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FACT SHEET

A REVIEW OF COMMON NEMATODES THAT AFFECT PLANTAIN AND BANANA IN HAITI AND OTHER TROPICAL COUNTRIES

Suggested low-cost methods to control plant parasitic nematodes in banana

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Anatomical Aspect and Lifestyle

Nematodes (phylum Nemata) are roundworms, with an unsegmented body unlike the earthworm that is segmented and belongs to the phylum Annelida. Their length varies from 0.3 mm for the smallest to 8 meters for the longest and the width is between 0.01 to 0.05 mm. They are the most abundant multicellular organisms on earth and feed on a wide range of organisms such as bacteria, fungi, insects, animals, other nematodes and plants (Figure 1) (Coyne et al., 2018).

The plant feeders are generally less than 1000 cells and can be up to 4 mm long. They are transparent, long and slender with a tubular body plan, except for the females of some sedentary species that become swollen and rounded in their adult stage (Figure 2) (Lambert, K. and Bekal, S. 2002).

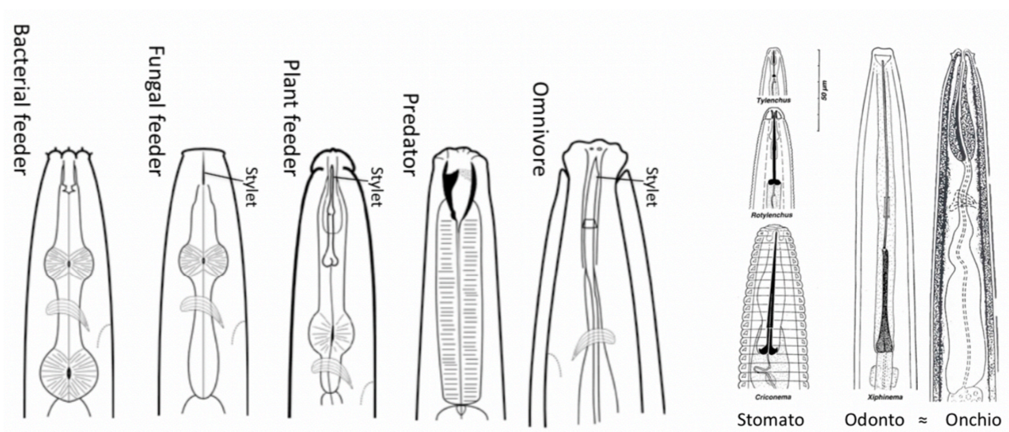

Figure 1. Mouth part structure of different trophic group of nematodes and different types of stylets of plant feeding nematodes. Photo credit: (Brantley, 2017)

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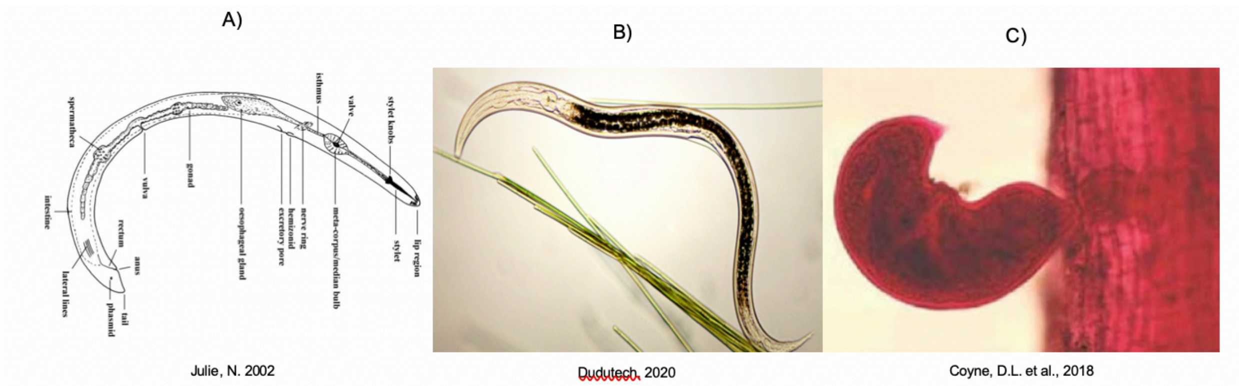

Figure 2. Structural appearance of plant parasitic nematodes. A and B represent the slender structure of a typical plant parasitic nematode while C represents a swollen adult female with a kidney shape (Reniform nematode).

