Dear Dr.Jeevan H.,

Study on Impact of Soil Chemical Characteristics on Nematode Distribution across geographical regions of Meghalaya

Abstract:

This study looks at the relationship between soil chemical characteristics and nematode communities in Meghalaya's agricultural landscapes. Nematodes, which are important bioindicators of soil health, were studied in connection to soil characteristics such as pH, Electrical Conductivity (EC), Organic Carbon (OC), and nutrient levels (N, P, K) in various parts of Meghalaya. The study found strong relationships between soil chemistry and the spread of various nematode taxa. Acidic soils with lower pH and higher organic carbon were shown to have higher populations of plant-parasitic nematodes such as *Meloidogyne* sp. and *Xiphinema* sp., both of which have been shown to reduce agricultural productivity. Soils with greater EC, on the other hand, have fewer of these damaging nematodes, implying that modifying soil salinity could be a viable technique for controlling nematode infestations. Furthermore, nutrient-rich soils, particularly those high in phosphorus and potassium, were associated with larger abundances of *Tylenchorhynchus* sp., emphasising the intricate relationship between soil fertility and nematode dynamics. The study highlights the critical impact of soil chemical characteristics in influencing nematode communities, as well as the importance of specific soil management strategies to improve crop health in Meghalaya. Farmers can use these findings to build targeted methods for controlling nematode populations, decreasing crop loss and encouraging sustainable agricultural practices in the region. This study offers useful recommendations for enhancing soil health and increasing agricultural productivity in some regions of Meghalaya's agroecosystems.

Keywords: Nematode communities, soil chemical characteristics, crop health.

Introduction:

The northeastern hill region of India, a key part of the Indo-Malayan biodiversity hotspot, is exceptionally rich in both flora and fauna, serving as a crucial gateway to much of India's biodiversity (Chakravarty *et al.*, 2012). Situated in the northeastern Himalayas, Meghalaya is recognized as one of the world's most diverse biomes, characterized by high levels of endemism and the presence of rare species (Anonymous, 2005). The agro-climatic conditions in Meghalaya are conducive to the proliferation of pests and diseases (Azad Thakur *et al.*, 2013). Soil-dwelling nematodes, which feed on a wide range of living organisms, are abundant in this region and contribute significantly to the overall soil biota.

Nematodes, a group of roundworms in the phylum Nematoda, are an important component of belowground fauna diversity. With over 27,000 identified species (Hodda, 2011), they are found in practically every habitable region on the planet and account for over 80% of belowground metazoan taxonomic and functional diversity (Hodda *et al.*, 2009). Nematodes are thus an important component of the soil microbiota, helping to regulate a variety of ecological processes including as mineral cycling, succession, and energy flow (Andrén *et al.*, 1995). Soils in terrestrial ecosystems are projected to support around 25% of global biodiversity (Bach *et al.*, 2020). Soils are important reservoirs of biodiversity and contribute to ecosystem functioning (Bardgett & van der Putten, 2014).

Soil fauna's functional diversity has been proven to improve ecological processes such as primary production, nutrient cycling of carbon, phosphorous, and nitrogen (Brussaard, 1997), organic matter decomposition, and carbon assimilation in food webs. These activities contribute to the regulation of energy transfer between ecosystem components below and above ground (Hunt & Wall, 2002; Krumins *et al.*, 2013). Soil chemical variables influence the composition, variety, and functionality of nematode communities in terrestrial environments. Nematodes, which are important components of soil fauna, are sensitive to fluctuations in soil chemistry, such as pH, nutrient availability, organic matter concentration, and the presence of toxins or pollutants. These chemical qualities have an impact not only on the quantity of nematode species, but also on their distribution across trophic levels, affecting the overall soil food web and ecological processes such as nutrient cycling, decomposition, and energy flow.Understanding the interplay between soil chemistry and nematode communities is critical for ecological research and agricultural management because they can serve as markers of soil health and fertility. Furthermore, because nematodes occupy a wide range of ecological niches, from herbivores to predators, their responses to soil chemical changes might shed light on the resilience and viability of soil ecosystems under a variety of environmental situations (Bardgett & van der Putten, 2014).The purpose of this study is to investigate how soil chemical variables affect the form and function of nematode communities in the selected districts of Meghalaya state. This work will contribute to a better understanding of soil ecosystem dynamics and the possible use of nematodes as bioindicators for soil health and environmental monitoring by looking at how certain chemical variables influence nematode diversity, trophic interactions, and ecosystem roles.

