EXCELLENT PUBLISHERS

Int.J.Curr.Microbiol.App.Sci (2026) *15*(7): 180-199

International Journal of Current Microbiology and Applied Sciences
ISSN: 2319-7706 **Volume 15 Number 7 (2026)**
Journal homepage: http://www.ijcmas.com

Original Research Article https://doi.org/10.20546/ijcmas.2026.1507.017

Spatial-Temporal Nematode Distribution on Banana (*Musa* AAA) Plantations in Ecuador during the Last 10 Years (2016-2025)

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Keywords

Bananas, *Helicotylenchus* spp., *Meloidogyne* spp., *Musa* AAA, nematode population, *Pratylenchus* spp., *Radopholus similis*, root samples.

Article Info

Received: 11 May 2026
Accepted: 26 June 2026
Available Online: 10 July 2026

ABSTRACT

An analysis of the plant-parasitic nematodes found in the banana (*Musa* AAA) plantations in Ecuador between 2016 and 2025 was carried out. Nematode extraction was done from 25 g of fresh roots that were macerated in a kitchen blender and from which nematodes were recovered in a 0.025 mm (No 500) mesh sieve. Data was subjected to frequency analysis, and the absolute frequency was calculated for each individual genus. Four plant parasitic nematodes were detected, and based on their frequencies and population densities the relative importance of nematode genera was established in decreasing order as follows: *Helicotylenchus* spp. > *R. similis* > *Meloidogyne* spp. > *Pratylenchus* spp. *Helicotylenchus* spp. was the most abundant and frequent nematode, representing between 36.4 and 64.4% of the total population of phytoparasitic nematodes in the roots, followed by *Radopholus similis* with between 24.1 and 38.5% of the population throughout the different analyzed years. From a total of 14833 root samples, 14373 (97%) contained *Helicotylenchus* spp., 13288 (89.6%) *R. similis*, 9261 (62.4%) *Meloidogyne* spp., 7638 (51.5%) *Pratylenchus* spp., and when all phytoparasitic nematodes present were pooled (total nematodes) 14799 (99.8%) of the samples had nematodes. Large number of samples with nematode population above the economic threshold suggested by AGROCALIDAD, INIAP and ANEMAGRO of 2500-3000 nematodes per 100 g of roots or 1000 nematodes per 100 g of functional roots were observed in all the years, months and the 5 (Cañar, El Oro, Guayas, Los Ríos, Cotopaxi) provinces. The statistical differences (P< 0.0001) detected for average nematodes and frequencies among years, months and provinces more likely are associated to the high number of samples included in each year, month and province, since variations in average nematode and frequencies for each nematode genus were small. These high plant parasitic nematode populations together with the adverse effects of climate change which include rising temperatures, changes in rainfall patterns, and increased frequency of extreme weather events which it is known that poses significant risks to food security and with the lack of nematode control measures, due to the restrictions imposed by certifying bodies and supermarkets, are more likely related to the low productivity reported of between 1600 and 2200 boxes per hectare.

Introduction

Bananas (*Musa* AAA cv Grande Naine, Valery, and Williams) are cultivated in Ecuador for export markets. It represents approximately 2% of the gross national product and close to 35% of the agricultural gross national product (ACORBANET 2026). In 2025, 377, 31 mill boxes of 43 pounds were exported (PortalFruticola.com 2026), produced on 210000 ha (Banana Export 2025), which gave a total income of US $4063 million (Ekos 2026).

Besides the constraints of banana market requirements and demands, there are other factors limiting production. Among the important abiotic factors constraining banana yield include reduced radiation, low temperature in part of the year, a shallow soil water table level and edaphic soil conditions, mainly due to clay texture, poor structure and high Na content. These constraints differ between farms and provinces, and not all happen in a specific farm. Plantations are found in flat areas with no more than 4% of slope, with a lot of the planted area close to see level with no more than 100 masl.

Among the biotic factors, root parasitic nematodes are second after black Sigatoka caused by *Pseudocercospora fijiensis*. In local plantations, usually only polyspecific communities occur, consisting mainly of a mixture of *R. similis* and *Helicotylenchus* spp., with some populations of *Meloidogyne* spp., and *Pratylenchus* spp. Based on nematode frequency and population densities, Aguirre *et al.,* 2016a, 2016b) and Chávez and Araya (2010, 2001) suggested a relative importance as follows: *R. similis* > *Helicotylenchus* spp. > *Meloidogyne* spp. > *Pratylenchus* spp. Nematodes increase the time for leaf emission, reduce bunch weight and plant longevity, and increase the crop cycle duration (Jaramillo *et al.,* 2023, 2019, Medina *et al.,* 2022, Chávez *et al.,* 2020, Araya 2004a, Quénéhervé *et al.,* 1991a, 1991b) ending in yield lost.

To avoid or reduce nematode damage, the only management strategy currently available is the regular application of chemical nematicides, from which growers know that it is economically feasible. However, nematicide application is done only in farms handled in intensive way.

Then, there are many large, medium and small farms that end with low yield due in part to heavy nematode root damage since nematode control measurements are not normally used.

Economic and environmental constraints dictate rational use of chemical nematicides at minimum rates. To achieve this, more research is needed in evaluation of biocontrol agents, cultural practices, nematicide rotations and application systems to prevent nematode population build up and root damage.

The objective of this study was to update quantitative information about population densities and frequencies of the major nematode pest in Ecuadorian banana plantations between 2016 and 2025. This information will be useful to identify more appropriate research areas on nematode management and as a basis to justify investment.

Materials and Methods

Nematode data included in the analysis were from root samples of long-term commercial banana plantations of the provinces of Cañar, El Oro, Guayas, Los Ríos, and Cotopaxi, where the crop is cultivated in the country. Farms vary in soil type, texture, structure, content of macro and micronutrients and climatic conditions. The age of the plantations ranges between 10 and 50 years with a plant density between 1300 and 1500 plants ha^{-1} and the cultivars sown were mainly of the Cavendish subgroup: Grande Naine, Valery, Williams. Bunching plants were supported by tying them to adjacent plants with double polypropylene twine, propping with wood poles or by aerial guying.

Various banana cultural practices (fertilization, control of weeds, aerial spraying of fungicides to control black Sigatoka and in some farms nematode control were carried out during the years, which may have influenced the nematode population behavior reported in this paper.

Desuckering was carried out every six to eight weeks throughout the years, leaving the production unit with a bearing mother plant, a large daughter sucker, and a small grand-daughter (peeper) when available.

Usually, water requirements are supplied by rainfall during the rainy season from January to April, while from May to December, sprinkle irrigation was necessary each year. Average rainfall (between 2016 and 2025) in the main production province El Oro varied between 800 and 1500 mm each year. A complex system of primary, secondary and tertiary drains was installed to carry off excess water, lower the water table and prevent waterlogging during heavy rains.

Data of the samples recorded by Nemalab S.A. during the last 10 years (between 2016 and 2025) were used for this study. A total of 14833 root samples were processed from January 2016 to December 2025 and entered into a computer database along with farm identity, province, county, month and year of sampling. Each root sample consisted of the roots of 10 randomly selected production units, which consisted of a mother plant, follower sucker and sometimes a small peeper. Samples were taken either in front of the follower sucker of 1.25 to 1.75 m height or in the area between the recently flowered plants (within eight days of flower emergence) and their follower suckers of 1.25 to 1.75 m height. A hole of about 20 cm long, 20 cm wide and 30 cm deep (soil volume of 12 L) was dug with a shovel at the plant base. Roots from each hole were collected, placed in labeled plastic bags, and delivered to the laboratory in insulated chests.

In the lab, root samples were registered and processed as soon as possible following the Taylor and Loegering method (1953) modified by Chávez *et al.,* (2026), and when it was necessary, stored in a Lab refrigerator (General Electric) adjusted to 6-8 ºC until being processed. Roots were rinsed free of soil, separated into living roots (white or cream-colored roots), dead roots by nematodes (with symptoms of nematode damage, reddish-brown lesions on the outer part of the roots penetrating throughout the cortex and then turns necrotic along the entire root; in the epidermis, cortical parenchyma, and vascular cylinder, but without root decay) and dead roots by other causes (rotten roots by excess water, snapping). During the root separation process, if in some roots, it was necessary to cut some damaged parts, they were classified accordingly. Each root type was left to dry off the surface moisture for 1 hour and weigh each individually.

The nematode extraction was made from 25 g of roots keeping the proportion of each root type. For example, in a root sample of 132 g of total roots, with 80.1 g of living roots, 48.9 g of dead roots by nematodes, and 3 g of dead roots by other causes, there would be 60.7% of living roots, 37% of dead roots by nematodes, and 2.3% of dead roots by other causes. Then the sample size used of 25 g, would have of living roots 25 * 60.7% / 100= 15.17 g, of dead roots by nematodes 25 * 37% / 100= 9.25 g and of dead roots by other causes 25 * 2.3% / 100= 0.57 g. 15.17 + 9.25 + 0.57 = 24.99 g. Roots were macerated in an Osterizer kitchen blender for 10 sec at low and 10 sec at high speed, and the resulting mixture was washed from the blender through a series of nested sieves of 0.25/0.106/0.025 mm (No 60/140/500). The residue on 0.25 and 0.106 mm mesh sieves were discarded and that on the 0.025 mm sieve was washed into a 250 ml beaker, and the nematodes counted. The nematodes were identified at the genus and species level, when possible, based on the morphological characteristics under a light microscope, following the key of Siddiqi (2000). All counts were made with a Micromaster microscope at 4X magnification and values converted to numbers per 100 g of fresh roots.

Data was subjected to frequency distribution analysis for each nematode by year, month and province. The absolute frequency was calculated as a percentage by the No of samples containing a species / No samples collected * 100 (Barker 1985). Additionally, in each nematode genus, samples were distributed according to specific ranges of population densities as follows: free of nematodes, from 1 to 2500, from 2501 to 5000; from 5001 to 10000; from 10001 to 20000; from 20001 to 30000; and samples over 30000 individuals per 100 g of fresh root. The mean number of nematodes and percentage of samples containing a nematode genus was compared among years, months and provinces using the log transformation as link function and the negative binomial probability distribution to model the errors.

Results and Discussion

Irrespective of the year, the major plant-parasitic nematodes present in the sampling areas were *Helicotylenchus* spp. which varied between 36.4 and 64.4% and *R. similis* varying between 24.1 and 38.5% (Figure 1). *Meloidogyne* ssp. and *Pratylenchus* spp. were less detected and when present their contribution to the total plant parasitic nematode population was low, varying between 2.3 and 13.5%, and between 1.0 and 19.3% respectively.

