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Relationship between Nematodes and Some Soil Properties in the Rhizosphere of Banana Plants

Amal Ahmed Mohammed Al-Ghamdi*

Department of Biological Sciences, Faculty of Science, King Abdulaziz University, PO Box 35009 Jeddah 21488, Saudi Arabia.

*Corresponding author e-mail: amalalgamdi@gmail.com

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Abstract. Nematodes are plant-parasitic organisms that cause alterations in the chemical and physical environment of soils. This study investigates the relationship between nematode occurrence and some soil parameters. The results showed that the proportion of nematodes in soil was negatively correlated with soil pH (r^2= 0.89); however, it increased with increasing electrical conductivity (EC) (r^2 = 0.95), soil moisture (SM) (r^2 = 0.60), and organic matter (OM) content (r^2= 0.78). A positive correlation was found between the proportion of nematodes in the roots and the amount of coarse sand, while a negative correlation existed between the proportion of nematodes and the amount of fine sand, clay, and silt. The degree of colonization by nematodes increased with increasing coarse sand content (r^2= 0.91). Conversely, the soil nematode population decreased with increasing fine sand content (r^2= 0.83), clay (r^2= 0.80), and silt content (r^2= 0.97). The nematode population in banana roots correlated with soil phosphorus (r^2 = 0.88), potassium (r^2 = 69), calcium (r^2 = 0.78), and magnesium levels (r^2=0.78). Conversely, a negative correlation was found between nitrogen concentration and the nematode population in banana roots (r^2=0.76). Overall, the population of nematodes in soil affects its pH, EC, SM, and OM content.

Introduction

Bananas and plantains are the fourth most important global food commodity and are grown in over 100 countries, with approximately 88 million tons produced annually (Frison and Sharrock, 1999). They are among the most important crops in the world, representing a staple food for millions of people in developing countries (Roux et al., 2008). Additionally, they provide food security and income to persons living in rural areas (Roux et al., 2008). Of these two crops, bananas are considered promising due to their economic importance for farmers (Delvaux ,1995).

Nematodes are reported to be one of the most important and widespread agricultural pests (Koenning et al., 1996). They are also one of the most common pests that attack the roots of banana and plantain plants (Gowen et al., 1995). These organisms are common in banana plantations and have been reported to be one of the most destructive pests in banana cultivars, leading to heavy crop losses in banana plantations (Wang and Hooks, 2009).

Physical and chemical soil parameters affect the activity of living organisms within the soil. Five major properties, including temperature, moisture, and water holding capacity of the soil, as well as soil pH and electrical conductivity, play an important role in soil functioning and diversity, and various soil factors are reportedly responsible for the distribution of soil nematodes (Castro et al., 1990). The chemical characteristics of soil affect the density and diversity of soil organisms (Arnold et al., 2010), including the composition and structure of nematode communities (Cardoso et al., 2012). Additionally, soil type affects both the composition of nematode species in soil and how well the host plants can grow. Of note is the fact that soil acidity has been found to be an important physicochemical factor in soil that affects soil physicochemical and biological properties and, consequently, plant growth and soil biota (Kabata-Pendias, 2000). Soil salinity and salt accumulation are other important factors that are both affected by weather changes, improper watering, and plant fertilization. Organic matter (OM) constitutes a fundamental soil component that serves as a source of carbon and energy for plants and soil organisms; however, OM also affects root infestation by nematodes.

Field practices, such as crop irrigation and mechanical, chemical, or biological methods, may alter the soil environment and, consequently, affect root growth in soil (Watt et al., 2006). These alterations may include soil temperature and moisture and the activities of soil biota, including those of plant-parasitic nematodes. For example, investigations have shown that when compared to bare soil, mulched soil has a lower temperature (Kader et al., 2017). Similarly, when crops are grown too close together, the soil temperature in the area may be lower than normal, and the soil may be more humid than that in fields where fewer plants are grown (Stigter, 1984). These findings are corroborated by research that showed a significant and positive correlation between mulch and plant density root necrosis in *Pratylenchus goodeyi*. At higher temperatures, reproduction is negatively affected in *P. goodeyi* (Coyne et al., 2018), explaining why this species thrives in soils that are more heavily mulched.

This study investigates the relationship between nematode composition and physiochemical properties of soil.