From the roots to the flowers, the plant parasitic nematodes feed on all parts of the plants, even the seeds, by using a special feature of their mouth part called stylet. It is used for penetration, suction of plant juice and for secretion of enzymes inside the plant tissues. The stylet varies in size and shape (Stomatostylet, Odontostylet and Onchiostylet) depending on the feeding mode of the species (Figure 2). Some nematodes kill the cells of the plants by withdrawing all their content, resulting in large lesions in the plant tissue (ex: *Helicotylenchus* spp., *Pratylenchus* spp. *Radopholus* spp.). Some others modify the cells of the plant by creating a long-term feeding site in the plant tissue. This feeding site can be created by the fusion of adjacent cells by the movement of the nematode through the cell walls (cist nematodes), or by the continuous nuclear division of a single cell in absence of cell division caused by gland secretion of the nematode (root knot nematodes) (Lambert, K. and Bekal, S. 2002).

Foliar nematodes damage the leaves of the plants by feeding directly on the foliage and destroy their aesthetic value. In the case of many ornamental plants, the damage is often more economic than lethal, because the plants become less attractive during and after the infection without affecting their physiological functions in many cases. However, in severe infection, the pathogen can cause remarkable injuries in the leaves, induce defoliation and inhibit or limit the flowering process of the affected plant. The symptoms produced by plants affected by foliar nematodes are different depending on the stage of development of the plant. They can cause the young leaves to curl, twist and stunt, but the leaves remain on the plant. Yet, in more mature plants, blotches that are small, angular and vein limited can be observed. In advanced stages, the blotches turn brown and dry and may eventually fall leaving a hole on the leaf (Meyers and Hudelson, 2014) (Southey, 1993). Also, foliar nematodes can cause gall formation on the leaves or the seeds of the affected plant, leaf stripes, bleaching and discoloration of leaves, internal stem necrosis, inflorescence necrosis and other similar symptoms (Coyne et al., 2018).

Root feeding nematodes in contrast, damage the root system of plants, thus resulting in a reduction of the root mass and an alteration in the root structure. This morphological modification reduces their ability to absorb water and nutrients from the soil. Plants infected display the following symptoms above ground: yellowing of the leaves, fewer and smaller leaves, nutrient deficiency, wilting, stunting, yield reduction, and in the most drastic stage, the death of the plant (Lambert, K. and Bekal, S. 2002).

Feeding Habits of Plant Parasitic Nematodes (Types of Plant Parasitic Nematodes)

The root feeding nematodes are generally separated into three different categories based on their feeding habits and their motility. The categories are: migratory endoparasites (ex: *Radopholus similis, Pratylenchus* spp.), sedentary endoparasites (*Meloidogyne* spp. or root knot nematodes*, Heterodera* spp. or cist nematode) and ectoparasites (*Helicotylenchus* spp.).

The migratory endoparasites are mobile nematodes that feed inside the plant root tissue and move from one cell to another to look for new feeding sites. Also, these nematodes can migrate outside the plant tissue to find a fresh spot to feed on. All t stages of their life cycle are mobile except for the eggs that are usually laid on the cortical tissue or the roots or in the soil surrounding the roots of the plant (Figure 3) (Coyne et al., 2018).

The second-stage juvenile of sedentary endoparasite migrate from the soil to look for a feeding site inside the root of a host plant as an "infective" wormlike female. Once a feeding site is found, the female becomes sedentary for her total lifetime and develops into an adult female with a swollen body that is either spherical, lemon, kidney or ovoid shape. The males of this category are not infective and feed on the surface of the roots of the host plant. Their role is to fertilize the females and die a few days later in the soil. There is a subcategory of this group that includes nematodes that are also sedentary but only part of their body is inside the root tissue (*Rotylenchulus* spp. or reniform nematodes). The other half of their body stays in the soil where they lay their eggs. This category is called semi-endoparasitic (Figure 3) (Coyne et al., 2018).

The ectoparasites are nematodes that feed directly on the outer surface of the root hair or on the cortical tissues but live in the soil. Even found in high densities, they are generally not considered as a major problem except when the plant is already affected by other biotic problems. Some of these nematodes are often considered as virus vectors through their stylet as they can be feeding from one plant to another (Figure 3) (Coyne et al., 2018).

