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IMPACT OF ABIOTIC FACTORS ON THE SPATIAL DISTRIBUTION OF PLANT-PARASITIC NEMATODES IN VEGETABLE CROPS

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ABSTRACT

The research aimed to investigate the distribution of various plant-parasitic nematodes (PPNs) affecting vegetable crops and influences of soil temperature, soil moisture and rainfall on their population development. The study was carried out at the experimental horticulture farm of Assam Agricultural University, Jorhat-13, from September, 2021 to August, 2022. Five species of PPNs were recorded from around the rhizosphere of vegetable crops from the analyzed soil and root samples. The most frequently observed and widely distributed PPN species were *Helicotylenchus dihystera* followed by *Meloidogyne incognita*, *Macroposthonia onostris*, *Rotylenchulus reniformis* and *Hoplolaimus indicus*. The present investigation revealed that soil temperature, soil moisture and rainfall had significant influence on population development of these genera. Maximum soil population were obtained during the warmer months of the year with soil temperature ranging from 24.5-28.0^{o}C and soil moisture ranges from 17.5-22 percent, while minimum were recorded during winter months.

Key words**:** Plant-Parasitic Nematodes, soil temperature, soil moisture, rainfall, population dynamics.

Introduction

The presence of plant-parasitic nematodes (PPNs) is one of the greatest barriers to the productive development of crops, particularly vegetable crops. By lowering their yield, productivity, and quality, PPNs that parasitize plants pose a severe danger to the successful cultivation of many economic crops.

The population dynamics of PPNs are affected by various environmental factors such as soil temperature and soil moisture levels in addition to host plant resistance (Castillo *et al*., 1996; Govaerts *et al*., 2007). Geographical fluctuations in ecological and soil-related factors cause variations in the diversity and quantity of flora and wildlife. PPNs are the main microfauna in soil ecosystems. But despite their popularity, little is known about the ecological and edaphic factors that govern their distribution and population abundance, even in forests and agricultural regions that have been thoroughly researched (Hánel, 1993).

According to a detailed worldwide analysis, PPNs in main agricultural plants are estimated to cause an astounding USD 173 billion in crop yield losses per year (Elling, 2013). Given that PPNs are poikilothermic creatures, temperature is a crucial abiotic element for their biology (Lee, 2002). Temperature variations can lead to shortened generation times and affect the dispersion of PPNs (McSorley, 2003; Treonis and Wall, 2005). Even at zero percent relative humidity, PPNs have been found to flourish across a broad variety of temperatures (Wall and Virginia, 1999). But when conditions are not ideal, some PPNs need more time to mature because they are more susceptible to severe temperatures (Charchar and Santo, 2001). Likewise, changes in annual rainfall patterns directly affect soil moisture content, which in turn affects the habitat of PPNs (Nisa *et al*., 2021). Particularly in regions with native plants, soil undergoes progressive changes in both its physical and chemical characteristics. The movement of PPNs is reliant on water films or soil pores that are filled with water (Pitcher, 1975). Therefore, changes in water supply might impact their activity right away and eventually change the numbers of PPNs and the structures of their communities (Nzogela *et al*., 2020).

The seasonal variations of these PPNs, which are located near the root zone of vegetable crops in Assam, are not well understood, despite their detrimental impacts. Due to its subtropical climate, Assam has substantial seasonal variations in its ecological factors. With the established influence of ecological and edaphic factors on PPN diversity, this study aims to explore how ecological parameters such as soil temperature, soil moisture content and rainfall influence the abundance of PPNs associated with vegetable crops in Assam, India. In the context of Assam, this study is unique in that it focuses on the seasonal variations of PPN populations surrounding the root zones of vegetable crops. The research fills a significant information gap and lays the groundwork for further PPN ecology and management research by describing the seasonal variations in PPN populations.

Materials and Methods

The study on distribution of PPNs in relation to soil moisture content, soil temperature and rainfall was conducted at the Experimental Horticulture Farm, Assam Agricultural University, Jorhat-13 (26.726575, 94.201917) which is purely upland situation with sandy loam soil.

Soil samples were periodically (at fortnight interval) collected from a fixed area of horticultural farm, where vegetable crops were organically grown throughout the year. From every examination site, the samples of root and soil were collected from the rhizospheric region of vegetable crops. The samples of soil were obtained from 15-20 cm below ground in a zigzag pattern with the help of a soil auger using the sub-sampling method. Each sample consisted of 50 g of soil and 1 g of root. These soil samples were properly blended to obtain a homogenous sample of 200 cc soil. Nematodes from the soil samples were extracted by following modified Cobb's decanting and sieving technique (Christei and Perry, 1951). Extracted nematodes were identified under stereo-zoom binocular microscope and enumerated mostly in living condition. If needed, nematodes were killed and simultaneously fixed by pouring equal volume of 8% boil formalin to the nematode suspension.

