Web enabled and weather based forewarning of yellow stem borer [Scirpophaga incertulas (Walker)] and leaf folder [Cnaphalocrocis medinalis (Guenee)] for different rice growing locations of India


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ABSTRACT. Loss in yield and quality of crop produce due to pest infestation could be reduced considerably if the pest occurrence is known in advance and timely remedial measures are taken. Weather plays an important role in pest development. Therefore, weather based models can be an effective scientific tool for forewarning pests in advance. In this
study, weather based forewarning models have been developed for yellow stem borer \( Scirpophaga \) incertultas(Walker) and leaf folder \( Cnaphalocrocis medinalis \)(Guenee) of rice for different locations, viz., Aduthurai (Tamil Nadu), Chinsurah (West Bengal), Karjat (Maharashtra), Mandya (Karnataka), Ludhiana (Punjab) and Raipur (Chhattisgarh). The pest data comprised of population of yellow stem borer and leaf folder moths caught in light trap per week for different locations. Weather data relating to maximum and minimum temperature \( ^\circ \mathrm{C} \), morning and evening relative humidity \( \% \) and rainfall (mm) in respect of the locations were obtained from the meteorological observatories of the locations per se. Data of pest and weather on weekly basis in respect of \textit{Kharif} and \textit{Rabi} seasons of 11 years (2000-2010) for all locations, and of 16 years (1995-2010) for Mandya (KA) were used for developing the forewarning models. Weather of six lag weeks from week of forecast were used for development of weather indices. These weather indices were used as independent variables in model building against the pest population as dependent variables. Stepwise regression models for predicting the yellow stem borer population for peak periods of occurrence during \textit{Kharif} [Aduthurai (TN), Karjat (MH) & Raipur (CG)] and \textit{Rabi} [Chinsurah (WB) & Mandya (KA)] were developed with \( R^2 \geq 0.9 \). Prediction of leaf folder for different weeks of \textit{Kharif} for Aduthurai (TN) (32-35 SMW) and Ludhiana (PB) (32-36 SMW) and of \textit{Rabi} for Aduthurai (TN) (44-47 SMW) gave \( R^2 \) between 0.6 and 0.8, respectively indicating better leaf folder prediction for \textit{Rabi} over \textit{Kharif} season at Aduthurai (TN). Validation of the models for subsequent years (2011) has been done for all cases. These developed models were converted into web-based forewarning system using 3-tier architecture. Net Beans 8.0.1 IDE (Integrated Development Environment), MS SQL Server, Java Server Pages (JSP) technologies have been used for the development of the web enabled forecasting of the two rice pests.

\textbf{Key words} – Yellow stem borer, Leaf folder, Weather, Forewarning, Rice, \textit{Kharif}, \textit{Rabi}.

\section{1. Introduction}

Rice, the most important cereal crop of India occupies 24 per cent of the country’s gross cropped area and is one of the staple food in India. Based on per capita daily requirement of rice (230 gms/day) and estimated population growth, it was projected that by 2025, India would require around 113.6 million tones of rice (CRRI, 2006). There is an urgent need to step up production as insect pests infesting rice in tropical and sub-tropical Asia, the yellow stem borer (\textit{Scirpophaga incertultas} (Walker); Lepidoptera) is a monophagous insect of significant importance. Insect larvae bore into the stem and feed on internal tissues, stem and panicles. Excessive feeding causes “dead heart” symptom at vegetative stage which drastically reduces the grain formation. Leaf folder \( Cnaphalocrocis medinalis \)(Guenee)] is another lepidopteran pest wherein caterpillars fold the rice leaf and feed from folded leaf which reduces the effective photosynthetic area of the plant. Economic threshold value of 2 egg mass / sq. m or 10% dead hearts for \textit{Scirpophaga incertultas} and 2 damaged leaves (with larva)/hill for \textit{Cnaphalocrocis medinalis} are used for initiating insecticidal control measures [Prakash et al. (2014)]. Forecasting of the development of population occurrence with as much accuracy as possible, and describing the population dynamics correctly enable better management of this pest thus minimizing the yield loss caused by them. Efficient, economical and environmentally friendly management of the stem borer and leaf folder can be done through knowledge of its timing of attack in relation crop phenology and the prevalent weather factors modelled to enable prediction of its occurrence that allows growers to take timely action in an efficient manner for crop management.

