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SYMPTOMATOLOGICAL STUDIES IN YELLOWING AFFECTED BLACK PEPPER GARDENS: A META-ANALYSIS IN RELATIONSHIP BETWEEN SOIL CHARACTERISTICS AND PLANT PARASITIC NEMATODES IN HUMID TROPICS REGION OF KERALA, INDIA

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ABSTRACT

After foot rot disease, the main constraint in black pepper cultivation is the incidence of yellowing where the production is found to decline year after year. The symptoms of yellowing were highly varying from plant to plant. The symptoms of yellowing started from leaf tip and spread to entire lamina, when it was severe the leaves turned bright yellow. The investigations revealed that the per cent severity of yellowing was significantly higher during October-November (21.09) at fag end of monsoon and was on par during summer (20.36). Experiment results clearly indicated that pH, EC did not show significant difference in rhizosphere soils from yellowing affected, apparently healthy and healthy plants. The organic carbon content in the rhizosphere soil of experimental plants ranged from (0.77 to 1.84), during survey the population of plant parasites encountered both soils and plant samples of yellowing affected pepper plants. On the other hand nematode population was significantly lower in healthy plants during all the three seasons in year, whereas, yellowing affected and apparently healthy plants were statistically on par, based on seasonal variations nematode population was significantly highest during October-November, the findings of the field experiment demonstrated that the rhizosphere soils had optimum range of nutrients in soil but the root system was destroyed due to heavy incidence of endoparasitic nematodes.

Key words : Black pepper, Nematodes, Soils, Yellowing, Yield.

Introduction

A spice known as "black gold" (*Piper nigrum* L.), black pepper has been an important part of human trade since the beginning of recorded history. The product is made and shipped out of India. In India, there is a restricted productivity of 471 kg/ha, an area occupied of 1,35,915 ha, and a production of 64000 tonnes (Spice Board, 2018). Black pepper is one of the biotic variables that suffers a significant economic loss due to the presence of plant parasitic nematodes (Ahmed M. Saad, 2021). Black pepper production is gradually falling (Krishnamoorthy and Parthasarathy, 2010). Fungus and nematodes, which parasitize plants, are the two most dangerous diseases that may affect black pepper (Bong and Saad, 1986; Ramana and Eapen, 2000; Thakamani *et al.*, 2008). Slow decline, or yellowing disease, is one of the most significant threats to black pepper crops (Mohnadas and Ramana, 1987). Due to root damage and nematode incidence and ineffective management and an epidemic of pests and illnesses, output and productivity has plummeted (Babu *et al.*, 2019).

In addition to these biotic & abiotic factors and soil and plant nutrients, majorly environmental factors like low in soil moisture and high temperature and erratic rains were also key factors for induce yellowing in black pepper. Among nutrients, deficiency of nitrogen, potassium, calcium, magnesium, iron, manganese, boron *etc.* are reported to cause chlorosis, yellowing, and retardation of growth and production in black pepper. The study contrasts to our findings (Frostegard *et al.*, 1993; Haynes and Naidu, 1998). The short term application of lime to often surplus microbial activity and reduces organic carbon content in the soil. However, lime application affects soil bio chemical properties; it includes carbon and nitrogen mineralization.Poor accessible soil nutrient status, insufficient fertilizer delivery, and management are the reasons given for the low production as compared to other developing nations. Similar findings noticed (Sadanandan *et al.*, 2002; Srinivasan *et al.*, 2007).

The majority of nations that cultivate black pepper have seen a yellowing and "slow decrease" in pepper quality due to plant parasitic nematodes, either on their own or in combination with fungus. Fungal diseases and nematodes, which parasitize plants can cause significant illnesses the prevoious results similar to our findings (Bong and Saad, 1986; Ramana and Eapen, 2000; Thankamani *et al.*, 2008). *Meloidogyne* spp., the root knot nematode, and *Radopholus similis*, the burrowing nematode, are the main nematodes implicated. Foliar yellowing and necrosis at the distal ends of the lamina are apparent signs of a nutrient shortage in crops that are impacted by gradual wilt (Wahid and Kamalam, 1982).

These symptoms were thought to go away when the monsoons started because the plants were taking in more nutrients and new feeder roots were sprouting up, but they came back after the monsoons because the soil was too wet and the plants weren't taking in as many nutrients. There have been recent reports regarding the emergence and spread of yellowing as a significant issue in the Thrissur area of Kerala's black pepper farming. The current study set out to answer several important questions about plant disease symptoms and yellowing. Specifically, it aimed to determine the impact of soil electrochemical properties and plant nematode analysis on yellowing and black pepper yield, as well as to identify potential management strategies and research avenues for reducing yellowing.

Materials and Methods

Description of the experimental location

The researcher conducted both laboratory and field experiments to study the effects of black pepper (*Piper nigrum* L) yellowing. This was the primary focus of our quantitative and qualitative literature evaluation. A comprehensive purposive sampling survey was conducted in the pepper growing tracts of Thrissur so as to initially identify the intensity and spread of yellowing. Based on the survey, six different fields were selected for conducting the experiment.Fields in the Thrissur district and the College of Horticulture in Vellanikkara were chosen for the experiments (Table 1). Black pepper gardens were surveyed to determine the extent of disease spread and the degree of yellowing. Based on a study of the whole Thrissur district, fields were chosen from the locations with the highest concentration of general yellowing. Plants were categorized as either "a" for healthy, "b" for seeming healthy, or "c" for yellowing-affected in the chosen tracts, (Fig. 3) and samples were taken according to this scale. A 3×2×3 factorial design with 15 replications was used for the experiment. Factors one and two were the time of year (2017–18 and 2018–19), factor three was the category or illness condition, and factor four was the season (July–August, October–November, and February–March) (healthy, apparently healthy and yellowing affected plants).