Soil temperature was recorded with the help of a soil thermometer, inserting it up to a depth of 15 cm for a period of 5-10 minutes at the time of sampling. Soil moisture was determined following Gravimetric method (Khanna and Yadav, 1979) at the time of sampling. Rainfall data was collected from the Department of Agricultural Meteorology, Assam Agricultural University, Jorhat.

Results

During the period of study, soil temperature of the experimental horticulture farm of Assam Agricultural University, Jorhat was ranging from 15.5°C - 28.0°C; with a soil moisture level of 15.0-22.0 percent and monthly rainfall of 0.6-302.2 mm (Fig. 1). Temperature during winter (November, December, January and February) months' rangers from 15.5- 17.5°C with a minimum amount of rainfall (0.6-45 mm). Soil moisture content showed a constant trend throughout the year with a range of 15-22 percent. More PPN population was recorded during warmer months (April-August) while soil temperature ranges from 24.5-28.0°C and soil moisture ranges from 17.5-22 percent. However, the monthly rainfall was also maximum (215.8-302.2mm) during these months. Total PPN population decreased during the winter months to reach its minimum during January when soil temperature was 15.5°C, soil moisture was 15.5% and monthly rainfall was 18.9 mm (Fig. 1).

A bimodal pattern in population abundance was exhibited with a prominent peak during summer season and a low peak during winter season. The major genera identified were *Helicotylenchus dihystera* followed by *Meloidogyne incognita*, *Macroposthonia onostris*, *Rotylenchulus reniformis* and *Hoplolaimus indicus*. The temporal changes in the PPN population showed a statistical correlation with soil temperature, moisture and rainfall levels.

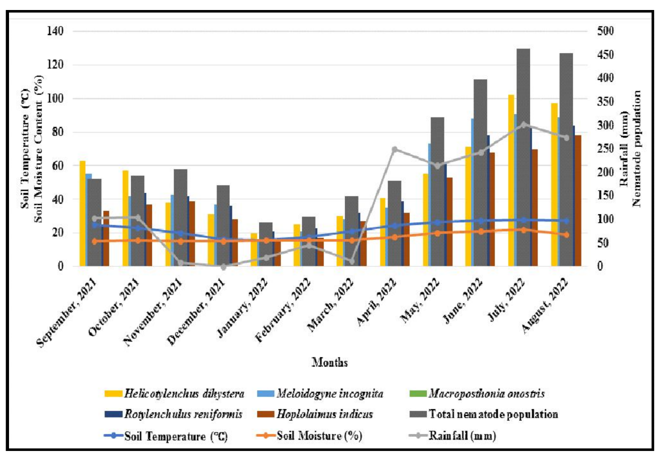

Fig. 1: Graphical representation of effect of soil temperature (°C), soil moisture content (%) and rainfall (mm) on population dynamics of some economically important PPNs associated with various vegetable crops at horticultural farm of Assam Agricultural University, Jorhat during 2021-2022.

Helicotylenchus dihystera

- **Soil temperature:** For every 1°C increase in soil temperature, the population of *H. dihystera* increases by approximately 5.13 individuals. With

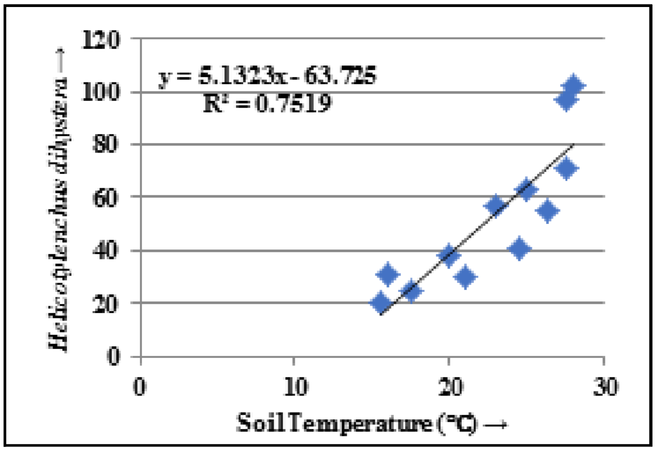

Fig. 2a: Graphical representation of relationship between Soil Temperature (°C) (x) and *H. dihystera* (y) at the horticultural farm of Assam Agricultural University, Jorhat during 2021-2022.