Material and Methods

Soil and root sample collection

Soil and root samples were randomly collected from the rhizosphere of banana soil at temperatures ranging from 13–32°C in Ain, Al-Sarawat, Saudi Arabia, in April 2019. These samples were placed into plastic bags to retain moisture and kept at 4°C.

Soil physicochemical properties

The samples were analyzed for pH, OM content, soil moisture (SM), and electrical conductivity (EC). To measure soil pH, 10 mL of distilled water was added to a flask containing 10 g of soil. The mixture was stirred and allowed to stand for 10 minutes. The mixture was then filtered using a filter paper to separate the soil from water. A pH meter (Mettler Toledo AG) was then placed into the filtrate to measure the pH level (Conklin, 2005). Before measuring the pH, the ion-sensitive electrode was calibrated using a standard buffer solution of pH 7.

The EC of the 1:2 soil:water extract was measured after shaking it for 30 minutes (Hesse, 1971). Organic matter was measured by placing 5 g of soil into an oven at 110°C for two hours and allowed to cool in a desiccator before weighing. The soil was later placed inside a furnace at 500°C for three hours and then allowed to cool overnight. The incinerated soil was again placed in the desiccator before it was weighed (Wilde et al., 1972). The OM content in the soil sample was obtained by using the formula below:

$$\left(\frac{\text{Dry soil (g)} - \text{incinerated soil (g)}}{\text{Dry soil (g)}}\right) \text{X } 100$$

The sieve method described by Al-Yamani and Al-Desoki (2006) was used to measure soil texture. The soil moisture content was determined by drying 100 g of soil at 105°C for 24 hours. Then, the sample was weighed and placed back into an oven and dried again. The process was repeated until there was no change in the weight of the soil sample (Yousef, 1999; Conklin, 2005). The formula below was used to estimate the soil water content:

$$\left(\frac{\text{Wet soil (g)} - \text{Dry soil (g)}}{\text{Wet soil (g)}}\right) \text{X } 100$$

The samples were also analyzed for their nitrogen, phosphorus, potassium, calcium, and magnesium composition. The Kjeldahl technique was used to measure the total soil nitrogen using the Technicon Auto Analyzer II. The phosphorus concentration in soil was determined using the molybdenum blue method with ammonium fluoride (NH_4F) as the extractant (Bray and Kuntz No. 2). The color formation was measured using the Spectrophotometer UV-120-01 at a wavelength of 880 nm. The calcium, potassium, and magnesium contents were determined using the leaching method, which involved the application of aqueous ammonium oxide (NH_4O_{ac}) at a pH of 7. Soil potassium content was determined using the 5100 pc Atomic Absorption Spectrophotometer, Perkin Elmer, while the amount of available phosphorus was determined by using reagents prepared by following the Acetic Acid-NH_4F Method described by van Lierop (1988).

Extraction of banana nematode

To extract nematodes from banana roots, five root pieces were cut into segments measuring 1 cm each and divided into 5 g subsamples, which were then added to 50 mL of water (Hooper, 1990; Speijer et al., 1999). Two layers of one-ply paper towel were placed on a Baerman tray, onto which the macerate was poured, with the water touching the roots (McSorley, 1987). The water was decanted two days later, and fresh water was poured into the tray to increase extraction efficiency. The nematodes were then counted in two 2.5 mL aliquots of the suspension using a light microscope. The final number of nematodes was determined on the fifth day, and the value was added to the two-day count. Nematode identification was limited to the genus level based on morphological features.

Statistical analysis

The data were analyzed using Statistix® Version 10 (Analytical Software, Tallahassee, Florida). The relationship between some soil properties and soil nematodes was determined using Pearson's correlation coefficient, while the relationship between soil properties and the degree of nematode infection was determined using regression analysis.

Results

Three plant-parasitic genera were identified: *Meloidogyne* sp., *Paratylenchus* sp., and *Pratylenchus* sp. Figure 1 shows a significant relationship between soil pH and the proportion of soil nematode population ($P < 0.05$). Additionally, a strong correlation was observed between the pH value and soil nematode infection rate ($r^2 = 0.89$). The pH values of the soil samples were high, ranging from approximately 7.99 to 8.22. A slight increase in soil pH value showed that the nematode population rate decreased considerably.

Figure 2 shows a significant relationship between soil EC and the proportion of soil nematodes ($P < 0.05$). Also, a strong correlation was found between the EC value and soil nematode infection rate ($r^2 = 0.95$).