Weather is an important determinant in the population dynamics of the pests. Most of the earlier workers have utilized regression models (both linear and nonlinear) for insect pest disease forewarning [Desai et al. (2004); Chattopadhyay et al. (2005a, 2005b); Dhar et al. (2007); Agrawal and Mehta (2007); Laxmi and Kumar (2011a, 2011b); Kumar et al. (2012) and Kumar et al. (2013)]. However, they provide no insight into quantitative prediction of the yellow stem borer and leaf folder on the rice crop for different seasons. Hence, the present study was undertaken to develop weather based forecast models for yellow stem borer and leaf folder for different locations across India during \textit{kharif} and \textit{rabi} seasons well in advance of their actual arrival on the crop. These developed models were converted into web-based forewarning system using 3-tier architecture. Net Beans 8.0.1 IDE (Integrated Development Environment), MS SQL Server, Java Server Pages (JSP) technologies based on weather information have been used for the development of the web enabled forecasting of the two rice pests with the need based pest management advisory.

\section{2. Materials and methods}

\subsection{2.1. Data accrual and organisation}

Light trap was installed at various locations \textit{viz.}, Mandya (12° 52’ N, 76° 9’ E) (Karnataka), Raipur (20° 91’ N, 82° E) (Chhattisgarh), Ludhiana (30° 54’ N, 75° 48’ E) (Punjab), Chinsurah (22° 91’ N, 82° E) (West Bengal), Karjat (18° 91’ N 73° 3’ E) (Maharashtra) and Aduthurai (11° N, 79° 3’ E) (Tamil Nadu) in India. The light source was an incandescent bulb of 200 watt
capacity. The trap was operated overnight between 6.00 pm to 6.00 am hours daily. The trapped yellow stem borer (YSB) and leaf folder (LF) adult moths, both male and female were counted daily. Standard meteorological weekwise (SMW) data sets on yellow stem borer and leaf folder count were worked out for kharif and rabi seasons. The pest data comprised of population of yellow stem borer in different centers (Aduthurai (TN): 2000 to 2010; Chinsurah (WB): 2000 to 2010; Karjat (MH) 2000 to 2010; Mandya (KA): 1995 to 2010; Ludhiana (PB): 2000 to 2010 and Raipur (CG): 2000 to 2010). The data pertaining to the weather variables - maximum temperature, minimum temperature, morning relative humidity, evening relative humidity and rainfall (X1 to X5) were considered as independent variables. For leaf folder a rice pest, pests data were obtained for the period from 2000 to 2010 at Ludhiana and Aduthurai centers only. For Ludhiana weekly forewarning models were developed for kharif (32 to 36 SMW) seasons while for Aduthurai weekly models were developed for kharif (32 to 35 SMW) as well as rabi (44 to 47 SMW) season for leaf folder. Weather data on maximum temperature, minimum temperature, morning relative humidity, evening relative humidity and Rainfall [X1 to X5] were considered as independent variables.

2.2. Development of forewarning models

In this approach, for each weather variable two indices were developed, one as simple total value of weather variables and the other one as weighted total, weights being correlation coefficients between variable to forecast and weather variables in respective weeks. The first index represents the total amount of different weather variables prevalent during the period under consideration while the other one takes care of distribution of weather variables with special reference to its importance in different weeks in relation to the variables of forecast. Similarly, for joint effects of weather variables, weather indices were developed as weighted accumulations of product of weather variables (taken 2 weather variables at a time), weights being correlation coefficients between variable of forecast and product of weather variables considered in respective weeks. The form of the model was (Agrawal et al., 2007; Desai et al., 2004).

\[ Y_{t} = a_{0} + \sum_{i=1}^{p} \sum_{j=0}^{q} a_{ij} Z_{ij} + \sum_{i=1}^{p} \sum_{j=0}^{q} b_{ij} + e \]

\[ Z_{ij} = \sum_{w=t-6}^{t-d} r_{iw} X_{iw} \]

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\[ r_{iw} \] - correlation coefficient between \( Y \) and \( X_i \) in \( w \)th week

\[ r_{iw} \] - correlation coefficient between \( Y \) and \( X_i \) in \( w \)th week

\[ r_{ij} \] - correlation coefficient between \( Y \) and product of \( X_i \) and \( X_j \) in \( w \)th week

\[ Y_{t} \] - variable of forecast

\[ X_{iw} \] - value of \( i \)th weather parameter in \( w \)th week

\[ r_{iw} \] - correlation coefficient between \( Y \) and \( i \)th weather parameter in \( w \)th week

Stepwise regression technique was used for selecting important variables to be included in the model. The forecasting performance of various models was judged by Mean Absolute Percentage Error (MAPE).

\[ \text{MAPE} = \frac{1}{n} \sum_{i=1}^{n} \left| \frac{Y_{t} - F_{t}}{Y_{t}} \right| \times 100 \]

where, \( Y_{t} \) is actual observation, \( F_{t} \) is the forecast from model and \( n \) is the total number of test data point.

