Prediction of Nematode Population Dynamics using Weather Variables in Leguminous Crops

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ABSTRACT
Background: The soil nematodes can affect the crops in various ways. The plant-parasitic nematodes can lead to severe yield losses. The extent of crop yield loss depends on the susceptibility of the variety or host tolerance, population density of the nematode and various environmental variables. However, no tool is available for the prediction of nematode population buildup in soil therefore it has been difficult to issue advisories for timely management of these pathogens. Here we developed a method to accurately predict the nematode population buildup in soil for its timely management.

Methods: Nematode population index of a plant-parasitic nematode Tylenchorhynchus was taken from two crops i.e. mung bean and crotalaria. The model was developed considering various weather variables to predict the population of the Tylenchorhynchus in the fields of mung bean and crotalaria. Weather parameters such as maximum and minimum temperature, relative humidity, wind speed and sunshine hours were considered for developing the model for Tylenchorhynchus population prediction. Stepwise regression method was applied to predict the nematode population.

Result: The regression analysis between estimated and observed values of Tylenchorhynchus population gave the R² value as 0.98 for mung bean and 0.87 for crotalaria. Well timed prediction can help the growers to apply the required management practices to make it beneficial economically. This method can be extended to predict the population buildup of other serious nematode pests of crops.

Key words: Crotalaria, Leguminous crops, Mung bean, Nematode, Prediction model.

INTRODUCTION
The soil is the microhabitat for diverse organisms of various physiological activity and ecosystem function. The conducive agricultural soils are the soil type where various oil organisms infect plants and cause diseases (Topalović et al, 2020). Although nematodes have an important role in the biological community in agricultural soils, the plant-parasitic nematodes cause damage to root systems and reduce the yield of most crops (Evans et al., 1993; Luc et al., 2005). On one hand some nematodes feed on soil organisms such as bacteria and fungi, thereby regulate the populations of these micro-organisms resulting in increase in the availability of nutrients required by plants (Ingham et al., 1985; Yeates and Wardle, 1996; Ferris et al., 1998; Chen and Ferris, 1999; Stirling, 2014), on the other hand, plant-parasitic nematodes are considered an intractable problem in agriculture as they damage many economically important crops by using up the resources required by plants for their growth (Rius et al., 2017). Tylenchorhynchus is one such genus of soil dwelling nematodes that are well known plant parasites. Many species of Tylenchorhynchus are found to feed ectoparasitically on roots causing diseases in the plants (Stirling et al., 2017). Since Tylenchorhynchus inhabit the same soil as plants, they can cause stress or disease in the roots of the plants. However, the presence of plant parasitic nematodes in itself is not a point of concern. Nematodes have to be present above a certain population level, also known as Economic Threshold Level, in order to be harmful to crop. Population dynamics plays an important role in the damage caused by the plant-parasitic nematodes.

Most efficient way of nematode management is the timely knowledge of occurrence in terms of population dynamics. If predicted on time the efficacy of the management increases many folds. There are several factors (biological and physical) contributing to the population density of the nematodes. Several physical variables like environmental variables and soil parameters have a direct effect on the population density of the nematodes. A significant relationship is found between the changing climatic variables and population of nematodes in the soil as reported by Colagiero et al., 2011. Silva et al., 2019 also reported a strong effect of climatic and soil parameters in the structure and composition of the nematode population. Thus, in this study, an effort has been made to predict the population of the nematode, Tylenchorhynchus, in the fields of leguminous crops like mung bean and crotalaria, so that the information can be used for the control measure to stop the damage.
MATERIALS AND METHODS

In the current study, an effort has been made to predict of population of the nematode, *Tylenchorhynchus* in the fields of mung bean and crotalaria (leguminous crops), so that the information can used for the control measure to stop the damage.

Data source

The data of *Tylenchorhynchus* (nematode) population index collected from the fields of Indian Agricultural Research Institute (IARI) was used as the output variable for the training and the climatic variables affecting the populations were also collected from IARI for the years 2013 to 2018. The data of population index of *Tylenchorhynchus* was collected in the month of July every year. Weather parameters were collected from the Meteorological department at IARI for the required years. Weather variables such as maximum and minimum temperature (MaxiT and MiniT), Relative humidity for morning and evening (RH1 and RH2), Sunshine hours (SS) were taken into consideration. The weather variables dataset had daily data as the data points which were aggregated to weekly data points to increase the processing speed of the model which would otherwise be slow. Weather indices for the year 2014-2019 were made and weeks 17-23 and weeks 23-30 (crotalaria) were considered for the purpose of prediction model development as the population dynamics of *Tylenchorhynchus* on both the crop fields was recorded in the 28th-30th week.

Regression model using weather indices (WI)

For the current study we used regression model based on weather indices as predictors for the development of our model. The effort includes the prediction of population using a regression-based prediction model in which various climatic parameters were used as the independent input parameters and *Tylenchorhynchus* population was used as the dependent output parameter. The climatic parameters used as the independent variables were MaxiT, MiniT, RH1, RH2 and SS while PopI was used as the dependent output variable. To identify the correlation coefficient between the dependent and independent variables two different indices were used (Unweighted and weighted). Unweighted index stipulates the sum of simple values of the independent variables during the considered period and Weighted index stipulates the independent variables to consider its weekly importance in relation to dependent variable. The form of the model was

\[
Y = a_0 + \sum_{i=1}^{p} \sum_{j=0}^{1} a_{ij} Z_{ij} + \sum_{i=1}^{p} \sum_{j=0}^{1} b_{ij} Z_{ij} + \epsilon
\]

where,

\[
Z_{ij} = \sum_{w=1}^{n} r_{ijw} X_{iw}
\]