Methods and methodology:

Soil samples collection

Soil samples were obtained randomly from agricultural, fallow, and forest regions throughout three districts in Meghalaya (Nongpoh, East Khasi hills, and West Jaintia hills). A total of 30 soil and root samples from various crops were collected (tomato, potato, paddy, pineapple, citrus, arecanut, cabbage/cauliflower). Soil samples were gathered at a depth of 15-20 cm from the collection site using a hand shovel, with each sample having a composite of 3-5 random subsamples. These samples were combined to form a composite sample, from which 250 cc of soil was taken for further processing. Prior to leaving the sampling site, the hand shovels were sterilised with 70% ethanol. Samples were packed in plastic bags to prevent dehydration, marked with the relevant information, and transferred to the laboratory.

Extraction and Identification of nematodes from the soil samples

Cobb's sieving and decanting process (Cobb, 1918) was employed to extract nematodes from soil samples. The nematode suspension was collected and then processed for identification. Standard morphological criteria were used to identify nematodes. Nematodes were preserved and dried according to Seinhorst's (1959) process, and slides were prepared for identification. The taxonomic key defined by Goodey (1963), Ahmad *et al.* (2010), Siddiqi (2000), Jairajpuri (1992), and Pervez (2006) was used to identify species up to the generic level. Nematodes were collected, treated in hot TAF (Triethanol Amine Formalin), and stored for population studies. The nematode population in each sample was counted five times using a Syracuse counting dish under a stereoscopic zoom microscope, and the average value was computed.

Estimation of soil chemical parameters

P^H and EC estimation

The determination of pH is basically a measurement of hydrogen ion activity in the soil-water system. The pH of a soil indicates whether the soil is acidic, neutral, or alkaline. Nutrient availability is determined by soil response. The amount of soluble salts in a sample is expressed as electrical conductivity (EC) and measured using a conductivity meter. The PH and EC were determined using a PH and EC meter in accordance with the normal technique.

Comment [vk1]: Correct the abbreviation's

Formatted: Highlight

Organic carbon (OC) estimation

A suitable amount of soil is digested with chromic acid and sulphuric acid using heat of sulphuric acid dilution, and soil organic matter is oxidised. A titration with standard Ferrous Ammonium Sulphate solution using diphenylamine as an indicator determines the excess of chromic acid that has not been reduced by the soil's organic matter (Sahrawat, 1982).

Available Nitrogen in Soil (N)

The available N was estimated using the alkaline permanganate method. A known weight of soil is combined with an alkaline potassium permanganate (KMnO4) solution and distilled. The organic matter in the soil is oxidised by the nascent oxygen liberated by potassium permanganate in the presence of sodium hydroxide, and the released ammonia is condensed and absorbed in a known volume of a boric acid with a mix indicator to form ammonium borate, the excess of which is titrated with a standard sulphuric acid (Subbiah and Asija, 1956).

Phosphorous in soil (P)

Phosphorus is removed from the soil using 0.5 m $NaHCO_3$ and a relatively constant pH of 8.5. In an acidic media, the phosphate ion in solution reacts with ascorbic acid to form a blue complex. Olsen *et al.* (1954) method was used for quantitative measurement of phosphorus in soil.

Potassium in soil (K)

The accessible potassium, which includes exchangeable and water-soluble potassium, is evaluated by extracting soil with a neutral normal ammonium acetate solution. Potassium is estimated using a flame photometer. The Hanway and Heidel (1952) estimation approach was adopted.

Community analysis

Community analysis was conducted by determining metrics such as absolute frequency, density, and prominence value, as reported by Norton (1978). Nematode community structure was described using parameters such as Absolute frequency (AF%), Relative frequency (RF%), Relative density (RD%), and Prominence value.

Absolute frequency % = Number of samples containing a species / total number of samples examined × 100 (Tandzi *et al.*, 2020)

Relative frequency % = Frequency of the species / Sum of frequencies of all species × 100 (Shiferaw *et al.*, 2011)

Relative density % = Density of the species / Sum of mean density of all nematode species × 100 (Hossain *et al.*, 2016)

Prominence value = Density × √Frequency (Murdia *et al.*, 2016)

Statistical Analysis:

The data were examined with R version 4.4.1. Pearson's correlation coefficient was used to determine the association between specific soil characteristics and soil nematodes.