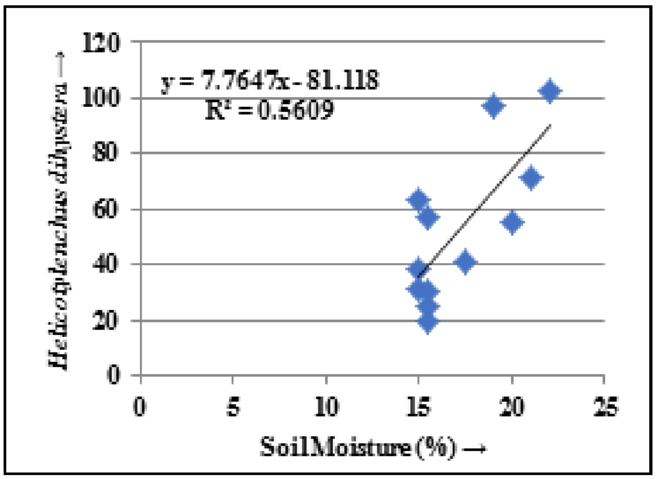

Fig. 2b: Graphical representation of relationship between Soil Moisture (%) (x) and *H. dihystera* (y) at the horticultural farm of Assam Agricultural University, Jorhat during 2021-2022.

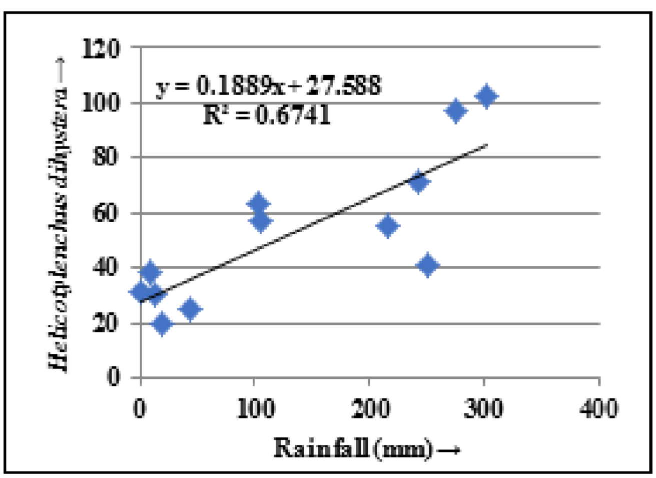

Fig. 2c: Graphical representation of relationship between Rainfall (mm) (x) and *H. dihystera* (y) at the horticultural farm of Assam Agricultural University, Jorhat during 2021-2022.

an R^2 value of 0.7519, approximately 75.19% of the variation in PPN population can be explained by changes in soil temperature. The soil temperature (°C) contributes around 5.13 per cent to the population build-up of PPNs (Fig. 2a).

- **Soil Moisture Content (%):** The PPN population increases by approximately 7.76 individuals for every 1% rise in soil moisture. The R^2 value of 0.5609 suggests that 56.09% of the variation in PPN population is explained by soil moisture. The soil moisture content (%) contribute around 7.76 per cent to the population build-up of PPNs (Fig. 2b).
- **Rainfall:** The PPN population increases by approximately 0.18 individuals for every 1% rise in soil moisture. The R^2 value of 0.6741 indicates that 67.41% of the variation in the PPN population is accounted for by rainfall. The rainfall (mm) contributes around 0.18 per cent to the population build-up of PPNs (Fig. 2c).

Meloidogyne incognita

- **Soil temperature:** The PPN population increases by approximately 5.19 individuals for every 1% rise in soil moisture. The R^2 value of 0.7575 indicates that 75.75% of the variation in PPN population is explained by changes in soil temperature. The soil temperature (°C) contributes around 5.19 per cent to the population build-up of PPNs (Fig. 3a).
- **Soil moisture content:** The PPN population increases by approximately 8.86 individuals for every 1% rise in soil moisture. The R^2 value of 0.7191 shows that 71.91% of the variation in population density is due to soil moisture changes. The soil moisture content (%) contribute around 8.86 per cent to the population build-up of PPNs (Fig. 3b).
- **Rainfall:** The PPN population increases by approximately 0.18 individuals for every 1% rise in soil moisture. The R^2 value of 0.6603 suggests that 66.03% of the variation in population is attributable to rainfall. The rainfall (mm) contributes around 0.18 per cent to the population build-up of PPNs (Fig. 3c).

Macroposthonia onostris

- **Soil temperature:** The PPN population increases by approximately 5.46 individuals for every 1% rise in soil moisture. The relatively low R^2 value suggests that soil temperature alone

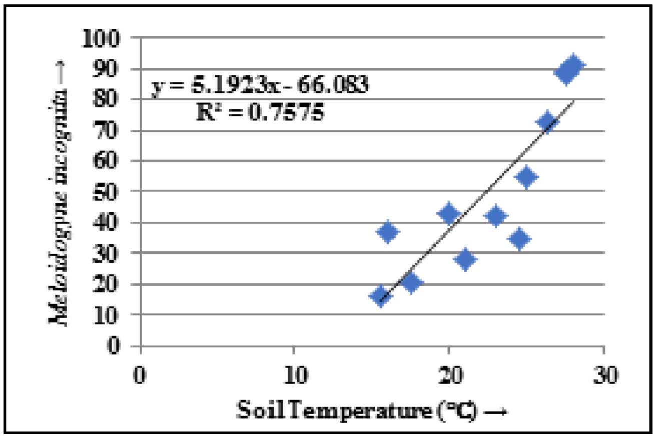

Fig. 3a: Graphical representation of relationship between Soil Temperature (°C) (x) and *M. incognita* (y) at the horticultural farm of Assam Agricultural University, Jorhat during 2021-2022.