The experimental location had a normal tropical climate with warm and humid conditions, with the southwest and northeast monsoons providing additional benefits. May, June, July and August were the wettest months in the experimental region. The analysis found that the lowest recorded temperature was 23.3 degrees Celsius and the highest was 33 degrees Celsius. A relative humidity of 74% was recorded on average. A total of 2360.6 millimeters of rain fell. The location is 22.5 meters above mean sea level and the coordinates are 100.32 degrees north latitude and 76.013 degrees east longitude.

Varieties of Black pepper and seasons of study

A number of black pepper types were considered for the study, including Vijay, Karimunda, Panniyur 1, Panniyur 2 and Panniyur 3. At regular intervals, plants in the chosen fields were tagged and examined for the onset of yellowing symptoms and how it affected yield. It was used to determine the percent disease severity (PDS) the method developed by Raja-Kumar *et al.* (2012). At each of the three seasons, soil samples were taken from the designated areas. (Feb–March, October–November, and July–August). Separate polythene bags were used to gather 45 bag samples in total.

A conventional approach was used to assess the soil pH, electrical conductivity and organic carbon, as outlined in similar findings (Jackson, 1958; Walkley and Black, 1934). The Thrissur black pepper farms' soil samples were gathered from several examined places. According to Cobb's method of decanting and sieving (Cobb, 1918). Out from composite sample, 250 cc of soil was weighed and thoroughly mixed with one liter of water in a pan. It was stirred well and the clods and clumps were broken. After 10-20 seconds, the soil suspension was passed to

Table 1 : Locations of survey for collection of disease samples of black pepper Sl.

S. no.	Thrissur locations	Seasons (2017-2019)	Tagged plants
1.	Black pepper research unit, Dept. of Plantation Crops & Spices, College of Horticulture	July-August (Season-1) October-November (Season-2) February-March (Season-3)	Yellowing affected plants Apparently healthy plants
2.	Gokhale Block, Dept. of Plantation Crops & Spices, College of Horticulture	July-August, (Season-1) October-November (Season-2) February-March (Season-3)	Yellowing affected plants Apparently healthy plants
3.	Ameena. K. K Chirakakkode, (Farmers field)	July-August (Season-1) October-November (Season-2) February-March (Season-3)	Yellowing affected plants Apparently healthy plants
4.	Joseph. P Vaniyampara, (Farmers field)	July-August (Season-1) October-November (Season-2) February-March (Season-3)	Yellowing affected and apparently healthy plants
5	N. Bose Chelakkara, (Farmers field)	July-August (Season-1) October-November (Season-2) February-March (Season-3)	Yellowing affected plants Apparently healthy plants
6	Dr. Anitha. M University Nagar, Mannuthy, (Farmers field)	July-August (Season-1) October-November (Season-2) February-March (Season-3)	Healthy plants only

pan II through a 20 mesh sieve leaving heavy soil particles. The suspension of pan II was stirred gently, waited for 5-10 seconds and then poured through a series of 60, 100, 200 and 350 mesh sieves (mesh: number of apertures/ linear inch) and the filtrates were discarded from 350 mesh sieve. The soil samples were processed, the nematode suspension thus obtained was made up to a constant volume (50 ml) by adding water. An aliquot of 5 ml was pipetted out in to a counting dish and the number of nematodes present was counted under stereo microscope. The total population of nematodes extracted from 250 cc soil sample was estimated by multiplying the average population with dilution factor.

Influence of weather variables on yellowing

Meteorological data recorded by Department of Agricultural Meteorology, College of Horticulture, Vellanikkara were utilized to study the effect of weather parameters if any, on yellowing.

Correlation with weather variables

Weather data *viz.*, maximum and minimum temperature, relative humidity and rainfall and recorded during survey period from the observatory maintained by Department of Agricultural Meteorology, College of Horticulture, Vellanikkara.

Results and Discussion

Per cent disease severity (PDS)

The research has shown that working closely with black pepper plants the yellowing symptoms diversified as per seasons. The symptoms of yellowing generally developed at the fag end of monsoon. As it can be seen from (Table 2), per cent severity of yellowing was least during monsoon. The Per cent severity of yellowing was significantly higher during October-November (21.09) at fag end of monsoon and was on par during summer (20.36). In case of mild yellowing developed at fag end of monsoon, it was observed that there was recovery during July-August (12.74) and onset of monsoon. In all the three seasons yellowing affected plants (32.96) showed significantly higher per cent severity of yellowing than apparently healthy plants (20.99), whereas, healthy plant (0.24) showed significantly lower intensity yellowing.

Symptoms of yellowing plants

Both the top and bottom of the pepper column showed signs of yellowing. On sometimes, a cluster of leaves might turn yellow at the same moment. The terminal leaves of some elder plants were yellow. The yellowish base of the lamina near the petiole was visible in a few leaves. Only the edges and tips of the lamina remained yellowed. Yellowing between the veins was noted in a few additional cases. In some instances, only a few leaves on a branch became yellow, while in others, every leaf on a lateral branch turned yellow. Leaves at every developmental stage showed signs of fading. The entire plant gradually turned yellow. The yellowing might begin at the very tip of the leaf and work its way down the entire lamina. In extreme cases, the leaves would become a brilliant yellow. When minor yellowing occurred, it usually cleared up by the time the monsoons arrived in July or August. The field's yellowing worsened over time, and the plants that were most badly impacted never recovered. Such plants did not experience flushing or blooming. In about two or three years, these plants would perish the similar results with black pepper (Mohandas and Ramana, 1987).