Results and Discussion

Nematode Community Structure

The analysis of the nematode community revealed a diverse assemblage of genera, with varying abundance, dominance, and prevalence indices (Table 1). *Hoplolaimus* sp. demonstrated the highest absolute frequency (AF) at 56.67%, contributing significantly to the nematode community with a relative frequency (RF) of 8.33%. It exhibited a relative dominance (RD) of 4.65% and an absolute dominance (AD) of 4.60, making it a notable taxon in this study. The high relative prevalence (RPV) of *Hoplolaimus* sp. at 5.48% further underscores its ecological significance in the surveyed habitat. *Meloidogyne* sp. was another prominent genus, with a notable AF of 50.00% and an RF of 7.35%. The genus displayed the highest AD and RD values, 17.27 and 17.47%, respectively, indicating its dominance in the community. The prevalence values, both PV (122.09) and RPV (19.31%), were significantly higher than other taxa, suggesting a potential role in the regulation of plant-parasitic nematode populations in the soil ecosystem. Other genera, such as *Longidorus* sp., *Helicotylenchus* sp., *Xiphinema* sp., and *Pratylenchus* sp., exhibited moderate levels of frequency and dominance. For instance, *Pratylenchus* sp. had an AF of 46.67% and an RF of 6.86%, with corresponding AD and RD values of 9.87% and 9.98%, respectively. This genus also showed a relatively high prevalence, indicating its consistent presence across the samples. The bacterial-feeding nematodes, such as *Cephalobus* sp. and *Acrobeloides* sp., presented an AF of 46.67% and 43.33%, respectively, with moderate dominance and prevalence values. These genera play a crucial role in nutrient cycling and soil health, as they contribute to the decomposition of organic matter and nutrient mineralization (Bongers, 1990). Predatory nematodes like *Iotonchus* sp. and *Mylonchulus* sp. had lower AF values but exhibited considerable RD and RPV, suggesting their potential influence on controlling herbivorous nematode populations. The presence of these predatory genera indicates a balanced nematode community, where predator-prey interactions help maintain ecological stability (Ferris *et al.*, 2001).

Ecological Implications

The dominance of genera like *Meloidogyne* sp. and *Hoplolaimus* sp. highlights the potential risks to agricultural crops, as these genera are well-known plant parasites associated with significant yield losses (Jones *et al.*, 2013). Plant parasitic nematodes and its isolated crops are depicted in Fig. 1. Their high prevalence across the samples indicates that these taxa could be major contributors to crop damage in the region. On the other hand, the presence of bacterial feeders and predators suggests a complex and functional nematode community that can contribute to soil health and productivity by regulating the populations of harmful nematodes and enhancing nutrient availability. The overall structure of the nematode community, as depicted in this study, aligns with previous research conducted in similar agroecosystems (Neher, 2001). The diverse assemblage of nematodes, including plant-parasitic, bacterial-feeding, and predatory types, reflects the multifaceted roles these organisms play in soil ecosystems. Moreover, the high prevalence of certain genera, such as *Meloidogyne* sp. and *Pratylenchus* sp., warrants further investigation into their management to mitigate potential crop losses. In conclusion, this study provides valuable insights into the composition and ecological roles of nematode communities in the surveyed region. The findings underscore the importance of maintaining a balanced nematode community to promote soil health and ensure sustainable agricultural practices. Future research should focus on developing integrated pest management strategies that consider the ecological dynamics of nematode populations.