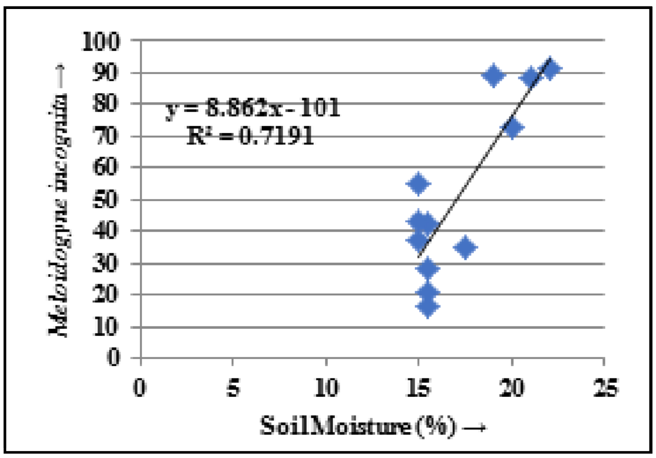

Fig. 3b: Graphical representation of relationship between Soil Moisture (%) (x) and *M. incognita* (y) at the horticultural farm of Assam Agricultural University, Jorhat during 2021-2022.

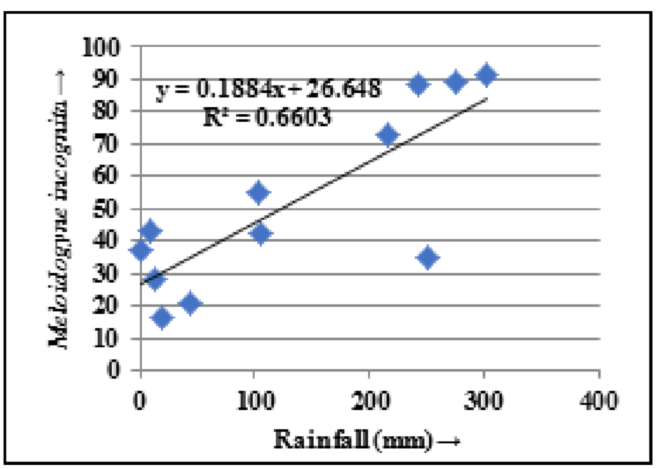

Fig. 3c: Graphical representation of relationship between Rainfall (mm) (x) and *M. incognita* (y) at the horticultural farm of Assam Agricultural University, Jorhat during 2021-2022.

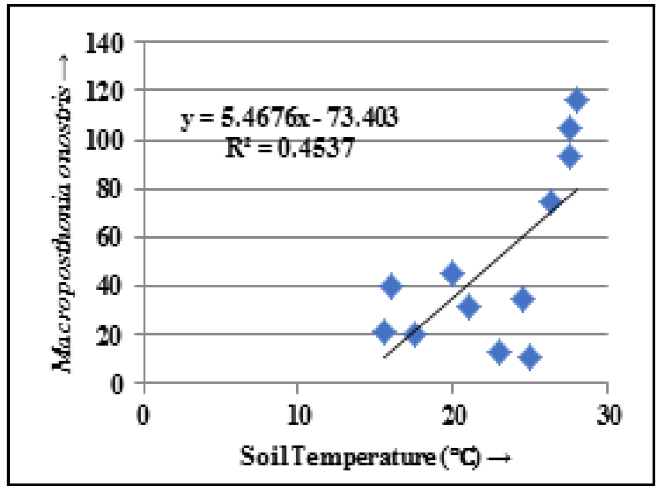

Fig. 4a: Graphical representation of relationship between Soil Temperature (°C) (x) and *M. onostris* (y) at the horticultural farm of Assam Agricultural University, Jorhat during 2021-2022.