A strong and positive relationship was observed between soil moisture and the soil nematode population ($r^2 = 0.60$; Figure 3). Soil moisture significantly influenced the proportion of nematodes in the soil samples ($P < 0.05$). The proportion of soil nematodes gradually increased as the moisture level in the soil increased. The highest soil moisture was recorded at around 4.77% and the lowest was at 4.59%.

The proportion of nematodes in the banana roots significantly correlated with the proportion of soil OM ($P < 0.05$; Figure 4). The OM content in the soil was relatively low, varying between 0.78% and 0.68% of the total soil sample ($r^2 = 0.78$).

The proportion of coarse sand, fine sand, clay, and silt was significantly associated with the proportion of soil nematodes in the banana roots ($P < 0.05$). Conversely, the amount of coarse sand was strongly associated with the proportion of soil nematodes ($r^2 = 0.91$; Figure 5a). Furthermore, an inverse relationship was found between the proportion of soil nematodes in the banana roots and fine sand ($r^2 = 0.83$), clay ($r^2 = 0.80$), and silt ($r^2 = 0.97$) (Figures 5 b, c, and d).

An analysis of nutrients (phosphorus, nitrogen, potassium, calcium, and magnesium) showed that the concentration of nutrients was significantly associated with soil nematode population in the banana roots ($P < 0.05$). The highest and lowest concentrations of the soil nutrients are as shown in Figures 6 a, c, d, and e ($r^2 = 0.88$ for phosphorus, $r^2 = 69$ for potassium, $r^2 = 0.78$ for calcium, and magnesium $r^2 = 0.78$). Similarly, a strong positive correlation existed between the nitrogen level and the percent of soil nematode population ($r^2 = 0.76$; Figure 6 b).

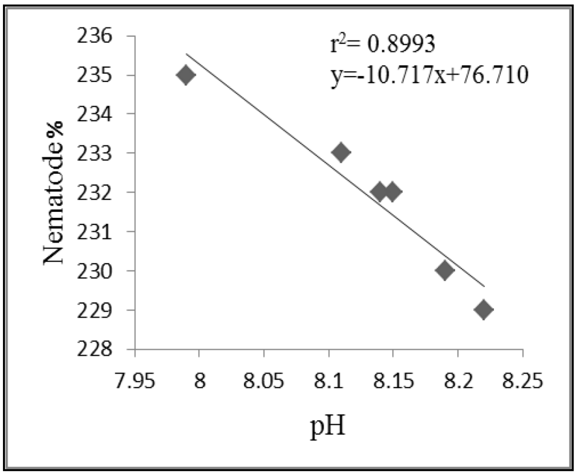


Figure 1. Relationship between soil pH and the proportion of soil nematodes.

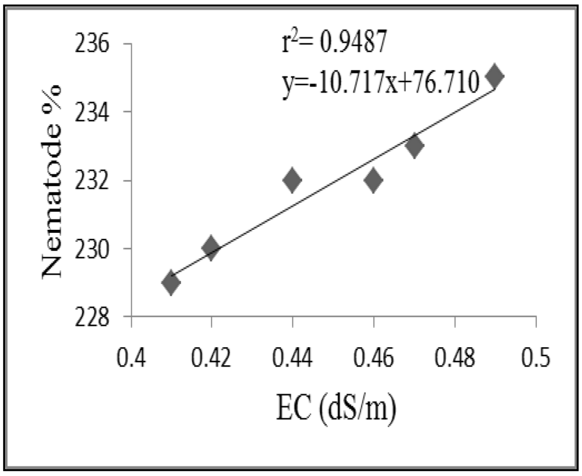


Figure 2. Relationship between soil electrical conductivity and the proportion of soil nematodes.

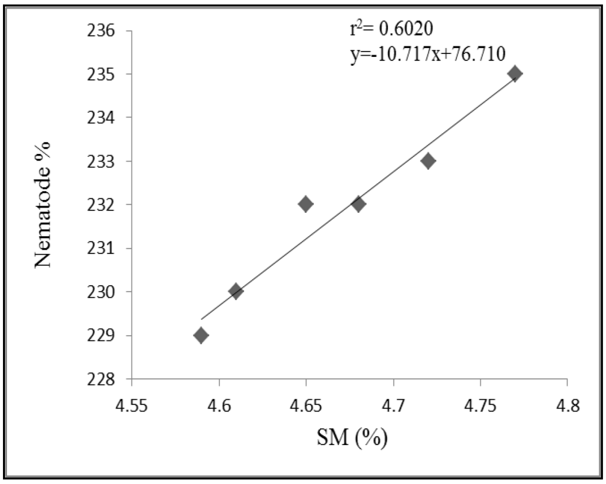


Figure 3. Relationship between soil moisture and the proportion of soil nematodes.