Economic Importance of Plant Parasitic Nematodes

Plant parasitic nematodes are a major challenge in agriculture production systems, especially when the need for food is increasing. They reduce up to 12.3% of the global food production on an annual basis, which can be evaluated, to more than US $157 billion worldwide (Singh et al., 2015). It has been estimated that damage caused by nematodes are higher in the United States than those caused by insects. One of the crops most affected by plant-parasitic nematodes is banana and plantain.

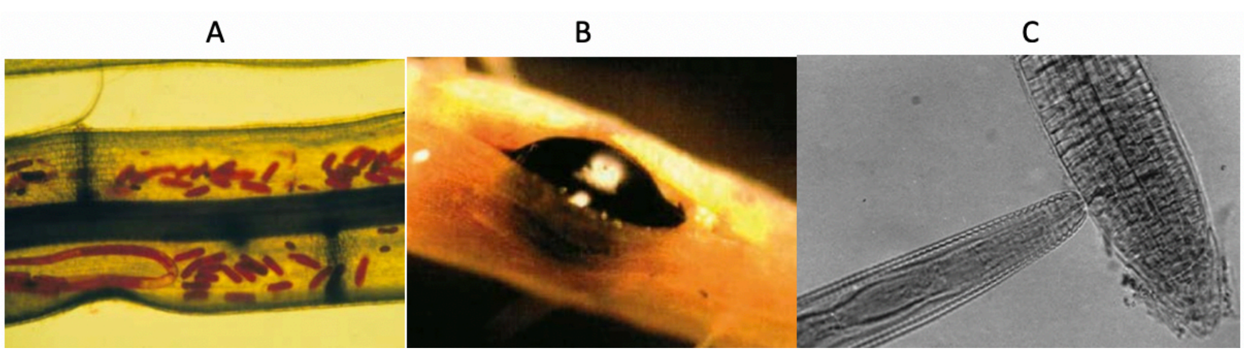

Figure 3. Types of plant parasitic nematodes. A) migratory endoparasitic nematode (Hirshmanniella spp.) female in rice root. B) Sedentary endoparasite (cist nematode: Heterodera spp.) in rice root. C) Ectoparasite (Aulosphora spp.) feeding on root rice

General introduction to Banana Production

Banana and plantain are ranked among the most important crops in the world. Their combined annual production is above 150 million tons of fruit produced on approximately 10 million hectares worldwide (FAOSTAT, 2017). As the major exported and consumed fruit globally, banana plays an important role in human nutrition and in the economy since it generates income and employment for millions of households (Tripathi et al., 2015). Recent statistics about banana export in 2016 indicate that this industry generates approximately US $9 billion annually although 85% of world production is consumed in the producer's household or sold in local markets (FAOSTAT, 2017). Banana and plantain originated in Southeast Asia, but they are currently produced and consumed in nearly 140 countries in the tropics and subtropics. This perennial crop stands as one of the most important staple foods after rice, maize, wheat, cassava and potato in many African, Asian, American and Caribbean countries (Tripathi et al., 2015).

In Haiti, banana and plantain are produced on over 90,000 ha for an annual production of approximately 505,000 tons of fruits in 2018 (FAOSTAT, 2018). The crop is produced on all the cultivated areas in Haiti but more than 70% of the total production is concentrated in the West (19.74%), Artibonite (18.1%), North (14%), Centre (12.9%), Grand'Anse and Northwest departments (CNSA, 2013) (MARNDR, 2017). The crop is cultivated in monoculture in high-production regions and in agroforestry systems in high altitude areas with other high-value and staple crops (CJ Consultants, 2012).

Banana cultivars grown in Haiti are separated in three categories including: Plantain (also called "Miske" in creole), banana (Figue banane) and some ABB types that fall in the "Poban" category. "Miske", types are most widely consumed and usually cooked or fried and served as a main dish or side dish. The "figue banane" are eaten mostly fresh but in certain areas are also eaten cooked for breakfast. The "Poban" type is mainly produced for flour (Jean-Pierre et al., 2013).

