MATHEMATICAL MODELING OF COTTON LEAF CURL VIRUS WITH RESPECT TO ENVIRONMENTAL FACTORS

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Received: April 12, 2015; Accepted: April 28, 2015

This study mathematically correlates incidence of cotton leaf curl virus (CLCuV), environmental factors (i.e., rainfall, humidity and temperature), and silverleaf whitefly population in agricultural system of Pakistan. It has been concluded that the disease is directly linked with rainfall and humidity. The third most influential factor in defining CLCuV incidence is the vector population, which is also strictly dependent upon monthly mean temperature of Pakistan. Developed mathematical interrelation is capable of predicting disease incidence of future months. Therefore, it will help agriculturists to control disease in agricultural areas of Pakistan. It is strongly advised on the basis of current research that vector population controlling practices should be immediately applied after detecting small elevations in mean monthly temperature.

Keywords: disease incidence, Pearson's coefficient, meteorological model, correlation, sine wave, cosine wave

Introduction

Cotton leaf curl virus (CLCuV) belongs to genus begomovirus; one of the most important genera of family geminiviridae. All the members of this genus are economically important as they are pathogens of various plant species, such as radish, tomato, etc. [1, 2]. They are a serious problem of dicots in tropical and subtropical regions where they are obligatorily transmitted by silverleaf whitefly (*Bemisia tabaci*). Infected plants show characteristic symptoms of leaf curling, stunted growth, poor yield, and leaf yellowing [3].

CLCuV is ranked among devastating pathogens globally, as well as in Pakistan [4]. In Pakistan, it is responsible for high cotton yield losses each year resulting in serious damage to the country's economy [5]. The pathogen is completely dependent upon silverleaf whitefly for its successful transmission. Therefore, the controlling strategies have been totally diverted towards the control of its insect vector [6], but still, it has never been efficiently controlled due to its very fast reproduction and developmental rate. Moreover, the disease initiation is too quick to be con-

trolled by some crop protection measure. Therefore, there is only one method left applicable: application of preventive insecticide sprays. However, it will only be successful if exact prediction of the disease is made [7].

It is a commonly known phenomenon that shows seasonal contrasts in abiotic factors, e.g., temperature, rainfall, and humidity. In particular, rainfall provides adequate moisture for growth of plant hosts [8]. They also affect the success or failure of oviposition and egg development of the vector. Thus, it can be concluded that abiotic environmental factors (EFs) modulate the viral disease incidence. Therefore, by relying upon previous CLCuV infection rate with respect to agricultural climatic data, a mathematical model has been constructed in this study. Along with the disease prediction, the model also correlates the different EFs with disease rate throughout the year. Moreover, the dynamics of disease development have been compared with vector population in Pakistan's agricultural system. Having expected disease rate in Pakistan, the mathematical approach described here will help agriculture experts to develop some strategy for controlling the disease.

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Methodology

Data collection about EFs

Cyclic dynamics of agricultural environment and annual rotations of environmental factors were determined from previous literature and the meteorological department of Pakistan. Literature also provided the information about CLCuV infection status in Pakistan for past 83 years (1930–2012) [9]. Month-wise mean temperatures (maximum, minimum, and average temperature in Celsius scale) along with the mean humidity (%age) and rate of rainfall (cm) were calculated by consulting the previous studies, e.g., Cheema et al. [10] and Farooqi et al. [11]. These environmental factors were considered for the cotton zone of Pakistan. All these pieces of information were expressed in graphical form, revealing the comparative variations of disease and environment in Pakistan. Moreover, trends of all these parameters (represented in graph) were developed at standard deviation value of $\leq 0.5\%$. Then, those trend lines were used to determine numerical changes in all the parameters in different months of the year.

Data analysis

The trend lines of environmental factors were mathematically processed for developing interrelations among them. Mathematical equations for all environmental factors were developed to numerically describe their variations throughout the year. Those equations lead to predict Pakistani environment after incorporating the month code. Hence, codes of months start from “0” for January and “11” for December. Similarly, January of next year will serially be coded with “12.” In a parallel mathematical operation, dynamics in whitefly population were also numerically determined (number of individuals/leaf). These interrelations gave an indirect disease incidence value.

Correlations among EFs

Data were also subjected to Pearson's correlation coefficient (PCC) test to determine the strength of interrelations among EFs. Moreover, all the EFs along with whitefly population were also correlated with disease incidence. It constructed a final equation in which all the EFs and vector population have their significant share to determine disease incidence in a particular month of the year.

Results

Previous studies have generated a graph of environmental factors (rainfall, humidity, and temperature), showing their individual trends throughout the year in Pakistan (Fig. 1). All these EFs have schematic fluctuations and occur in annual repetitive cycles. Similarly, disease incidence (CLCuV) and vector population (whitefly) also vary during the different months of a year. These parameters have also rhythmic annual fluctuations and can be interlinked with EFs through mathematical equations.

Disease incidence wave of CLCuV showed a dramatic boost in the month of May and attained its peak in the month of August, whereas vector population did not show any extraordinary elevation in that particular period. Moreover, neither disease incidence nor vector population approached to zero during the whole year. In contrast to the other factors, humidity is the only factor which showed high values at the start and end of the year (January and December), with one additional peak in the month of August (Fig. 1).

Trend of rainfall

Rainfall showed a sine wave on the plotted graph. Its trend can mathematically be described in the following equation, which indicates the behavior of rainfall throughout the year.