Table 1: Community analysis of plant and soil nematodes associated

	AF (%)	RF (%)	AD	RD (%)	PV	RPV (%)
Hoplolaimus sp. [p]	56.67	8.33	4.60	4.65	34.63	5.48
Meloidogyne sp. [p]	50.00	7.35	17.27	17.47	122.09	19.31

Longidorus sp. P	50.00	7.35	4.23	4.28	29.93	4.74
Helicotylenchus sp. P	46.67	6.86	6.07	6.14	41.44	6.56
Xiphinema sp. P	46.67	6.86	2.27	2.29	15.48	2.45
Pratylenchus sp. P	46.67	6.86	9.87	9.98	67.40	10.66
Cephalobus sp. B	46.67	6.86	4.77	4.82	32.56	5.15
Acrobeloides sp. B	43.33	6.37	5.07	5.13	33.35	5.28
Iotonchus sp. PR	40.00	5.88	7.10	7.18	44.90	7.10
Parahadronchus sp. PR	40.00	5.88	7.27	7.35	45.96	7.27
Panagrolaimus sp. B	36.67	5.39	4.17	4.22	25.23	3.99
Mesorhabditis sp. B	33.33	4.90	4.27	4.32	24.63	3.90
Mylonchulus sp. PR	30.00	4.41	3.03	3.07	16.61	2.63
Hadronchoides sp. PR	30.00	4.41	6.57	6.64	35.97	5.69
Diplogaster sp. PR	30.00	4.41	6.57	6.64	35.97	5.69
Tylenchorhynchus sp. P	26.67	3.92	3.47	3.51	17.90	2.83
Hemicriconemoides sp. P	16.67	2.45	0.97	0.98	3.95	0.62
Hirschmanniella sp. P	10.00	1.47	1.30	1.32	4.11	0.65
	680.00	**100.00**	**98.83**	**0.00**	**632.14**	**100.00**
P- Plant parasitic nematodes; PR- Predatory nematodes; B- Bacterivorous nematodes; AF- Absolute frequency; RF- Relative frequency; AD- Absolute density; RD- Relative density; PV- Prominence valve; RPV- Relative prominence valve						

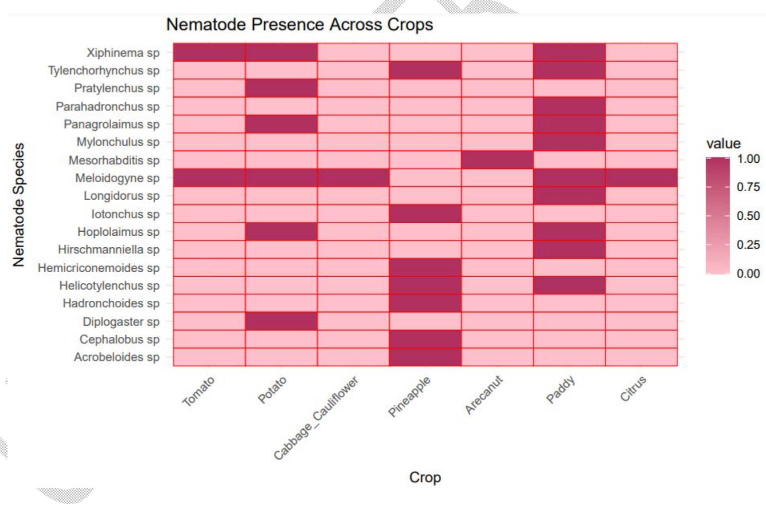


Fig. 1 Heat map represents the presence and absence of various nematode community in the cropping ecosystem of all three districts of Meghalaya.

Soil chemical properties

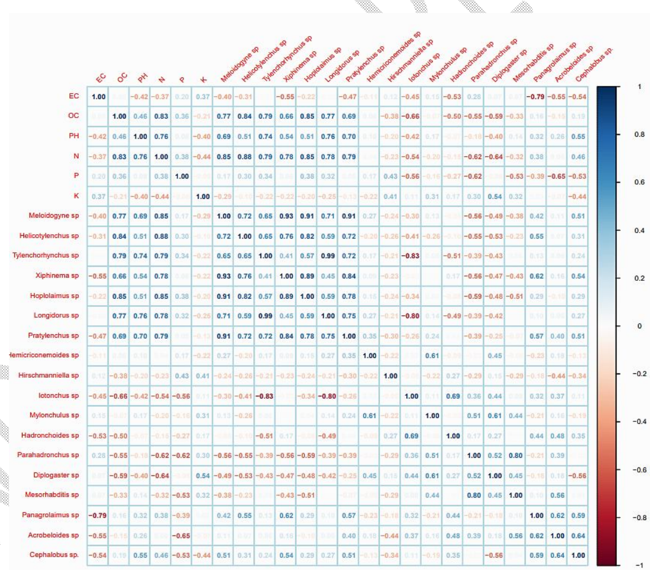
The soil chemical properties in different regions of Meghalaya reveals notable variability. In the Nongpoh region, Electrical Conductivity (EC) ranges from 0.09 to 0.23 dS/m, indicating low salinity, while Organic Carbon (OC) varies between 0.11% to 1.45%, suggesting low to moderate organic matter content. The soil is acidic, with pH values from 5 to 5.9. Nitrogen (N) content is moderate, ranging from 39.56 kg/ha to 60.25 kg/ha, with Phosphorus (P) levels from 12.37 kg/ha to 34.12 kg/ha, and Potassium (K) content between 111.56