pH of rhizosphere soil

According to Table 3, the pH of the soil in the rhizosphere of plants that appeared to be healthy actually had a far lower pH than plants that did not appear to be healthy. Still, there was no statistical difference between the yellowing-affected and seemingly healthy plants. When looking at the pH values throughout the year, the peak in February and March was 6.14, which was much higher than the other two seasons. Compared to the other two seasons, October–November had the lowest soil pH at 5.54. Root development and pepper crop productivity are affected by pH, according to previous results (Zu *et al*., 2014)). The pH levels of 5.54 were indicative of gardens that were 15 years old, whereas those of 10-year-old orchards averaged 5.64. Its average pH was 5.28 when it was 28 years old. One of the primary reasons for the yellowing of black pepper in Wayanad is a soil nutrient imbalance, which was also noted by previous results (Sreekumar, 2015 and Aloka, 2016). In contrast, the pH levels of the yellowing-affected gardens in this study fell within the optimal range for black pepper, which is 5.28 to 6.58. The experimental plots' soil pH was within the ideal range for black pepper, according to DRIS standards proposed by Hamza *et al*. (2007), which falls between 4.75 to 6.15. The presence of *Mycobacterium incognita* and *Mycobacterium javanica* was positively correlated with soil pH levels, according to similar findings (Kerry, 2000).

Electrical conductivity

Plants that appeared to be healthy and those that were yellowing had equivalent EC levels in the soil of the rhizosphere. As seen in, the EC was noticeably lower in soils from healthy plants' rhizospheres (Table 4). February and March had the greatest EC value (0.17 dS m^{-1}), which was far greater than the other two seasons. In July and August, EC was 0.11 dS m^{-1}, which is a considerable decrease compared to October and November. Extremely high electrical conductivity was observed in the rhizosphere soils of plants that appeared to be in good condition throughout the months of February and March (0.22 dS m^{-1}). However, electrical conductivity was much lower (0.10 dS m^{-1}) in the rhizosphere soils of plants that were not yellowing than in plants that were. The results

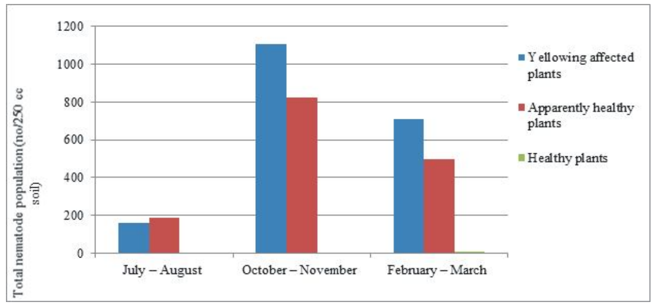


Fig. 1 : Total nematode population in rhizosphere soils of healthy, apparently healthy and yellowing affected plants.

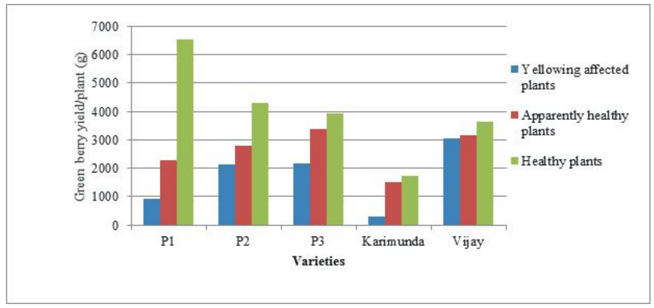


Fig. 2 : Green berry yield per plant (g) in healthy, apparently healthy and yellowing affected of black pepper varieties.

showed a positive correlation with species, and environmental factors have a significant impact on the structure of the soil microbial community and the quality and quantity of nutrients released into the rhizosphere. (Kerry, 2000).

Organic carbon

Rhizosphere soils with a lower organic carbon level (1.10) were found in plants that were not yellowing, whereas those that were yellowing had a concentration of 1.61 and 1.64, respectively, as shown in Table 5. When it came to statistics, the last two groups were neck and neck. The organic carbon content was 1.69 times greater in the winter months of February and March than in the other two seasons. There was a considerable decrease in the organic carbon content from October to November to July and August (1.20) &(1.47). Our results (Frostegard *et al*., 1993; Haynes and Naidu, 1998) show that lime, when applied for short periods of time, lowers soil organic carbon content and typically causes an excess of microbes. Soil biochemical characteristics, such as the mineralization of carbon and nitrogen, are impacted by lime application. In spite of the fact that the experimental fields in this study had very low organic carbon content, it was shown that healthy plants had far lower organic carbon concentration in their rhizosphere soil compared to plants afflicted by yellowing. Healthy plants may have had low organic matter content in their rhizospheres due to the

Table 2 : Per cent severity of yellowing during different seasons of yellowing affected, apparently healthy, healthy black pepper plants during study.

Category / Year	July – August A1			October – November A2			February – March A3		
	2017 B1	2018 B2	Category mean	2017 B1	2018 B2	Category mean	2018 B1	2019 B2	Category mean
Y	30.46 (5.44)	24.53(4.64)	**27.50 (5.04)**	38.39 (6.18)	35.30(5.91)	**36.85 (6.05)**	35.74 (5.93)	33.32(5.43)	**34.53 (5.68)**
A.H	5.76 (2.37)	15.72 (3.81)	**10.74 (3.09)**	29.00 (5.28)	22.92(4.76)	**25.96 (5.02)**	20.64(4.14)	31.89(5.48)	**26.27(4.81)**
Healthy	0.00 (0.71)	0.00 (0.71)	**0.00(0.71)**	0.82(1.03)	0.11(0.76)	**0.47 (0.90)**	0.32(0.85)	0.22(0.81)	**0.27(0.83)**
Year mean	**12.07** (2.84)	**13.42** (3.05)		**22.74** (4.17)	**19.45** (3.81)		**18.90** (3.64)	**21.81** (3.90)	
Seasonal mean	**12.74** (2.95)			**21.09** (3.99)			**20.36** (3.77)		