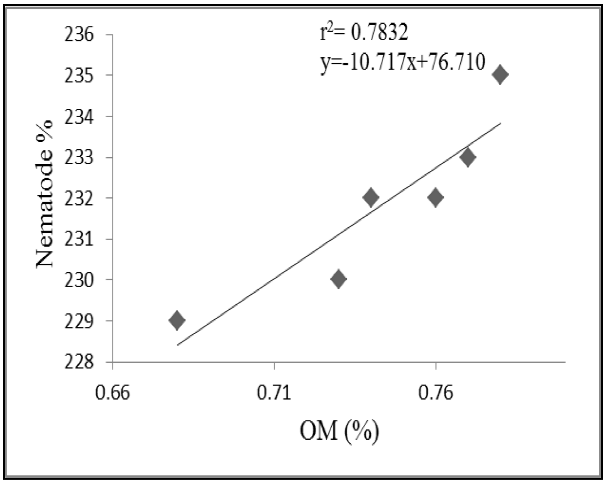
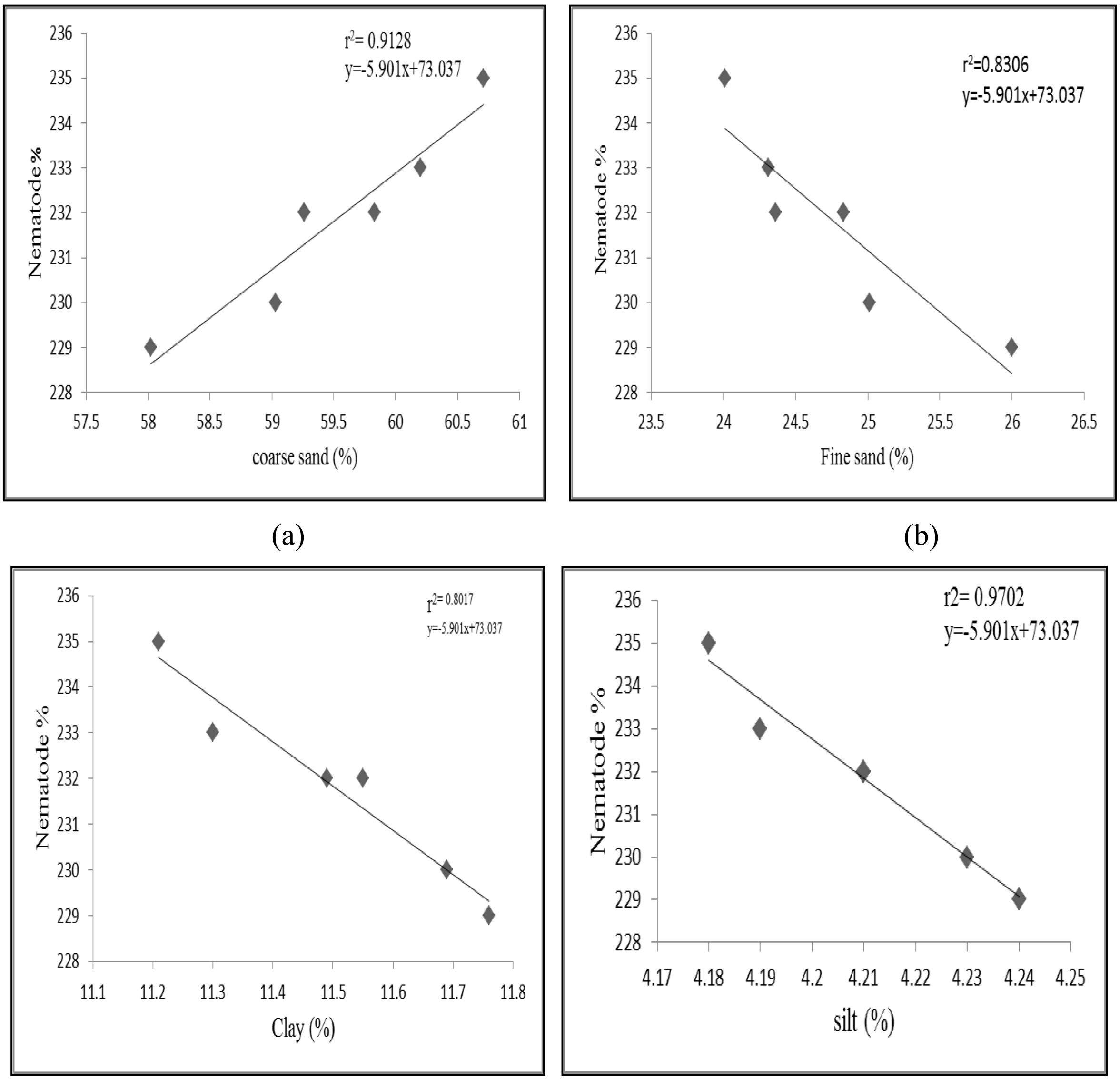
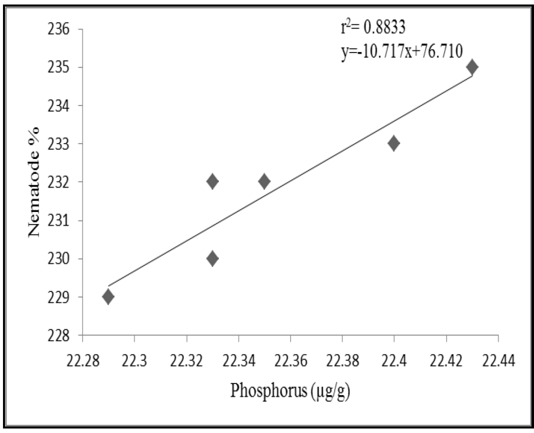