kg/ha to 190.32 kg/ha. In the East Khasi Hills, EC ranges from 0.26 to 0.62 dS/m, indicating low salinity, while OC is relatively high, ranging from 1.98% to 4.01%. The soil remains acidic, with pH values ranging from 4.8 to 6.0. Nitrogen levels range from 39.45 kg/ha to 75.12 kg/ha, indicating moderate to high concentration, whereas phosphorus levels range from 14.23 kg/ha to 36.26 kg/ha, and potassium levels range from 118.64 kg/ha to 198.47 kg/ha. In the West Jaintia Hills, EC ranges from 0.16 to 0.38 dS/m, suggesting low salinity, whereas OC ranges from 1.11% to 3.25%, indicating considerable organic matter. The soil is acidic, with pH values ranging from 4.8 to 6.3, while nitrogen levels range from 29.56 kg/ha to 56.12 kg/ha. Phosphorus levels range from 17.19 kg/ha to 46.97 kg/ha, with potassium levels ranging from 116.23 kg/ha to 178.21 kg/ha.

Correlation between the soil chemical properties and nematode community

a. West Jaintia Hills

The correlation matrix reveals key relationships between soil properties and nematode abundance, providing insights into soil health and nematode community dynamics (Fig. 2). *Hoplolaimus* sp. and *Meloidogyne* sp. showed strong positive correlations with electrical conductivity (EC) and organic carbon (OC) (r = 0.77 and r = 0.91, respectively), suggesting that these genera thrive in saline and organic-rich soils. *Meloidogyne* sp. also correlated positively with nitrogen (N) and phosphorus (P) (r = 0.74 and r = 0.70), highlighting its potential to proliferate in nutrient-rich environments, which aligns with previous findings on the impact of soil nutrients on plant-parasitic nematodes (Jones *et al*., 2013). In contrast, *Cephalobus* sp. and *Acrobeloides* sp., both bacterial feeders, negatively correlated with OC and N, indicating their preference for lower nutrient levels, which may reduce competition with plant-parasitic

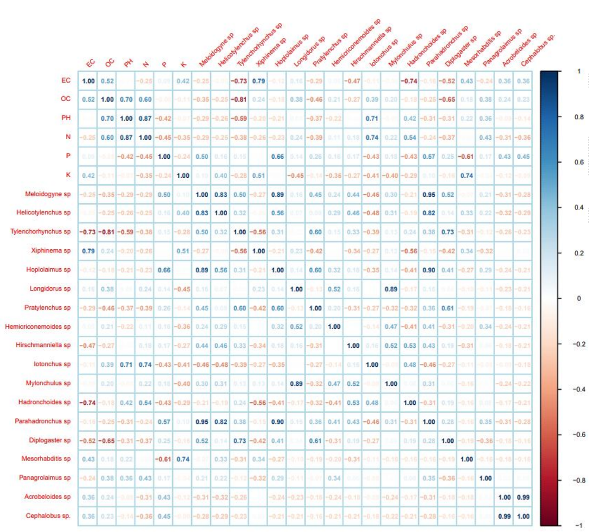


nematodes (Neher, 2001). *Tylenchorhynchus* sp. showed a positive correlation with soil pH (r = 0.76), suggesting a preference for slightly alkaline conditions, consistent with prior research on pH influences (Bongers, 1990). These correlations underscore the need for balanced soil management practices. High nutrient levels, while beneficial for crops, may inadvertently promote harmful nematode populations. Conversely, promoting bacterial feeders could enhance soil health and natural pest control (Ferris *et al*., 2001). Understanding these interactions is crucial for sustainable agricultural practices, ensuring crop productivity while minimizing nematode-related damages.