2.3. Web enabling of the forecast system

A web based forewarning system for YSB and LF of rice was developed for the developed forecast models. The system consisted of several functional requirements such as incorporation of the statistical models, weather data entry (permitted only for administrator and authorized users) and graphic-user interface for multi users of different levels. The system was developed based on 3-tier architecture consisting of Client Side Interface Layer (CSIL), Application Logic Layer (ALL) and Database Layer (DBL). CSIL was implemented by HTML (Hyper...
Text Markup Language), CSS (Cascading Style Sheet) and JavaScript (for validation purpose). ALL has been implemented by the JSP (Java Server Pages) technology which provides a framework to create dynamic content on the server. Location and time specific pest forecast models have been coded in this language was saved on the server. DBL was used for storing the site and time specific weather related data (Fig. 1). In this system, only administrators have the provision of feeding the weather information into the database. A sample template is also provided for the administrator and authorized users to upload new weather data directly to the database are given in Fig. 2.

The system functions on a server running Windows operating system. MSSQL and Apache were used for database management server and web server, respectively. Weather data acquisition and process is site and time specific. After selecting the projected place and session corresponding to the crop-pest the system integrates weather data with specific forecast model to forecast the pests of rice for the particular site and session. System can be browsed over internet from any client machine having Internet Explorer, Netscape or any other web browsers.

3. Results and discussion

A weather-based model can be an effective scientific tool to thwart the impending attack of pest by forewarning so that timely plant protection measures can be taken up. The extent of weather influence on pest development depends not only on the total magnitude but also on the distribution of weather variables over small time intervals. However, the use of data in small time intervals increases the number of variables in the model and in turn a large number of model parameters needs to be evaluated. This requires a long series of data for precise estimation of the parameters which may not be available in practice. Thus, a technique based on relatively smaller number of model parameters and at the same time taking care of entire weather distribution was used by taking weighted accumulation of weather variables and giving weights according to their importance in different time period.
Observed vs Prediction population of Yellow stem borer (YSB)

Fig. 3. Comparison of predicted and observed YSB for various locations in different year

| Table 1: Models for forewarning of yellow stem borer
<table>
<thead>
<tr>
<th>Locations and State</th>
<th>Week of forecast (data used)</th>
<th>Model equation</th>
<th>$R^2$</th>
<th>Observed</th>
<th>Forecast</th>
<th>MAPE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aduthurai (TN)</td>
<td>49 (43-48)</td>
<td>$Y = \cdot -12147 + 509.35 Z_{41} + 2319.29 Z_{21}$</td>
<td>0.92</td>
<td>1389</td>
<td>1528</td>
<td>10.00</td>
</tr>
<tr>
<td>Chinsurah (WB)</td>
<td>16 (10-15)</td>
<td>$Y = -37.12 + 0.367 Z_{450} + 0.22 Z_{341} + 1.48 Z_{351}$</td>
<td>0.92</td>
<td>277</td>
<td>369</td>
<td>33.21</td>
</tr>
<tr>
<td>Karjat (MH)</td>
<td>37 (31-36)</td>
<td>$Y = 896.36 + 94.93 Z_{210} + 0.34 Z_{41}$</td>
<td>0.84</td>
<td>56</td>
<td>47.3</td>
<td>15.54</td>
</tr>
<tr>
<td>Mandya (KA)</td>
<td>17 (11-16)</td>
<td>$Y = -6842.53 + 143.44 Z_{21} - 0.42 Z_{230}$</td>
<td>0.86</td>
<td>150</td>
<td>286</td>
<td>90.67</td>
</tr>
<tr>
<td>Raipur (CG)</td>
<td>35 (29-34)</td>
<td>$Y = 37945 + 1163.69 Z_{21} + 2.96 Z_{131} + 0.71 Z_{210}$</td>
<td>0.93</td>
<td>609</td>
<td>630</td>
<td>3.45</td>
</tr>
</tbody>
</table>

Obs = Observed, Fore = Forecast

3.1. Models for yellow stem borer

The forewarning models developed for YSB for different weeks along with the coefficient of determination are given in Table 1. The adequacy of models as inferred through $R^2$ values indicated the effectiveness of the weighted indices of weather variables explaining the YSB population in the range of 86 to 94% across locations. The comparison of predicted and observed populations of YSB for various locations in different years are presented in Fig. 3, this showed that predicted values are closed to the observed in most of the cases.

