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

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सार – कीटनाशी फसल की घटनाओं का पहले से ही पता चलने पर और समय पर सुधारात्मक उपाय करने से कीटनाशी घटनाओं के कारण होने वाले फसल की पैदावार और गुणवत्ता की कमी को काफी हद तक कम किया जा सकता है। कीट के विकास में मौसम महत्वपूर्ण भूमिका निभाता है। अत: पहले से ही कीटनाशी घटनाओं की पूर्व चेतावनी के लिए मौसम आधारित मॉडल प्रभावशाली वैज्ञानिक उपकरण हो सकते है। अत: विभिन्न स्थानों अर्थात अदुथुराई (तमलिनाडु), चिनसुराह (पश्चिम बंगाल), करजात (महाराष्ट्र), मंडया (कर्नाटक), लुधियाना (पंजाब) और रायपुर (छत्तीसगढ़) के लिए फसल के येलो स्टेम बोरर (*Scirpophager incertulas* (Walker) और लीफ फोल्डर (*Cnaphalocrocis medinalis* (Guenee) के लिए मौसम आधारित पूर्व चेतावनी के मॉडल विकसित किए गए। येला स्टेम बोरर और लीफ फोल्डर कीटों की जीव-संख्या को लेकर अलग-अलग स्थानों के लिए प्रति सप्ताह कीट आंकड़ें प्राप्त किए जाते है। स्थानिक मौसम वैज्ञानिक वेधशालाओं से उन स्थानों के अधिकतम और न्यूनतम तापमान (°C) प्रात:कालीन और सायंकालीन सापेक्षिक आर्द्रता (%) और वर्षा (मि. मी.) संबंधी मौसम के आंकड़ें प्राप्त किए गए। पूर्व चेतावनी मॉडलों के विकास के लिए सभी स्थानों के 11 वर्षों (2000-2010) के खरीफ और रबी मौसम के लिए साप्ताहिक आधार पर कीट और मौसम के आंकड़ें तथा मंडया कर्नाटक) के लिए 16 वर्षों (1995-2010) के आंकड़ों का उपयोग किया गया। मौसम सूचनाओं के विकास के लिए पूर्वानुमान वाले सप्ताह से लेकर छ: देरी वाले सप्ताहों के मौसम का उपयोग किया गया। इन मौसम सूचनाओं का उपयोग निर्भर परिवर्तिताओं के रूप में कीट जीव संख्या के विरूद्ध मॉडल बनाने के लिए स्वतंत्र परिवर्तिताओं के रूप में किया गया है। खरीफ (अदुथुराई (तमलिनाडु), करजात (महाराष्ट्र) और रायपुर (छत्तीसगढ़) व रबी की फसल चिनसुराह (पश्चिम बंगाल) और मंडया (कर्नाटक) के लिए घटनाओं की चरम सीमाओं में येलो स्टेम बोरर की प्रागुक्ति के लिए क्रमवार समाश्रयण मॉडल $R^2 \geq 0.9$ के साथ विकसित किए गए। अदुथुराई (तमलिनाडु) (32-35 SMW) और लुधियाना (पंजाब) (32-36 SMW) के लिए खरीफ की फसल के विभिन्न सप्ताहों के लिए लीफ फोल्डर की प्रागुक्ति और अदुथुराई (तमलिनाडु) (44-47 SMW) सभी मामलों के लिए परवर्ती वर्षों (2011) के लिए मॉडलों का मान्यकरण किया गया। इन विकसित मॉडलों को 3 पंक्तिबद्ध संरचना का उपयोग करते हुए वेब-आधारित पूर्व चेतावनी प्रणाली में बदला गया। दो चावल की कीटनाशी फसल के वेब आधारित पूर्वानुमान के विकास के लिए नेट बीन्स 8.0.1 IDE (समाकलित विकास पर्यावरण), MS SQL, सर्वर, जावा सर्वर पेजिस (JSP) प्रौद्योगिकियों का उपयोग किया गया।

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 incertulas*(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 (°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 *Kharif* and *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 *Kharif* [Aduthurai (TN), Karjat (MH) & Raipur (CG)] and *Rabi* [Chinsurah (WB) & Mandya (KA)] were developed with $R^2 \geq 0.9$. Prediction of leaf folder for different weeks of *Kharif* for Aduthurai (TN) (32-35 SMW) and Ludhiana (PB) (32-36 SMW) and of *Rabi* for Aduthurai (TN) (44-47 SMW) gave R^2 between 0.6 and 0.8, respectively indicating better leaf folder prediction for *Rabi* over *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.

Key words – Yellow stem borer, Leaf folder, Weather, Forewarning, Rice, *Kharif*, *Rabi*.

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 rice growth rates were static in all the rice growing regions during the last decade. While various constraints exist for improving the rice production, the minimization of loss caused by the key insect pests would pay an immediate dividend to the rice bowl. Amongst the various insect pests infesting rice in tropical and sub-tropical Asia, the yellow stem borer (*Scirpophaga incertulas* (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 *Scirpophaga incertulas* and 2 damaged leaves (with larva)/hill for *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 *kharif* and *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.