Fig. 1. Environmental conditions of Pakistan in comparison with CLCuV disease incidence and whitefly population throughout the year. Graph is based upon the data of past 83 years collected from literature and official reports of environmental institutes. It contains two different scales, both on the left and right side of plot area. Each parameter has been mentioned along its suitable scale. Mean monthly (M. M.) values of environmental parameters across Pakistan have been plotted throughout the year

This equation of rainfall can give a numeric value of rain in any month of the year. The equation also needs a variable of time (months), which should be given in code values (i.e., 0–11 as months pass from January to December).

$$R = 2.2 \sin\left(\frac{T\pi}{3} + \frac{\pi}{6}\right) + 3.4 + [0.8T - 1.8]\delta(T', T),$$

$$\begin{cases} T' = T & \text{where } T \in [4, 7] \\ T' \neq T & \text{otherwise} \end{cases}$$

R = rainfall,

T = time (months of the year; codes range from 0 to 11 for January–December, respectively).

Humidity

Humidity trend throughout the year was plotted in the form of “cosine” wave on the graph. Its relation with disease incidence and other EFs can be described by using the following equation. According to underlying relation, humidity also requires time period (codes of months). Moreover, it also contains angle value in radian (π).

$$H = 10.3 \cos\left(\frac{T\pi}{3} + \frac{\pi}{3}\right) + 53.2,$$

H = humidity,

T = time (month codes),

Value of angle has been mentioned in radian (π).

Temperature

Temperature ran across the x axis by developing a sine wave. Therefore, the equation derived from temperature line was as follows:

$$\text{Temperature} = 20.6 \sin\left(\frac{T\pi}{12}\right) + 10.4,$$

T = time in terms of codes of months (0–11 for January–December, respectively),

The value of angle has been mentioned in radian (π).

Vector population

Whitefly population was found having a mathematical trend throughout the year. Its trend was defined through under-mentioned equation, in which the population has strictly been dependent upon different months of the year.

Vector population = v ,

$$v^2 + T^2 - 0.47v - 11.2T - 0.4 + [v - 8.78T + 22.59]\delta(T, T'') = 0,$$

$$\begin{cases} T = T'' & \text{where } T \in [4, 5] \\ T \neq T'' & \text{otherwise} \end{cases}$$

Only positive values of v will be considered because whitefly population can never be negative.

Disease incidence

Disease incidence was found to be linked with all the EFs studied in this investigation. The overall dependence of disease incidence upon other EFs can be precisely represented by following equation

$$\text{Disease} = C(\text{Temperature})^{3/2}Rv,$$

C = proportionality constant; the value of C is 1/900,

R = rainfall,

v = vector population.

Correlations of disease incidence with EFs and vector population

According to PCC, the strongest correlation of disease incidence was recorded with rainfall. It was also the strong-

Fig. 2. Correlation of environmental factors with whitefly population and disease incidence. It consists of PCC values and depicts the interaction of each factor with all other factors

est direct relation among all the factors. The second most influential factor to disease incidence was humidity, which directly triggers the disease rate with 0.89 PCC value. The interrelation of rainfall and humidity was ranked to be the fourth strongest interrelation among all factors, while temperature was found to maneuver vector population with the third highest PCC value of 0.88. The overall index of factors influencing the disease incidence was: rainfall > humidity > vector population > temperature. Temperature has the least positive interaction with rainfall and humidity. It can be assumed that humidity and temperature have the minimum correlation with temperature. However, temperature strongly modulates the vector population in environment with 0.88 PCC value. Humidity also has moderate direct interaction with vector population with PCC value of 0.63.

Discussion

Environmental factors have a unique and long term trend in a specific geographical area. Trends of these factors can be expressed in the form of mathematical or graphical models [12, 13]. Environmental factors prevailing in Pakistan have been mathematically described in this study. These mathematical descriptions depict a generalized trend of the environment of Pakistan. It may be helpful to study all types of pathogens and other agriculture related factors of this area. Agricultural policies may also be constructed by keeping in mind the environmental trends described in the present investigation.

It has been clearly understood that, during the period of the highest elevation in CLCuV incidence (May to August), there was no similar boost in vector population. This phenomenon reveals that the increasing rate of disease incidence is not completely dependent upon vector population [3, 14]. There must be some other factors which make the conditions conducive for the pathogen. These factors may be the 1) reduction in plant resistance against CLCuV due to EFs, 2) development of viral symptoms for previous latent infections, or 3) availability of some vector other than whitefly.

The inoculum for viral pathogen is constantly available during the whole year, and this is the major reason due to which disease has not been controlled even after serious management techniques [15]. On the basis of this study, it is highly recommended that disease inoculum should be wiped-out after the cultivation of cotton crop [16]. It can also be concluded that humidity is the key factor which supports CLCuV and prevents the elimination of its inoculum in the time of minimum disease incidence because it is the only factor showing higher values at both ends of a year [17].

Plant diseases are associated with environmental factors, which not only act as predisposing factors for diseases but also control the outburst of disease [18, 19]. The distribution and incidence of these diseases can be synchronized with EFs by some numerical methods. The

present study has defined the environmental factors of Pakistan in graphical and mathematical form. It has also correlated the disease incidence with EFs in different months of the year.

CLCuV is an alarming threat to global cotton production, and according to current investigation, this disease is strongly correlated with rainfall. The second important factor controlling this disease is humidity. Vector population has been proved as third important influencing factor in disease establishment. On the basis of these disclosed facts, researchers and agriculture experts may plan and advise some disease management strategies. For example, this research highly recommends the application of insect management practices during the rainy season in Pakistan. Before the start of the rainy season, no serious efforts are required for disease control [18, 20, 21].

According to this study, the whitefly population is strictly dependent upon the mean temperature of the area. Vector population also has significant effect on disease incidence of CLCuV. It is also important that the vector population is the only factor which can easily be controlled. Therefore, farmers and agriculture experts are advised to keep an attentive eye on temperature fluctuations in their area. Timely application of insect control measures will lead to the reduced spread of disease and ultimately lesser damages.

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