Even though a statistical difference ($P< 0.0001$) was detected among years for the frequency of the different nematode genera, the values for each genus were close in the different years studied (Table 1). The highest frequency was always found in *Helicotylenchus* spp. above 96%, followed by *R. similis* which ranged between 79 and 97%, then *Meloidogyne* spp. which varied between 15 and 85% and finally *Pratylenchus* spp. between 17 and 82%. Considering the total phytoparasitic nematodes, practically all the samples in every year had at least one nematode genus reaching a frequency higher than 99%.

The four nematode genera were detected in all months of the year, with very small variation in their individual frequencies (Table 2) although statistical differences (P< 0.0001) were reported.

The highest frequency was always found in *Helicotylenchus* spp. above 95% followed by *R. similis* above 87%. For *Meloidogyne* spp. and *Pratylenchus* spp. the frequency varied between 49 and 71% and between 38 and 64%, respectively. For the total phytoparasitic nematode population the frequency was above 99%.

Similar trend was observed for frequencies among provinces where statistical differences (P< 0.0001) were declared even though the variation within each genus was small (Table 3). In descending order, the highest frequency was detected for total nematodes with over 97% followed by *R. similis* between 87 and 100% and *Helicotylenchus* spp. between 56 and 100%. For *Meloidogyne* spp. the frequency varied between 60 and 75%, while for *Pratylenchus* spp. it varied between 42 and 65%.

The distribution of the root samples by specific nematode population ratios clearly indicated that *Helicotylenchus* spp. showed the highest population (Figure 2). From the 14833 recorded root samples, only 460 (3.1%) were free of the nematode, 6230 (42%) were above 5000 and 10449 (70%) were above 2500 nematodes by 100 g of roots (Figure 2). For *R. similis* 1545 (10.4%) of the samples were found negative, 3936 (26.5%) had levels above the 5000 and 7073 (47.6%) had more than 2500 individuals by 100 g of roots. For *Meloidogyne* spp. more than 37.6% (5572) of the samples were free of it, 1.7% (256) showed densities higher than 5000 nematodes and 7.6% (1130) were with more than 2500 nematodes by 100 g of roots. *Pratylenchus* spp. was present in 52.5% (7638) of the samples, with 2.8% (417) with densities higher than 5000 nematodes and 10.1% (1505) had more than 2500 nematodes by 100 g of roots. When all nematodes were pooled (total nematodes) it was observed that only few samples 34 (0.23%) were free of nematodes, 11768 (79.3%) samples contained more than 5000 and 13549 (91.3%) showed more than 2500 nematodes per 100 g of roots.

Because all four genera, *Helicotylenchus* spp., *R. similis*, *Meloidogyne* spp., and *Pratylenchus* spp., cause damage to the banana root system it was decided to show the average of the total plant parasitic nematodes present by year, month and province and the total nematode density distribution by years, months and provinces. The average number of total phytoparasitic nematodes varied (P< 0.0001) among years, months and provinces (Figure 2A-C). The average among years varied between 7979 and 14153, among months between 9936 and 12267 and among provinces between 9694 and 14664 by 100 g of roots (Figure 3A-C).

A stable trend in the number of samples (between 68.7 and 88.4%) with levels higher than 5000 plant parasitic nematodes was observed among the different years analyzed and when considering above 2500 nematodes, the percentages increased to between 88.3 and 96.3% of the samples (Figure 4). In every month of the year, between 72.5 and 84.8% of the samples presented more than 5000 and between 88.4 and 93.4% of the samples had more than 2500 phytoparasitic nematodes by 100 g of roots and less than 1% of the samples were free of nematodes (Figure 5). Similar pattern was detected among provinces, where between 69.7 and 91.4% of the samples showed populations over 5000 and between 81.7 and 97.8% presented more than 2500 phytoparasitic nematodes per 100 g of roots and less of 2.3% of the samples were free of it (Figure 6).

The four nematode genera (*Helicotylenchus* spp., *R. similis*, *Meloidogyne* spp., *Pratylenchus* spp.) encountered in this study are consistent with those found earlier in Ecuador by Larrea-Bernal *et al.,* (2025), Jaramillo *et al.,* (2023, 2019), Chávez *et al.,* (2020), Aguirre *at al*. (2016a, 2016b), Chávez and Araya (2010, 2001), Triviño (2006), Jiménez *et al.,* (1998), Gómez (1997), Asanza *et al.,* (1995), Quimí (1981). Also are in line with those reported in Colombia (Volcy 2011, Cubillos *et al.,* 1980, Gómez 1980), Venezuela (Haddad *et al.,* 1975), Bolivia (Quispe, 2004), Brasil (Lima *et al.,* 2013, Zem *et al.,* 1981), México (Romero *et al.,* 2024, Guzmán *et al.,* 1995), Costa Rica (Araya and Vargas 2018, Araya 2004a, 2004b, Araya *et al.,* 2002, Araya *et al.,* 1995), Belize (Ramclam and Araya 2006, Pinochet and Ventura 1977), Martinique (Chabrier *et al.,* 2002), Australia (Pattison *et al.,* 2024, Jackson *et al.,* 2003, Stanton and Pattison 2000, Stanton 1994), Phillipines (Davide 1994, Boncato and Davide 1992), India (Gantait *et al.,* 2011), Ivory Coast (Quénéhervé *et al.,* 1991a, 1991b), South Africa (Daneel 2024, Daneel *et al.,* 2015), Democratic Republic of Congo (Kamira *et al.,* 2013), and other African countries (Blomme *et al.,* 2013, Dubois and Coyne 2011).

The four nematode genera detected are well known pathogens in banana roots (Sikora *et al.,* 2018, Baker *et al.,* 2014, Volcy 2011, Dubois and Coyne 2011, Gowen *et al.,* 2005, Moens and Araya 2002, De Waele 2000, Gowen 2000a, 2000b, De Waele and Davide 1998, Marín *et al.,* 1998, Bridge *et al.,* 1997, Sarah *et al.,* 1996, Davide 1996, Gowen 1995, Fogain 1994, Gowen and Quénéhervé 1990, Sarah 1989, McSorley and Parrado 1986, Tarté and Pinochet 1981, Pinochet 1977, Loos 1962).

Nematodes were present in all the years, provinces and months because of the susceptibility of the varieties cultivated (Hartman *et al.,* 2010, Moens *et al.,* 2005, Araya 2004a, Davide and Marasigan 1992), the continual monoculture of bananas and favorable edaphic and climatic conditions. The statistical significance that was detected in all frequencies by year, month and province more likely came from the high number of observations in each case. The low variation in the nematode frequencies may have been due in part to the stable soil moisture since, in the dry season, water was supplied by sprinkle irrigation, which also reduces the soil temperature variation.

The high population densities and frequencies found for *Helicotylenchus* spp. and *R. similis* are encouraged by the long-time banana monoculture and lack of nematode control and coincided with other local studies Aguirre *et al.,* (2016a, 2016b), Chávez and Araya (2010, 2001), Jiménez *et al.,* (1998), Gómez (1997), Asanza *et al.,* (1995), and with studies from Colombia (Jaramillo and Quirós 1984), Costa Rica (Araya and Vargas 2018, Araya *et al.,* 2002, Araya *et al.,* 1995), Belize (Ramclam and Araya 2006) and with studies from Philippines (Davide 1994).

The insufficient nematode control measures, superficial water table level, and inadequate knowledge of the farmers could also have contributed to the heavy infestations. In many cases, the insufficient nematode control may be due to the restrictions imposed by certifying bodies and supermarkets. The re-entry intervals associated with the application of certain nematicides also restrict their use, as they interfere with plantation management activities. However, these approaches and trends contrast with food production. According to Hens and Quynh (2016) in 1961, on average, each person on earth had a share of 0.41 ha of cropland while in 2015 was only 0.25 ha, despite the increase in arable land surface, and the expectation is to decrease further to 0.20 ha per person by 2050. These policies also contrast with the availability of food for the growing global population. According to the United Nations (2026) the current world population of 7.6 billion is expected to reach 8.6 billion in 2030, 9.8 billion in 2050 and 11.2 billion in 2100. With roughly 83 million people being added to the world's population every year, the upward trend in population size is expected to continue, even if fertility levels will continue to decline.

These high plant parasitic nematode populations together with the adverse effects of climate change which include rising temperatures, changes in rainfall patterns, and increased frequency of extreme weather events which it is known that poses significant risks to food security (Mwangi 2023) and the lack of nematode control measures are more likely related to the low productivity reported of between 1600 and 2200 boxes per hectare (Zambrano and Gallardo 2022), while in areas with nematode control the yield overpasses the 3000 boxes by hectare (Jaramillo *et al.,* 2023, 2019, Chávez *et al.,* 2020).

These results confirm that banana nematodes continue to be a serious threat to banana production in Ecuador as has been reported by Jaramillo *et al.,* (2023, 2019) and Chávez *et al.,* (2020) who found that those nematodes reduced banana yield. Similarly, in Costa Rica Medina *et al.,* (2022), Vargas *et al.,* (2006), Moens *et al.,* (2004) and Araya and Lakhi (2004), found that those nematodes equally reduced banana yield. Then, this agreed with Dita *et al.,* (2013) thoughts, that nematodes continue to be a serious threat to banana production in Latin America and the Caribbean. Even more, the increase in production reported because of nematodes control is agreed with Salguero *et al.,* (2016), Quénéhervé *et al.,* (1991a, 1991b), Charles *et al.,* (1985), and Guerout (1972) who cited negative and significant linear correlations between the populations of *R. similis*, *Helicotylenchus* spp. and total nematodes with bunch weight in bananas.

Based on found nematode frequency and population densities, the relative importance of nematode genera in commercial banana clones appears to be in decreasing order as follows: *Helicotylenchus* spp. > *R. similis* > *Meloidogyne* spp. > *Pratylenchus* spp., which changed with that found earlier by Aguirre *et al.,* (2016a, 2016b) and Chávez and Araya (2010, 2001) of *R. similis* > *Helicotylenchus* spp. > *Meloidogyne* spp. > *Pratylenchus* spp. This high population and frequency of *Helicotylenchus* spp. more likely is related with the insufficient nematode control done in Ecuadorian banana plantations, which result in more root damage and since even though the nematode is an obligate biotrophic migratory ecto-endoparasite (Sikora *et al.,* 2018, Guzmán-Piedrahita 2011, Orion and Bar-Eyal 1995, Blake 1966) it is found in necrotrophic tissue (Araya and Centeno 1995) where it can stay longer because its feeding behavior.