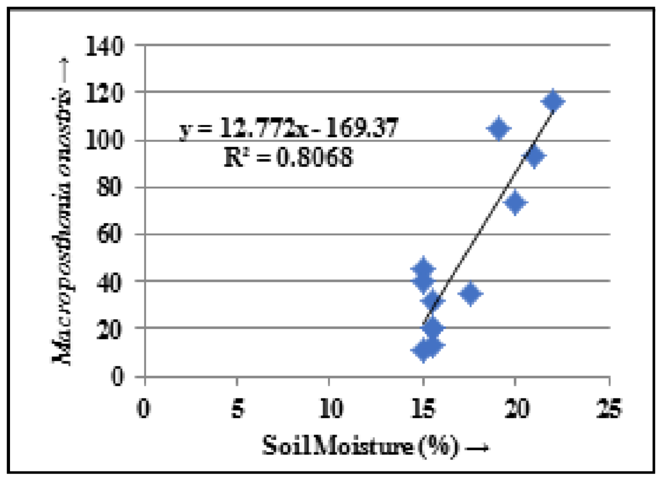

Fig. 4b: Graphical representation of relationship between Soil Moisture (%) (x) and *M. onostris* (y) at the horticultural farm of Assam Agricultural University, Jorhat during 2021-2022.

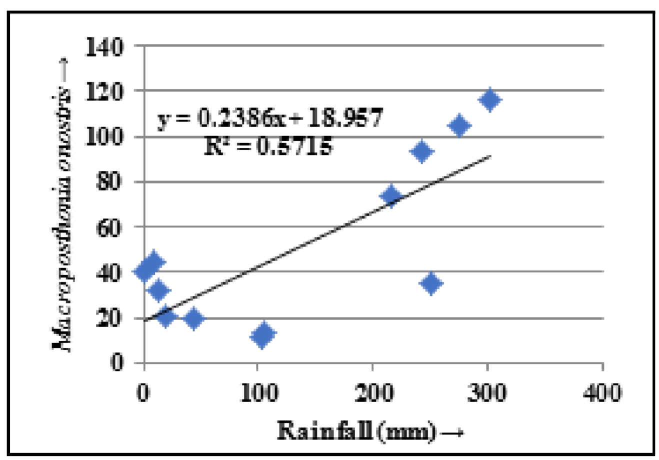

Fig. 4c: Graphical representation of relationship between Rainfall (mm) (x) and *M. onostris* (y) at the horticultural farm of Assam Agricultural University, Jorhat during 2021-2022.

explains only 45.37% of the variation in PPN population. The soil temperature (°C) contributes around 5.46 per cent to the population build-up of PPNs (Fig. 4a).

- **Soil moisture content:** The PPN population increases by approximately 12.77 individuals for every 1% rise in soil moisture. The high R^2 value indicates that soil moisture explains about 80.68% of the variation in PPN population. The soil moisture content (%) contribute around 12.77 per cent to the population build-up of PPNs (Fig. 4b).
- **Rainfall:** The PPN population increases by approximately 0.23 individuals for every 1% rise in soil moisture. The R^2 value indicates that rainfall explains 57.15% of the variation. The rainfall (mm) contributes around 0.23 per cent to the population build-up of PPNs (Fig. 4c).

Rotylenchulus reniformis

- **Soil temperature:** For every 1°C increase in soil temperature, the PPN population increases by approximately 4.05 individuals. The moderate R^2=0.625 indicates that about 62.5% of the variation in PPN abundance is explained by changes in soil temperature. The soil temperature (°C) contributes around 4.05 per cent to the population build-up of PPNs (Fig. 5a).
- **Soil moisture content:** The PPN population increases by approximately 7.97 individuals for every 1% rise in soil moisture. The strong R^2=0.7883 implies that 78.8% of the variation in *R reniformis* abundance is explained by soil moisture content. The soil moisture content (%) contribute around 7.97 per cent to the population build-up of PPNs (Fig. 5b).
- **Rainfall:** The PPN population increases by approximately 0.16 individuals for every 1% rise in soil moisture. The R^2 = 0.6711 signifies that 67.1% of the variation in PPN populations is explained by rainfall. The rainfall (mm) contributes around 0.16 per cent to the population build-up of PPNs. (Fig. 5c)

Hoplolaimus indicus

- **Soil temperature:** For every 1°C increase in soil temperature, the PPN population increases by approximately 3.88 individuals. With an R^2 value of 0.7166, approximately 71.66% of the variation in PPN population can be explained by changes in soil temperature. The soil temperature

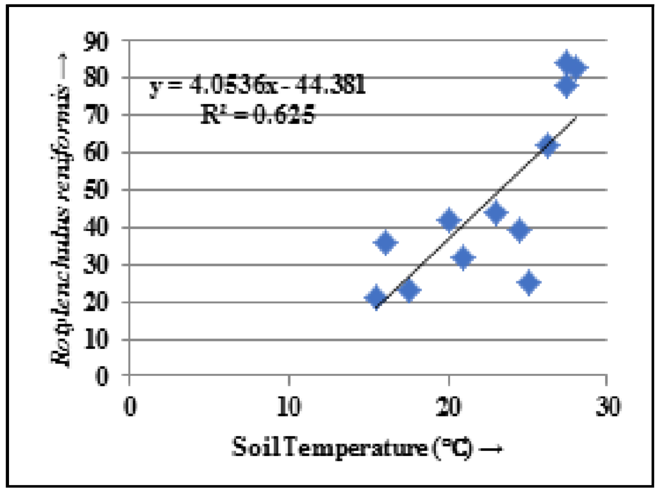

Fig. 5a: Graphical representation of relationship between Soil Temperature (°C) (x) and *R. reniformis* (y) at the horticultural farm of Assam Agricultural University, Jorhat during 2021-2022.