Banana is an important component in Haitian diet (Per capita consumption can be over 60kg/person/year) and an essential asset for farmers economy growth (IICA, 2012) (Jean-Pierre et al. 2013). It has been estimated that this industry alone is worth $150 million and contributes to approximately 8% of gross domestic product (Organization for the Rehabilitation of the Environment, 2016).

Despite of its importance to Haitian diet, banana production in Haiti is subjected to numerous abiotic (drought, hurricanes, lack of resources) and biotic stresses (fungal and bacterial diseases) that negatively impact yield (MARND, 2014). Moreover, the vegetative reproduction of this crop accelerates the spread of certain pathogens such as nematodes (Loebenstein et al., 2015) (Herradura et al., 2012).

Several plant parasitic nematodes that infect banana and plantains are common worldwide. These include *Radopholus similis*, some *Pratylenchus* spp., *Helicotylenchus multicintus*, *Meloidogyne incognita, Hoplolaimus pararobustus, Heterodera oryzae* and *Heterodera oryzicola* (CABI, 2017). The first three nematodes listed above are the most important and widespread for this crop (Gowen et al., 2005). These nematodes have been documented in West African banana producing countries, South and Central America, Florida and in other Caribbean countries including the Dominican Republic (CABI, 2017). *Radopholus similis*, *Helicotylenchus multicintus* and *Pratylenchus* spp. have been reported in Haiti, however, more extensive and thorough research needs to be done in order to confirm their presence and distribution to develop a comprehensive management plan.

Symptoms, pathogenicity, biology and life cycle of the principal plant parasitic nematodes affecting banana in Haiti

Radopholus similis

Generalities

R. similis, also known as the burrowing nematode, is the most damaging and widespread nematodes pest of bananas in the tropics. Its worldwide occurrence was facilitated by the international trade of infected propagative plant materials between banana-producing countries (Gowen et al., 2005) (O'Bannon, 1977).

Symptoms and economic importance

The persistent damage caused by *R. similis* can cause up to 75% of yield loss in banana. Where it occurs, it causes the "black head toppling disease" (Gowen et al., 2005). The nematode affects the root cortex but can also feed on the rhizome or corm and produce lesions similar to those it causes in the roots. One diagnostic feature for the presence of the burrowing nematode in a plant is a reddish lesion in the larger roots that can be revealed by a longitudinal section of the root (McSorley, 1986). Furthermore, the injuries caused by this nematode usually provide an entry that favors secondary infections by fungi and/or bacteria, inducing the development of other diseases (O'Bannon, 1977).

Yield reduction caused by *R. similis* is due to the inability of affected plants to absorb water and nutrients which results in a reduction of the bunch weight and flower production, as well as the stunting and the toppling of the plants which root systems are destroyed by the parasite (Speijer, 1999).

Biology and life cycle

As a migratory endoparasitic nematode, all the infective stages of *R. similis* can complete their life cycle within the root tissue. From the second-stage juvenile to the adult stage (except the adult males that are not infective due to a degenerate stylet), the nematodes use their stylet to penetrate the root system. The penetration usually occurs at the tip of the root although it can occur anywhere along the root length (Kaplan and Opperman, 2000) (Loos, 1962). The invasion is made via the epidermis of the roots from where they migrate to occupy an intracellular position in the cortex. By extracting the cytoplasmic content of the nearby cells, the cell walls collapse to form lesions and cavities that will be eventually occupied by fungi. Short root stubs at the base of the corm are often observed (Loos, 1962).

The life cycle (from egg to egg) of the parasite is completed within 20 to 25 days at 24-32°C and females lay 4-5 eggs daily for 2 weeks which take 8-10 days to hatch. (Loos,1962).

***Helicotylenchus* spp.**

Generalities

Helicotylenchus spp. and *R. similis* frequently occur together in banana plantation even under optimal conditions and are of greatest concern (Wang and Hooks, 2009). *H. multicintus,* also called spiral nematode, may be considered as the most damaging nematode of bananas after the burrowing nematode in subtropical regions where the conditions are suboptimal for banana production and for *R. similis* (Quénéhervé, 2009; McSorley and Parrado, 1986).

Symptoms

Spiral nematodes feed on the outer cells of the roots and cause small and shallow necrotic lesions that take a longer time to develop than those caused by lesion nematodes. Nevertheless, in a heavy infestation, the small lesions merge to form extensive necrotic lesions in the outer cortex of the roots (Quénéhervé and Cadet, 1985). Other typical plant parasitic nematode symptoms such as stunted plants, lengthening of vegetative phase, reduction of plant and bunch size as well as toppling can be observed under high infestation of *H. multicintus* (Gowen et al., 2005).