The increase in the frequency and population density of *Meloidogyne* spp. could be in relation to the decrease in the population of *R. similis*. Santor and Davide (1992) found that the presence of *R. similis* on the galls caused deterioration and disintegration of the giant cells, which affected the development and reproduction of *M. incognita*. *Pratylenchus* spp. increased its presence and densities, which is reasonable because it has the same habitat as *R. similis* which decreases its population ending in less competition.

The presence of nematodes with different parasitic habits; *R. similis* and *Pratylenchus coffeae* migratory endoparasite, *Helicotylenchus* spp. an ecto-endoparasite and *Meloidogyne* spp. sedentary endoparasite most likely exacerbates root damage since lesions can develop at feeding sites and through root tissue. In addition, plants often activate post-infection resistance mechanisms, even in cases where the population of nematodes increases over time, and the nematode-plant interaction is compatible. Therefore, together these processes can represent a high energy expenditure for plants that can interfere with the filling and development of the bunch. Given that the four nematode genera cause damage to the crop, for the implementation of options for their management, the population of all the phytoparasitic nematodes present should be considered, as has been suggested by Aguirre *et al.,* (2016a; 2016b), Salguero *et al.,* (2016), and Ramclam and Araya (2006).

Globally, *R. similis* is recognized as the main banana root nematode (Orton and Siddiqi 1973) including African countries (Baker *et al.,* 2014, Blomme *et al.,* 2013, Speijer and Fogain 1999, Kashaija *et al.,* 1999, Fargette and Quénéhervé 1988), Australia (Pattison *et al.,* 2024, Stanton 1994), Philippines (Davide 1994), the Pacific Islands (Pone 1994), Ecuador (Jiménez *et al.,* 1998), Colombia (Gómez 1980), Costa Rica (Medina *et al.,* 2022, Araya *et al.,* 2002, 1995).

In local conditions, the Instituto Nacional Autónomo de Investigaciones Agropecuarias-INIAP (2025) recommend the application of chemical nematicides when *R. similis* is over 10000 individuals per 100 g of total roots in samples taken between the mother plant and its follower sucker, or over 2500 per 100 g of total roots in samples taken in front of the follower suckers.

The local laboratory Análisis Nematológico para el Agro S.A.-ANEMAGRO (2025) suggest the use of chemical nematicides when *R. similis* is over 10000 individuals per 100 g of total roots, or over 2000 per 100 g of functional roots in samples taken from recently flowered plants and when samples are taken in front the follower suckers, over 3000 per 100 g of total roots or over 1000 per 100 g of functional roots.

These economic thresholds considers only *R. similis*, however, there exist scientific knowledge that *H. multicinctus*, *H. dihystera* (Das *et al.,* 2014, Hartman *et al.,* 2010, Chau *et al.,* 1997, Mani and Al Hinai 1996, McSorley and Parrado 1986, Davide 1996) damage the banana root system and reduce yield between 19% (Speijer and Fogain 1999) and 34% (Reddy 1994). Also, it is well known that *Meloidogyne* spp. (Moens and Araya 2002, Patel *et al.,* 1996, Fogain 1994, Santor and Davide 1992, Davide and Marasigan, 1992) and *Pratylenchus* spp. (Moens and Araya 2002, Bridge *et al.,* 1997, Rodriguez 1990, Tarté 1980, Pinochet 1978) damage banana roots and reduce yield. Therefore, deciding on nematode management, it would be convenient to consider the total phytoparasitic nematode population as has been suggested by Aguirre *et al.,* (2016a, 2016b), Salguero *et al.,* (2016), Ramclam and Araya (2006) since all the four genera damage the banana root system and reduce yield. If we consider that threshold of 2500 individuals per 100 g of roots, more than 88.3% of the samples each analyzed year required nematode control. When such threshold was checked by month, more than 88.4.7% of the samples were over, requiring nematode control, and by provinces 81.7% of samples exceed the value needed pest control.

In Ecuador, Jaramillo *et al.,* (2023) as well as Medina *et al.,* (2022) in Costa Rica, reported that nematode populations lower than 5000 per-100 g of roots, in some samplings were not enough to develop root symptoms but they reduced ratooning and yield. If we assume this higher threshold, even 68.7, 72.5 and 69.7% of the samples each year, month and province require control, respectively. It is known that if banana roots are still white and cream, it does not mean that they are free of nematodes.

Figure.1 Nematode population distribution in banana (*Musa* AAA) plantations between 2016 and 2025 (Ecuador).

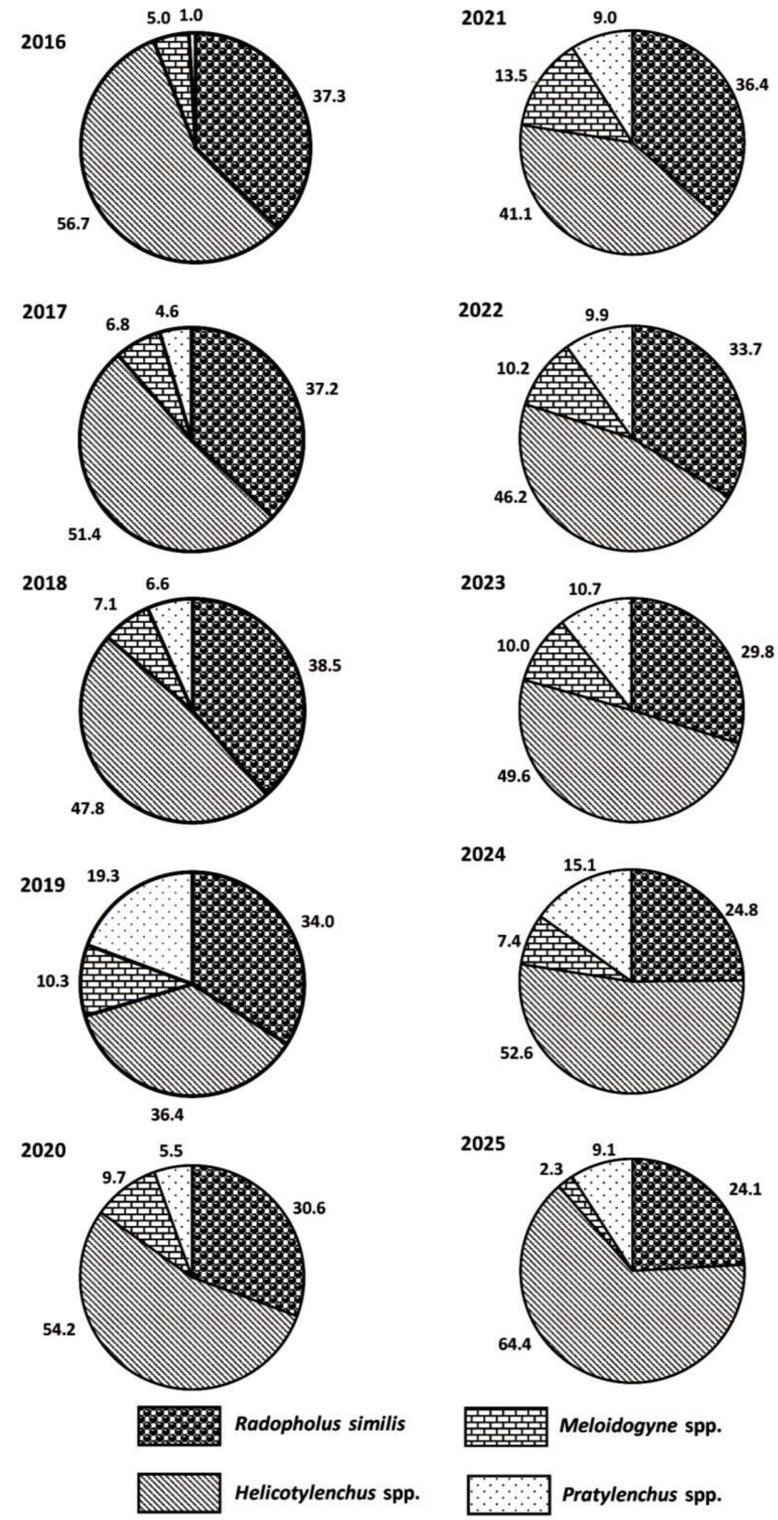

Figure.2 Frequency of each nematode genus according to the specific ratios per 100 g of fresh roots in 14833 banana (*Musa* AAA) root samples recorded in the last 10 years (between 2016 and 2025) in Ecuadorian plantations. Total nematodes = *R. similis* + *Helicotylenchus* spp. + *Meloidogyne* spp. + *Pratylenchus* spp.