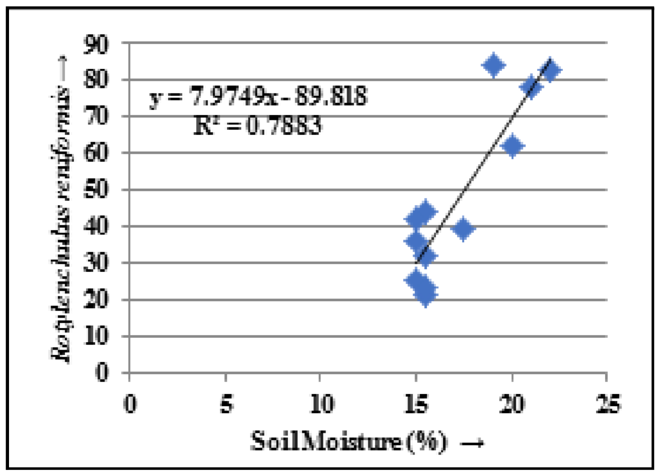

Fig. 5b: Graphical representation of relationship between Soil Moisture (%) (x) and *R. reniformis* (y) at the horticultural farm of Assam Agricultural University, Jorhat during 2021-2022.

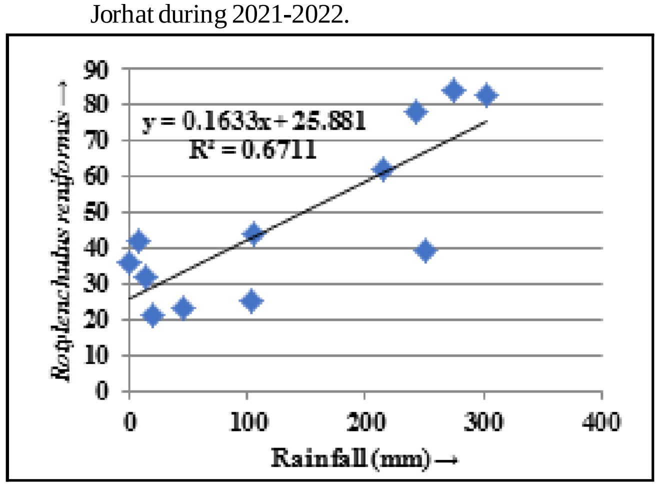

Fig. 5c: Graphical representation of relationship between Rainfall (mm) (x) and *R. reniformis* (y) at the horticultural farm of Assam Agricultural University, Jorhat during 2021-2022.

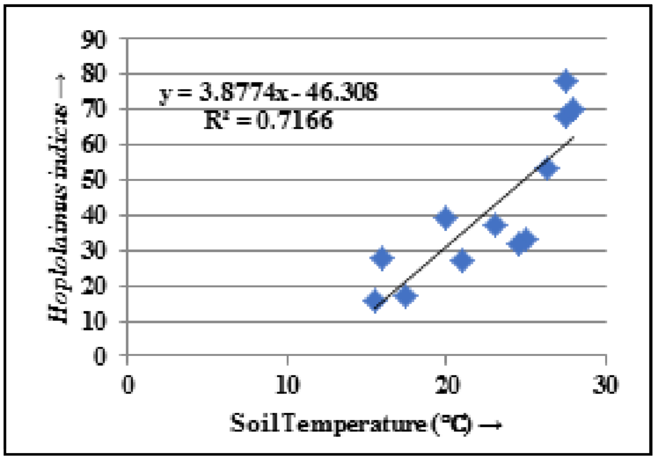

Fig. 6a: Graphical representation of relationship between Soil Temperature (^{O}C) (x) and *H. indicus* (y) at the horticultural farm of Assam Agricultural University, Jorhat during 2021-2022.

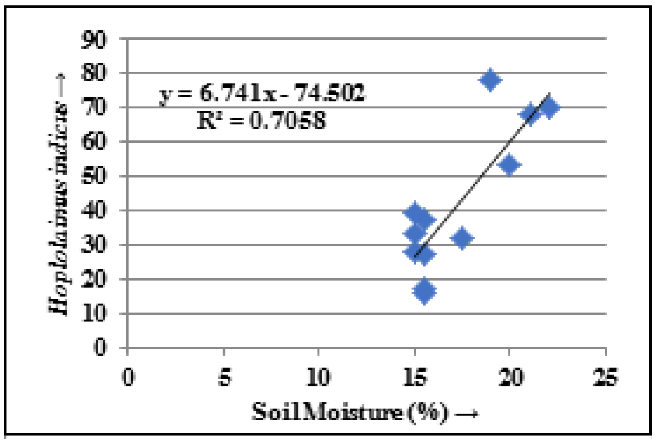

Fig. 6b: Graphical representation of relationship between Soil Moisture (%) (x) and *H. indicus* (y) at the horticultural farm of Assam Agricultural University, Jorhat during 2021-2022.

