody>
<tr>
<td>0</td>
<td>0 (0,00%)</td>
<td>0 (0,00%)</td>
<td>0 (0,00%)</td>
<td>0 (0,00%)</td>
<td>0 (0,00%)</td>
</tr>
<tr>
<td>1 a 2500</td>
<td>7 (6,67%)</td>
<td>9 (9,29%)</td>
<td>1 (0,95%)</td>
<td>0 (0,00%)</td>
<td>17 (16,73%)</td>
</tr>
<tr>
<td>2501 a 5000</td>
<td>27 (25,71%)</td>
<td>30 (28,57%)</td>
<td>18 (16,73%)</td>
<td>8 (7,67%)</td>
<td>75 (72,13%)</td>
</tr>
<tr>
<td>5001 a 10000</td>
<td>31 (29,52%)</td>
<td>30 (28,57%)</td>
<td>18 (16,73%)</td>
<td>7 (6,67%)</td>
<td>74 (70,48%)</td>
</tr>
<tr>
<td>10001 a 20000</td>
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<td>30 (28,57%)</td>
<td>18 (16,73%)</td>
<td>8 (7,67%)</td>
<td>74 (70,48%)</td>
</tr>
<tr>
<td>20001 a 50000</td>
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<td>0 (0,00%)</td>
<td>0 (0,00%)</td>
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<td>6 (5,71%)</td>
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<tr>
<td>&gt; 50000</td>
<td>7 (6,67%)</td>
<td>0 (0,00%)</td>
<td>0 (0,00%)</td>
<td>0 (0,00%)</td>
<td>7 (6,67%)</td>
</tr>
</tbody>
</table>

Figure 5. Frequency of nematodes according to the specific ratios in 105 individual banana (*Musa* AAA) root samples recorded on the San Pablo farm. Total nematodes = *R. similis* + *Helicotylenchus* spp. + *Meloidogyne* spp. + *Pratylenchus* spp.
Figure 6. Frequency of nematodes according to the specific ratios in 115 individual banana (Musa AAA) root samples recorded on the La Rebusca farm. Total nematodes = *R. similis* + *Helicotylenchus* spp. + *Meloidogyne* spp. + *Pratylenchus* spp.
Figure 7. *Radopholus similis* according to sucker height (cm) or phenological banana (*Musa AAA* cv. ’Grande naine’) plant stage.

Each point is the mean ± standard error of 15 samples. All the samples were taken in a maximum of 3 days. Each sample was composed of the roots of 5 plants. The p values correspond to the comparison among the means of the different sucker heights or plant stages. The names in the upper right corner are the farms where the experiment was done.
Figure 8. *Helicotylenchus* spp. according to sucker height (cm) or phenological banana (*Musa* AAA cv. ‘Grande naine’) plant stage.

Each point is the mean ± standard error of 15 samples. All the samples were taken in a maximum of 3 days. Each sample was composed of the roots of 5 plants.
The problem of banana root deterioration and its impact on production with 300 \textit{R. similis}. Fallas \textit{et al.} (1995), evaluating ‘Valery’ plants in 0.8 L pots inoculated with 100 \textit{R. similis}, found decreases in root weight of 11 to 53\% after 12 weeks. A reduction in the K concentration in the root dry matter was observed when ‘Grande naine’ plants were inoculated with different initial \textit{R. similis} populations (Figure 10B). Other nutrients that varied significantly were N, S, Ca and Cu.

Fogain and Gowen (1995) found root necrosis of 3 to 12\%, 6 weeks after inoculating ‘Grande naine’ plants in 1 L pots with 300 \textit{R. similis}. Fogain \textit{et al.} (1996) observed...
a high root lesion index in follower suckers of plantain cultivars in 10 L pots inoculated with 1000 *R. similis*. Moens *et al.* (2001) found a significant correlation between *R. similis* and root necrosis or damage, ranging from 0.62 to 0.75, in root samples from commercial banana plantations.

‘Giant Cavendish’ bananas inoculated with 1000, 2000, 3000 or 4000 *R. similis* suffered bunch weight reductions of 17, 42, 51, and 61% respectively (Davide and Marasigan, 1985). In a local study, ‘Grande naine’ plants, initially grown in 1.8 L pots, were inoculated with 1000 *R. similis* or *M. incognita* or *P. coffeae* or *H. multicinctus*. The *R. similis* and *P. coffeae* were cultured on carrot disks and *M. incognita* and *H. multicinctus* on potted banana plants. Three weeks later, plants were transferred to 200 L drums containing sterilized soil and allowed to develop until harvest, when root content, damage

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**Figure 10.** Effect of initial *Radopholus similis* inoculation densities per ml of substrate or numbers per 1.8 L pots on *Musa* AAA cv. Grande naine. A) root weight. Each point is the mean ± standard error of 12 repetitions over 8 weeks of exposure. B) % K of the dry root weight. Each point is the mean ± standard error of 12 repetitions, with an exposure time of 12 weeks.
and bunch weight were recorded. Plants inoculated with *R. similis* had 3.6 kg (66%) less root weight, 6.4 kg (27%) less bunch weight and 262% more root damage than non-inoculated plants (Figure 11A-B).