Fig. 2 Graph represent a correlation matrix showing relationships between various soil chemical properties (like EC, OC, PH, N, P, K) and different nematode species (e.g., *Meloidogyne sp.*, *Helicotylenchus sp.*, *Tylenchorhynchus sp.*, *Xiphinema sp.*, etc.) of West Jaintia Hills. The graph includes numbers that range from -1 to +1. These represent the correlation coefficients between pairs of variables.

b. East Khasi Hills

The correlation matrix illustrates significant relationships between soil properties and nematode genera, highlighting how these interactions influence soil health and nematode dynamics (Fig. 3). *Hoplolaimus* sp. and *Meloidogyne* sp. showed strong positive correlations with electrical conductivity (EC) and organic carbon (OC), suggesting their preference for saline and organic-rich soils, consistent with findings that certain nematodes thrive in such conditions (Bakonyi *et al*., 2007). Conversely, *Hadronchoides* sp. and *Parahadronchus* sp. negatively correlated with EC, indicating a preference for lower salinity.*Meloidogyne* sp. also positively correlated with nitrogen (N), phosphorus (P), and potassium (K), highlighting its proliferation in nutrient-rich environments, aligning with reports on nutrient impacts on plant-parasitic nematodes (Jones *et al*., 2013). In contrast, *Cephalobus* sp. negatively correlated with N, indicating its

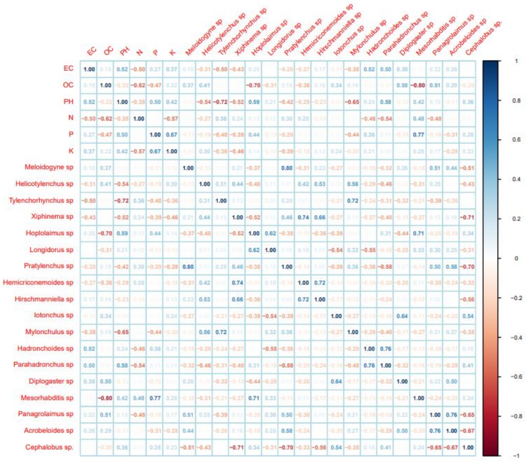


prevalence in soils with lower nutrient levels, likely due to reduced competition (Neher, 2001).Soil pH influences nematode distribution, with *Tylenchorhynchus* sp. positively correlated with higher pH and *Acrobeloides* sp. with lower pH, supporting previous research (Bongers, 1990). These correlations emphasize the importance of balanced soil management to control nematode populations, as excessive nutrients could enhance nematode pests, while appropriate organic matter and pH could promote beneficial nematodes (Ferris *et al*., 2001).Understanding these dynamics is crucial for sustainable agricultural practices that optimize soil health and crop productivity while minimizing nematode damage.

Fig. 3 Graph represent a correlation matrix showing relationships between various soil chemical properties (like EC, OC, PH, N, P, K) and different nematode species (e.g., *Meloidogyne sp*., *Helicotylenchus sp.*, *Tylenchorhynchus sp.*, *Xiphinema sp.*, etc.) of East Khasi Hills. The graph includes numbers that range from -1 to +1. These represent the correlation coefficients between pairs of variables.

c. Nongpoh region

The correlation matrix provided illustrates the relationships between various soil parameters (EC, OC, PH, N, P, K) and nematode species (Fig. 4). Positive correlations, represented in blue, suggest that as one variable increases, so does the other, while negative correlations, represented in red, suggest an inverse relationship. For instance, the nematode *Meloidogyne* sp. shows a strong positive correlation with phosphorus (P) and potassium (K), indicating that higher concentrations of these nutrients might favor the presence of this species. Conversely, it shows a negative correlation with nitrogen (N) and pH, suggesting that *Meloidogyne* sp. is less likely to thrive in soils with higher nitrogen content and more alkaline pH levels. This aligns with research indicating that nematodes in the genus Meloidogyne often proliferate in nutrient-rich soils, particularly those high in phosphorus, which is critical for root development and is often targeted by these parasitic nematodes (Ferris *et al*., 2013). On the other hand, *Hoplolaimus* sp. displays a significant positive correlation with organic carbon (OC) and nitrogen, indicating that it is more likely to be



found in soils with higher organic matter and nitrogen content. This is consistent with the understanding that *Hoplolaimus* species thrive in soils with high organic content, which provides a conducive environment for their growth (Norton, 1978). These correlations suggest complex interactions between soil fertility parameters and nematode populations, with implications for soil health and agricultural productivity. Future studies should investigate these relationships further to develop targeted soil management strategies.