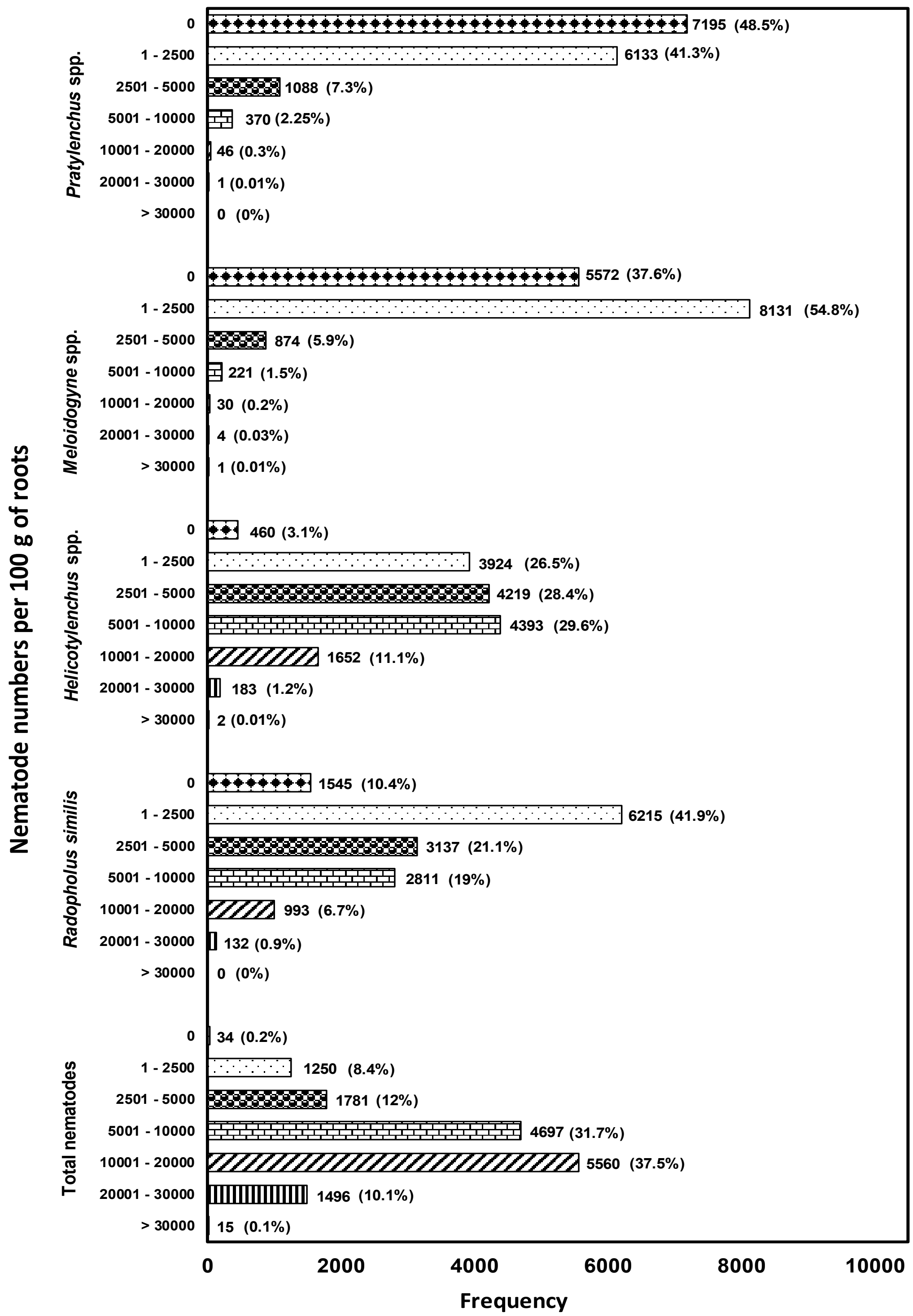

Figure.3A-C. Mean number in the last 10 years (between 2016 and 2025) of the total population of plant parasitic nematodes by 100 g of banana (*Musa* AAA) roots by year (A), month (B) and province (C).

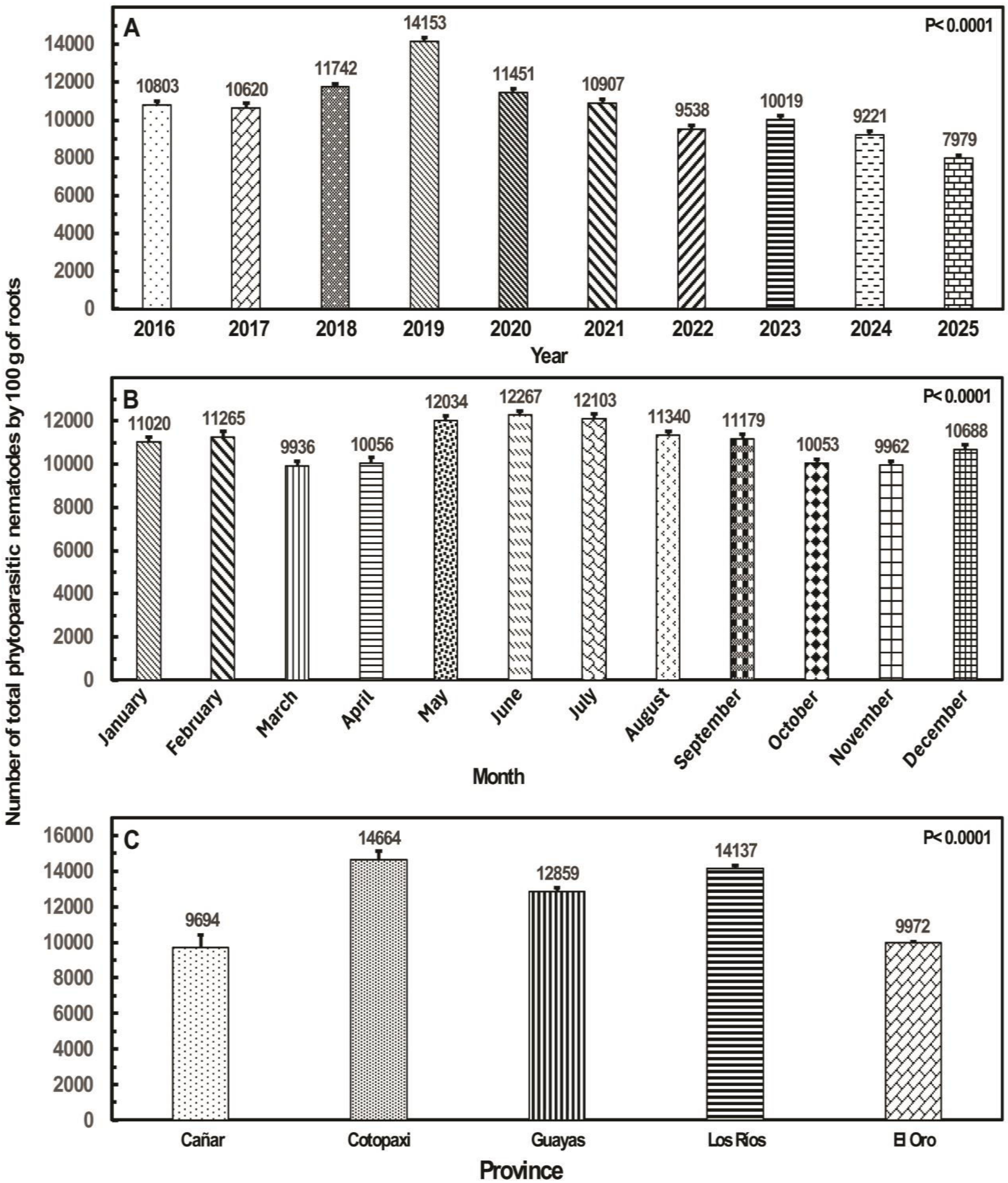

Figure.4 Sample distribution of the total nematode population densities (Sum of *R. similis* + *Helicotylenchus* spp. + *Meloidogyne* spp. + *Pratylenchus* spp.) according to the specific ratios per 100 g of fresh banana (*Musa* AAA) roots in the last 10 (between 2016 and 2025) analyzed years. Values in ( ) are the frequencies.

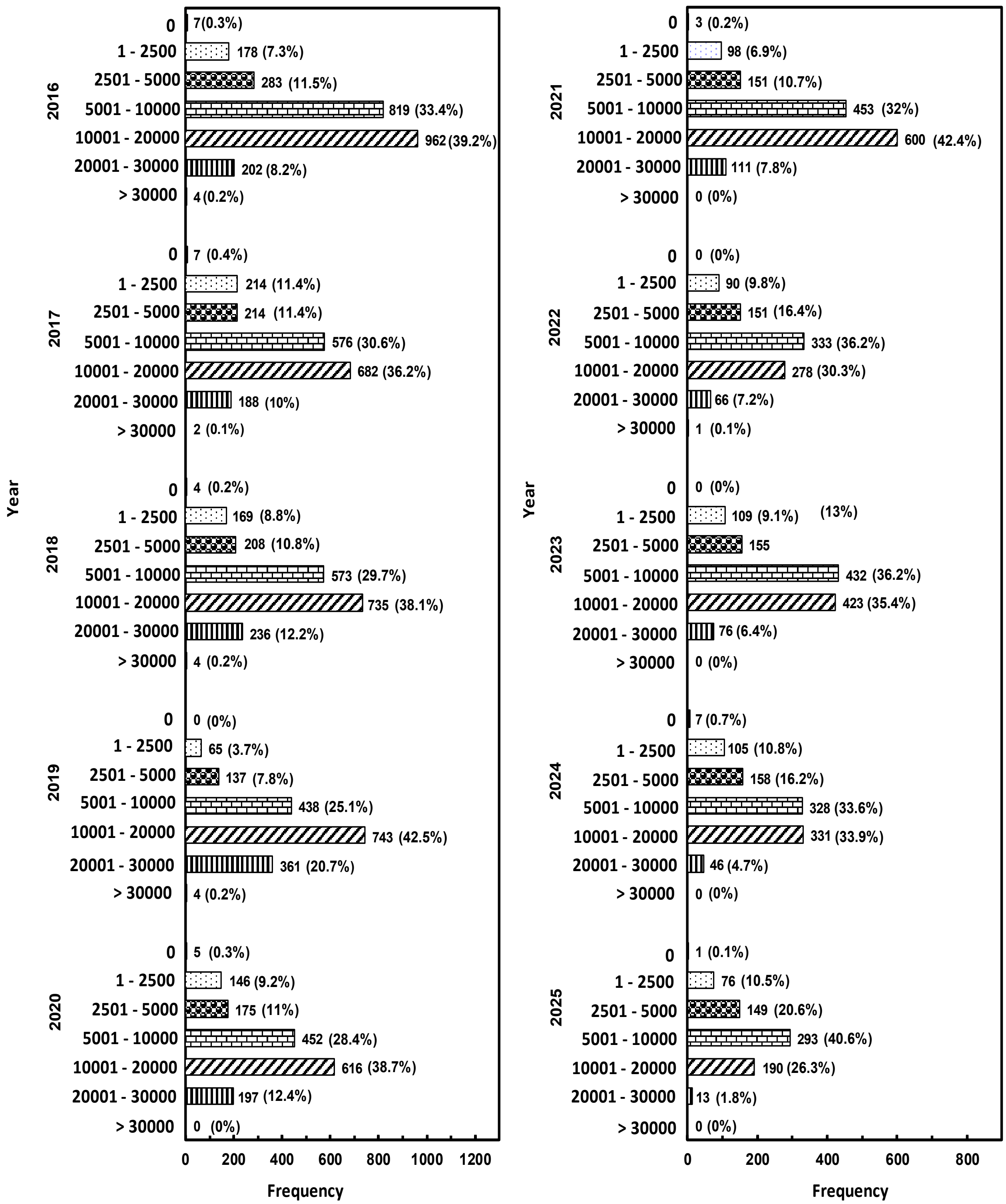

Figure.5 Sample distribution of the total nematode population densities (Sum of *R. similis* + *Helicotylenchus* spp. + *Meloidogyne* spp. + *Pratylenchus* spp.) according to the specific ratios per 100 g of fresh banana (*Musa* AAA) roots in the different months of the last 10 (between 2016 and 2025) years. Values in ( ) are the frequencies.