The root and corm symptoms (Figure 12A-D) agree with those reported in the literature (Tarté and Pinochet 1981, Gowen and Quénéhervé 1990, Gowen 1995, Sarah 2000). Black and brown discoloration was observed in roots and corm after washing the surface free of soil. However, in early infections pre-symptomatic roots (Figure 12C) hold a lot of nematodes and when there is excess soil water, symptoms are easily confused with those caused by waterlogging. When the corm was lightly peeled, a purple, reddish-brown discoloration was easily seen, similar to that found in longitudinally split roots, where lesions extended from the epidermis towards the vascular cylinder.

**Pathogenicity and symptoms of *Meloidogyne incognita***

In pot experiments with 22 Vietnamese banana genotypes, fresh root weight increased significantly in 2 of the 3 experiments in plants inoculated with 500 to 4000 *Meloidogyne*.

![Figure 11](image-url)
The problem of banana root deterioration and its impact on production

Parasitic nematodes on *Musa* AAA C.A. Gauggel et al. (Van den Bergh et al. 2002a). Also, in very young banana roots under in vitro conditions, *M. incognita* can penetrate the roots and cause damage (Coosemans et al. 1994). Jonathan and Rajendran (2000a) found a significant reduction in root weight for the higher initial inoculations in their study working with increasing inoculations from 0 to 10 000 individuals in pots of 105 kg soil capacity. In contrast, no negative effect on growth was observed in *Musa* AAB plants, inoculated with *M. incognita* and cultivated in 10 L pots in Ivory Coast (Adiko 1989).

In Malaysia, Razak (1994) reported stunted growth and small bunches due to the infection of *M. incognita* in ‘Pisang nangka’ and ‘Pisang mas’. Similar effects on plant growth have been reported in India (Patel et al. 1996) where a delay in flowering was also observed. Van den Bergh et al. (2000) reported that *Meloidogyne* spp. had the most negative effect on the bunch characteristics of banana plants in Vietnam. High

![Image of banana roots and corm symptoms](image-url)

**Figure 12.** *Radopholus similis* and infection-induced symptoms in banana roots and corm. A) Adult female of *R. similis* at 20x magnification. B) In the center a healthy root (cream-white color) and on either side, roots with purple, reddish-brown discoloration extending from the epidermis to the vascular cylinder, C) On the right, two apparently healthy, asymptomatic roots containing 19 240 *R. similis* per 100 g of roots. On the right, three roots completely damaged first by *R. similis* (88 560 / 100 g of roots) and later by waterlogging, and D) Reddish-brown discoloration on the corm tissue.
Meloidogyne spp. populations, up to 66,000 per 100 g of roots, have been reported in ‘Grande naine’ vitroplants in field conditions in Cameroon (Fogain 1994).

‘Giant Cavendish’ bananas, inoculated with 1000, 10 000 or 20 000 *M. incognita*, suffered bunch weight reductions of 26, 45 and 57% respectively (Davide and Marasigan 1985). In our experiment, carried out in 200 L drums, *M. incognita* (Figure 13A-C) did not significantly reduce root weight, 0.5 kg (9%), and did not significantly increase root damage, but it did significantly suppress bunch weight by 7.5 kg (32%) (Figure 11A-B). This reduction in yield coincides with Jonathan and Rajendran’s results (2000b), which found bunch weight increases of 31% when controlling this nematode with nematicide. The observed root symptoms (Figure 13D) are close to those reported by Sikora and Schlösser (1973), Pinochet (1977), Tarté and Pinochet (1981), De Waele and Davide (1998) and De Waele (2000). Deformation, bifurcation, swellings and stunting on primary and secondary roots are the most common symptoms where fine roots are rare. Sometimes gall formation is observed close to the root tip.

![Image of Meloidogyne incognita and its symptoms](Figure 13. *Meloidogyne incognita* and its symptoms induced by the infection on banana roots. A) Infective stage of *M. incognita* (20x magnification). B) Stages of *M. incognita* extracted from banana roots (20x magnification). C) Female of *M. incognita* in a banana root (20x magnification) and D) Swelling and deformation of roots with gall formation close to the root tip.)
Pathogenicity and symptoms of *Pratylenchus coffeae*

Van den Bergh *et al.* (2002a) observed a reduction in fresh root weight in 3 experiments with 24 Vietnamese genotypes of banana inoculated with 1,000 *P. coffeae*. Pinochet (1978), Tarté (1980), Rodríguez (1990), Bridge *et al.* (1997) also found that *Pratylenchus* spp. damaged banana roots and reduced yield. In our experiment, carried out in 200 L drums, *P. coffeae* (Figure 14A) did not significantly reduce root weight - 0.58 kg (11%), but it did significantly increase root damage by 129%, and significantly suppressed bunch weight by 5.6 kg (24%) (Figure 11A-B). Symptoms (Figure 14B) induced by *P. coffeae* infection were very similar to those caused by *R. similis* and coincided with those described by Pinochet (1978), Bridge *et al.* (1997) and Gowen (2000a). Purple or black necrosis of the epidermis and cortical root parenchyma with surface cracks occurred.