Y → Variable to forecast

\[X_{iw} \] → Value of ith weather variable in wth week

\[r_{ijw} \] → Correlation coefficient between ith weather variable in wth week and Y

\[r_{ijw} \] → Correlation coefficient between product of Xi and X' in wth week and Y

p → Number of weather variables

n → Initial week of weather data was included in the model

n → Final week of weather data was included in the model

e → Error

Obtained weather indices having maximum temperature (MaxiT), minimum temperature (MiniT), relative humidity in the morning (RH1), relative humidity in the evening (RH2), Sunshine hours (SS) as weather variables for the year 2014-2019 were used as the input/independent variables for the model and *Tylenchorhynchus* population index for the crop mung bean and crotalaria was taken as the output/dependent variable for the model. To identify and select the main variables for the inclusion in the model, we used a stepwise regression technique.

Model evaluation

Mean Absolute Percentage Error (MAPE) was used to as the error function in the model of the study. The difference between the estimated output and the original output was calculated to find the actual error.

MAPE calculation:

\[
MAPE = \frac{1}{n} \sum \left| \frac{Y_t - \hat{Y}_t}{Y_t} \right| \times 100
\]

n → Number of data points

\[Y_t \] → Original output

\[\hat{Y}_t \] → Predicted/estimated output

RESULTS AND DISCUSSION

The model was developed using the population index of *Tylenchorhynchus* in IARI mung bean and crotalaria crop fields. Various weather parameters like maximum temperature (MaxiT), minimum temperature (MiniT), relative humidity in the morning (RH1), relative humidity in the evening (RH2), Sunshine hours (SS) for the year 2014-2019 were used as the input/independent variables for the model and *Tylenchorhynchus* population index for the crop mung bean and crotalaria was taken as the output/dependent variable for the model. The model was developed as shown in Table 1 with observed and predicted values for the year 2013-2019, which also showed the significant weighted interaction between Maximum temperature and Sunshine Hours. For mung bean, data from the 17th to 23rd standard meteorological weeks (SMWs) was used, whereas for
Crotalaria, data from 23rd to 30 SMWs was take as these weeks coincide with respective crop growing seasons. For mung bean, the model 'Y = 447.14008 +3.91139 * Z_{151}' was developed which gave a highly significant correlation coefficient of 0.98. Using this model, the predicted values are presented in table 1 and Fig 1. For crotalaria, the model generated was 'Y = 569.77867 +1.3077 * Z_{151}', resulting in a correlation coefficient of 0.87 (Table 1, Fig 2). Both the fig 1 and 2 show significant similarity between the pattern of actual and predicted population data, demonstrating the utility of the models. For both the crops, significant interaction between Maximum temperature with Bright sunshine hour were observed.

The results were evaluated using the Mean Absolute Percentage Error (MAPE) method by calculating the errors in the predicted and original values with the error percentage as 5.52 in mung bean and 15.6 for crotalaria. Fig 1 and Fig 2 shows the graphs presenting the pattern of observed values and predicted values of population index of Tylenchorhynchus in mung bean and crotalaria fields respectively. As seen in the Figs, results were significant in predicting the population index of Tylenchorhynchus and may be useful for its timely management.

Although several researchers have explored models to predict nematode population dynamics and damage (Ehwaeti et al., 2000; Viscardi and Brzeski, 1992; Ferris, 1976); literature on models correlating nematode population to various weather parameters is scant. Predictions by our model were precise, but further improvement can be done by adding more data (for e.g. soil moisture), as well as nematode reproductive strategies. We can use the new prediction technologies such as artificial neural networks, provided the population data for more than 20 years is available.

### Table 1: Models developed using data from 2013 to 2019 (MaxiT, MiniT, RHI, RHII and SS).

| Crop                  | Models                                      | Year      | Population Index (PopI) | R²  |
|-----------------------|---------------------------------------------|-----------|-------------------------|-----|
| **Mung Bean (17-23 SMW)** | Y = 447.14008 +3.91139 * Z_{151}             | 2013-14   | 890                     | 0.98|
|                       |                                             | 2014-15   | 902                     | 871.19|
|                       |                                             | 2015-16   | 770                     | 715.80|
|                       |                                             | 2016-17   | 900                     | 902.93|
|                       |                                             | 2017-18   | 275                     | 309.12|
|                       |                                             | 2018-19   | 325                     | 314.06|
|                       |                                             | 2013-14   | 610                     | 596.92|
|                       |                                             | 2014-15   | 650                     | 617.27|
| **Crotalaria (23-30 SMW)** | Y = 569.77867 +1.3077 * Z_{151}             | 2015-16   | 320                     | 432.86|
|                       |                                             | 2016-17   | 410                     | 349.06|
|                       |                                             | 2017-18   | 250                     | 205.24|
|                       |                                             | 2018-19   | 210                     | 248.62|

![Fig 1: Observed and predicted values of population index of Tylenchorhynchus in Mung bean field.](image1.png)
Indian Journal of Agricultural Research

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**CONCLUSION**

The study indicates that there is a clear relationship between the weather variables and population index. The developed model showed significant weighted interaction between Maximum Temperature and sunshine hours. If the prediction is done timely it can help the farmers/end users to take the necessary action if the population index is high enough to be a threat to the crop yield. The prediction of population index will be in time as the weather indices taken were 23-30 SMW for the mung bean and 17-23 SMW taken for crotalaria based on their sowing dates in Northern India. As per the indices the prediction can be made well in advance to provide an early warning system to provide the growers time to apply the necessary management practices. This method can also be extended to other plant parasitic nematodes for wider benefits.

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