3.2. Models for leaf folder

Forewarning models were developed for leaf folder for two locations only, viz., Aduthurai and Ludhiana considering the importance of the pest. Models developed for different weeks of kharif (32 to 36 SMW) for
TABLE 2
Models forewarning of leaf folder during kharif at Ludhiana (PB) along with the comparison of observed and forecast values

<table>
<thead>
<tr>
<th>Week of forecast</th>
<th>Model</th>
<th>$R^2$</th>
<th>2010 Observed forecast</th>
<th>2010 Observed forecast</th>
<th>2011 Observed forecast</th>
<th>2011 Observed forecast</th>
<th>MAPE</th>
</tr>
</thead>
<tbody>
<tr>
<td>32</td>
<td>$Y = -14104.0 + 283.612 Z_{21}$</td>
<td>0.58</td>
<td>1348</td>
<td>846</td>
<td>465</td>
<td>458</td>
<td>19.37</td>
</tr>
<tr>
<td>33</td>
<td>$Y = 10017.0 + 1.32678 Z_{131}$</td>
<td>0.61</td>
<td>-</td>
<td>881</td>
<td>-</td>
<td>368</td>
<td>27.75</td>
</tr>
<tr>
<td>34</td>
<td>$Y = -2999.01 + 1.571 Z_{131} + 651.219 Z_{21} - 4.611 Z_{121}$</td>
<td>0.67</td>
<td>-</td>
<td>882</td>
<td>-</td>
<td>597</td>
<td>31.48</td>
</tr>
<tr>
<td>35</td>
<td>$Y = -3993.32 + 1.202 Z_{131} + 575.427 Z_{21}$</td>
<td>0.67</td>
<td>-</td>
<td>891</td>
<td>-</td>
<td>544</td>
<td>25.45</td>
</tr>
<tr>
<td>36</td>
<td>$Y = -2475.10 + 1.920 Z_{131} + 692.289 Z_{21}$</td>
<td>0.68</td>
<td>-</td>
<td>880</td>
<td>-</td>
<td>614</td>
<td>33.38</td>
</tr>
</tbody>
</table>

TABLE 3
Models forewarning of leaf folder during kharif at Aduthurai (TN) along with the comparison of observed and forecast values

<table>
<thead>
<tr>
<th>Week of forecast</th>
<th>Model</th>
<th>$R^2$</th>
<th>2010 Observed forecast</th>
<th>2010 Observed forecast</th>
<th>2011 Observed forecast</th>
<th>2011 Observed forecast</th>
<th>MAPE</th>
</tr>
</thead>
<tbody>
<tr>
<td>32</td>
<td>$Y = 284.95613 + 5.43956 Z_{11} + 0.00209 Z_{151}$</td>
<td>0.64</td>
<td>23</td>
<td>16</td>
<td>41</td>
<td>35</td>
<td>22.53</td>
</tr>
<tr>
<td>33</td>
<td>$Y = 415.81011 + 6.89016 Z_{11} - 0.04315 Z_{50}$</td>
<td>0.63</td>
<td>-</td>
<td>17</td>
<td>-</td>
<td>20</td>
<td>38.65</td>
</tr>
<tr>
<td>34</td>
<td>$Y = 343.87866 + 5.65894 Z_{11}$</td>
<td>0.64</td>
<td>-</td>
<td>16</td>
<td>-</td>
<td>20</td>
<td>40.83</td>
</tr>
<tr>
<td>35</td>
<td>$Y = 89.91513 + 2.25598 Z_{11} + 0.00527 Z_{151}$</td>
<td>0.67</td>
<td>-</td>
<td>15</td>
<td>-</td>
<td>21</td>
<td>41.78</td>
</tr>
</tbody>
</table>

TABLE 4
Models forewarning of leaf folder during rabi at Aduthurai (TN) along with the comparison of observed and forecast values