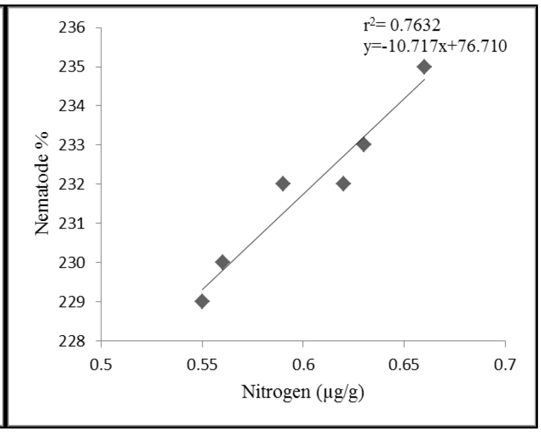
Figure 4. Relationship between soil organic matter and the proportion of soil nematodes.



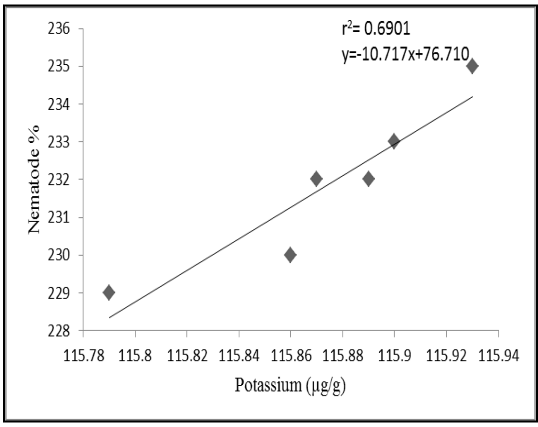
(c) (d)

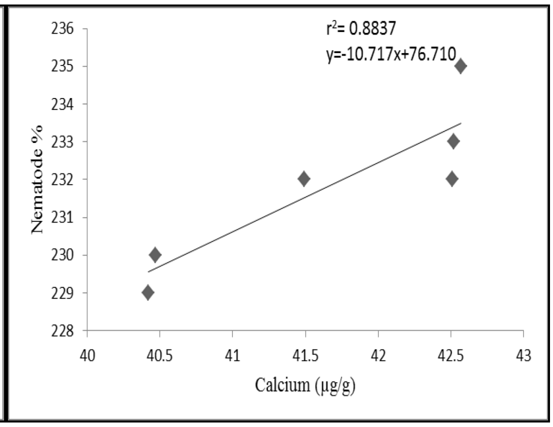
Figure 5. Relationship between the proportion of (a) coarse sand (b) fine sand (c) clay and (d) silt in the soil and the proportion of soil nematodes.