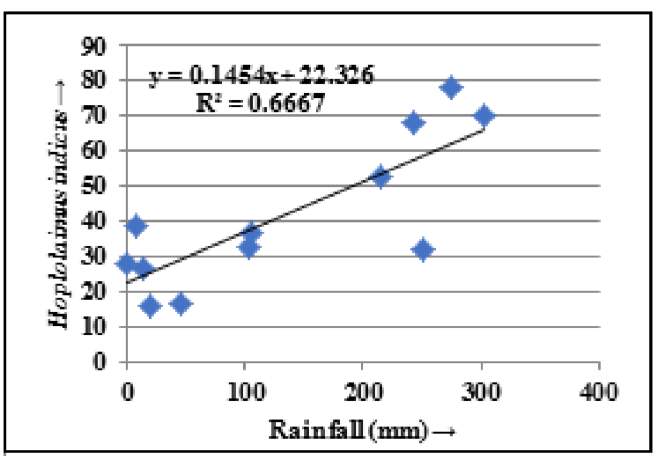

Fig. 6c: Graphical representation of relationship between Rainfall (mm) (x) and *H. indicus* (y) at the horticultural farm of Assam Agricultural University, Jorhat during 2021-2022.

(°C) contributes around 3.88 per cent to the population build-up of PPNs (Fig. 6a).

- **Soil moisture content:** The PPN population increases by approximately 6.74 individuals for every 1% increase in soil moisture content. The strong R^2=0.7058 implies that 70.58% of the variation in PPN abundance is explained by soil moisture content. The soil moisture content (%) contribute around 6.74 per cent to the population build-up of PPNs (Fig. 6b).
- **Rainfall:** For every 1 mm increase in rainfall, the PPN population increases by approximately 0.14 individuals. The R^2=0.6667 signifies that 66.67% of the variation in PPN populations is attributed to changes in rainfall. The rainfall (mm) contributes around 0.14 per cent to the population build-up of PPNs (Fig. 6c).

Discussion

Our study revealed that the abundance of all PPN genera was low during the winter months (December, January and February) due to the low temperature and high moisture of the soil, which is consistent with the research of Dwivedi and Misra (1990) and Khan *et al.*, (1971). Khan and Sharma (1990) and Pandey (1999) found that the PPN population was low in December, which might be attributed to the low temperature. As temperatures rose during the spring months of March, April and May, PPN populations tended to increase. Boag (1980) reported that temperature affects PPN feeding rates, reproduction and other factors, leading to a population surge as temperature rises. PPN populations' abundance in our study increased from June onwards, reaching a peak in August/September, likely due to optimal soil moisture and moderate temperatures, as also noted by Azmi (1995) and Siddiqui (2007). During the present study, we observed that maximum population abundance was observed at a soil temperature of 19.7-25.5°C which is in agreement with Khan *et al.*, (2014) and Munteanu (2017) who reported that the PPNs best perform at a temperature range from 15 to 25°C. Our results are consistent with Bakonyi *et al.*, (2007) who reported that soil temperature has a major impact on PPN population growth. The positive correlation between PPN abundance and temperature is in agreement with other studies (Karuri *et al.*, 2017 and Namu *et al.*, 2018). However, a consensus emerges among these studies that factors such as soil moisture and temperature exert a notable influence on the growth of PPN populations (Kumar 2002; Sen *et al.*, 2008 and Nisa *et al.*, 2021).

The present study sheds light on the influence of key environmental factors—soil temperature, soil moisture content, and rainfall—on the population dynamics of five economically important PPN species in the soil ecosystem: *H. dihystera*, *M. incognita*, *M. onostris*, *R. reniformis*, and *H. indicus*. Each environmental parameter plays a distinct role in shaping the population density of these PPNs, and their interactions highlight the complex relationship between abiotic factors and PPN ecology.

Soil Temperature

The differential responses of the five PPN species to the environmental factors highlight species-specific ecological adaptations. Soil temperature showed the strongest correlations for *M. incognita* (R^2 = 0.7575) followed by *H. dihystera* (R^2 = 0.7519), *H. indicus* (R^2 = 0.7166), *R. reniformis* (R^2 = 0.625) and *M. onostris* (R^2 = 0.4537), highlighting its pivotal role in promoting population growth. The regression analysis indicates that for every 1°C increase in soil temperature, PPN populations increase significantly—ranging from approximately 3.87 individuals (*H. indicus*) to 5.46 individuals (*M. onostris*). Across all species, the positive relationships emphasize the thermal sensitivity of PPNs, where higher temperatures likely accelerate developmental cycles, boosting population densities.