Category / Year (C)	2017 (B1)	2018 (B2)	Treatment Mean
Yellowing affected plants	34.86 (5.85)	31.05 (5.33)	**32.96 (5.59)**
Apparently healthy plants	18.47 (3.93)	23.51 (4.68)	**20.99 (4.31)**
Healthy plants	0.38 (0.86)	0.11 (0.76)	**0.24 (0.81)**
Category/Year mean	**17.90 (3.55)**	**18.23 (3.59)**	

	CD (0.05)		CD (0.05)
Season- (A)	**0.32**	Season x Year (A x B)	**0.45**
Year – (B)	**0.22**	Season x Category (A x C)	**0.56**
Category – (C)	**0.32**	Year x Category (B x C)	**0.45**
		Season x year x Category (A x B x C)	**0.78**

Yellowing affected plants (Y), Apparently healthy plants (A.H), Healthy plants (H)
Fig in the parenthesis are SQRT transformed values calculated using the formula $\sqrt{(x+0.5)}$.

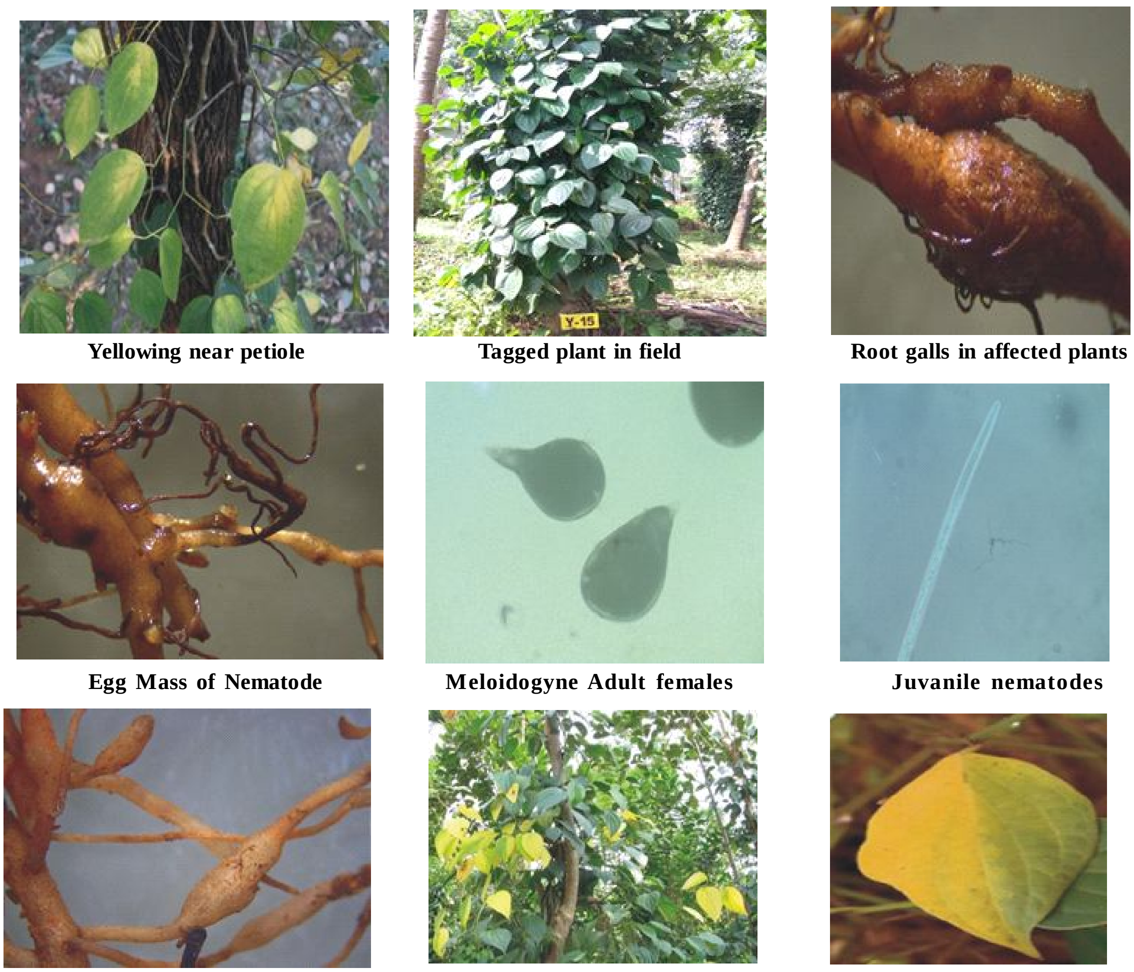
poor organic matter status of the plot. Plant health did not improve with the increased organic matter content of rhizosphere soil, perhaps because of root injury and inadequate absorption. The ideal range for organic carbon concentration in black pepper rhizosphere soil, according to DRIS standards proposed by previous study (Hamza *et al.*, 2007) was 2.00 to 7.50. The results showed that the experimental plots' organic carbon content was below the threshold values. Organic carbon concentration was found to be low in 21% of samples, medium in 38%, and high in 41%, according to research by Sreekumar, (2015) carried out in Wayanad.

Total nematode population in rhizosphere soils

The nematode population was monitored during the three seasons that were considered (Figs. 1 and 3). In the months of October and November, the nematode population in the soil around healthy plants was much lower than that of plants that were either seemingly healthy or afflicted by yellowing. Similar results noticed by Subila and Suseela Bhai (2020) like *Phytopthora capsci* and *Meloidogyne incognita* and *Radopholus similis* are Major threat for this crop. When plants were in good condition in July and August, the number of nematodes was surprisingly low. In contrast, there was no statistical difference between plants that were yellowing and those that seemed healthy. When contrasted with the months of October–November and February–March, the rhizosphere nematode population was much lower in July–August. In rhizosphere soils, the nematode

Yellowing affected plants **Apparentley healthy plants** **Healthy plants**

Fig. 3 : Symptoms of different categories of plants selected for study.