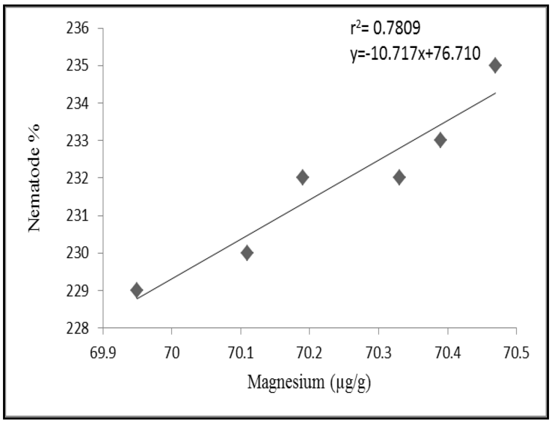


(a) (b)





(c) (d)



(e)

Figure 6. Relationship between the concentrations of (a) phosphorus, (b) nitrogen, (c) potassium, (d) calcium, and (e) magnesium (mg/kg) in the soil and the proportion of soil nematodes

Discussion

Previous researches demonstrated a relationship between different soil properties and plant pathogens (Fajardo et al., 2011; Wang and McSorley, 2005). However, little is known about the effect of the environment on nematodes and how these parasites can affect banana growth and production. Available data in the literature mostly reported on the effects of mulching and intercropping on the propagation of *Radopholus similis* and *Helicotylenchus multicinctus* (Auwerkerken et al., 2005), *R. similis* interactions (Bwamiki, 2004), and root damage due to colonization by *P. goodeyi* in plants grown under suboptimal conditions (Talwana et al., 2003). In general, the microenvironment has a strong effect on nematodes, which help indicate soil health status and many soil functions (Gebremikael et al., 2016). Of note is that nematodes are functionally disparate organisms that are widespread and quickly respond to alterations in the environment. The interwoven relationships that have been described between soil characteristics and the proportion of nematodes in diverse functional guilds (Fiscus and Neher, 2002) have been used to create criteria to assess soil.

In agriculture, the proportion and diversity of nematodes are utilized to determine soil process rates (Yeates, 2003) and functions (Yeates, 2003). A variety of abiotic and biotic factors affect the establishment of nematode communities in soil. Plant-parasitic nematodes are, in general, aerobic and originally aquatic organisms that require adequate moisture and aeration from adsorbed soil water films (moisture levels ranging between 40% and 60% of field capacity) (Dropkin, 1980; Kim, 2015). Soil acidity has also been reported to affect nematode populations. For example, the proportion of *Meloidogyne incognita* and *R. similis* were generally decreased in either extremely acidic or alkaline soils; however, *R. similis* was more tolerant to soil with a very low pH than *M. incognita* (Davide, 1980).

In Gade and Howare's (2017) study, soil pH level was not associated with the proportion of nematodes. Additionally, no correlation was found between soil moisture and nematode diversity. Furthermore, a positive correlation was found between temperature and electrical conductivity and nematode diversity. Finally, a negative correlation was found between soil moisture and pH and the proportion of nematodes, but no correlation was found between soil moisture content and nematode diversity (Gade and Hiware, 2017). In a study that investigated the infection of pineapple by *Pratylenchus brachyurus,* Sarah et al. (1991) found a negative relationship between nematode population densities and soil pH.

Previously, it was reported that soil organic matter contents correlated with a lower proportion of plant-parasitic nematodes, suggesting that the addition of organic compounds is a way to suppress these parasites (Barros et al., 2017). However, soil OM contents were also positively correlated with free-living nematodes, probably by favoring the growth of microbes (bacteria and fungi), which increased the nematode population (Berry et al., 2005). Therefore, soil OM affects the spatial soil distribution of nematodes (Cadet and Spaull, 2003) and has a significant effect on mycophagous nematode communities (Pen-Mouratov et al., 2010). Furthermore, soil OM affects the density of bacteriophage nematodes when the added organic material is rich in nutrients and has a low carbon: nitrogen ratio (Berg and Bengtsson, 2007).