2. Materials and methods

2.1. *Data accrual and organisation*

Light trap was installed at various locations *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 (X_1 to X_5) 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).

$$Y_t = a_0 + \sum_{i=1}^{p} \sum_{j=0}^{1} a_{ij} Z_{ij} + \sum_{i \neq i}^{p} \sum_{j=0}^{1} b_{ii'j} + e$$

$$Z_{ij} = \sum_{w=t-6}^{t-1} r_{iw}^{j} X_{iw}$$

$$Z_{ii'j} = \sum_{w=t-6}^{t-1} r_{ii'w}^{j} X_{iw} X_{i'w}$$

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

$r_{ii'w}$ - correlation coefficient between Y and product of X_i and $X_{i'}$ in w^{th} week

r_{yw} - is correlation coefficient between *Yt* and *Yw*

Y_w - is pest population in w^{th} week

p - number of weather parameters

n_1 - initial week for which weather data were included in the model

n_2 - final week for which weather data were included in the model

e - error term

Stepwise regression technique was used for selecting important variables to be included in the model. The forewarning models for yellow stem borer and leaf folder were developed for different SMWs taking data up to 6 lag weeks from week of forecast. In addition to weather indices, the pest count index based on pest population in weeks lagged by different weeks was also used as regressors as the pest population in different lag weeks determine the subsequent population. The forecasting performance of various models was judged by Mean Absolute Percentage Error (MAPE).

$$\text{MAPE} = \frac{1}{n} \sum \left| \frac{(Y_t - F_t)}{Y_t} \right| \times 100$$

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

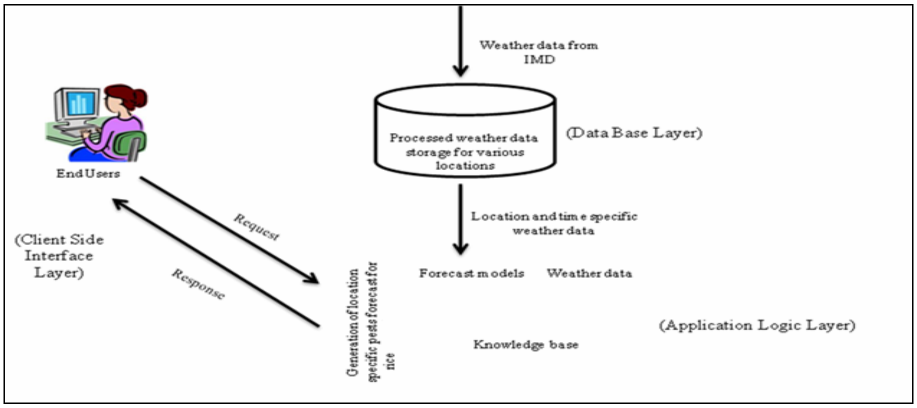

Fig. 1. Overall architecture of the system

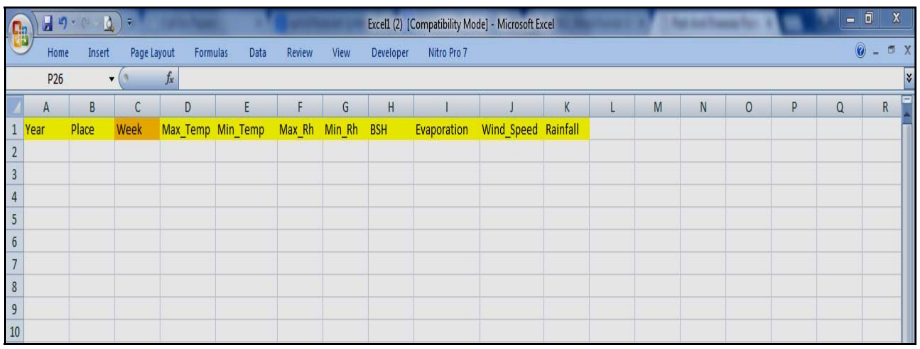

Fig. 2. Sample template for administrator

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.