Yellowing near petiole **Tagged plant in field** **Root galls in affected plants**

Egg Mass of Nematode **Meloidogyne Adult females** **Juvanile nematodes**

Root galls and necrosis **Lemon yellow discoloration of leaf** **Severe interveinal yellowing from leaf base**

Fig. 4 : Symptoms and nematode damage in yellowing affected black pepperplan.

population was much higher in October and November than in February and March or July and August.The number of galls in the roots was also significantly highest during October-November and lowest during July-August. Nematode populations follow a similar pattern, with a rise in June and July and a peak in September and October (Ramana *et al.*, 1987). There is evidence that rain has a positive impact on nematode populations by lowering soil temperatures, stimulating host plant root formation, and increasing soil moisture, all of which facilitate nematode migration to healthy roots. A total of 35 nematode species, the majority of which belonged to

Table 3 : pH rhizosphere soils of yellowing affected, apparently healthy, healthy black pepper plants.

Category / Year	**July – August A1**			**October – November A2**			**February – March A3**		
	2017 B1	**2018 B2**	**Category mean**	**2017 B1**	**2018 B2**	**Category mean**	**2018 B1**	**2019 B2**	**Category mean**
Y	6.19	5.87	**6.03**	6.09	5.28	**5.68**	6.58	5.66	**6.12**
A.H	5.90	5.79	**5.85**	6.09	5.24	**5.67**	6.56	6.13	**6.35**
Healthy	6.14	5.33	**5.74**	5.55	5.00	**5.28**	6.42	5.50	**5.96**
Year mean	**6.08**	**5.67**		**5.91**	**5.17**		**6.52**	**5.76**	
Seasonal mean	**5.88**	**5.54**	**6.14**						

Category (C)/Year	**2017 (B1)**	**2018 (B2)**	**Treatment Mean**
Yellowing affected plants	6.29	5.60	**5.94**
Apparently healthy plants	6.19	5.72	**5.95**
Healthy plants	6.04	5.28	**5.66**
Category/Year mean	**6.17**	**5.53**	

	CD (0.05)		**CD (0.05)**
Season- (A)	**0.13**	Season x Year (A x B)	**0.19**
Year – (B)	**0.11**	Season x Category (A x C)	**0.24**
Category- (C)	**0.13**	Year x Category (B x C)	**0.19**
		Season x year x Category (A x B x C)	**0.34**

Yellowing affected plants (Y), Apparently healthy plants (AH), Healthy plants (H).

Table 4 : EC of rhizosphere soils of yellowing affected, apparently healthy, healthy black pepper plants.

Category/Year	**July – August A1**			**October – November A2**			**February – March A3**		
	2017 B1	**2018 B2**	**Category mean**	**2017B1 B1**	**2018B2 B2**	**Category mean**	**2018 B1**	**2019 B2**	**Category mean**
Y	0.15	0.12	**0.14**	0.14	0.15	**0.15**	0.24	0.15	**0.20**
A.H	0.10	0.11	**0.11**	0.13	0.12	**0.13**	0.22	0.23	**0.22**
Healthy	0.09	0.09	**0.09**	0.11	0.11	**0.11**	0.12	0.09	**0.11**
Year mean	**0.12**	**0.10**		**0.13**	**0.13**		**0.19**	**0.16**	
Seasonal mean	**0.11**	**0.13**	**0.18**						

Category (C)/Year	**2017 (B1)**	**2018 (B2)**	**Treatment Mean**
Yellowing affected plants	0.18	0.14	0.16
Apparently healthy plants	0.15	0.15	0.15
Healthy plants	0.11	0.10	0.10
Category/Year mean	**0.15**	**0.13**	

	CD (0.05)		**CD (0.05)**
Season- (A)	**0.01**	Season x Year (A x B)	**0.02**
Year – (B)	**0.01**	Season x Category (A x C)	**0.02**
Category- (C)	**0.01**	Year x Category (B x C)	**0.02**
		Season xYear x Category (A x B x C)	**0.03**

Yellowing affected plants (Y), Apparently healthy plants (AH), Healthy plants (H).

Table 5 : Percent of organic carbon content in rhizosphere soils of yellowing affected , apparently healthy, healthy black pepper plants.

Category/Year	July – August A1			October – November A2			February – March A3		
	2017 B1	**2018 B2**	**Category mean**	**2017B1 B1**	**2018B2 B2**	**Category mean**	**2018 B1**	**2019 B2**	**Category mean**
Y	1.44	1.35	**1.39**	1.59	1.72	**1.65**	1.76	1.83	**1.79**
A.H	1.40	1.46	**1.43**	1.83	1.84	**1.83**	1.62	1.73	**1.67**
Healthy	1.04	0.51	**0.77**	0.87	0.98	**0.92**	1.59	1.63	**1.61**
Year mean	**1.29**	**1.10**		**1.43**	**1.51**		**1.66**	**1.73**	
Seasonal mean	**1.20**	**1.47**	**1.69**						

Category (C)/Year	2017 (B1)	2018 (B2)	Treatment Mean
Yellowing affected plants	1.59	1.63	**1.61**
Apparently healthy plants	1.61	1.67	**1.64**
Healthy plants	1.16	1.03	**1.10**
Category /Year mean	**1.45**	**1.44**	

	CD (0.05)		CD (0.05)
Season- (A)	**0.12**	Season x Year (A x B)	**0.18**
Year – (B)	**0.10**	Season xCategory (A x C)	**0.22**
Category- (C)	**0.12**	Year x Category (B x C)	**0.18**
		Season x Year x Category (A x B x C)	**0.316**

Yellowing affectedplants (Y), Apparently healthy plants (AH), Healthy plants (H).

the sp. Meloidogyne incognita were identified in pepper plants from Vietnam by Thuy *et al*. (2012). When soil moisture was low, these signs were more noticeable. July often saw less foliar yellowing and defoliation than April and May. Black pepper likewise showed similar trends when studied by Pervez 2018 and Koshy *et al*. (2005). Roots with many galls in plants that are yellowing are the focus of these studies.