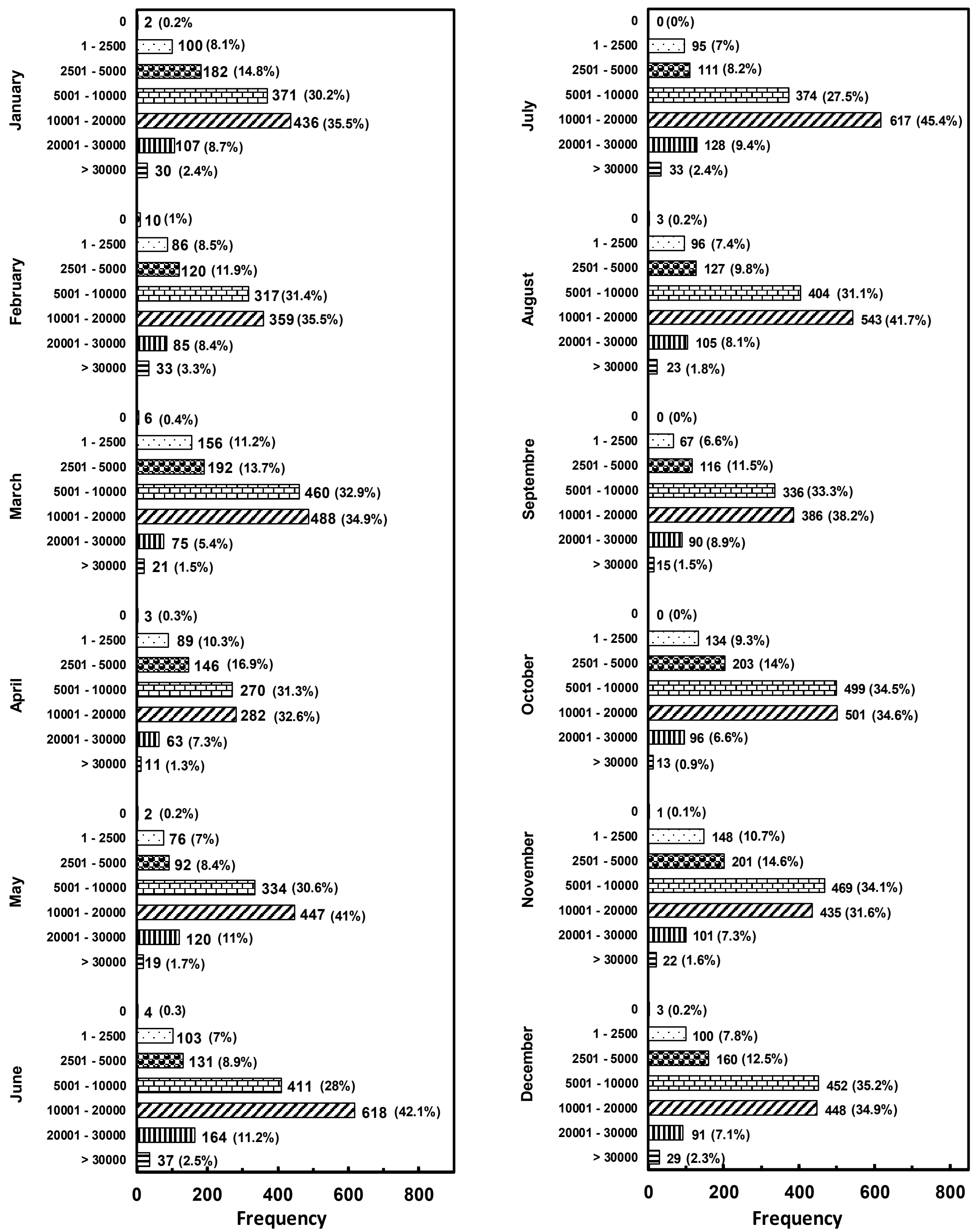

Figure.6 Sample distribution of the total nematode population densities (Sum of *R. similis* + *Helicotylenchus* spp. + *Meloidogyne* spp. + *Pratylenchus* spp.) according to the specific ratios per 100 g of fresh banana (*Musa* AAA) roots of the last 10 years (between 2016 and 2025) in the different provinces. Values in ( ) are the frequencies.

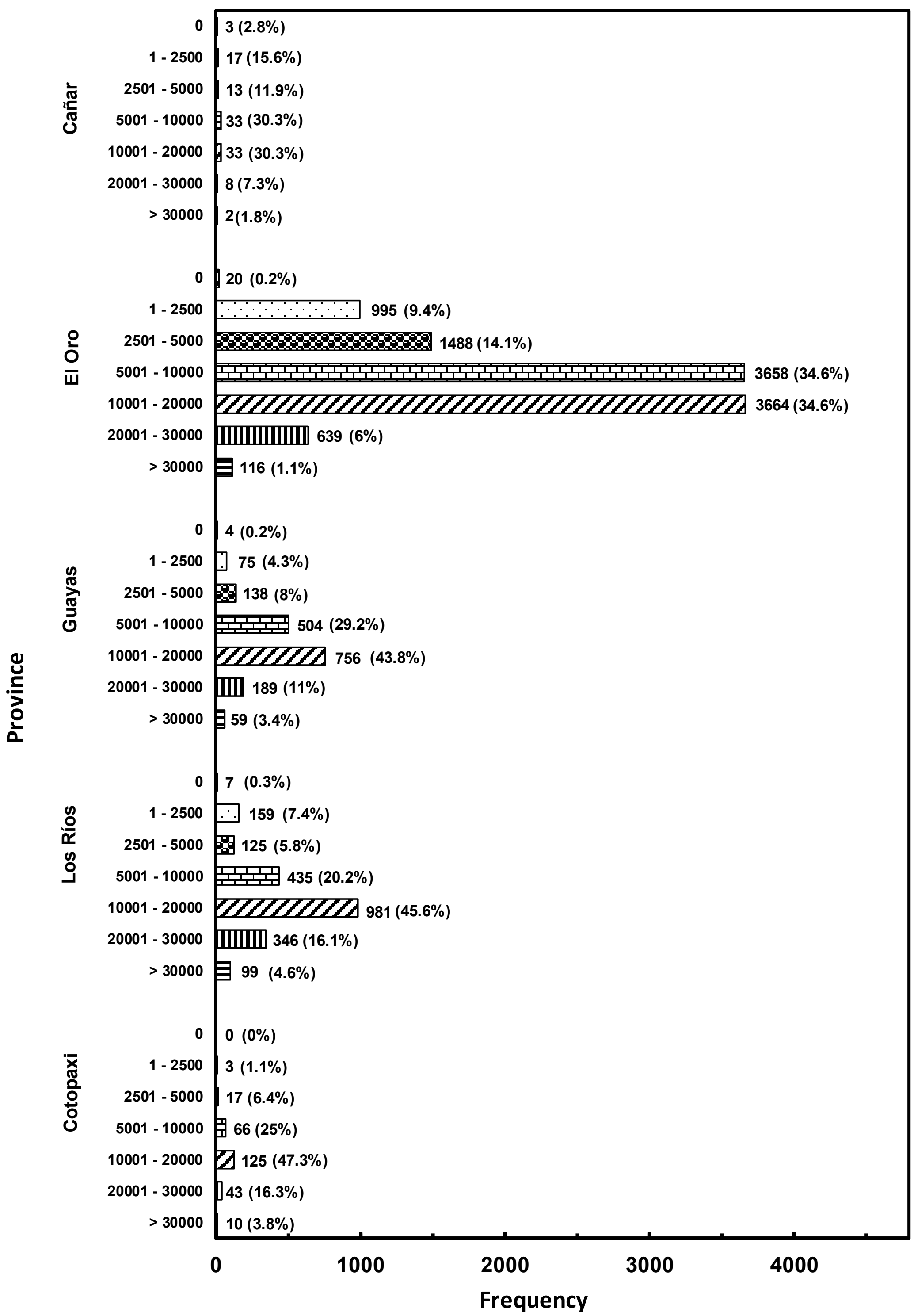

Table.1 Percentage of banana (*Musa* AAA) root samples each year from which various plant-parasitic nematodes were recorded in Ecuadorian plantations in the last 10 years (between 2016 and 2025).

Nematode	Years										
	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	Mean
Number of root samples	2455	1883	1929	1748	1591	1416	919	1195	975	722	14833
Radopholus similis	90	88	94	97	92	91	88	83	81	79	88
Helicotylenchus spp.	97	96	98	97	97	97	98	96	97	98	97
Meloidogyne spp.	39	59	63	83	72	85	75	72	52	15	62
Pratylenchus spp.	17	39	48	82	54	69	64	63	66	44	54
Total nematodes	100	100	100	100	100	100	100	100	99	100	100

Total nematodes = *R. similis* + *Helicotylenchus* spp. + *Meloidogyne* spp. + *Pratylenchus* spp.

Table.2 Mean percentage per month in the last 10 years (between 2016 and 2025) of banana (*Musa* AAA) root samples from which various plant-parasitic nematodes were recovered from Ecuadorian plantations.

	Months												
Nematode	J	F	M	Ap	My	J	Jl	A	S	O	N	D	Mean
Number of root samples	1228	1010	1398	864	1090	1468	1358	1301	1010	1446	1377	1283	14833
Radopholus similis	92	91	88	89	89	90	87	90	92	90	88	90	90
Helicotylenchus spp.	97	95	97	97	98	97	97	98	98	97	96	96	97
Meloidogyne spp.	61	60	49	55	60	66	71	67	69	61	61	67	62
Pratylenchus spp.	50	50	38	43	44	50	56	59	64	55	52	56	51
Total nematodes	100	99	100	100	99	100	100	100	100	100	100	100	100

Total nematodes = *R. similis* + *Helicotylenchus* spp. + *Meloidogyne* spp. + *Pratylenchus* pp.

Table.3 Mean percentage by province in the last 10 years (between 2016 and 2025) of banana (*Musa* AAA) root samples from which various plant-parasitic nematodes were recovered in Ecuadorian plantations.

Nematode	Provinces					Mean
	Cañar	El Oro	Guayas	Los Ríos	Cotopaxi	
Number of root samples	109	10580	1725	2152	267	14833
Radopholus similis	87	89	94	89	100	88
Helicotylenchus spp.	83	98	56	94	100	90
Meloidogyne spp.	72	60	60	72	75	73
Pratylenchus spp.	42	49	52	60	65	50
Total nematodes	97	100	100	100	100	99

Total nematodes = *R. similis* + *Helicotylenchus* spp. + *Meloidogyne* spp. + *Pratylenchus* pp.

As indicated by Mai (1985), McKenry and Roberts (1985) and Ayoub (1980), extensive loss of yield can occur when one or more nematode species may be feeding on a given plant, without showing obvious or specific plant symptoms. It is known that in white-cream roots infected with nematodes histological and physiological cell alterations occur (Jones *et al.,* 2016, Haegeman *et al.,* 2010, Grunewald *et al.,* 2009, Wyss 2002, Blake 1966) which restrict water and nutrients uptake (Lilley *et al.,* 2024, Sikora *et al.,* 2018, Haegeman *et al.,* 2010, Agrios 2005). This agreed with that mentioned by Lahm *et al.,* (2017) that nematode damage often goes unnoticed due to the hidden nature of the pest and the non-specific damage symptoms, which can be confused with soil fertility, drought or other soil pest or pathogen problems. Then, more likely one of the reasons of the low yield in Ecuadorian banana plantations is the lack of nematode control.