Soil Moisture Content

Soil moisture showed a universally strong correlation with PPN populations, underscoring its significance as an ecological determinant. The regression analyses indicate steep slopes, reflecting higher sensitivity of PPN populations to changes in soil moisture. For instance, *M. onostris* (R^2 = 0.8068) showed the highest response, with populations increasing by approximately 12.77 individuals per 1% rise in moisture content followed by *R. reniformis* (R^2 = 0.7883), *M. incognita* (R^2 = 0.7191), *H. indicus* (R^2 = 0.7058) and *H. dihystera* (R^2 = 0.5609), as reflected by the steep slope of the regression equation. Soil moisture content was also a significant determinant, with the latter species exhibiting a near-linear increase in population density as moisture content increased. This variation likely reflects differences in moisture preferences, as well as lifecycle strategies. The steeper slopes for soil moisture suggest a greater reliance on high moisture for movement and reproduction. These results confirm the critical role of moisture in creating conducive conditions for PPN survival and proliferation by enhancing mobility, host-seeking ability, and egg hatching. The findings suggest that soil moisture serves as a vital environmental driver for PPN population build-up, influencing their ability to move, infect plant roots, and sustain metabolic activities.

Rainfall

Rainfall was positively correlated with PPN population densities across all species but had a relatively weaker influence compared to soil temperature and soil moisture. Regression equations indicate population increases of 0.14 (*H. indicus*) – 0.23 (*M. onostris*) individuals per millimeter of rainfall across species. The relatively lower slope values and moderate R^2 values suggest that rainfall likely influences PPN populations indirectly, through its effects on soil moisture and microclimatic conditions. This suggests that rainfall plays a role in facilitating PPN movement and activity, its impact is secondary to soil moisture content. These species may have developed adaptations to fluctuating precipitation patterns, such as desiccation resistance or the ability to exploit host plants more effectively under suboptimal moisture conditions.

Nevertheless, rainfall remains an important factor, especially during periods of drought or excessive precipitation, which can create stress conditions for PPNs or alter their habitat suitability. This finding suggests that excessive rainfall may lead to leaching or waterlogging, conditions that are detrimental to PPNs.

All the PPN species taken for the study attained highest population density between 25°C-27.5°C, which was similar to the findings of Bird & Mai (1967); Wallace (1969); Dao (1970); Das and Rahman (1996) and Deuri and Das (2013). Moisture plays an important role in the population density of all the species, which confirms with the findings of Khan *et al.*, (1971) and Deuri and Das (2013) as they observed the population of *Helicotylenchus* sp. and *Hoplolaimus* sp. closely related to soil moisture. Malik & Jairajpuri (1983) observed that soil moisture appeared to be more important factor than soil temperature in determining the population size. Although, it was seen that there was no significant effect of average rainfall on the population dynamics of PPN species in the present study but with the increase or decrease of average rainfall, there were fluctuations of total PPN population. Whitehead (1969) found that relative frequency of *Meloidogyne* sp. in East Africa correlated with temperature, rainfall and altitude but not with soil texture. Avhad *et al.*, (2014) observed highest population of PPNs at high soil moisture content. However, they stated that soil moisture as well as soil temperature was equally important in determining PPN population. Wulandari *et al.*, (2021) also reported that soil temperature had positive effect on abundance of PPN species. All these findings support the findings of the present investigation.

Understanding the environmental determinants of PPN populations is crucial for developing effective management strategies. The strong correlations observed for soil temperature and moisture suggest that interventions targeting these parameters could significantly reduce PPN populations.

The findings of this study have significant implications for the management of PPNs in agricultural systems. The strong correlations between PPN populations and soil temperature and moisture highlight the importance of monitoring these environmental factors to predict PPN outbreaks.

Conclusions

Across all PPN species, soil temperature and moisture emerge as the most influential factors affecting population density, with rainfall playing a secondary but still notable role. The increase in temperature and soil moisture content percent was associated with the increase in PPN population within the range of favourable condition which is in between 15.5°-28.0° (ideally around 25°); with a soil moisture level of 15.0-22.0 percent and monthly rainfall of 0.6-302.2 mm. These findings emphasize the need to consider environmental variables in PPN management strategies, particularly in the context of climate change, which may alter soil temperature, moisture availability, and rainfall patterns, thereby affecting PPN population dynamics and agricultural productivity. This study underscores the complexity of PPN ecology in shaping the population dynamics of *H. dihystera*, *M. incognita*, *M. onostris*, *R. reniformis*, and *H. indicus*.

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