Soil compactness and porosity are determined by several conditions such as soil texture, soil type (sand, silt, clay particles), and OM content. Nematodes rely on the availability of moisture and aeration to thrive in crop fields (Moore and Lawrence, 2013). In general, nematodes thrive more in light sandy soils than in heavy clay soils due to the better aeration in soils containing coarse particles; however, these parasites have a more nefarious effect on plants growing in conditions of water stress because water drainage is facilitated in coarse particulate sandy soils (Dropkin, 1980). *M. incognita* and *Hoplolaimus columbus* thrive in soils with a high sand content (Koenning et al., 1996; Kim et al., 2017). In this study, the nematode density was increased when the proportions of sand, silt, and clay were 48%, 35%, and 17%, respectively. Van Gundy et al. (1964) reported that *Tylenchulus semipenetrans* reproduced well in soils with a low proportion of clay (10% to 15%). *T. semipenetrans* can thrive in any soil texture, but they cause extensive damage to plants grown in shallow, poorly drained soils that have an organic matter content of approximately 2% to 3% (O'Bannon and Essar, 1985). However, these findings showed that the population of nematodes in soils was highest in those with an organic carbon content of approximately 1.5%.

Previous reports have shown that soil texture had a significant effect on the occurrence of some *Pratylenchus* species (Griffin, 1996). Of note is that the amount of sand in the soil is an important factor that affects the density of root-lesion nematodes (Chen et al., 2012). Previous research showed that a higher proportion of root-lesion nematodes, especially *Pratylenchus penetrans*, was found in loamy sand, and these species were reportedly less prevalent in heavy soils (Szczygieł and Zepp, 2004). This finding is consistent with that of Szczygieł et al. (1983), who reported that *P. penetrans* was more prevalent in light (0.0% and 7.5% of clay) than in heavy soils

(45.0% and 60.0% of clay). Our results showed that *Pratylenchus* nematodes were prevalent in sandy clay loam, which is consistent with the findings of Szczygieł and Zepp (2004). In their study, Szczygieł and Zepp (2004) reported that *Pratylenchus crenatus* was mostly prevalent in loam and clay soils, including sandy clay loam. Additionally, they identified *Pratylenchus neglectus* in various soil types; however, these nematodes were less frequent in heavy soil (Szczygieł and Zepp, 2004).

These results showed that in citrus plants, standard critical levels of nitrogen, phosphorus, and potassium that were necessary for their growth were also adequate for nematode activities. Increased levels of these elements in soil caused an increase in the population density of nematodes, except for the case of nitrogen, where an increase in its level resulted in a decrease in the nematode population. Sorribas et al. (2008) found that the density of nematodes in the soil where citrus plants were thriving was negatively correlated with the nitrogen concentration but positively correlated with soil potassium concentration. Other investigators have also reported that ammonia had a nematocidal effect (Rodriguez-Kábana, 1986), which was improved when ammonia-releasing fertilizers were combined with alkaline amendments (Oka et al., 2006). In a pot experiment, it was shown that when urea was applied at a rate of 160 kg ha^{-1}, *Tylenchulus semipenetrans* could not infect or develop on rough lemon plants (Mangat and Sharman, 1981). Additionally, it has been reported that soil potassium content was positively correlated with the densities of J2 and males in soil (Pettigrew et al., 2005).

Previous studies conducted on tobacco plants showed a positive relationship between nematode density and alkaline earth metals (magnesium and potassium) for root-knot nematodes (Kincaid et al., 1970). Similar results were reported about root-knot nematodes in tomato plants (Dabiré et al., 2007) and *Scutellonema* spp. in maize and bean plants (Kandji et al., 2001). The population density of *P. goodeyi* was significantly and positively correlated with soil potassium in Butare-Gitarama, which is an area known to have the lowest soil potassium concentration. In other ecoregions that did not have low potassium concentrations, no such relationships were found (Gaidashova et al., 2009).

Conclusion

This study identified *Meloidogyne* sp., *Paratylenchus* sp., and *Pratylenchus* sp as the most common plant-parasitic nematode population types in banana plants. Additionally, soils' physical properties were related to the proportion of nematodes in the banana plant, with the rate of nematode colonization of banana roots increasing with the increase in phosphorus, potassium, calcium, and magnesium concentration and decreasing with the increase in nitrogen concentration. This study has demonstrated the importance of soil properties as a regulating factor on nematodes. Thus, research on soil management should investigate the adequate source and quality of organic material to improve soil quality and suppress the growth of parasitic nematodes.

Conflict of Interest

None

Acknowledgement

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