Author Contributions

Orlando Aguirre: Conceived the original idea and help to write the manuscript. César Chávez: Planned the analysis and help to write the manuscript. Eduardo Corrales: Made the statistical analysis and help to write the manuscript. Eduardo Salas: Structure the nematode data base and help to write the manuscript. Mario Araya: Organize and structure the information, write the draft, and review it.

Author Contributions

Orlando Aguirre: Investigation, formal analysis, writing—original draft. César Chávez: Validation, methodology, writing—reviewing. Eduardo Corrales:—Formal analysis, writing—review and editing. Eduardo Salas: Investigation, writing—reviewing. Mario Araya: Resources, investigation writing—reviewing.

Data Availability

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethical Approval Not applicable.

Consent to Participate Not applicable.

Consent to Publish Not applicable.

Conflict of Interest The authors declare no competing interests.

References

ACORBANET 2026. EUDE, junto a los líderes económicos de cada país, impulsa el talento del sector bananero ecuatoriano. https://acorbanec.com/2026/03/12/eude-junto-a-los-lideres-economicos-de-cada-pais-impulsa-el-talento-del-sector-bananero-ecuatoriano/

Agrios GN. 2005. Plant pathology. Fifth Edition. Elsevier Academic Press, 922p.

Aguirre O, Chávez C, Giraud A, Araya M. 2016a. Frequencies and population densities of plant-parasitic nematodes on banana (*Musa* AAA) plantations in Ecuador from 2008 to 2014. Agronomía Colombiana 34(1):61-73. Doi.org/10.15446/agron.colomb.v34n1.53915

Aguirre O, Chávez C, Giraud A, Araya M. 2016b. Spatial and temporal nematode distribution on banana (*Musa* AAA) plantations in Ecuador during the last 20 years (1996-2015). VI International Banana Congress-CORBANA and XXI International Meeting-ACORBAT. Miami, April 19-22.

Análisis nematológico para el agro S.A. ANEMAGRO 2025. Resultados de calidad de raíces y nematodos en raíces totales. Banano. 1p.

Araya M, Vargas R. 2018. Frecuencia y densidades poblacionales de los nematodos parásitos de las raíces del banano (*Musa* AAA) en Costa Rica del 2000-2008. CORBANA 44(64): 71-96.

Araya M, Lakhi A. 2004. Response to consecutive nematicide applications using the same product in *Musa* AAA, cv. Grande Naine originated from *in vitro* propagative material and cultivated on a virgin soil. Nematologia Brasileira 28(1): 55-61.

Araya M. 2004a. Los fitonematodos del banano (*Musa* AAA subgrupo Cavendish cultivares Grande Naine, Valery y Williams) su parasitismo y combate. Pp: 84-105. *En* XVI Reunión ACORBAT, Oaxaca, México.

Araya M. 2004b. Situación actual del manejo de nematodos en banano (*Musa* AAA) y plátano (*Musa* AAB) en el trópico americano. pp. 79-102. In: Rivas, Rosales F. eds. Manejo convencional y alternativo de la Sigatoka negra, nematodos y otras plagas asociadas al cultivo de musáceas en los trópicos. Guayaquil, Ecuador 11-13 agosto 2003. International Plant Genetics Resources Institute.

Araya M, De Waele D, Vargas R. 2002. Occurrence and population densities of nematode parasites of banana (*Musa* AAA) roots in Costa Rica. Nematropica 32, 21-33.

Araya M, Centeno M. 1995. Recuperación de *Radopholus similis*, *Helicotylenchus* spp., *Meloidogyne* spp. y *Pratylenchus* spp. de raíz funcional, no funcional y combinada de banano (*Musa* AAA). CORBANA 20(44):11-16.

Araya M, Centeno M, Carrillo W. 1995. Densidades poblacionales y frecuencias de los nematodos parásitos del banano (*Musa* AAA) en nueve cantones de Costa Rica. Corbana 20(43), 6-11.

Asanza P, Venegas F, Behm J. 1995. Uso continuo de Counter® (Terbufos) para controlar *Radopholus similis* en banano en el Ecuador. pp. 489-494. *In*: XI Reunión ACORBAT, San José, Costa Rica.

Ayoub SM. 1980. Plant nematology an agricultural training AID. NemaAid Publication. Sacramento, California. 195p.

Banana Export 2025. Prohibición de nuevas siembras en banano un saludo a la bandera. https://bananaexport.com/2025/07/16/prohibicion-de-nuevas-siembras-en-banano-un-saludo-a-la-bandera/

Baker R, Bragard C, Candresse T, Gilioli G, Grégoire JC, Holb I, Jeger MJ, Karadjova OE, Magnusson C, Makowski D, Manceau C, Navajas M, Rafoss T, Rossi V, Schans J, Schrader G, Urek G, Vloutoglou I, Winter S, Van der Werf W. 2014. Scientific opinion on the pest categorization of *Radopholus similis* (Cobb) Thorne and *Radopholus citrophilus* Huettel, Dickson and Kaplan. European Food Safety Authority EFSA Journal 12(10), 3852. 36p.

Barker KR. 1985. Sampling nematode communities. pp. 3-17. *In*: Barker KR, Carter CC, Sasser JN. eds. An advanced treatise on *Meloidogyne*. Volume II: Methodology. North Carolina State University Graphics.

Blake CD. 1966. The histological changes in banana roots caused by *Radopholus similis* and *Helicotylenchus multicinctus*. Nematologica, 12:129-137. DOI: 10.1163/187529266X00121.

Boncato AA, Davide RG. 1992. *Radopholus similis* on Giant Cavendish banana in Davo del Norte: host range, relative distribution, and density. Pp. 45-52. *In*: Davide RG. (eds.). Studies on nematodes affecting bananas in the Philippines. Philiphine Agriculture and Resources Research Foundation, Inc. Los Baños, Laguna, Philippines.

Blomme G, Ploetz R, Jones D, De Langhe E, Price N, Gold C, Pillay M, Tinzaara W, Teycheney PY, Lepoint P, Karamura E. 2013. A historical overview of the appearance and spread of *Musa* pests and pathogens on the African continent: highlighting the importance of clean *Musa* planting materials and quarantine measures. Annals of Applied Biology 162, 4-26.

Bridge J, Fogain R, Speijer P. 1997. The root lesion nematodes of banana. *Pratylenchus coffeae* (Zimmermann, 1898) Filip. & Schu. Stek., 1941. *Pratylenchus goodeyi* Sher & Allen, 1953. *Musa* Pest Fact Sheet No. 2. INIBAP, Montpellier, France. 4p.

Chabrier C, Hubervic J, Quénéhervé P. 2002. Evaluation of Fosthiazate (Nematorin® 10G) for the control of nematodes in banana fields in Martinique. Nematropica 32, 137-147.

Charles JSK, Venkitesan TS, Thomas Y, Varkey PA. 1985. Correlation of plant growth components to bunch weight in banana infested with burrowing nematode, *Radopholus similis* (Cobb). Indian J. Nematol, 15(2):186-190.

Chávez C, Chávez-Santos C, Aguirre O, Araya M. 2026. Nematode extraction from banana (*Musa* AAA) and plantain (*Musa* AAB) roots at Nemalab, Ecuador. International Journal of Current Microbiology and Applied Sciences. 15(3):244-261. https://doi.org/10.20546/ijcmas.2026.1503.026

Chávez C, Rubio D, Tobar M, Salas E, Araya M. 2020. Number of nematicide cycles per year on banana (*Musa* AAA cv Valery) root nematode control and crop yield. International Journal of Science and Research, 9(7):1651-1663.

Chávez C, Araya M. 2010. Spatial-temporal distribution of plant-parasitic nematodes in banana (*Musa* AAA) plantations in Ecuador. Journal of Applied Biosciences 33: 2057-2069.

Chávez C, Araya M. 2001. Frecuencia y densidades poblacionales de los nematodos parásitos de las raíces del banano (*Musa* AAA) en Ecuador. NEMATROPICA 31:25-36.

Chau NN, Thanh NV, De Waele D, Geraert E. 1997. Plant-parasitic nematodes associated with banana in Vietnam. International Journal of Nematology 7(2), 122-126.

Cubillos G, Barriga R, Pérez L. 1980. Control químico de nematodos en banana Cavendish cv Grande Naine en la región de Urabá, Colombia. Fitopatología Colombiana 9(2), 58-70.

Daneel M. 2024. Nematodes in banana. Pp:1-25. *In*: Drenth A, Kema GHJ Eds. Achieving sustainable cultivation of bananas. BURLEIGH DODDS SERIES IN AGRICULTURAL SCIENCE. http://dx.doi.org/10.19103/AS.2022.0108.16

Daneel M, De Jager K, Van den Bergh I, De Smet M, De Waele D. 2015. Occurrence and pathogenicity of plant-parasitic nematodes on commonly grown banana cultivars in South Africa. Nematropica 45, 118-127.

Das SC, Balamohan TN, Poornima K, Seenivasan N, Velalazan R, Ven den Bergh I, De Waele D. 2014. Screening of banana hybrids (Phase II hybrids) for resistance to *Helicotylenchus multicinctus*. Indian Journal of Nematology 44(1), 9-16.

Davide R. 1996. Overview of nematodes as a limiting factor in *Musa* production. pp. 27-31. *In*: Frison EA, Horry JP, and De Waele D. (eds.). Proceedings of the workshop on New Frontiers in Resistance Breeding for Nematode, *Fusarium* and Sigatola, 2-5 October, 1995, Kuala Lumpur, Malaysia. International Network for the Improvement of Banana and Plantain, Montpellier, France.

Davide RG. 1994. Status of nematode and weevil borer problems affecting banana in the Philippines. pp. 79-88. *In*: Valmayor RV, Davide RG, Stanton JM, Treverrow NL, Roa VN. (eds.). Banana nematodes and weevil borers in Asia and the Pacific. Proceedings of a Conference-Workshop on nematodes and weevil borers affecting bananas in Asia and the Pacific., Serdang, Selangor, Malaysia, 18-24 April, 1994. INIBAP Network for Asia and The Pacific.

Davide RG, Marasigan LQ. 1992. Yield loss assessment and evaluation of resistance of banana cultivars to the nematode *Radopholus similis* and *Meloidogyne incognita*. pp. 79-93. *In*: Davide, R.G. (eds.). Studies on nematodes affecting bananas in the Philippines. Philiphine Agriculture and Resources Research Foundation, Inc. Los Baños, Laguna, Philippines.