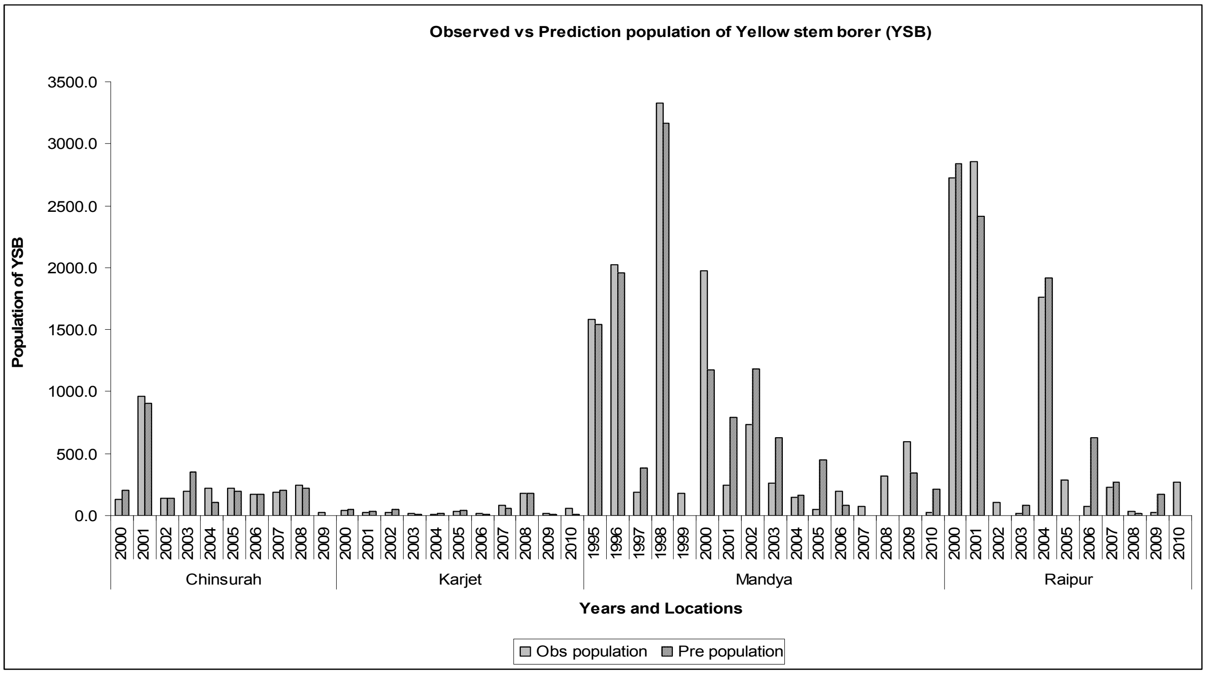

Fig. 3. Comparison of predicted and observed YSB for various locations in different year

TABLE 1

Models for forewarning of yellow stem borer

Locations and State	Week of forecast (data used)	Model equation	R^2	Population per week (2011)		MAPE
				Observed	Forecast	
Aduthurai (TN)	49 (43-48)	$Y = - 12147 + 509.35\ Z_{41} - 2319.29\ Z_{21}$	0.92	1389	1528	10.00
Chinsurah (WB)	16 (10-15)	$Y = - 37.12 + 0.367\ Z_{450} + 0.22\ Z_{341} + 1.48\ Z_{351}$	0.92	277	369	33.21
Karjat (MH)	37 (31-36)	$Y = 896.36 + 94.93\ Z_{210} + 0.34\ Z_{141}$	0.84	56	47.3	15.54
Mandya (KA)	17 (11-16)	$Y = - 6842.53 + 143.44\ Z_{21} - 0.42\ Z_{230}$	0.86	150	286	90.67
Raipur (CG)	35 (29-34)	$Y = 37945 + 1163.69\ Z_{21} + 2.96\ Z_{131} + 0.71\ Z_{230}$	0.93	609	630	3.45

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

Week of forecast	Model	R^2	Moth population/week				MAPE
			2010		2011		
			Observed	forecast	Observed	forecast	
32	$Y = -14104.0 + 283.612\ Z_{21}$	0.58	1348	846	465	458	19.37
33	$Y = 10017.0 + 1.32678\ Z_{131}$	0.61	-	881	-	368	27.75
34	$Y = -2991.01 + 1.571\ Z_{131} + 651.219\ Z_{21} - 4.611\ Z_{121}$	0.67	-	882	-	597	31.48
35	$Y = -3993.32 + 1.202\ Z_{131} + 575.427\ Z_{21}$	0.67	-	891	-	544	25.45
36	$Y = -2475.10 + 1.920\ Z_{131} + 692.289\ Z_{21}$	0.68	-	880	-	614	33.38

TABLE 3

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

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

TABLE 4

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

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

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

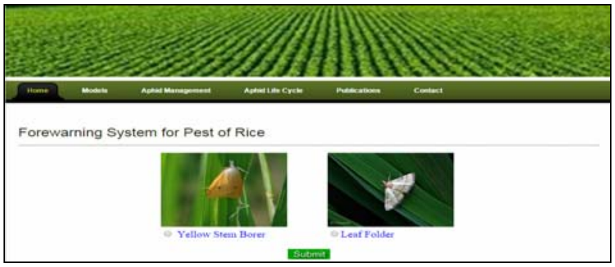

Fig. 4. Pest selection for rice

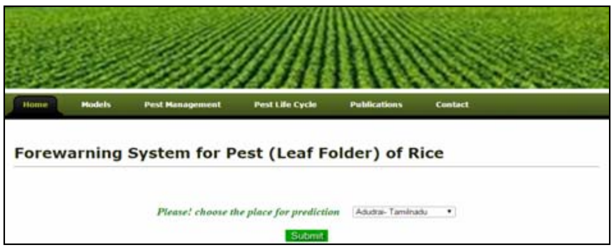

Fig. 5. Selected place (Aduthrai) for leaf folder prediction

Fig. 6. Selected sessions (2010-11) and week (32 *kharif*) for leaf folder prediction

Fig. 7. Forecast information of leaf folder in rice

Fig. 8. Forecast information of yellow stem borer in rice

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.

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