It can take anything from two or three weeks to almost a year for a plant-parasitic nematode to complete its life cycle, however this might vary greatly depending on soil temperature, crop sensitivity, and length. In tropical and subtropical regions, there are nematodes that can have many generations each season and can be so abundant that their concentrations exceed 104 g^{-1}/root. (Whitehead, 1997).

Yield and yield contributing characters

All of the yield-and yield-contributing traits in black pepper plants that were healthy or seemingly healthy had greater positive values than those in plants that were yellowing-affected. In terms of yield per plant, all types except for one showed a marked decrease in yield when yellowing plants were compared to healthy ones. Vijay in that order (Fig. 2). In Panniyur 2, plants that were in good health had a far greater bearing column height than plants that were either seemingly healthy or impacted by yellowing. A higher number of laterals per unit area was seen in healthy plants compared to yellowing-affected plants in the Panniyur 1, Panniyur 2, and Karimunda types. In both Panniyur 1 and 2, the number of spikes per unit area was not substantially different among the yellowing afflicted, seemingly healthy, and healthy plants. In this study, fusarium infection is significant because it shortens the life cycle of black pepper plants from 20 to 6-7 years and decreases their yield per plant from 3.0-1.5 kg (Anandaraj, 2000). Similar findings to those of Bhagavantagoudra *et al.* (2008) and NageshNaik *et al.* (2013) are produced by yield components. There was no resistant variation to the yellowing that affected all types. There was no discernible pattern to when or how a plant's yellowing appeared. The work of Nagesh Naik and colleagues in (2013). It was shown that Panniyur-1 had a 38% higher incidence of Phytophthora foot rot disease (PDI). Major insect infestations did not occur in these accessions. Based on the findings, it appears that low pH stunts plant growth and is linked to low root nutrient concentrations of Ca and Mg. This might be the reason

Table 6 : Correlation of yellowing with rhizosphere soils nutrients of healthy, apparently healthy and yellowing affected plants during study.

	Yellowing	pH	EC	O.C	Fe	Mn	Z	Cu	B	N	P	K	Ca	Mg	S	Al
Yellowing	1.000															
pH	0.183**	1.000														
EC	0.150*	0.147*	1.000													
O.C	0.288**	0.182**	0.038^{NS}	1.000												
Fe	-0.058^{NS}	-0.117^{NS}	-0.039^{NS}	0.031^{NS}	1.000											
Mn	0.077^{NS}	-0.163**	-0.157**	0.030^{NS}	0.012^{NS}	1.000										
Zu	-0.064^{NS}	0.227**	-0.167**	0.166**	0.109^{NS}	-0.102^{NS}	1.000									
Cu	0.025^{NS}	0.088^{NS}	-0.021^{NS}	0.093^{NS}	-0.131*	-0.054^{NS}	0.225**	1.000								
B	0.082^{NS}	0.108^{NS}	-0.104^{NS}	0.030^{NS}	0.004^{NS}	0.046^{NS}	0.125*	-0.039^{NS}	1.000							
N	-0.111^{NS}	-0.051^{NS}	-0.250**	-0.095^{NS}	0.145*	0.136*	0.000^{NS}	-0.053^{NS}	0.026^{NS}	1.000						
P	-0.067^{NS}	-0.088^{NS}	-0.015^{NS}	-0.123*	0.059^{NS}	0.047^{NS}	-0.051^{NS}	-0.033^{NS}	0.017^{NS}	0.012^{NS}	1.000					
K	-0.159**	0.122*	-0.104^{NS}	-0.123*	-0.049^{NS}	-0.148*	0.412**	0.229**	0.154*	0.109^{NS}	0.037^{NS}	1.000				
Ca	-0.270**	0.102^{NS}	-0.284**	-0.099^{NS}	0.048^{NS}	-0.012^{NS}	0.443**	0.230**	0.127*	0.100^{NS}	-0.082^{NS}	0.450**	1.000			
Mg	0.050^{NS}	0.263**	-0.087^{NS}	0.101^{NS}	-0.042^{NS}	-0.004^{NS}	0.199**	0.104^{NS}	0.137*	0.120*	-0.097^{NS}	0.246**	0.208**	1.000		
S	0.032^{NS}	0.082^{NS}	-0.293**	-0.048^{NS}	0.070^{NS}	0.041^{NS}	0.185**	0.140*	0.230**	0.060^{NS}	0.056^{NS}	0.129*	0.240**	0.125*	1.000	
Al	-0.233**	0.045^{NS}	-0.044^{NS}	-0.293**	-0.010^{NS}	0.112^{NS}	-0.054^{NS}	-0.059^{NS}	0.035^{NS}	0.129*	0.161**	0.016^{NS}	0.112^{NS}	-0.058^{NS}	-0.039^{NS}	1.000

Table 7 : Correlation of soil nematode population with weather variables.

	Yellowing	Soil nematodes population	Maximum temperature	Minimum Temperature	Relative humidity	Rainfall
Yellowing	1.000					
Soil nematodes population	0.435**	1.000				
Maximum Temperature	0.162^{NS}	0.188^{NS}	1.000			
Minimum Temperature	-0.089^{NS}	-0.294**	0.097^{NS}	1.000		
Relative humidity	-0.158^{NS}	-0.213*	-0.996**	-0.059^{NS}	1.000	
Rainfall	-0.180^{NS}	-0.307**	-0.897**	0.144^{NS}	0.912**	1.000

why the seven pepper gardens saw a decrease in production (Zu *et al*., 2014).