Biology and life cycle

Helicotylenchus species are often classified as endoparasitic nematodes as the eggs, both sexes, and all juvenile stages can be found in the cortex of the plant roots (Zuckerman and Strich-Harari, 1964). A few days after entry *Helicotylenchus* can be found in the cortex usually to a depth of 4 to 6 cells. They feed on the cytoplasm of cells close to the epidermis (Blake, 1966), and cause different kinds of cellular damage such as rupture of cell wall, nucleus enlargement, contracted cytoplasm and other impairments. Females lay eggs in roots, which hatch within 5 to 6 days. Under suitable conditions in the field, the life cycle is reported to be completed in approximately 32 days. *Helicotylenchus multicintus* is bisexual and reproduces by cross-fertilization or amphimixis (Southey, 1973) but many other *Helicotylenchus* spp. reproduce by parthenogenesis.

Pratylenchus **spp.**

Generalities

Pratylenchus spp. are another migratory endoparasitic nematode that affect banana. Only two of the eight reported *Pratylenchus* species attacking *Musa* spp. worldwide are documented as the most common and damaging pathogens for this crop (*P. coffeae* and *P. goodeyi*). (Quénéhervé, 2009; Gowen et al., 2005). This species is considered a pan-tropical species and an important pest of tuber crops, ornamentals coffee, banana and other fruit trees (Gowen et al., 2005).

Symptoms and economic importance

Plants infested with *Pratylenchus* present the same symptoms as those attacked by *R. similis* (plant stunting, extended vegetative phase, reduced size of the bunch andnumber of leaves and toppling). Epidermal and cortical tissue present extensive black or purple necrotic areas that are often subjected to secondary infections (Bridge and Page,1984). *P. goodeyi* can eventually penetrate and destroy the cortical parenchyma of the roots and the corm which impair root functions (De Guiran and Vilardebó, 1962).

Biology and life cycle

As migratory endoparasites, *P. coffeae* and *P. goodeyi* complete their life cycle within the cortex of the roots and corm of banana. Adults and juvenile stages of both sexes are invasive (Gowen et al., 2005).

Once in the roots, the migration is done between and within cells to reach and occupy a position parallel to the stele from where they feed on the cytoplasm of surrounding cells. Their feeding habit creates cavities that collapse as described for *R. similis*. The cortical parenchyma is also destroyed but no cell enlargement is observed as described for *R. similis* (Pinochet, 1978) (Blake, 1961).

The life cycle form egg to egg for this pathogen is typically completed within 27 days on average at 25-30C (Gotoh, 1964).

Control methods of plant parasitic nematodes

Controlling plant parasitic nematodes associated with banana can be a tedious endeavor considering that banana is a perennial crop. As a perennial that continually grows in the same site, there tends to be a "building up" of these parasites in the roots and in the soil rhizosphere. This makes it more challenging than managing this pest in an annual crop (Wang, 2009). There are several strategies to control nematodes in banana plantations. The strategies practical for Haiti are classified into three categories: prevention, cultural control, and plant genetics.

Nematode prevention

In terms of prevention methods, **soil fumigation,** as a pre-plant treatment is one of the most effective methods used to prevent plant parasitic nematodes in banana plantations. However, due to the long-life cycle of the crop, the plant parasitic nematodes tend to repopulate the soil and cause damage to the plant, which results in production losses (Wang, 2009). Other alternatives to the use of chemical applications that can decrease the effect of these nematodes include crop rotation, the use of clean planting material and solarization.

Crop rotations with sugarcane (Stoyanov, 1967), cassava (Zem and Alves, 1983) or pineapple (Sarah, 1989) for example have been practiced in the second half of the past century in our region. However, due to the high cost associated with the logistics of rotating different crop and the reduction of incomes, farmers have been reluctant to practice it despite of its efficiency.