<table>
<thead>
<tr>
<th>Week of forecast (data used)</th>
<th>Model</th>
<th>$R^2$</th>
<th>2010 Observed forecast</th>
<th>2010 Observed forecast</th>
<th>2011 Observed forecast</th>
<th>2011 Observed forecast</th>
<th>MAPE</th>
</tr>
</thead>
<tbody>
<tr>
<td>44 (38-43)</td>
<td>$Y = 274.25 + 1.614 Z_{41} + 0.142 Z_{121}$</td>
<td>0.85</td>
<td>47</td>
<td>13</td>
<td>36</td>
<td>18</td>
<td>61.17</td>
</tr>
<tr>
<td>45 (39-44)</td>
<td>$Y = 68.269 + 0.064 Z_{121} + 2.393 Z_{41}$</td>
<td>0.94</td>
<td>-</td>
<td>30</td>
<td>-</td>
<td>30</td>
<td>26.42</td>
</tr>
<tr>
<td>46 (40-45)</td>
<td>$Y = 43.360 + 0.054 Z_{121} + 2.392 Z_{41}$</td>
<td>0.88</td>
<td>-</td>
<td>27</td>
<td>-</td>
<td>30</td>
<td>29.61</td>
</tr>
<tr>
<td>47 (41-46)</td>
<td>$Y = -18.083 + 0.098 Z_{121} + 2.266 Z_{41}$</td>
<td>0.88</td>
<td>-</td>
<td>31</td>
<td>-</td>
<td>41</td>
<td>23.97</td>
</tr>
</tbody>
</table>

Ludhiana (PB) (Table 2) and for both kharif (32 to 35 SMW) (Table 3) and rabi (44 to 47 SMW) of Aduthurai (TN) (Table 4) indicated almost similar predictive abilities of the models at both the locations during kharif ($R^2$ values around 0.6) and a much better prediction during rabi at Aduthurai (TN) ($R^2$ values around 0.9).

During kharif, maximum and minimum temperatures and rainfall without pest index was found significant. On the other hand, the interactions of maximum and minimum temperature, and of minimum temperature and rainfall along with pests index were important in most of the cases for rabi season. The greater variations in the monsoon over years at the study locations with no definite trend of influence on the pest populations (YSB and LF) could be the reason for the absence of pest index in the models of kharif season. On the other hand, the more consistent weather during rabi besides the occurrence of
well-established population of both the pests in the cropping system following kharif season makes the pest population relevant to their own prediction. Forecasts for subsequent years (not included in the model development) were obtained which are shown in Tables (2-4). This table reveals that the forecasts of pests in different seasons are close to the observed ones. These, weather-based forecasting systems may be useful to reduce the cost of production by optimizing the timing and frequency of chemicals usages for control measures of pests (Kaundal et al., 2006).

3.3. Web based forewarning system

Forewarning becomes a success when the models or the information on prediction developed is disseminated at the right time to the specific users in a large scale. The urgent need for distribution of forewarning information and the relevant pest management advisory to the target groups in space and time is possible now a days with the use of Information and Communication Technology (ICT). Availability of an online forecast system bridges the gap between the scientific information and the field application effectively. In the web enabled forecast system developed, the users have to fill the form by choosing the crop pest of their interest corresponding to their location and season by accessing the website through (http://172.16.30.80:8080/WebApplication2/CSSTEMPLATE/dh1269/index.html) wherein the developed site specific statistical model will fetched at back-end utilizing the weather file uploaded by the administrator. The sequence of selections involve the insect pest first followed by the location, season and time period of forecast (Figs. 4-8). The utility of the forecast system requires the users to know beforehand the time period of forecast and timely access for its success.

The use of models at present would be restrictive to convey the size of the population of adults in the rice ecosystem that is expected to contribute to the forthcoming generation of larvae that are damage causing stages. Although it is generally understood that there is direct relation between size of moth population and the severity of crop damage in either of the insect pests, further precision in the forecast system and direct applicability would be based on the incorporation of the relation established between the moth catches and the field infestation. Once the prediction of damage is possible, an additional feature of interpreting the output with a given set of pest specific rules based on their respective economic threshold values and generation of management recommendation for application of insecticides are possible.
5. Conclusion

The sophistication of the reliable empirical models requires an ICT back up for its utility. In the changing scenario of climate, weather based forewarning of pests is a tool to improvise pest management. The forecast models developed in the present study for YSB and LB would lie in text books, or find applicability only when specific attempts to forecast are made limited to an interest group with an ability to work out mathematically the forecast variables after acquiring weather variables of interest. Development of forewarning models as well as their web enabling has rendered instant model applicability for different locations. While this study has demonstrated the feasibility of web enabled forecast system for rice crop protection against two major insect pests. Further improvements in terms of additional pests, damage predictions and issuing of pest management advisories can be linked with this forewarning systems for better adoptions of ICT based technologies.

References