![Figure 14. *Pratylenchus coffeae* and its symptoms induced by the infection on banana roots. A) Adult of *P. coffeae* (20x magnification). B) Purple and black necrosis extending from the root epidermis to the vascular cylinder.](figure)

Pathogenicity and symptoms of *Helicotylenchus multicinctus*

*Helicotylenchus multicinctus* and *H. dihystera* (McSorley and Parrado 1986, Davide 1996, Mani and Al Hinai 1996, Chau *et al.* 1997) damage the banana root system and reduce yield by 19% (Speijer and Fogain 1999) to 34% (Reddy 1994). There are mixed reports on the effect of *H. multicinctus* in potted plants. Barekye *et al.* (1999) found a root weight reduction in some *H. multicinctus* inoculated plants compared with plants without nematodes. In Uganda, a non-significant reduction in root weight was observed in *Musa* AAA-East Africa cultivar ‘Kisansa’ plants inoculated with 1000 *H. multicinctus* (Barekye *et al.* 2000). In greenhouse experiments, we observed fresh root weight reductions in *Musa* AAA ‘Grande naine’ plants inoculated with 515 *H. multicinctus*.

In Florida, *H. multicinctus* can cause severe root damage resulting in the toppling of mature plants (McSorley 1986, Gowen 1995). According to McSorley and Parrado (1986), this nematode is more important in subtropical banana production areas. In Lebanon, *H. multicinctus* is considered the most important banana root parasitic nematode (Sikora and Schlösser 1973). The same authors felt that this nematode, together
with *M. incognita*, was associated with the general decay of the banana root system observed.

In our experiment carried out in 200 L drums, *H. multicinctus* (Figure 15A) did not significantly reduce either root weight, 0.42 kg (8%), or increase root damage, 19%, or suppress bunch weight, 0.9 kg (4%) (Figure 11A-B). However, in Israel, bunch weight increased by 18% when controlling this nematode with nematicide (Minz *et al.* 1960). The symptoms (Figure 15B) in the plants infected with *H. multicinctus* in drums coincide with those observed by McSorley (1986) and Gowen (2000b). Tertiary roots appeared necrotic and fell off when the roots were handled. Thicker and larger roots showed small black-brown surface lesions and larger necrotic areas.

![Figure 15. Helicotylenchus multicinctus and its symptoms induced by the infection on banana roots. A) Adult of *H. multicinctus* (20x magnification). B) Small black-brown root surface lesions and larger necrotic areas.](image)

**Practical implications of mixed nematode populations**

The different parasitic habits of the nematode genera present - migratory endoparasites (*R. similis* and *Pratylenchus* spp.), sedentary endoparasites (*Meloidogyne* spp.) and ecto-endoparasites, feeding on subsurface tissue (*H. multicinctus*) - are likely to exacerbate root damage, because of lesions at feeding sites in the root cortex and throughout the root tissue. Usually control is recommended when *R. similis* population density exceeds a specific number per 100 g of roots, but the other nematodes also reduce the root system and yield. Therefore, development of nematode management tactics requires consideration of the damage caused by the total phytonematode population.

In current breeding programmes, resistance to black Sigatoka is, together with a high yield and good postharvest qualities, the most important factor in the screening process. Nevertheless, some programs could also incorporate resistance to *R. similis*. This is the case in different FHIA hybrids. Part of the ‘Pisang jari buaya’ group (*Musa* AA) demonstrated resistance (Wehunt *et al.* 1978, Viaene *et al.* 2000 and 2003), and this trait was, through the SH-3142 improved diploid (Pinochet and Rowe 1979), successfully incorporated into a series of FHIA hybrids. Other potential sources of resistance to *R. similis* are ‘Kunnan’ and ‘Paka’ (*Musa* AA section Eumusa) (Collingborn and Gowen 1997), and the Fe’i varieties ‘Menei’ and ‘Rimina’ (section Australimusa) (Stoffelen
et al. 1999a). Even if this resistance was identified, isolated and incorporated into commercial cultivars, this would not resolve the problem, because of the existence of polyspecific nematode communities. Changes in the nematode composition will occur, favouring root parasitic nematodes to which these hybrids are not resistant. Also, differences in the aggressiveness of *R. similis* have been reported (Sarah et al. 1993, Fallas et al 1995, Marin et al. 1999) when comparing populations. Therefore, broad-spectrum resistance should be sought, conferring resistance to a wide range of known *R. similis* biotypes, and to the other important parasitic nematodes. Up to now, ‘Yangambi km5’ shows resistance to *R. similis* (Sarah et al. 1992, Price 1994) and *P. coffeae* (Viaene et al. 1998), but its progeny produce abnormal leaves and/or erect and semi-erect bunches (Stoffelen et al. 1999a). Another source of resistance to these two nematodes is *Musa acuminata* spp. *burmannicoides ‘Calcutta 4’* (Viaene et al. 2000). This variety has already been used in the IITA breeding programme (Swennen and Vuylsteke 1993, Tenkouano et al. 2003), and experiments are on-going.

**References**