The **use of clean planting material** can be a very effective preventative method. Starting a plantation with plantlets produced in-vitro and free of parasites is one of the best alternatives to prevent plant-feeding nematodes. However, this resource is not always available to farmers especially the ones living in developing countries such as Haiti. Alternatively, farmers can clean their planting materials by mechanically removing all the necrotic areas infected by nematodes including the infected roots. After cleaning the plantlets, they can expose them to the sun for a more thorough treatment (Quénéhervé and Cadet, 1985b). Hot water treatment of planting material is a method used to clean plants potentially affected by nematodes prior to planting. This consists of immersing the suckers in water at 65□C for 5 minutes (Mallamaire, 1939) or at 55□C for 25 minutes (Blake, 1961) (Figure 4). In the absence of material for the hot water treatment, farmers can always wrap transparent plastic bags around the suckers and expose them to the sun (Layman's approach). This method is still under study to determine the exposure time required for the most effective treatment and to prevent killing the plants (Figure 4) (Wang, 2009). It's important to mention however that these cleaning methods may not be effective at destroying all the nematodes in the infected suckers (Quénéhervé, 2009).

Figure 4. Physical treatment of infected banana suckers prior establishing a plantation in absence of tissue culture plantlets (Wang, 2009).

Soil solarization is a good technique that can be used to eliminate pathogens in the soil before the establishment of a banana plantation. It consists in heating moistened soil underneath a transparent plastic sheet that lay down so that it is air-tight to eliminate the pathogen. The sun needs to heat the soil under the plastic and maintain a high temperature over a period of time to kill the nematodes. This is done prior to preparing the soil for planting. It has been is used for many years and can be considered as a good alternative for tropical countries (Wang, 2009).

Cultural control

Cover cropping and the use of organic amendments to increase organic matter in the soil can be effective cultural methods to control nematodes. Studies have shown that certain plants can act as suppressors of plant parasitic nematodes such as sunn hemp (Crotalaria juncea) and marigold (Tagetes patula). These plants have shown the potential of reducing initial levels of the root knot nematode in banana plantations. This effect can be continuous as certain cultivars of marigold are as effective as soil fumigants in suppressing plant parasitic nematodes in banana plantations (Wang, 2009).

Many authors have investigated the effect of organic amendments (Chitin, crop residues or green manure) in controlling nematodes and have found inconsistent, yet promising results (Rodriguez-Kabana et al., 1987; Buena et al., 2007; Abawi and Widmer, 2000). The efficacy of the control will depend on the nature of the organic amendment. According to a research carried out with four different amendments, organic materials with medium to high C:N ratio (17-39) such as sugarcane bagasse, have higher potential in suppressing plant parasitic nematodes in banana than those that decompose faster (Tabarant et al., 2011). Organic matter can stimulate and increase the presence of microfauna in the soil that can suppress plant parasitic nematodes mainly through predation.

Fallowing can be practiced as a cultural as well as a preventive method to control plant parasitic nematode. It consists in leaving the soil free of crops for a long period of time (at least 1 year), preferably after ploughing, to allow the sun to kill the nematodes in the soil. The nematodes also die by starvation due to the absence of a host plant to feed on. During that period, it is recommended to keep the soil moist to encourage egg hatch (Perry and Ploeg, 2010).

Plant-based genetic resistance

While the utilization of nematode resistant plant material may be the most economic and environmentally friendly method of control, farmers choose their cultivars primarily based on yield, market value and resistance to other major key abiotic and biotic threats rather than their resistance to plant nematodes. Currently there is little information on the nematode resistance of traditional varieties of banana and plantain grown in Haiti.

None of the methods mentioned above are 100% effective in controlling plant parasitic nematodes in banana and plantain. Many of the methods confer only partial control and may not be effective in the long term. Thus, an integrated pest management strategy, which is the combination of different technics for a long term prevention and/or control of nematode is presented as the most suitable method to control this pest as previously suggested by Quénéhervé (2009) and Wang and Hooks (2009).

Conclusion

Plant parasitic nematodes cause serious damage to agriculture around the world and can impact the food safety of our communities especially in countries where the agriculture is practiced essentially to meet basic needs of the households. In Haiti, banana is one of the staple foods and one of the major cash crops that sustain the economy in the rural communities where it is produced. Knowing what nematodes are and applying the control methods described above can help reduce loss and enhance the resilience of Haitian farmers.