De Waele D, Davide RG. 1998. The root-knot nematodes of banana. *Meloidogyne incognita* (Kofoid & White, 1919) Chitwood, 1949. *Meloidogyne javanica* (Treub, 1885) Chitwood, 1949. *Musa* pest factsheet No. 2. INIBAP, Montpellier, France. 4p.

De Waele D. 2000. Root knot nematodes. pp. 307-314. *In*: Jones DR. Ed. Diseases of Banana, Abacá and Enset. CABI Publishing,

Dita MA, Garming H, Van den Vergh I, Staver C, Lescot T. 2013. Banana in Latin America and the Caribbean: current state, challenges and perspectives. Acta Horticulurae 986, 79-86.

Dubois T, Coyne DL. 2011. Integrated Pest Management of Banana Pests. pp: 121-144. *In*: Pillay M, Tenkouano A. (eds.). Banana Breeding Progress and Challenges. CRC Press Taylon & Francis Group.

Ekos 2026. Ecuador exporta USD 4.063 millones en banano en 2025 y consolida su liderazgo global. Ekos / Economía. 16 abril 2026. https://ekosnegocios.com/articulo/ecuador-exporta-usd-4-063-millones-en-banano-en-2025-y-consolida-su-liderazgo-global

Fargette M, Quénéhervé P. 1988. Populations of nematodes in soil under banana, cv. Poyo, in the Ivory Coast. 1. The nematofauna occurring in the banana producing areas. Revue Nematol. 11(2), 239-244.

Fogain R. 1994. Root knot nematodes: a serious threat to banana productions in Cameroon? MusaAfrica 4(3), 3.

Gantait VV, Bhattacharya T, Chatterjee A. 2011. Temporal variation in abundance of nematodes in a banana plantation of West Bengal, India. Nematol medit. 39, 9-15.

Gómez JT. 1997. Dispersión y niveles de infestación de *Radopholus similis* Cobb en algunas plantaciones bananeras del Ecuador. Nematropica 27(2), 111 abstract.

Gómez JT. 1980. Determinación de la infestación de fitonematodos en plantaciones bananeras de Urabá, Colombia. Fitopatología Colombiana 9(1), 19-32.

Gowen SR, Quénéhervé P, Fogain R, 2005. Nematode parasites of bananas and plantains. *In*: Luc M, Sikora RA, J. Bridge J. (eds). Plant parasitic nematodes in subtropical and tropical agriculture. CABI Publishing, pp. 611-643.

Gowen SR. 2000a. Nematode pathogens: Root-lesion nematodes. pp. 303-306. *In*: Jones DR. (eds.). Diseases of Banana, Abacá and Enset. CABI Publishing, Wallingford, UK.

Gowen SR. 2000b. Nematode pathogens: spiral nematode. pp. 306-307. *In*: Jones DR. (eds).

Diseases of Banana, Abacá and Enset. CABI Publishing, Wallingford, UK,

Gowen S. 1995. Pests. pp. 382-402. *In*: Gowen S. (eds.). Bananas and plantains. Chapman & Hall.

Gowen S, Quénéhervé P. 1990. Nematodes parasites of bananas, plantains and abacá. pp. 431-460. *In*: Luc M, Sikora RA, Bridge J. (eds.). Plant parasitic nematodes in subtropical and tropical agriculture. CAB International, Wallingford, UK.

Grunewald W, Cannoot B, Friml J, Gheysen G. 2009. Parasitic nematodes modulate PIN-mediated auxin transport to facilitate infection. PLoS Pathogens 5(1):1-7.

Guerout R. 1972. Relation entre les populations de *Radopholus similis* Cobb et la croissance du bananier. Fruits 27:331-337.

Guzmán GS, Orozco SM, Farias LJ, Bibián RM. 1995. Efecto del fosthiazate sobre la población del nematodo *Radopholus similis* en banano Gran Enano. pp. 495-502. *In*: XI Reunión ACORBAT, San José, Costa Rica.

Guzmán-Piedrahita OA. 2011. Importancia de los nematodos espiral, *Helicotylenchus multicinctus* (Cobb) Golden y *H. dihystera* (Cobb) Sher, en banano y plátano. Agron 19(2):19-32.

Haddad GO, Meredith JA, Martínez RGJ. 1975. Nematodos parasíticos asociados a cultivares y clones de bananos en Venezuela. Nematropica 5(2), 33-39.

Haegeman A, Elsen A, De Waele D, Gheysen G. 2010. Emerging molecular knowledge on *Radopholus similis*, an important nematode pest of banana. Molecular Plant Pathology 11(3):315-323.

Hartman JB, Vuylsteke D, Speijer PR, Ssango F, Coyne DL, De Waele D. 2010. Measurement of the field response of *Musa* genotypes to *Radopholus similis* and *Helicotylenchus multicinctus* and the implications for nematode resistance breeding. Euphytica 172, 139-148.

Hens L, Quynh LX. 2016. Environmental space. Pp: 1356-1363. *In*: Earth Systems and Environmental Sciences. https://doi.org/10.1016/B978-0-12-409548-9.09739-6

Instituto Nacional Autónomo de Investigaciones Agropecuarias-INIAP, 2025. Estación Experimental del Litoral Sur. Diagnóstico Nematológico. 1p.

Jackson GVH, Ruabete TK, Wright JG. 2003. Burrowing and lesion nematodes of banana. 2nd ed Pest Advisory leaflet / Secretariat of Pacific Community No 5. 4p.

Jaramillo J, Vintimilla M, Andino A, Decker E, Soto G, Tobar M, Delgado J, Salas E, Araya M. 2023. Banana (*Musa* AAA cv Williams) response to biological and chemical nematicides and their rotation. International Journal of Current Microbiology and Applied Sciences 12(11):89-113. https://doi.org/10.20546/ijcmas.2023.1211.010

Jaramillo J, Vintimilla M, Rubio D, Soto G, Tobar M, Salas E, Araya M. 2019. Effect of nematicide rotation on banana (*Musa* AAA cv. Williams) root nematode control and crop yield. Agronomía Colombiana 37(2):153-165. Doi: 10.15446/agron.colomb.v37n2.79099113.

Jaramillo R, Quirós J. 1984. Evaluación de cinco nematicidas en el control de *Radopholus similis* (Cobb) Thorne en la zona bananera de Urabá, Colombia. Augura 10(2), 73-88.

Jiménez FMaI, Triviño C. Velasco L. 1998. Influencia de la temperatura y la precipitación en la fluctuación poblacional de *Radopholus similis* en las zonas Oriental y Central del Ecuador. pp. 547-555. *In*: Memorias XIII Reunión ACORBAT 1998. Guayaquil, Ecuador.

Jones MGK, Iqbal S, Fosu-Nyarko JF. 2016. Below ground defense strategies against migratory nematodes. Pp. 253-278. *In*: Vos CMF and Kazan K eds. Below ground defense strategies in plants, signaling and communication in plants. Springer International Publishing Switzerland.

Kamira M, Hauser S, Van Asten P, Coyne D, Talwana HL. 2013. Plant parasitic nematodes associated with banana and plantain in Eastern and Western Democratic Republic of Congo. Nematropica 43, 216-225.

Kashaija IN, Fogain R, Speijer PR. 1999. Habitat management for control of banana nematodes. pp. 109-118. *In*: Frison EA, Gold CS, Karamura EB, Sikora RA. (eds.). Mobilizing IPM for sustainable banana production in Africa. Proceedings of a workshop on banana IPM held in Nelspruit, South Africa, 23-28 November 1998. International Network for the Improvement of Banana and Plantain, Montpellier, France.

Lahm GP, Desaeger J, Smith BK, Pahutski TF, Rivera MA, Meloro T, Kucharczyk R, Lett RM, Daly A, Smith BT, Cordova D, Thoden T, Wiles JA. 2017. The discovery of fluazaindolizine: A new product for the control of plant parasitic nematodes. Bioorganic & Medicinal Chemistry Letters

27:1572-1575. https://doi.org/10.1016/j.bmcl.2017.02.029

Larrea-Bernal SM, Pillasagua-Sánchez JW, Palacios-Mayorga AS, Cabrera-Gaspar EJ, Vera-Rodríguez JH. 2025. Nematodos fitopatógenos asociados al cultivo de banano (*Musa* x *paradisiaca* L.). Multidisciplinary Collaborative Journal 3(4):91-100. https://doi.org/10.70881/mcj/v3/n4/93

Lilley CJ, Moura de Souza VH, Eves-van den Akker S. 2024. Plant diseases caused by nematodes. Pp: 607-649. *In*: Oliver, R.P. Eds. Agrios´ Plant Pathology Sixth edition.

Lima RS, Muniz MFD, Castro JMC, Oliveira ERL, Oliveira PG, Siqueira KMS, Machado ACZ, Costa JG. 2013. Frequencies and population densities of the major phytonematodes associated with banana in the state of Alagoas, Brazil. Nematropica 43, 186-193.

Loos CA. 1962. Studies on the life-history and habits of the burrowing nematode, *Radopholus similis*, the cause of black-head disease of banana. Proceedings of the Helminthological Society 29(1), 43-52.

Mai WF. 1985. Plant-parasitic nematodes: their threat to agriculture. *In*: Sasser JN, Carter CC. Eds. An advanced treatise on *Meloidogyne*: Vol I Biology and control. Raleigh, NC: North Carolina State University Press Pp: 12-17.

Mani A, Al Hinai MS. 1996. Population dynamics and control of plant parasitic nematodes on banana in the Sultanate of Oman. Nematol. Medit. 24, 295-299.

Marín DH, Sutton TB, Barker KR. 1998. Dissemination of bananas in Latin America and the Caribbean and its relationship to the occurrence of *Radopholus similis*. Plant Disease 82(9), 964-974.

McKenry MV, Roberts PA. 1985. Phytonematology study guide. Division of Agriculture and Natural Resources University of California. 56p.

McSorley R, Parrado JL. 1986. Nematological reviews. *Helicotylenchus multicinctus* on bananas: an international problem. Nematropica 16(1), 73-91.

Medina L, Sojo J, Picado J, Delgado J, Salas E, Araya M. 2022. Banana (*Musa* AAA cv Williams) response to chemical and biological nematicides. International Journal of Current Microbiology and Applied Sciences 11(11): 214-236. https://doi.org/10.20546/ijcmas.2022.1111.025

Moens T, Araya M. 2002. Efecto de *Radopholus similis*, *Meloidogyne incognita*, *Pratylenchus coffeae* y *Helicotylenchus multicinctus* en la producción de *Musa* AAA cv. Grande Naine. Corbana 28(55), 43-56.