Correlation of yellowing and soil nutrients

The correlation of different rhizosphere soil characters with yellowing is given in Table 6. The soil pH, EC and organic carbon were significantly and positively correlated with yellowing. There was no significant correlation of N, P, Mg, S, Fe, Mn, Zn, Cu and B content of rhizosphere soil with yellowing in black pepper. K, Ca and Al content of rhizosphere soils showed significant negative correlation yellowing. The similar results indicated that increase rainfall with increase growth of pepper and bioavailability nutrients required (Yap Chin Ann, 2012). The sandy soils are more favorable for nematode infestation. (Loubser, 1988).

Correlation of soil nematode population with weather variables

There was a negative association between soil nematode population and lowest temperature, relative humidity, and rainfall (as per mentioned Table 7). Yellowing was positively correlated with the soil nematode population. As stated by a study by Ramana *et al*. (1987). Temperature was important in nematode development and severity of galling and resistance breakdown occurred at a high temperature (Loubser, 1988).

Conclusion

The results of the field experiment showed that plants experiencing yellowing had optimal pH and EC values, and that healthy plants had far lower organic carbon content in their rhizosphere soil than plants experiencing yellowing. Plant health did not improve with the increased organic matter content of rhizosphere soil, perhaps because of root injury and inadequate absorption. An urgent measure is required to limit the nematode population since the soil nematode population was worrying. This experiment confirmed that all types were prone to yellowing. Monthly rainfall averaged 241.7 mm in October and November, and on a monthly basis, the temperature peaks at 31.7 degrees Celsius and dips to 22.3 degrees Celsius. The observed relative humidity was 81%. Between October and November, there was a noticeable increase in the nematode population in the soil and roots of the rhizosphere. Yellowing and discoloration in the top canopy of diseased pepper plants are symptoms of what might be a significant problem with the feeder roots. Our research shows that extensive infestations of endoparasitic nematodes decimated the root systems in rhizosphere soils, which otherwise possessed an ideal range of soil nutrients. When nematodes were infesting the roots of plants, nitrogen intake was significantly impaired. Nonetheless, in an optimal setting, these plants made a full recovery. The return of greenery from previously yellowed plants signaled the beginning of feeder root development during optimal season. After a nematode's life cycle was complete in one plant, it would move on to another. Under poor conditions, plants that seemed healthy began to show signs of yellowing. A combination of nutritional shortages in plant tissue and damage caused by nematodes must be responsible for the yellowing that is being seen.

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References

Ahmed, M. Saad, Heba M. Salem, Amira M. Tahan, El. Mohamed T. El-Saadony, Saadony, Saqer S. Alotaibi, Ahmed M. El-Shehawi, Taia A. Abd EL-Mageed, Ayman E. Taha, Mohammed A. Alkatani, Ahmed Ezzat Ahmed and Ayman Swelum A. (2021). Biological control: An effective approach against nematodes using Black pepper plants (*Piper nigrum* L). *Saudi J. Biolog. Sci*., **29**, 2047-2055.

Ann, Yap Chin (2012). Determination of nutrient uptake characteristic of black pepper (*Piper nig*rum L.). J. Agricult. Sci. Technol., **B 2 (10B)**, 1091-1099.

Aloka, Y.G. (2016). Gypsum as a soil amelioration for black pepper (*Piper nigrum* L.) in acid soils of Wayanad. *M.Sc. (Ag) thesis*, Kerala Agricultural University, Thrissur,104p.

Anandaraj, M. (2000). Diseases of black pepper. In Ravindran P.N. (Ed.), Black Pepper, *Piper nigrum*. (pp. 239-252). Volume 13 of the book series Medicinal and Aromatic Plants-Industrial Profiles. Amsterdam, The Netherlands: Harwood Academic Publisher.

Babu, M.S., Sujatha V.S., Mini Raj N., Reshmi V.R., Suresh K.P., Pathrose B. and Ragesh G. (2019). Influence of major nutrients and seasons in yellowing affected black pepper fields. *J. Pharmacog. Phytochem.*, **8(5)**, 2368-2373.

Bhagavantagoudra, K.H., Sheshagiri K.S., Venkateshamurthy P and Dinesh Kumar M. (2008). Performance of black pepper varieties in coffee based cropping system. *Karnataka J. Agric. Sci.*, **21 (2)**, 256-258. Doi 10.18805/asd.v0iOF.4435

Bong, C.F.J. and Saad M.S. (1986). Pepper (*Piper nigrum* L.) in Malaysia. University Pertanian Malaysia, Cawangan, Sarawak.

Cobb, N.A. (1918). Estimating the nematode population of soil, with special reference to the sugar-beet and root-gall nematodes, *Heterodera schachtii* Schmidt and *Heterodera radicicola* (Greef) Müller and with a description of *Tylencholaimus aequalis* n. sp. US Government Printing Office.

Frostegard, A., Baath E. and Tunlio A. (1993). Shifts in the structure of soil microbial communities in limed forests as revealed by phospholipid fatty acid analysis. *Soil Biol. Biochem.*, **25**, 723-730.

Hamza, S., Srinivasan V. and Dinesh R. (2007). Nutrient diagnosis of black pepper (*Piper nigrum*) L. gardens in Kerala and Karnataka. *J. Spices Aromat. Crops*, **16**, 77-81.

Haynes, R.J. and Naidu R. (1998). Influence of lime, fertilizer and manure applications on soil organic matter content and soil physical conditions: A review. *Nutrient Cycling in Agro ecosystems*, **51**, 123-137. https://doi.org/10.1023/A:1009738307837.

Jackson, M.L. (1958). *Soil chemical analysis*. Prentice Hall of India Private Limited, New Delhi, 498p. https://doi.org/10.1002/jpln.19590850311.