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References

1. Abawi, G. S., & Widmer, T. L. (2000). Impact of soil health management practices on soilborne pathogens, nematodes and root diseases of vegetable crops. Applied soil ecology, 15(1), 37-47.
2. Blake, C. D. (1961). Root rot of bananas caused by Radopholus similis (Cobb) and its control in New South Wales. Nematologica, 6(4), 295-310.
3. Blake, C.D. (1966) The histological changes in banana roots caused by Radopholus similis and Helicotylenchus multicinctus. Nematologica, 12(1), 129–137.
4. Bridge, J., & Page, S. L. M. (1984). Plant nematode pests of crops in Papua New Guinea. Journal of Plant Protection in the Tropics, 1(2), 99-109.
5. Buena, A. P., García-Álvarez, A., Díez-Rojo, M. A., Ros, C., Fernández, P., Lacasa, A., & Bello, A. (2007). Use of pepper crop residues for the control of root-knot nematodes. Bioresource Technology, 98(15), 2846-2851.
6. CABI: Commonwealth Agricultural Bureaux International. (2017). Distribution Maps of Plant Diseases: A leading resource for worldwide distribution data of plant diseases of economic or quarantine importance. Retrieved from: https://www.cabi.org/dmpd/search/?q=banana&topics=0c6341f5352349a6afa5e1 57439918e8&rows=10&sort=Relevance&facets=1&facet1f=Geographical+Locati on&facet1v=Florida.
7. CJ Consultants. 2012. “Haïti: Étude de la filière banane.” Rapport de Consultation. Port-au-Prince, Haiti: IICA.
8. CNSA. 2013. “Evaluation previsionnelle de la performance des récoltes de La campagne agricole de printemps 2013.” Port-au-Prince, Haiti: MARNDR.
9. Coyne, D. L., Nicol, J. M., & Claudius-Cole, B. (2018). Practical plant nematology: A field and laboratory guide.
10. De Guiran, G., & Vilardebo, A. (1962). Le bananier aux îles Canaries. IV. Les nématodes parasites du bananier. Fruits, 17(6), 263-277.
11. FAOSTAT. (2017). Trade and Markets. Retrieved from: http://faostat.fao.org. (Accessed: 19th May 2019).
12. FAOSTAT. (2018). Banana, plantains and others. Retrieved from: http://faostat.fao.org. (Accessed: 26th May 2020).
13. Gotoh, A. (1964) The embryonic and larval development of Pratylenchus coffeae (ZIMMERMAN) (Nematoda: Tylenchida). Jpn. J. appl. Entomol. Zoo 8, 26-33.
14. Gowen, S. R., Quénéhervé, P., & Fogain, R. (2005). Nematode parasites of bananas and plantains. Plant parasitic nematodes in subtropical and tropical agriculture, 2, 611-643.
15. Herradura, E. L., Lobres, N. A. M., Waele, D.D., Davide, G. R., & Bergh, B. V.I. (2012). Yield response of four popular banana varieties from Southeast Asia to Infection with a population of Radopholus Similis from Davao, Philippines. Nematology, 14, 7, 889-897.
16. Institut Interaméricain de Coopération pour l’Agriculture (IICA). (2012). Haiti: Etude de la Filière Banane. Rapport de Consultation.
17. Jean-Pierre, Stephan, Helene Kiremidijan, and Junior Paul. 2013. “USAID/HAITI. Etude initiale des cinq filières prioritaires.” Washington, DC: USAID.
18. Kaplan, D. T., & Opperman, C. H. (2000). Reproductive strategies and karyotype of the burrowing nematode, Radopholus similis. Journal of Nematology, 32(2), 126.
19. Lambert, K., & Bekal, S. (2002). Introduction to plant-parasitic nematodes. The plant health instructor, 10, 1094-12-18.
20. Loebenstein, G., & Katis, N. I. (2015). Control of Plant Virus Diseases: Vegetatively-Propagated Crops. Amsterdam: Academic Press, 91.