Fig.4 Graph represent a correlation matrix showing relationships between various soil chemical properties (like EC, OC, PH, N, P, K) and different nematode species (e.g., *Meloidogyne sp*., *Helicotylenchus sp.*, *Tylenchorhynchus sp.*, *Xiphinema sp*., etc.) of Nongpoh region. The graph includes numbers that range from -1 to +1. These represent the correlation coefficients between pairs of variables.

Conclusion:

In conclusion, the study of nematode communities in connection to soil chemical characteristics in Meghalaya state sheds light on the intricate interactions between soil health and nematode populations. The study found that soil chemical characteristics such as electrical conductivity (EC), organic carbon (OC), pH, and important nutrients such as nitrogen, phosphorus, and potassium all had a substantial impact on the distribution and abundance of distinct nematode taxa. Notably, the data show that certain plant-parasitic nematodes, such as *Meloidogyne* sp. and *Xiphinema* sp., are strongly linked to specific soil conditions, such as lower pH and salinity. These nematodes prefer acidic, nutrient-rich environments, implying that soil management measures that alter these parameters could effectively restrict their populations and reduce their impact on crops. Furthermore, the study emphasises the need of understanding the ecological roles of various nematode taxa and how they interact with soil conditions. For example, the positive relationship between *Tylenchorhynchus* sp. and phosphorus and potassium levels suggests that this genus may thrive in nutrient-rich soils, thereby increasing crop risks if nutrient levels are not effectively maintained. On the other hand, the negative associations shown between EC and various worm taxa highlight the possibility of employing salinity modifications to manage nematode populations. Overall, this study adds to our understanding of soil ecology and nematology, with practical implications for Meghalaya's sustainable agriculture. Farmers and agricultural experts can use these data to develop tailored soil management practices that improve crop output while reducing the negative effects of destructive nematodes. Future research should look at these relationships across different soil types and climatic conditions in the region to further refine management approaches and maintain the long-term health of Meghalaya's agricultural ecosystems.