Kerry, B.R. (2000). Rhizosphere interactions and the exploitation of microbial agents for the biological control of plant-parasitic nematodes. *Annu. Rev. Phytopathol.*, **38**, 423-441. DOI: 10.1146/annurev.phyto.38.1.423.

Koshy, P.J., Santosh K., Eapen S.J. and Pandey R. (2005). Nematode parasites of spices, condiments and medicinal plant. In: Luc, M., Sikora R.A. and Bridge J. (eds). *Plant parasitic nematode in subtropical and tropical agriculture*. Wallingford (UK): CAB International. pp. 751-792. DOI:10.1079/9780851997278.0751

Krishnamoorthy, B. and Parthasarathy V.A. (2010). Improvement of black pepper. *CAB Reviews: Perspectives in Agriculture, Veterinary Science, Nutrition and Natural Resources,* **5(3)**, 1-12. DOI:10.1079/PAVSNNR20094085

Kueh, T.K., Gumbek M., Wong T.H. and Chin S.P. (1993). A field guide to diseases, pests and nutritional disorders of black pepper in Sarawak. Agricultural research centre Semongok, Department of Agriculture Kuching. Lee Ming Press Company, Sarawak, Malaysia. DOI:10.1007/s10327-012-0379-5

Loubser, J.T. (1988). Occurrence and Pathogensity of Root –Knot Nematodes (*Meloidogyne species*) in south African vine yards. *S. Afr. J. Enol. Vitic.*, **9(2)**, 22-27.

Mohandas, C. and Ramana K.V. (1987). Slow wilt disease of black pepper and its control. *Indian Cocoa Arecanut Spices J.*, **11**, 10-11.

Nagesh Naik, H., Lokesh M.S., Patil S.V. and Chandan K. (2013). Evaluation of selected black pepper (*Piper nigrum* L.) land races in arecanut (*Areca catechu* L.) mixed system of cultivation for higher yield and disease tolerance. *Asian J. Hort.*, **8(1)**, 328-331.

Pervez, R. (2018). Current status of plant parasitic nematodes and their management of major spice crops. *Trends Hortic.*, **1**. DOI:10.24294/th.v1i2.964

Raja Kumar, M., Ravindra Kumar K. and Seshakiran K. (2012). Management of *Phytophthora* foot rot disease in black pepper. *Green Farming*, **3(5)**, 583-585.

Ramana, K.V., Mohandas C. and Balakrishnan R. (1987). Role of Plant parasitic nematodes in the slow wilt disease complex of black pepper (*Piper nigrum* L.) in Kerala. *Indian J. Nematol.*, **17**, 225-230.

Ramana, K.V. and Eapen S.J. (2000). Nematode induced diseases of black pepper. In : Ravindran, P.N. (Eds.), Black Pepper, *Piper nigrum*. (pp. 269-296). Volume 13 of the book series Medicinal and Aromatic Plants- Industrial Profiles. Amsterdam, the Netherlands: Harwood Academic Publishers.

Sadanandan A.K., Peter K.V. and Hamza S. (2002). Role of potassium in improving yield and quality of spice crops in India. In: Pasricha, N.S. and Bansal S.K. (Eds.), Potassium for sustainable crop production, Potash Research Institute of India, Gurgaon and International Potash Institute, Switzerland, pp. 445–454.

Srinivasan, V., Dinesh R., Hamza S. and Parthasarathy V.A. (2007). Nutrient management for black pepper (*Piper nigrum* L.). *CAB Reviews: Perspective in Agriculture, Veterinary Science, Nutrition and Natural Resources*. DOI: 10.1079/PAVSNNR20072062

Spice Board (2018). Spice wise area and production. Spice Board of India. Ministry of Commerce and Industry.Govt. of India. Online [Access on 12 Dec. 2019]

Sitepu, D. and Mustika I. (2000). Diseases of black pepper and their management in Indonesia. In : Ravindran P.N. (Eds.), Black Pepper, *Piper nigrum*. (pp. 297-305). Volume 13 of the book series Medicinal and Aromatic Plants-Industria Profiles. Amsterdam, the Netherlands: Harwood Academic Publishers.https://doi.org/10.1201/9780203303870.

Subila, K.P. and Suseela Bhai R. (2020). *Pythium deliense,* a pathogen causing yellowing and wilt of black pepper in India. *New Disease Reports,* **42**, 6.

Sreekumar, K.M. (2015). S-IPRD [Sugandhi- Integrated Pepper Research and Development Project for Wayanad district] 2011-2015).Report of Sugandhi- Integrated Pepper Research and Development project. Kerala Agriculture University, Thrissur, 24p.

Thuy, T.T.T., Chi Yen, Anh N.T., Te L.T.N. and De Waele (2012). Fungi associated with black pepper plants in Quang Tri province (Vietnam) and interaction between *Meloidogyne incognita* and *Fusarium solani*. *Arch. Phytopathol. Plant Prot.*, **46**, 470-482. DOI:10.1080/03235408.2012.744621

Thankamani, C.K., Srinivasan V., Dinesh R., Santhosh J.E. and Rajeev P. (2008). Black pepper. *Indian Institute of Spices Research*. Retrieved from http://www.spices .res.in/ package/ pepper.pdf

Wahid, P.A. and Kamalam N.V. (1982). Mineral nutrition of slow wilt affected black pepper (*Piper nigrum* L.). *J. Plant. Crops,* **10**, 21-25.

Walkley, A.J. and Black I.A. (1934). Estimation of soil organic carbon by chromic acid titration method. *Soil Sci.*, **31**, 29-38.

Whitehead, A.G. (1997). *Plant Nematode Control*. UK: CAB Int. 384 pp.

Zu, C. (2014). Acid Soil is Associated with Reduced Yield, Root Growth and Nutrient Uptake in Black Pepper (*Piper nigrum* L.). *Agricult. Sci.*, **5**, 466-473. http://dx.doi.org/10.4236/as.2014.55047