21. Loos, C. A. (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 of Washington, 29(1), 43-52.
22. Mallamaire, A. (1939). La pourriture vermiculaire du bananier de Chine causée par Anguillulina similis Goodey en Afrique Occidentale Française. L'Agronomie Coloniale, Année 28, (254)32-42, (255)65-75.
23. McSorley, R., & Parrado, J. L. (1981). Population fluctuations of plant-parasitic nematodes on bananas in Florida [Meloidogyne incognita, Helicotylenchus multicinctus, Helicotylenchus dihystera]. In Proceedings of the ... annual meeting of the Florida State Horticultural Society (USA).
24. Meyers, M. and Hudelson, B. (2014). Foliar nematodes (Item No. XHT1238). Retrieved from https://hort.extension.wisc.edu/articles/foliar-nematodes/
25. Ministere de L'Agriculture, Des Resources Naturelles et du Developpement Rural (MARNDR). (2014). Resultats des Enquetes Nationales de la Production Agricole. Unite d'Etude et de Programmation Sous-Structure Statistique Agricole et Informatique.
26. Ministere de L'Agriculture, Des Resources Naturelles et du Developpement Rural (MARNDR). (2014). "Agricultural Production Data 2014 - 2016."
27. 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(6), 407-414.
28. O'Bannon, J. H. (1977). Worldwide dissemination of Radopholus similis and its importance in crop production. Journal of Nematology, 9(1), 16.
29. Organization for the Rehabilitation of the Environment. (2016). Black Sigatoka Has Decimated Banana Production in Haiti.
30. Perry, E.J. & Ploeg, A.T. (2010) Integrated Pest Management for Home Gardeners and Landscape Professionals.
31. Pinochet, J. (1978). Histopathology of the root lesion nematode, Pratylenchus coffeae, on plantains, Musa AAB. Nematologica, 24, 331-340.
32. Quénéhervé, P. (2009). Integrated management of banana nematodes. In Integrated Management of Fruit Crops Nematodes (pp. 3-62). Springer, Dordrecht.
33. Quénéhervé, P. & Cadet, P. (1985) Localisation des nematodes dans les rhizomes du bananier cv ... Revue de Nematol, 8(1), 3–8.
34. Quénéhervé, P. & Cadet, P. (1985b). Etude de la dynamique de l'infestation en nématodes transmis par les rhizomes du bananier cv. Poyo en Côte d'Ivoire. Revue Nématol., 8, 257-263.
35. Rodriguez-Kabana, R., Morgan-Jones, G., Chet, I., 1987. Biological control of nematodes: soil amendments and microbial antagonists. Plant Soil 100, 237–247.
36. Sarah, J-L. (1989). Banana nematodes and their control in Africa. Nematropica, 19, 199-216.
37. Singh, S., Singh, B., & Singh, A. P. (2015). Nematodes: A threat to sustainability of agriculture. Procedia Environmental Sciences, 29, 215-216.
38. Southey J.F. (1973). Helicotylenchus multicinctus. C.I.H. Descriptions of plant parasitic nematodes. CABI Publishing, 23(2), 350.
39. Southey, J. F. (1993). Nematode pests of ornamental and bulb crops. Plant parasitic nematodes in temperate agriculture., 463-500.
40. Speijer, P. R. (1999). East African highland banana production as influenced by nematodes and crop management in Uganda. International journal of pest management, 45(1), 41-49.
41. Stoyanov, D. (1967). Especies de nematodos parasitos del platano en Cuba y posibilidades de control. Revista de Agricultura, 1, 9-47.

42. Tabarant, P., Villenave, C., Risede, J. M., Roger-Estrade, J., Thuries, L., & Dorel, M. (2011). Effects of four organic amendments on banana parasitic nematodes and soil nematode communities. Applied Soil Ecology, 49, 59-67.
43. Tripathi, L., Babirye, A., Roderick, H., Tripathi, J. N., Changa, C., Urwin, P. E., ... & Atkinson, H. J. (2015). Field resistance of transgenic plantain to nematodes has potential for future African food security. Scientific reports, 5, 8127.
44. Wang, K. H., & Hooks, C. R. (2009). Plant-parasitic nematodes and their associated natural enemies within banana (Musa spp.) plantings in Hawaii. Nematropica, 39(1), 57-74.
45. Zem, A. C., & Alves, E. J. (1983). Effect of different cultivation practices on the population of Radopholus similis [Musa spp., banana, nematode, nematicide, cultivation practice, chemical control]. Publicacao-Sociedade Brasileira de Nematologia (Brazil).
46. Zuckerman, B.M. & Strich-Harari, D. (1963) The life stages of Helicotylenchus multicinctus (Cobb) in banana roots. Nematologica, 9(3), 347–353.

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