References

1. Ahmad, W., & Jairajpuri, M. S. (2010). *Mononchida- the predaceous soil nematodes.* Nematology monographs and perspective. E. J. Brill, Leiden, The Netherlands.
2. Andrén, O., Bengtsson, J., & Clarholm, M. (1995). Biodiversity and species redundancy among litter decomposers. In H. P. Collins, G. P. Robertson, & M. J. Klug (Eds.), *The significance and regulation of soil biodiversity: Proceedings of the international symposium on soil biodiversity, held at Michigan State University, East Lansing, May 3–6, 1993* (pp. 141–151). Developments in Plant and Soil Sciences. Springer Netherlands. https://doi.org/10.1007/978-94-011-0479-1_12
3. Azad Thakur, N. S., Firake, D. M., Behere, G. T., Firake, P. D., & Saikia, K. (2013). Biodiversity of agriculturally important insects in North Eastern Himalaya: An overview. *Indian Journal of Hill Farming, 25*(2), 37-40.
4. Bach, E., Ramirez, K., Fraser, T. D., & Wall, D. (2020). Soil biodiversity integrates solutions for a sustainable future. *Sustainability, 12*, 2662. https://doi.org/10.3390/su12072662
5. Bardgett, R. D., & van der Putten, W. H. (2014). Belowground biodiversity and ecosystem functioning. *Nature, 515*, 505–511. https://doi.org/10.1038/nature13855
6. Brussaard, L. (1997). Biodiversity and ecosystem functioning in soil. *Ambio, 26*, 563–570.
7. Chakravarty, S., Suresh, C. P., Puri, A., & Shukla, G. (2012). North-east India, the geographical gateway of India's phytodiversity. *Indian Forestry, 138*(8), 702-709.
8. Cobb, N. A. (1918). Estimating the nematode population of soil. *Agric. Tech. Circ. Bur. Pl. Ind. U.S. Dep. Agric, 1*, 23-25.
9. Goodey, T. (1963). *Soil and freshwater nematodes* (Revised by J. B. Goodey). Methuen, London.
10. Hanway, J. J., & Heidel, H. (1952). Soil analysis methods as used in Iowa State College Soil Testing Laboratory. *Iowa Agriculture, 57*, 1–13.
11. Hodda, M. (2011). Phylum Nematoda Cobb 1932. In: Z.-Q. Zhang (Ed.), *Animal biodiversity: An outline of higher-level classification and survey of taxonomic richness.* Zootaxa (Vol. 3148, pp. 63–95). https://doi.org/10.11646/zootaxa.3148.1.11
12. Hodda, M. E., Peters, L., & Traunspurger, W. (2009). Nematode diversity in terrestrial, freshwater aquatic, and marine systems.
13. Hossain, F., Follett, P., Vu, K. D., Harich, M., Salmieri, S., & Lacroix, M. (2016). Evidence for synergistic activity of plant-derived essential oils against fungal pathogens of food. *Food Microbiology, 53*, 24–30.
14. Jairajpuri, M. S., & Ahmad, W. (1992). *Dorylaimida: Free-living, predaceous and plant-parasitic nematodes.* E.J. Brill, Leiden, The Netherlands, and Oxford & IBH, New Delhi.
15. Murdia, L., Wadhwani, R., Wadhawan, N., Bajpai, P., & Shekhawat, S. (2016). Maize utilization in India: An overview. *American Journal of Food Nutrition, 4*, 169–176.
16. Norton, D. C. (1978). *Ecology of plant parasitic nematodes.* John Wiley and Sons, New York.
17. Olsen, S. R., Cole, C. V., Watanabe, F. S., & Dean, L. A. (1954). Estimation of available phosphorus in soils by extraction with sodium bicarbonate. *Circular U.S. Dept. Agric, 939*, 1-19.
18. Pervez, R. (2006). Population structure of plant parasitic and predatory nematodes associated from Firozabad districts (Uttar Pradesh). *Current Nematology, 16*(1-2), 51-54.
19. Sahrawat, K. L. (1982). Simple modification of the Walkley-Black method for simultaneous determination of organic carbon and potentially mineralizable nitrogen in tropical rice soils. *Plant and Soil, 69*, 73-77.
20. Seinhorst, J. W. (1959). A rapid method for the transfer of nematodes from fixative to anhydrous glycerin. *Nematologica, 4*, 67-69.
21. Shiferaw, B., Prasanna, B. M., Hellin, J., & Bänziger, M. (2011). Crops that feed the world 6. Past successes and future challenges to the role played by maize in global food security. *Food Security, 3*, 307.
22. Siddiqi, M. R. (2000). *Tylenchida – parasites of plants and insects* (2nd ed.). CABI Publishing, London, UK.
23. Subbiah, B. V., & Asija, G. L. (1956). A rapid procedure for the estimation of nitrogen in soils. *Current Science, 25*, 259-260.

24. Tandzi, L. N., & Mutengwa, C. S. (2020). Estimation of maize (Zea mays L.) yield per harvest area: Appropriate methods. *Agronomy, 10*, 29.
25. Bongers, T. (1990). The maturity index: An ecological measure of environmental disturbance based on nematode species composition. *Oecologia, 83*(1), 14-19. https://doi.org/10.1007/BF00324627
26. Ferris, H., Bongers, T., & de Goede, R. G. M. (2001). A framework for soil food web diagnostics: Extension of the nematode faunal analysis concept. *Applied Soil Ecology, 18*(1), 13-29. https://doi.org/10.1016/S0929-1393(01)00152-4
27. Jones, J. T., Haegeman, A., Danchin, E. G. J., Gaur, H. S., Helder, J., Jones, M. G. K., Kikuchi, T., Manzanilla-López, R., Palomares-Rius, J. E., Wesemael, W. M. L., & Perry, R. N. (2013). Top 10 plant-parasitic nematodes in molecular plant pathology. *Molecular Plant Pathology, 14*(9), 946-961. https://doi.org/10.1111/mpp.12057
28. Neher, D. A. (2001). Role of nematodes in soil health and their use as indicators. *Journal of Nematology, 33*(4), 161-168.