Moens T, Araya M, Swennen R, De Waele D. 2004. Enhanced biodegradation of nematicides after repetitive applications and its effect on root and yield parameters in commercial banana plantations. Biology and Fertility of Soils. 39:407-414.

Moens T, Araya M, Swennen R, De Waele D. 2005. Screening of *Musa* cultivars for resistance to *Helicotylenchus multicinctus*, *Meloidogyne incognita*, *Pratylenchus coffeae* and *Radopholus similis*. Australasian Plant Pathology 34: 299-309.

Mwangi L. 2023. Impact of climate change on agricultural food production. International Journal of Agriculture, 8(2), 1–10. https://doi.org/10.47604/ija.1994

Orion D, Bar-Eyal M. 1995. Observations on the life cycle and behavior of *Helicotylenchus multicinctus* in monoxenic culture of *Arabidopsis thaliana*. Nematropica 25(1), 67-70.

Orton WKJ, Siddiqi MR. 1973. *Radopholus similis*. C.I.H. Description of plant-parasitic–nematodes. No 27. Commonwealth Institute of Helminthology, England. 4p.

Patel BA, Byas RV, Patel DJ, Patel RS. 1996. Susceptibility of banana cultivars to root-knot nematodes (*Meloidogyne* spp.). InfoMusa 5(2), 26-27.

Pattison AB, Cobon JA, Araya VM, Chabrier C. 2024. Towards sustainable management of nematodes in banana. Pp: 1-32. *In*: Drenth A, Kema GHJ eds. Achieving sustainable cultivation of bananas. Volume 3. Diseases and pests. BURLEIGH DODDS SERIES IN AGRICULTURAL SCIENCE. http://dx.doi.org/10.19103/AS.2022.0108.17

Pinochet J. 1978. Histopathology of the root lesion nematode, *Pratylenchus coffeae* on plantains, *Musa* AAB. Nematologica 24(35), 337-340.

Pinochet J. 1977. Distribution of *Radopholus similis* on bananas in Belize. Journal of Nematology, 9(4), 280 abstact.

Pinochet J, Ventura O. 1977. Plant parasitic nematodes associated with bananas in Belize. Tropical Agriculture 54(4), 349-352.

Pone S. 1994. Status of nematode and weevil borer problems affecting banana in some of the Pacific Islands. pp. 90-105. *In*: Valmayor RV, Davide RG, Stanton JM, Treverrow NL, Roa VN (eds.). Banana nematodes and weevil borers in Asia and the Pacific. Proceedings of a Conference-Workshop on nematodes and weevil borers affecting bananas in Asia and the Pacific., Serdang, Selangor, Malaysia, 18-24 April, 1994. INIBAP Network for Asia and The Pacific.

PortalFruticola.com 2026. Ecuador exporta más de 377 millones de cajas de banano en 2025. https://www.portalfruticola.com/noticias/2026/01/28/banano-ecuador-2025-2/

Quénéhervé P, Mateille T, Topart P. 1991a. Effect of cadusafos compared with three other non-fumigant nematicides on the control of nematodes and on the yield of banana cv. Poyo in the Ivory Coast. Revue Nematol. 14, 207-211.

Quénéhervé P, Cadet P, Mateille T, Topart P. 1991b. Population of nematodes in soil under bananas cv. Poyo, in the Ivory Coast. 5. Screening of nematicides and horticultural results. Revue Nematol. 14, 231-249.

Quimí VH. 1981. Empleo de tres dosis de ethoprop, phenamiphos y carbofuran en el control de *Radopholus similis* en bananeras establecidas. Instituto Nacional de Investigaciones Agropecuarias (INIAP), Estación Experimental Boliche. Beletín Técnico No 41. 14p.

Quispe GJL. 2004. Densidad poblacional de nematodos fitoparásitos en plantaciones de banano (*Musa* AAA) en alto Beni, La Paz. Tésis Ing. Agr. Universidad Mayor de San Andrés, Bolivia. 89p.

Ramclam W, Araya M. 2006. Frequency of occurrence and abundance of root nematodes on banana (*Musa* AAA) in Belize. International Journal of Pest Management 52(1), 71-77.

Reddy PP. 1994. Status of banana nematodes in India. pp. 247-254. *In*: Valmayor RV, Davide RG, Stanton JM, Treverrow NL, Roa VN. (eds.). Banana nematodes and weevil borers in Asia and The Pacific. Proceedings of a Conference-workshop on nematodes and weevil borers affecting bananas in Asia and the Pacific. Serdang, Selangor, Malaysia, 18-22 April 1994. INIBAP/ASPNET, Los Baños, Laguna, Philippines.

Rodríguez RR. 1990. Los nematodos de la platanera (*Musa acuminata* AAA, subgrupo Cavendish Enana) en Canarias (1963-1984). Las Palmas de Gran Canarias, Caja Insular de Ahorros de Canarias. 58p.

Romero A, Ocampo E, Delgado J, Salas E, Guillén C, Araya M. 2024. Control de *Radopholus similis* en banano (*Musa* AAA) en Chiapas, México. ACORBAT Revista de Tecnología y Ciencia. Ciencia 1(1),60:472-480. https://doi.org/10.62498.ARTC.2460

Salguero D, Rudon G, Blanco R, Moya C, Ramclam W, Medina L, Azofeifa D, Araya M. 2016. Effect of different nematicide applications per year on banana (*Musa* AAA) root nematode control and crop yield. Journal of Applied Biosciences 101:9598-9609. http://dx.doi.org/10.4314/jab.v101i1.4

Santor RW, Davide RG. 1992. Interrelationship of *Radopholus similis* and *Meloidogyne incognita* in banana. pp. 71-77. *In*: Davide RG. (eds.). Studies on nematodes affecting bananas in the Philippines. Philippine Agriculture and Resources Research Foundation, Inc. Los Baños, Laguna Philippines.

Sarah JL, Pinochet J, Stanton J. 1996. El nematodo barrenador del banano, *Radopholus similis* Cobb. Plagas de *Musa* – Hoja divulgativa No. 1. INIBAP, Montpellier, Francia. 2p.

Sarah JL. 1989. Banana nematodes and their control in Africa. Nematological review. Nematropica 19(2), 199-216.

Siddiqi MR. 2000. Tylenchida: parasites of plants and insects. 2nd ed. CABI Bioscience, Egham, UK. https://doi.org/10.1079/9780851992020.0000

Siddiqi MR. 1972. *Pratylenchus coffeae*. C.I.H. Description of Plant-Parasitic Nematodes. Set 1, No 6. Commonwealth Institute of Helminthology, England. 3p.

Sikora R, Coyne D, Quénéhervé P. 2018. Nematode parasites of bananas and plantains. Pp: 617-657. *In*: Sikora RA, Coyne D, Hallmann J, Timper P. eds. Plant parasitic nematodes in subtropical and tropical agriculture. 3rd edition, CABI.

Speijer PR, Fogain R. 1999. *Musa* and Ensete nematode pest status in selected African countries. pp: 99-108. *In*: Frison EA, Gold CS, Karamura EB, Sikora RA. (eds.). Mobilizing IPM for sustainable banana production in Africa. Proceedings of a workshop on banana IPM held in Nelspruit, South Africa, 23-28 November 1998. International Network for the Improvement of Banana and Plantain, Montpellier, France.

Stanton JM, Pattison AB. 2000. Implementing strategic control of nematodes on banana. Final Report. Horticultural Research and Development Corporation, Queensland Department of Primary Industries, Queensland Government. March, 2000. Project FR96016. 98p.

Stanton JM. 1994. Status of nematode and weevil borer problems affecting banana in Australia. pp. 48-56. *In*: Valmayor RV, Davide RG, Stanton JM, Treverrow NL, Roa VN. (eds.). Banana nematodes and weevil borers in Asia and the Pacific. Proceedings of a Conference-Workshop on nematodes and weevil borers affecting bananas in Asia and the Pacific., Serdang, Selangor, Malaysia, 18-24 April, 1994. INIBAP Network for Asia and The Pacific. Nematology 1(3), 243-250.

Tarté R, Pinochet J. 1981. Problemas nematológicos del banano, contribuciones recientes a su conocimiento y combate. Panamá, UPEB. 32p.

Tarté R. 1980. La importancia del conocimiento de la biología y comportamiento de los nematodos parásitos del banano en el desarrollo de métodos eficientes de control. Augura 6(2), 13-21.

Taylor LQ, Loegering WQ. 1953. Nematodes associated with root lesions in abacá. Turrialba 3(1-2), 8-13.

Triviño GC. 2006. Determinación de la persistencia y eficacia del Rugby 10%G y otros nematicidas convencionales en la reducción de la densidad poblacional de *Radopholus similis* en plantas de banano. INIAP Estación Experimental Boliche. Convenio INIAP-FMC. Informe Técnico. 9p.

United Nations 2026. Department of Economic and Social Affairs. World population projected to reach 9.8 billion in 2050, and 11.2 billion in 2100. https://www.un.org/en/desa/world-population-projected-reach-98-billion-2050-and-112-billion-2100

Vargas R, Calvo C, Collado M, Araya M. 2006. Evaluación de estrategias de combate químico de nematodos en plantaciones de banano renovadas con plantas *in vitro*. CORBANA 32(59): 51-65.

Volcy C. 2011. Past and present of the nematode *Radopholus similis* (Cobb) Thorne with emphasis on *Musa*: a review. Agronomía Colombiana 29(3), 433-440.

Wyss U. 2002. Feeding behaviors of plant-parasitic nematodes. Pp: 233-259. *In*: Lee DL. The Biology of Nematodes. School of Biology University of Leeds, UK.

Zambrano CRA, Gallardo K. 2022. Análisis económico del banano en el Ecuador para determinar el crecimiento productivo en el período 2017-2022- Revista Científica Multidisciplinaria InvestiGo 3(5):79-91. DOI:10.56519/rci.v3i5.60

Zem A, Santos J, Alves E, Lordello L. 1981. Efeitos de nematicidas nas populacoes de nematoides e producao de bananeira "Nanicao". Sociedade Brasileira de Nematología. Piracicaba (5), 57-70.

How to cite this article:

Orlando Aguirre, César Chávez, Eduardo Corrales, Eduardo Salas and Mario Araya. 2026. Spatial-Temporal Nematode Distribution on Banana (*Musa* AAA) Plantations in Ecuador during the Last 10 Years (2016-2025). *Int.J.Curr.Microbiol.App.Sci.* 15(7): 180-199. **doi:** https://doi.org/10.20546/ijcmas.2026.1507.017